EMBODIED CARBON EMISSIONS BENCHMARKS OF RESIDENTIAL AND COMMERCIAL REFERENCE BUILDINGS IN THE UNITED STATES

by

MATTHEW A. JUNGCLAUS

B.S., University of Virginia, 2012

M.S., University of Colorado, 2023

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Committee Members:

Wil Srubar

Jay Arehart

Kyri Baker

Melissa Bilec

Gregor Henze

ABSTRACT

Jungclaus, Matthew A. (Ph.D., Civil, Environmental, and Architectural Engineering)

Embodied Carbon Emissions Benchmarks of Residential and Commercial Reference Buildings in the United States

Thesis directed by Professor Wil V. Srubar III

Buildings are responsible for 40% of global emissions. Embodied carbon (EC) emissions, or the emissions associated with the extraction, manufacture, use, and disposal of materials, represent 13% of global emissions, signifying an important priority for decarbonizing buildings. Despite its high global emissions, EC remains underrepresented in research, policy, and design relative to operational energy and carbon. EC benchmarks, which provide reference points for emissions in building construction, are a critical tool for quantifying and comparing the EC emissions of 'typical' building construction. This dissertation explores the central research question of 'What are the EC emissions of representative archetypal buildings in the US?' by establishing theoretical, science-based benchmarks for key US building typologies.

This dissertation proposes and implements a methodology for defining theoretical, science-based benchmarks through the use of material quantity takeoffs, deterministic life cycle assessment (LCA), and probabilistic LCA. The benchmarks proposed in this dissertation represent the three most commonly constructed building typologies in the US: single-family residential, commercial office, and multifamily residential apartment buildings. The scope of the LCAs conducted herein primarily account for a building's foundation, core, and shell, and consider both cradle-to-gate and cradle-to-grave emissions. The key metrics associated with these benchmarks are deterministic material use intensity (MUI, kg/m^2) results and both deterministic and probabilistic embodied carbon intensities (ECI, $kgCO_2e/m^2$) representing different building designs, LCA tools, and building typologies. This dissertation also considers biogenic carbon storage and whole-life energy and carbon emissions.

Chapter II is an investigation of the literature pertaining to EC benchmarking efforts globally and it summarizes the limitations of existing benchmarks. Chapter III establishes MUI and cradle-to-gate ECI benchmarks for single-family residential buildings. Chapter IV extends this analysis to a cradle-to-grave scope, as well as whole-life carbon and whole-life energy impacts. Chapter V applies a cradle-to-grave analysis to commercial office buildings, while also addressing design variability by modeling structural material choices and lateral loading scenarios. Chapter VI develops benchmarks for multifamily residential apartment buildings, and features parametric design that accounts for material quantity variability. Chapters III, V, and VI each consider uncertainty and variability in embodied carbon coefficients.

Findings reveal that EC results are highly dependent on building typology and design parameters, such as primary structural material, substructure type, and bay size. Deterministic cradle-to-gate ECIs range from 39 to 121 $kgCO_2e/m^2$ for single-family residential buildings, 114 to 337 $kgCO_2e/m^2$ for commercial office buildings, and 89 to 715 $kgCO_2e/m^2$ for multifamily residential buildings. Each chapter details critical differences in ECI per material, building design, and LCA tool. The probabilistic LCA results underscore the variability in LCA data and enable comparative statistical analyses.

This dissertation establishes a replicable framework for establishing theoretical EC benchmarks for buildings in the US. These benchmarks provide a foundation for building emissions comparisons, policy development, and stock-level analyses. The underlying methodologies enable future updates and expansions to the scope of this study to test alternative design strategies and new LCA data.

DEDICATION

This work is dedicated to the educators in my life who sparked my curiosity and fueled my passion for combatting climate change

and

to those who will do the same for future generations.

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ASCE	American Society of Civil Engineers
ASMI	Athena Sustainable Materials Institute
AWC	American Wood Council
B&T	Benchmarking and Transparency
CLF	Carbon leadership Forum
CLT	Cross-laminated timber
deQo	database of embodied Quantity outputs
DOE	US Department of Energy
EC	Embodied carbon
EC3	Embodied Carbon in Construction Calculator
ECI	Embodied carbon intensity
EIA	Energy Information Administration
EPA	US Environmental Protection Agency
EPD	Environmental product declaration
EU	European Union
GEA	Generation and emission assessment
Glulam	Glued laminated timber
IEA	International Energy Agency
KDE	Kernel density estimation
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
MQ	Material quantity
OC	Operational carbon
OCI	Operational carbon intensity
PNNL	Pacific Northwest National Laboratory
PT	Post-tensioned
RC	Reinforced concrete
RSP	Reference study period
SMQ	Structural material quantity
US	United States
WBLCA	Whole building life cycle assessment
WLCI	Whole-life carbon intensity

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CHAPTER I

1. Introduction and Motivation

1.1 Buildings are a significant contributor to global emissions

Responsible for 40% of global emissions in 2022, buildings are the greatest contributor to global greenhouse gas (GHG) emissions (IEA, 2023b). Given that anthropogenic GHG emissions are the primary driver of climate change (IPCC, 2023), building-related emissions must be addressed to limit the effects of global climate change. Twenty seven percent of building-related emissions stem from operational carbon (OC) emissions, or the emissions associated with building energy consumption, and 13% from embodied carbon (EC) emissions, or the emissions associated with the extraction, fabrication, transportation, use, and end-of-life treatment of building materials (IEA, 2022, 2023b; Simonen, 2014).

Addressing EC in the United States (US) building stock is crucial, as it is a top contributor to global carbon emissions. The US is the second-greatest contributor to global emissions, and was responsible for 11% of global emissions in 2023 (European Commission. Joint Research Centre. & IEA., 2024). Building-related emissions accounted for about 31% of US emissions or 3.4% of global emissions (Langevin & Wilson, 2024). Total building floor area is expected to increase by 23% by 2050 in the US (US EIA, 2023a). However, the construction of each new building presents an opportunity for EC reductions. There are many emergent EC reduction policies in the US focused on material-level emissions (e.g., Buy Clean), but EC codes and policies focused on the whole building are limited (Andrew Himes, 2024). Science-based building EC research would enable the development of robust whole-building EC targets and policies in the US.

EC emissions currently account for a smaller proportion of building-related emissions than OC in the US. However, this is expected to change in the coming years. EC emissions in the US comprise approximately 5% of annual GHG emissions, while OC

emissions are about 26% (Langevin & Wilson, 2024). The anticipated improvements in building energy efficiency over time will decrease per building OC emissions, but this can, in turn, lead to a substantial increase in EC due to the high emissions intensity of widely used high-performance building products (e.g., petroleum-based foam insulations) (S. J. Hong et al., 2020; IEA, 2023a; Méndez Echenagucia et al., 2023; Williams, 2023). The tradeoffs between EC and OC are complex due to the variable nature of emission rates for the US electric supply. It is expected that electricity emission factors in the US will decrease in the coming decades, thereby reducing per building OC emissions, though gross OC emissions in the US may increase due to growing demand (Gagnon et al., 2024; Grubert, 2021; Méndez Echenagucia et al., 2023).

Operational energy and OC have been a central focus of research and public policy in OECD countries for decades (Dixon et al., 2010; Kanellakis et al., 2013). Policies such as the Energy Independence and Security Act (EISA) in the US and the European Union's Energy Performance of Buildings Directive (EPBD) have driven dramatic energy efficiency improvements since their original releases in 2007 and 2002, respectively (Energy Performance of Buildings Directive 2002, 2002; Energy Independence and Security Act of 2007, 2007). New policies included in the US Inflation Reduction Act (IRA) and updates to the EPBD in the EU continue to reduce EUI targets foster the adoption of renewable energy and drive buildings toward net-zero energy (EPBD, 2024; Inflation Reduction Act of 2022, 2022). These and other efforts have led to global reductions in energy use intensity (EUI, kWh/m^2), a measure of normalized energy consumption. EUI has reduced by 1.3-1.9%, 2.2%-4%, and 2.5-8% annually from 2010-2023 worldwide, in the US and the EU, respectively (*Energy Efficiency 2023 – Analysis*, 2023; IEA, 2023a). Consequently, the focus on operational energy has helped reduce the overall carbon footprint of buildings.

1.2 Embodied carbon is a growing priority for decarbonization

In recent years, there has been an increase in global policy emphasis on reducing EC emissions. The European Union released the Level(s) framework in 2020 to promote sustainable building practices to reduce EC emissions by 60-80% by 2050 (European Commission, 2024). The Greater London Authority introduced mandatory whole-life carbon assessments for buildings in London, a first-of-its-kind policy globally (Greater London Authority, 2021, 2022). In the US, the IRA and several executive orders target specific reductions in construction material emissions (*FACT SHEET*, 2024; House, 2022), while many states, such as Colorado, California, New York, New Jersey, and Minnesota, have Buy Clean policies (Himes, 2024). As EC-related policies are developed, science-based EC benchmarks will be needed to support them.

Life cycle assessment (LCA) tools for EC quantification have developed substantially as industry and academic focus has shifted to LCA. LCA tools such as Sphera (GaBi) and SimaPro have been used to perform product-level LCAs since the 1990s, and the Ecoinvent database has fed the product and whole-building LCA spaces since 2003 (Sphera, 2024; "Why SimaPro," 2024; Woodley, 2023). In recent years, whole-building LCA (WBLCA) tools have become much more prevalent. In North America, tools such as Tally, the Athena Impact Estimator for Buildings, and One Click LCA are often used both for their underlying data and for their whole-building analysis functions (*AIE4B*, 2022; Building Transparency et al., 2022; One Click LCA Ltd., 2023). Relatedly, the environmental product declaration (EPD) database and calculator EC3 (the Embodied Carbon in Construction Calculator) is often leveraged for analyses where product-specific EPDs are desired (Building Transparency, 2019). The underlying data in EC3 are integrated into several BIM modeling interfaces (e.g., Revit) and can be used for WBLCA, even though EC3 is not a WBLCA tool on its own. Globally, many more tools have been developed by regional governments or private entities, such as eLCA, TOTEM, Umberto, and eTool (*eLCA*, n.d.;

eTool, 2024; *TOTEM*, 2024; iPoint Systems GMBH, 2024; Meex et al., 2018; Potrč Obrecht et al., 2020).

1.3 Benchmarks enable embodied carbon emissions reductions

Benchmarks are necessary to establish and achieve EC emissions reductions. Measuring and reducing CO_2 emissions in the built environment requires science-based benchmarks for EC emissions. Without defensible benchmarks, or reference points for the metric being studied, it is difficult to identify the characteristics of 'typical' building construction, understand the landscape of total EC emissions in a given building stock, and/or establish robust EC emissions reduction targets.

EC emissions benchmarks can help establish performance tracking, measurement, and comparison systems. Without robust, science-based benchmarks, practitioners and policymakers often do not have the right tools to establish EC emissions reduction goals. The operational energy field of study has long emphasized empirical benchmarks as a method to establish targets for known populations of buildings, set goals, and validate theoretical benchmarks using actual building data (*Building Energy Use Benchmarking*, 2023; Chung, 2011; Poess et al., 2010, 2010). Several empirical EC benchmarks for US buildings are under development (CLF, 2022; Fang et al., 2024; SE 2050, 2023), but those that are available are inconsistent in methodology and not representative of their constituent buildings (Simonen, Rodriguez, Barrera, et al., 2017). Operational energy researchers have long used archetypal models of typical, code-compliant buildings to measure the impact of energy improvements on entire building stocks (Deru et al., 2006; NREL, 2023b, 2023a), which are referred to as "theoretical benchmarks" in this dissertation. Theoretical EC emissions benchmarks are not widely available, with two applications of archetypal EC analyses in the US context (Ghorbany & Hu, 2024; Hu, 2023) identified in this dissertation. Theoretical, science-based benchmarks for US buildings would be a valuable tool for a host of building industry stakeholders to establish and

measure against agreed-upon targets for EC emissions. EC emissions benchmarks are necessary to understand the relative EC emissions of buildings in the US and set robust reduction targets.

1.4 Building typologies with the greatest US footprint

EC must be addressed in the most commonly constructed building typologies in the US to deliver the greatest impact. Focusing efforts on the most commonly constructed buildings first would enable goal-setting for the largest and highest-emitting divisions of the US building stock and, thus, unlock the greatest opportunities for EC reduction.

Single-family residential, multifamily residential, and commercial office buildings represent the three largest contributors to total floor space in the US. Single-family residential buildings represent most buildings by count (90%) and floor space (60%) in the US (US Census Bureau, 2019; US EIA, 2020). Multifamily residential buildings represent the second greatest contributor to nationwide floor space (11%), and commercial office buildings are third (5%) (US Census Bureau, 2019; US EIA, 2018a, 2020). Educational buildings and warehouses follow closely behind at approximately 4% of the total floor space each. In addition to their substantial contribution to total floor space in the US, single-family residential, multifamily residential, and commercial office buildings also represent the majority of new construction in the US, supporting the notion that these three building typologies will continue to represent the majority of floor space in the US for years to come (US Census Bureau, 2019; US EIA, 2023a). Due to their prevalence in the US building stock, single-family, multifamily residential, and commercial office buildings will be the focus of benchmark development within this dissertation

1.5 Research aims and dissertation organization

This dissertation defines theoretical EC emissions benchmarks for single-family residential, multifamily residential, and commercial office buildings in the US based on reference building models. Chapter II surveys and summarizes the current landscape of

operational and EC emissions benchmarks globally and in the US context and addresses gaps in existing research for developing EC emissions benchmarks for buildings. Chapter III proposes a methodology for establishing theoretical EC benchmarks for the cradle-to-gate EC emissions of single-family residential buildings in the US. These benchmarks are defined by establishing metrics for MUI (MUI, kg/m^2) and embodied carbon intensity (ECI, $kgCO_2e/m^2$) of archetypal reference buildings. Chapter IV builds on Chapter III by evaluating the whole-life carbon intensity (WLCI, $kgCO_2e/m^2$) of single-family residential reference buildings by expanding the scope of Chapter II to include operational energy and carbon emissions. Chapter V applies the methodology introduced in Chapters III and IV to define MUI, ECI, and WLCI benchmarks for medium and large commercial office buildings featuring different structural designs and loading conditions. Chapter VI applies benchmarking methods to multifamily residential apartment buildings while using a more robust framework for considering uncertainty and variability in both embodied carbon coefficients (ECC, $kgCO_2e/kg$) and material quantities (MQs). Chapter VII summarizes the key contributions of this work to the scientific community, acknowledges its limitations, and charts a path forward for related research.

CHAPTER II

2. Literature Review

2.1 Introduction to carbon benchmarks for buildings

2.1.1 Carbon benchmarks and environmental goals

Benchmarking, in this context, is the process of comparing a building's performance against a peer group of buildings. A benchmark is a reference point for performing such comparisons (*Building Energy Use Benchmarking*, 2023; ISO, 2020). Relevant benchmarks must be established to create and achieve environmental goals in buildings (e.g., energy or embodied carbon emissions reductions) (*Building Energy Use Benchmarking*, 2023; Harvard Energy & Facilities, n.d.; Simonen, Rodriguez, McDade, et al., 2017).

ISO 21678 establishes definitions for two types of building benchmarks – limit values and reference values. Limit values define minimum requirements for some aspect of performance. Reference values based on statistics, surveys, theoretical assessments, or demonstration projects (ISO, 2020). Chapters III-VI of this dissertation specifically consider reference value benchmarks.

In this chapter, most building-related benchmarks that are discussed are deemed empirical (e.g., survey-based) or theoretical (e.g., reference or building- or archetype-based). An empirical approach includes the measurement of carbon emissions for a statistically significant number of buildings in a particular categorization (e.g., building typology) (*Building Energy Use Benchmarking*, 2023; Kongsgaard, 2024; Rasmussen et al., 2022; SE 2050, 2023; Simonen, Rodriguez, Barrera, et al., 2017). Alternatively, a theoretical approach would model the 'typical' performance of reference buildings meant to represent a particular building typology (Lavagna et al., 2018). Then, realistic emissions reduction measures can be applied to these benchmark values to establish achievable emissions reduction targets.

The carbon emissions goalsetting process for buildings relies on benchmarking, in which the performance of a building is compared to its peers or established norms "with the goal of informing and motivating performance improvement" (*Building Energy Use Benchmarking*, 2023). Clear performance benchmarks are valuable tools for facility owners and operators, designers, and policymakers as they establish and achieve environmental goals, such as embodied carbon (EC) or operational energy reductions. Historically, operational energy benchmarks have been well-established and thoroughly studied within the scientific community (Arjunan et al., 2020; *Building Energy Use Benchmarking*, 2023; Chung, 2011; *ENERGY STAR Portfolio Manager*, 2023; Nikolaou et al., 2011; Poess et al., 2010; T. Sharp, 1996; Tereci et al., 2013). Their application has enabled considerable energy end-use reduction through data-driven target setting and studies of how improvements in codes, such as ASHRAE 90.1 or the International Energy Conservation Code (IECC), can impact building energy consumption and grid electricity demand over time (Douglas Maddox et al., 2024; Tyler et al., 2023). EC emissions benchmarks are still evolving, with many researchers focused on developing new benchmarking methods and collecting relevant LCA data (Alwan & Ilhan Jones, 2022; CLF, 2022; Pan & Teng, 2021; Pasanen & Castro, 2019; Röck, Sørensen, Steinmann, et al., 2022; Röck, Sørensen, Tozan, et al., 2022; Simonen, Rodriguez, McDade, et al., 2017; Tigani et al., 2024). However, theoretical EC emissions benchmarks have yet to be established for US buildings.

The remainder of this chapter summarizes the existing global research on carbon emissions and energy benchmarks for buildings. It briefly summarizes the field of study around operational energy benchmarking, as this field has been well-established since national laboratories in the US began exploring benchmarks in the late 1990s and early 2000s (Hicks & Clough, 1998; Sartor et al., 2000; T. Sharp, 1996; T. R. Sharp, 1998). Next, a deep review of EC emissions benchmarks is performed, including an analysis of the advantages, disadvantages, and gaps in existing approaches. This review provides the foundation for the remainder of this dissertation, in which environmental performance

benchmarks are calculated as a reference value to compare with buildings or groups of buildings based on operational or EC emissions.

2.1.2 Benchmarking taxonomy

Benchmarking can be categorized based on types of performance data and methodological approaches. Data for benchmarks can be empirical - based on actual data points (in this case, actual building energy use or carbon emissions profiles) - or theoretical - based on archetypal buildings meant to represent the performance of a 'typical' building of a certain use-type (e.g., mid-rise multifamily residential apartment buildings). Benchmarking can also be established from either a top-down or bottom-up approach. In a top-down approach, limit value benchmarks are often defined based on political targets, such as the 2-degree target specified in the 2015 Paris Climate Accords (Hollberg et al., 2019; ISO, 2020; Simonen, Rodriguez, McDade, et al., 2017; United Nations Framework Convention on Climate Change, 2015). However, they can also be derived from high-level economic input-output, energy, or material flow data at the regional, national, or international level (Acquaye et al., 2014; Han & Ji, 2016; S.-M. Hong et al., 2013; Langston et al., 2018; Minx et al., 2009; Vaisi, Firouzi, et al., 2023). With all top-down benchmarks, emissions or emissions reductions are sub-divided on a per-capita basis, by sector (e.g., buildings, manufacturing, energy generation), economic output, number of buildings, or other relevant organizing factors. A bottom-up benchmark can be derived from theoretical or empirical sources. Theoretical bottom-up benchmarks might be based on building archetypes or other models that represent 'typical' construction. Bottom-up benchmarks can also be empirically derived, meaning they are based on many observed values (Burman et al., 2014; Hicks & Clough, 1998; Hollberg et al., 2019). The sample of observed values must be sufficiently large and representative of the studied population to ascertain valuable summary statistics. Most operational and embodied impact benchmarks are bottom-up,

meaning that they are based on empirical building performance data or archetypal building models.

Studies sometimes conflate benchmarks with established goals, individual case studies, or aggregations of non-representative data. Goals for energy or emissions reductions can be based on benchmarks, but they are sometimes set through imprecise or unclear processes. Many industry organizations have established goals for different building use types in other geographic regions, but their derivation is not always clear (LETI, 2020; Ministère de l'environment, de l'energiue et de la mer, France & Ministère du logement et de l'habitat durable, France, 2016; Royal Institute of British Architects (RIBA) & Clark, 2019). Many studies also refer to collections of building performance data as benchmarks, even though the scope of analysis may not be consistent, and the buildings may not represent their populations (Simonen, Rodriguez, Barrera, et al., 2017). This review will not explore goals, individual LCAs, or targets that do not resemble environmental performance benchmarks for buildings.

2.2 Operational energy performance benchmarks for buildings

Benchmarks for operational performance in buildings almost exclusively focus on energy consumption, as energy consumption is more extensively studied by researchers and documented by building owners, while operational carbon (OC) emissions are not measured or reported in real time. Operational emissions can vary based on the region, power generation source, and time-of-use of operational energy (Eberle & Heath, 2020; Gagnon et al., 2024; Miller et al., 2022). Operational energy benchmarks are detailed in the following section, but to the author's knowledge, OC emissions benchmarks are not commonly established. Existing energy rating and benchmarking programs such as The National Australian Built Environment Rating System (NABERS) and the Energy Start Portfolio Manager estimate operational emissions using static emission factors for natural gas and grid electricity emissions, but in actuality, grid emission factors vary over time and

regionally (AUS DCCEEW, 2023; *ENERGY STAR Portfolio Manager*, 2023; NABERS, 2024; US EPA, 2020, 2024b). This makes it harder to establish stable benchmarks compared to energy use benchmarks due to the hourly fluctuation of grid emissions and rapid grid decarbonization efforts. For these reasons, operational performance is typically measured in terms of energy consumption and then converted to simplified carbon metrics as needed.

2.2.1 Empirical operational energy benchmarks

Empirical operational energy benchmarking is a practice that typically involves the collection and statistical analysis of energy consumption profiles for buildings. This practice has long been established across several global frameworks. The US federal government developed the Energy Start Portfolio Manager to allow both public and private entities to log the energy consumption of commercial, industrial, and government buildings, with the intent to compare building energy consumption and set energy use reduction targets across buildings based on typology, geography, and other classifications (*Building Energy Use Benchmarking*, 2023; *ENERGY STAR Portfolio Manager*, 2023; US EPA, 2023a). Similarly, the Energy Performance of Buildings Directive (EPBD) created a framework for benchmarking and improving energy performance, setting minimum energy performance standards for buildings across EU member states (EPBD, 2024). The NABERS rating system in Australia has meaningfully improved energy efficiency across commercial and public building sectors by establishing a building rating based on a comparison of building performance within a peer group (Damjanovski, 2024). The Chartered Institution of Building Service Engineers (CIBSE) and the University College London developed a benchmarking tool that includes over 45,000 buildings from the UK (as of July 2019) and have used the data to gain insight into the energy consumption profile of the UK building stock and develop tools for building portfolio managers to compare their energy consumption with peers (*Benchmarking Registration | CIBSE*, 2021). Additionally, all

homes in the UK are required to obtain Energy Performance Certificates (EPCs) at the point of sale, rental, or construction (*Selling a Home*, 2024). EPCs rate home energy performance for the purposes of driving improvement and comparison during the homebuying process (*EPCs in England and Wales*, 2023). Many other global examples of benchmarking and performance improvement tools exist, including The Enerdata World Energy Efficiency and Demand database and the Odyssee-Mure Project for the European Commission (Enerdata, n.d., 2024), the Scottish Public Sector Energy Benchmarking Tool (SPSEBT) (Zero Waste Scotland, 2024), and the Benchmarking and Energy-Saving Tool for Low Carbon Cities (BEST Cities) developed by Lawrence Berkeley National Lab (a tool for Chinese cities to benchmark their own buildings) (Stephanie Ohshita et al., 2016).

In the US context, operational energy is also sometimes benchmarked based on survey data. The US EIA conducts the Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and Manufacturing Energy Consumption Survey (MECS) to provide energy use data across building types, regions, building age, and other characteristics (US EIA, 2018a, 2018b, 2020). These datasets are based on building surveys from a statistically significant sample of buildings in the US that occur every 4-9 years. These data are used to analyze current energy use patterns and project typology-specific patterns over time (US EIA, 2023a).

Many energy benchmarking policies exist at state and local levels in the US as well, with six state-level policies and 50 local (county or city) policies across the US in 2023 (IMT, 2023). For example, New York City's Local Laws 84 and 133 require that certain building owners in the city measure their energy and water consumption and log the data in EnergyStar Portfolio Manager for the purposes of benchmarking (Local Law No. 84 of 2009, 2009, p. 8; Local Law No. 133 of 2016, 2016). Local Laws 95 and 33 establish a building energy efficiency score and an energy labeling requirement for certain buildings in the city (Local Law No. 33 of 2018, 2018; Local Law No. 95 of 2019, 2019). New York City publicly discloses Energy Star scores and efficiency grades for these buildings and requires that

building owners publicly post energy scores to encourage performance improvement (NYC Buildings, 2024).

Academic studies focused on US benchmarking and transparency (B&T) policies consider a wide range of analyses and improvements to existing benchmarks. There are several B&T policy reviews, including a high-level analysis of state and local benchmarks in the US by Seyrfar et al. (Seyrfar et al., 2020) and an extensive review of energy B&T policies and their outcomes by Lawrence Berkeley National Laboratory, which highlights a reported 3-8% reduction in EUI over a 2-4 year period after B&T policy implementation, and that there is a causal relationship between B&T policies and energy or energy cost savings (Mims et al., 2017). Analyses by Papadopoulos et al. and Meng et al. analyze historical B&T data to uncover patterns, with the former using machine learning to identify regional, temporal, and building typology-based patterns in energy use from B&T data (Meng et al., 2017; Papadopoulos et al., 2018). Kontokosta et al. used benchmarking data to analyze household energy cost burdens (Kontokosta et al., 2020). Several studies have offered improvements in energy benchmarking methodologies over the past several decades (Arjunan et al., 2020; Ding & Liu, 2020; Hsu, 2014; Matson & Piette, 2005).

Numerous additional studies establish empirical operational energy benchmarks across the US (Shang et al., 2020), China (Ding & Liu, 2020; Li & Li, 2018; Wei et al., 2018), Brazil (de Oliveira Veloso et al., 2020; Wong et al., 2020), Iran (Vaisi, Varmazyari, et al., 2023), and Australia (Khoshbakht et al., 2018), among other countries. Other studies establish new methodologies for performing energy benchmarks and analyzing benchmark data (Li & Li, 2018; Roth & Rajagopal, 2018). Several prominent reviews on empirical benchmark analyses and methods also exist (Borgstein et al., 2016; Chung, 2011; Ding & Liu, 2020; Nikolaou et al., 2011). These studies support the notion that empirical energy benchmarking for buildings is an established strategy for comparing the energy use intensity of comparable buildings worldwide.

2.2.2 Theoretical operational energy benchmarks

Theoretical operational energy benchmarks are typically bottom-up benchmarks based on archetypal energy models that represent typical buildings by typology and meet applicable building codes and standards. The US Department of Energy (DOE) hosts the most widely used archetypical building energy models in the US, representing 16 commercial and 32 residential buildings across 19 climate zones. These models are updated to meet new building codes and standards and vary based on building use type, climate zone, heating fuel type, size category, and other characteristics (Deru et al., 2006; EERE, US DOE, n.d.; Im et al., 2019; Im & New, 2018). The DOE prototype building models have been used to create tools that characterize building stocks (NREL, 2023a, 2023b; Reyna et al., 2022; E. Wilson et al., 2022; E. J. Wilson et al., 2017), influence building design (Abediniangerabi et al., 2020; Ng et al., 2021; Phillips et al., 2020), and represent code-compliant buildings that often serve as a reference for setting energy use reduction targets (10 CFR Part 443, 2022).

Many other examples of archetypal building energy models have been used to characterize building stocks worldwide. Mata et al. (2013) established archetypes in European Countries based on building typology, construction, and year of construction and present nation-level energy demand data (Mata et al., 2013). More recently, Pristerà et al. (2023) developed a methodology for creating a simplified set of regionally specific archetypes to represent the energy performance and material intensity of buildings across the entire European Union. However, the study did not establish energy or carbon benchmarks based on this methodology (Pristerà et al., 2023). A database of residential building archetypes for countries across Europe was developed as part of the Episcope Tabula project and has been utilized to perform building stock-level analyses on the impacts of building energy renovation projects (Institut Wohnen und Umwelt GmbH, 2016; Riccardo Pinotti & Roberta Pernetti, 2021). An et al. developed 151 prototype buildings representing several residential and commercial building typologies across different climate

zones and national standards to simulate the building performance of the Chinese building stock (An et al., 2023). Other global studies also employ archetypal building models to establish benchmarks and analyze building performance in their respective global regions (De Carli et al., 2019; W. L. Lee & Chen, 2008; Tereci et al., 2013).

2.3 Embodied carbon emissions benchmarks for buildings

Research focused on EC emissions benchmarking research is rapidly growing, but limited. Several studies claim to establish EC emissions benchmarks, and others propose frameworks for empirical data collection (Frischknecht, Balouktsi, et al., 2019; Lavagna et al., 2018; Pasanen & Castro, 2019; Rasmussen et al., 2022; Röck, Sørensen, Steinmann, et al., 2022; Röck, Sørensen, Tozan, et al., 2022; Simonen, Rodriguez, McDade, et al., 2017). Many of these studies use inconsistent data and have too few data points to deliver statistically significant benchmarks. Further, most of the available research on establishing empirical benchmarks is focused on the European building stock, leaving a considerable opportunity to characterize the US building stock.

EC benchmark studies include a variety of metrics and scope definitions. Most benchmark studies normalize EC emissions or whole-life carbon (WLC) emissions ($kgCO_2e$) by floor area (m^2), resulting in embodied carbon intensity (ECI) or whole-life carbon intensity (WLCI) ($kgCO_2e/m^2$). In some cases, this metric is also divided by a reference study period (RSP), resulting in ECI per annum or WLCI per annum ($kgCO_2e/m^2$-yr). LCA scope is very often defined based on the EN 15978/EN 15804 life cycle modules, which are summarized in **Figure 2-1.** The term 'cradle-to-gate' generally refers to life cycle modules A1-A3, and for the purposes of this dissertation, the term 'whole life' refers to life cycle modules A1-A5, B2-B6, and C1-C4 unless otherwise noted. Life cycle module B1 is not reported in the three tools primarily used in this dissertation: the Athena Impact Estimator for Buildings, One Click LCA, and Tally. Where specified in Chapters III and IV, biogenic carbon is accounted for in life cycle module D.

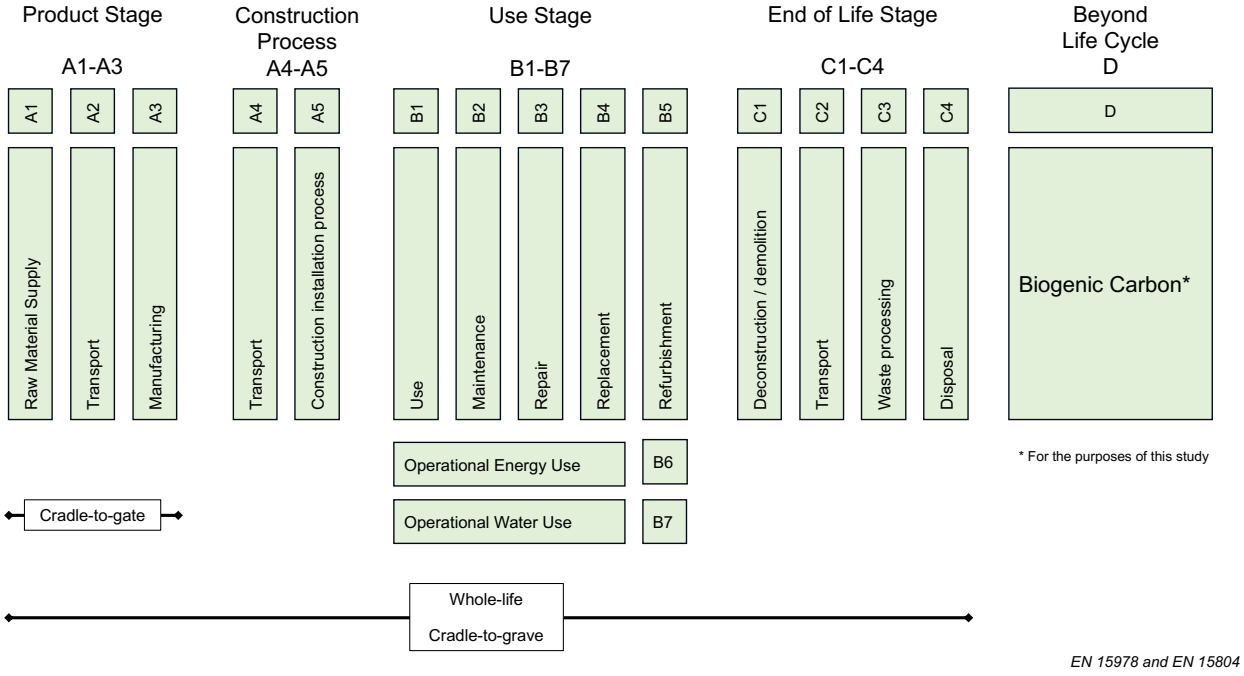

Figure 2-1. *Life cycle modules and stages as specified by EN 15978 and EN 15804 standards, including the definitions of cradle-to-gate and cradle-to-grave or whole-life impacts utilized in this dissertation (image after EN 15978) (CEN, 2011).*

The following subsections describe existing studies related to empirical and theoretical EC emissions benchmarks, with the ECIs and WLCIs in those studies summarized in **Table 2-1**. Where available, ECIs and WLCIs are reported for commercial office, single-family residential, and multifamily residential buildings, the three most commonly constructed building typologies in the US, as identified in Chapter I. These typologies will be the main focus of analysis in this dissertation.

Table 2-1. *Embodied carbon intensities and whole-life carbon intensities from literature.*

Location	Building typology		ECI ($kgCO_2e/m^2$)	ECI per annum ($kgCO_2e/m^2$-yr)	WLCI ($kgCO_2e/m^2$)	WLCI per annum ($kgCO_2e/m^2$-yr)	Ref. Study period (yr)	Benchmark Type	Source
Global	Residential	Single-family	32-1465	0.5-24.4			60 (assumed)	Empirical Dataset	(Simonen, Rodriguez, Barrera, et al., 2017)
Global	Commercial	Office	10-1314	0.2-21.9			60 (assumed)	Empirical Dataset	(Simonen, Rodriguez, Barrera, et al., 2017)
Global	Residential	Multifamily	42-2465	0.7-41			60 (assumed)	Empirical Dataset	(Simonen, Rodriguez, Barrera, et al., 2017)
North America	Residential	Single-family	32-747	0.5-12.5			60 (assumed)	Empirical Dataset	(Simonen, Rodriguez, Barrera, et al., 2017)
North America	Commercial	Office	32-1314	0.5-21.9			60 (assumed)	Empirical Dataset	(Simonen, Rodriguez, Barrera, et al., 2017)
North America	Residential	Multifamily	42-974	0.7-16.2			60 (assumed)	Empirical Dataset	(Simonen, Rodriguez, Barrera, et al., 2017)
Europe	Residential		120-600	2-10	480-4800	8-80	60 (assumed)	Empirical Ref Value	(Rasmussen et al., 2022)
Europe	Nonresidential		240-780	4-13	600-3600	10-60	60 (assumed)	Empirical Ref Value	(Rasmussen et al., 2022)
Europe	Residential		450-750	7.5-12.5			60 (assumed)	Empirical Dataset	(Röck, Sørensen, Tozan, et al., 2022)
Europe	Commercial	Office	400-550	6.7-9.2			60 (assumed)	Empirical Dataset	(Röck, Sørensen, Tozan, et al., 2022)
Europe	Residential	Single-family	440-1000	4.4-10			100	Theoretical Archetype	(Lavagna et al., 2018)
Europe	Residential	Multifamily	340-840	3.4-8.4			100	Theoretical Archetype	(Lavagna et al., 2018)
US	Residential	Single-family	1253-2847	20.9-47.5			60	Theoretical archetype	(Hu, 2023)
US	Residential	Multifamily	8024-9441	134-157			60	Theoretical archetype	(Hu, 2023)
US	Commercial	Office	50-105	0.8-1.8			60 (assumed)	Theoretical archetype	(Arehart, Pomponi, et al., 2020)
US	Residential		124-950	1.24-19			50-100 (varied)	Theoretical archetype	(Ghorbany & Hu, 2024)
Switzerland	All		660	11			60	Theoretical limit	(SIA, 2017)
Italy	Residential		380	3.8	1380	13.8	100	Empirical dataset	(Rasmussen et al., 2019)
Denmark	Residential		600	6	820	8.2	100	Empirical dataset	(Rasmussen et al., 2019)
Germany	Residential		100-675	2.0-13.5	275-1400	5.5-28	50	Mixed Dataset	(König & De Cristofaro, 2012)
Europe	Residential		420	7			60 (assumed)	Empirical Dataset	(One Click LCA Ltd., 2021)
Europe	Commercial	Office	520	8.7			60 (assumed)	Empirical Dataset	(One Click LCA Ltd., 2021)
Global	Residential		180-1050	3.6-21	518-4475	10.4-89.5	50	Normalized dataset	(Chastas et al., 2018)
Global	Residential	Multifamily	111-647	1.9-10.8			60 (assumed)	Empirical dataset (structure only)	(De Wolf et al., n.d.)
Global	Commercial	Office	86-661	1.4-11.0			60 (assumed)	Empirical dataset (structure only)	(De Wolf et al., n.d.)

2.3.1 Empirical embodied carbon emissions benchmarks

The most robust empirical EC emissions benchmarks available have been or are being developed in the European or global (multi-national) contexts. The Carbon Heroes Benchmark Program, developed by One Click LCA, compares EC emissions profiles for buildings across the globe using a consistent LCA scope (*i.e.,* LCA modules A1-A3, A4, B4-B5, C1-C4)) and methodology (Pasanen & Castro, 2019). Notably, these benchmarks exclude operational energy use, or LCA module B6. The primary use of the Carbon Heroes program is to rate buildings based on seven performance levels, each of which represents a range of cradle-to-grave emissions. The Carbon Heroes database is based on verified building assessments performed using One Click LCA software and its underlying methodological choices. The tool is only available for paid software subscribers, and the underlying data that informs the building ratings are not available. Because the underlying data are not available, it is difficult to confirm the consistency and applicability of the data to other whole-building LCAs (WBLCAs). As of 2021, Carbon Heroes included 3737 European buildings, with EC emissions ranging from 310-700 $kgCO_2e/m^2$. The average and median ECIs for all residential buildings reported for Europe are 420 and 360 $kgCO_2e/m^2$, respectively, and the average and median ECI for office buildings in Europe are 520 and 400 $kgCO_2e/m^2$, respectively (One Click LCA Ltd., 2021).

Additionally, there are many collections of empirical EC emissions data that are used to establish benchmarks in the European literature. Frischknecht et al. detail several environmental impact benchmarking case studies from across Europe (Frischknecht, Balouktsi, et al., 2019), and many benchmarks submitted as part of the related IEA EBC Annex 72 effort are detailed in a follow-up study (Rasmussen et al., 2022). Rasmussen et al. categorize the Annex 72 benchmark values into limit values (*i.e.,* upper bounds of allowable emission), reference values (*i.e.,* average values of typical or code-compliant construction for comparison), and target values (*i.e.,* goals), and they are sourced from Australia, Belgium,

Canada, Switzerland, the Czech Republic, Germany, Denmark, Spain, France, Hungary, the Netherlands, Norway, New Zealand, and Sweden (Rasmussen et al., 2022). The reference values for residential buildings span between 2 to 10 $kgCO_2e/m^2$-yr for embodied impacts and 8-80 $kgCO_2e/m^2$-yr for whole-life impacts (including operational emissions), while those for nonresidential buildings span from 4 to 13 $kgCO_2e/m^2$-yr for embodied impacts and 10-60 $kgCO_2e/m^2$-yr for whole-life impacts (Rasmussen et al., 2022). Although these ranges are quite broad, they can be used for comparison with benchmarks and datasets.

There is one often-cited EC Benchmark study from Simonen et al. (2017) that defines ranges of expected EC emissions values for different building types across the globe. While this dataset is readily available to the public (Simonen, Rodriguez, Barrera, et al., 2017), there are underlying inconsistencies that make it challenging to use for comparison or deriving reference values. First, the dataset is not statistically representative of current building practices. Second, there is a small sample size and a wide range of values for specific typologies and regions. Finally, the data are inconsistent due to varying LCA methodologies, data sources, and scopes. It is well-established that meaningful benchmark comparison can only be performed if methodological choices are consistent across the data points observed (Frischknecht, Balouktsi, et al., 2019; Röck, Balouktsi, et al., 2020). Although data presented by Simonen et al. (2017) should not be used in place of a statistically derived benchmark, they are useful for comparison. The reported ECIs for single-family residential buildings from Simonen et al. (2017) range from 32 to 1465 $kgCO_2e/m^2$ globally and 32 to 747 $kgCO_2e/m^2$ for North America. For commercial office buildings, ECIs range from 10 to 1314 $kgCO_2e/m^2$ globally and 32 to 1314 $kgCO_2e/m^2$ in North America. For multifamily residential, ECIs range from 42 to 2465 $kgCO_2e/m^2$ globally and 42 to 974 $kgCO_2e/m^2$ for North America. A second version of the benchmark report is currently under development, but the results and methods are not yet publicly available (CLF, 2022). Similar to the CLF benchmark database, the database of embodied Quantity

outputs (deQo) houses EC emissions estimates for structures in global building projects (De Wolf et al., n.d.). The deQo database reports structural system ECI ranges from 111-647 $kgCO_2e/m^2$ for multifamily residential buildings and 86-661 $kgCO_2e/m^2$ for commercial office buildings.

There are several known data collection efforts that are underway. The Built Environment Carbon Database (BECD) in the UK has officially launched, and aims to become a top source for EC benchmark data in the UK (*BECD*, 2024). The SE2050 database in the US is also accepting material quantity and EC data for building structures (SE 2050, 2023). The first data analysis and findings report of SE2050 data is in press, and preliminary results are included in the published executive summary (Fang et al., 2024).

Several studies establish supposed benchmarks for very narrow geographic regions. One study develops LCA benchmarks for residential buildings in Italy and Denmark based on a sample of 28 Italian and 7 Danish buildings (Rasmussen et al., 2019). A separate study establishes life cycle cost and environmental impact (including global warming potential) benchmarks based on a limit value approach for residential buildings in Germany, though it is not clear whether this approach is representative of all residential buildings in Germany (König & De Cristofaro, 2012). Additional studies aggregate single- or multi-building LCAs for comparison with benchmarks, targets, or other known metrics (Chastas et al., 2018; Kayaçetin & Tanyer, 2020; Magwood et al., 2023; Röck, Saade, et al., 2020). It is difficult to prove the representativeness of these aggregation studies for benchmarking purposes.

In some reports, EC emissions goals or targets are also mistaken for statistically derived benchmarks. In some cases, these targets are based on top-down calculations (i.e., distributing national carbon reduction goals to different sectors of the economy), a small set of empirical data points, or unclear derivations (LETI, 2020). Additionally, there are many private EC emissions datasets and benchmarks developed by companies that perform LCAs

across their building portfolios (CLF, 2022). However, these data are often unavailable to the public or are anonymized when included in benchmarking or comparative analysis.

Two studies by Röck et al. detail a methodology for collecting and analyzing data toward European benchmarks (Röck, Sørensen, Steinmann, et al., 2022; Röck, Sørensen, Tozan, et al., 2022) and present results for a select number of European building data. These studies found that there were sufficient data available in only 5 European countries to establish expected ranges of EC emissions in different building typologies in those countries. The authors note that these LCA data were developed using different methodological choices. Given this inconsistency and the lack of representation across Europe, these results are not intended to be a benchmark representing the European building stock. Nevertheless, the studies by Röck et al. establish important conclusions, including that building typology, design, and occupational patterns have a substantial influence on whole-life carbon emissions. These studies call for a move to central databases for whole-life carbon performance of buildings that make building data commonly available and encourage similar methodological choices across buildings. The ECIs reported by Röck et al. establish ECI ranges for single-family residential houses from 450-750 $kgCO_2e/m^2$ and for office buildings from 400-550 $kgCO_2e/m^2$. These reports build on prior studies by some of the same authors, which detail benchmarking methodologies and report select building LCA data (Röck, Balouktsi, et al., 2020; Röck, Saade, et al., 2020).

Some reports evaluate methodologies for developing consistent results suitable for benchmarking and direct comparison with one another. The Athena Sustainable Materials Institute has clearly articulated a methodology for procuring data and developing a whole-building LCA benchmark, including the definition of common LCA goals and scopes to ensure that the data used are comparable (ASMI, 2020, 2022; Bowick et al., 2017; Connor & Bowick, Matt, 2022). This work is expected to result in a pilot database of material quantities, which can be used for whole-building LCA benchmarking. A separate study proposes a benchmark for buildings in Germany, laying out a structure for improved

benchmarking databases and recommending a common set of methodological choices that can be used to generate comparable data (Schlegl et al., 2019). The authors suggest that, in addition to adhering to these common methods, greater quality control be introduced in the LCA process. Additionally, they propose that this database be expanded to include buildings across Europe.

2.3.2 Theoretical benchmarks

Several, but few studies evaluate the EC emissions of archetypal building models to establish EC emissions benchmarks for typical construction practices in a given region. The most relevant example from Lavagna et al. establishes 24 archetypes for single-family and multifamily housing in Europe. The study reports life cycle impacts between 440-1000 $kgCO_2e/m^2$ and 340-840 $kgCO_2e/m^2$ for single-family and multifamily residential buildings, respectively. These results could provide a useful point of comparison for similar studies in Europe. However, these benchmarks should be considered only in the context of the LCA goal and scope and the physical scope of the building archetypes, which includes much greater quantities of masonry, concrete, and brick than North American buildings (Lavagna et al., 2018).

A limited set of studies have sought to define and analyze the EC emissions of building archetypes in the US building stock. A 2024 study by Ghorbany and Hu (2024) presents 157 building archetypes to represent the residential buildings in the city of Chicago. The authors report an ECI of 124-950 $kgCO_2e/m^2$, inclusive of biogenic carbon storage, for the four archetypes that represent 90% of the buildings in the city. The archetypes are based only on physical building characteristics. Therefore, it is not possible to ascertain GWP by building typology or size. A 2023 study by Hu sought to use building archetypes derived from ResStock and the American Housing Survey to model the residential building stock in the US (Hu, 2023). The authors report ECIs between 1253-2847 $kgCO_2e/m^2$ for single-family and 8024-9441 $kgCO_2e/m^2$ for mid- to high-rise

multifamily residential buildings, which are at least one order of magnitude higher than other reported empirical values for residential buildings. While this building stock analysis can be used to interpret relative impacts, the results and methodological choices that led to these results are unclear. A 2020 study explores the embodied energy and carbon emissions of the non-structural materials in the US DOE's prototype commercial building models (Arehart, Pomponi, et al., 2020). This report makes use of a valuable source of archetypal building models in the US, reporting ECIs between 50-105 $kgCO_2e/m^2$ for non-structural materials in the DOE prototype building models for medium and large office buildings. The paper's results are a useful starting point for theoretical benchmarks. However, its methods should be improved by including building structural systems and US-specific LCA data.

Limit value benchmarks for EC emissions in buildings can also be developed by establishing carbon budgets for different societal sectors, including buildings. One such limit value benchmark is set by the Swiss Society of Engineers and Architects (SIA) for lifecycle building emissions, utilizing global GHG targets and per-capita budgeting (a top-down approach). This benchmark allocates 9 $kgCO_2e/m^2$-yr for building construction and 2 $kgCO_2e/m^2$-yr for building operations across all building typologies (SIA, 2017). A 2020 study by Röck et al. demonstrates that the SIA benchmark, while valuable in establishing goal-aligned targets, would be too stringent for many new and existing European buildings to achieve using current best practices (Röck, Balouktsi, et al., 2020). In addition to offering low carbon intensity targets for buildings, this limit value benchmark is not validated with building models that meet constructability constraints or empirical data. Such budgets could be used as a target for net emissions across the building sector. However, in their current form, they are difficult to interpret or use.

2.4 Characteristics of robust EC benchmarks

The most robust operational and embodied benchmarks available today have several commonalities that could inform the development of future benchmarks. First, several

studies highlight the criticality of developing and communicating a clear methodology for establishing the benchmark. Some studies conflate building performance data with empirical benchmarks – the latter requiring much more statistical rigor. The underlying methodological choices of any performance data used for benchmarking must be aligned during collection, data processing, and comparison. While this is most obvious when developing empirical benchmarks, it may also be relevant for theoretical, archetypal benchmarks. When developing building archetypes across different segments of the building stock, it is essential to develop them consistently and in a fashion that will collectively represent the building stock.

Strong EC benchmarks also utilize performance data with consistent LCA goals, scopes, methodologies, and approaches to obtaining quantity takeoffs. The underlying LCAs must have identical goals and scopes to assess EC emissions adequately. For instance, comparing LCAs that analyze different LCA modules for the same building can lead to highly inconsistent results and incorrect or misleading conclusions. If one LCA only accounted for cradle-to-gate EC emissions (LCA modules A1-A3) and another accounted for whole-life carbon emissions (A-C), the latter could report an ECI 2-8 times the former based on the data collected in **Table 2-1**. Similarly, comparing LCAs that analyze different physical building scopes can lead to dramatically different results for the same building. Many studies only examine a building's structure, core, and shell, while others account for finish materials and building systems, which can have highly variable carbon intensities and substantial maintenance-related EC emissions. Overall, synchronized methodologies are critical to developing a defensible benchmark whether they be theoretical or empirical.

An important consideration that can dramatically affect benchmarks is the RSP. The data discussed in this review and shown in **Table 2-1** underscore the importance of considering RSP in both EC and OC calculations. Although studies take different approaches to reporting whole-life carbon emissions, it is clear that both area-normalized ($kgCO_2e/m^2$) and area-time-normalized ($kgCO_2e/m^2$-yr) units each have their value. The

former demonstrates a total amount of emissions per unit area, which can be particularly useful when comparing the near-term impacts of cradle-to-gate EC emissions and estimating the impacts of new construction across a segment of the building stock. The latter metric is more useful for approximating the long-term effects of building operations and new construction together. In developing WLC benchmarks, it is particularly useful to report both metrics and/or clearly state the RSP for comparability. Many data sources do not report the RSP of the building, but several studies conservatively assumed an RSP of 60 years (Hu, 2023; SIA, 2017).

Additionally, normalization metrics, including floor area, must be scrutinized. In this study, metrics such as ECI and EUI are normalized based conditioned floor area or the area served by mechanical heating and cooling. Conditioned floor area is a suitable proxy for usable floor area in most buildings. Gross (total) floor area is sometimes used when calculating EUI or ECI. However, using gross floor area can unfairly report a difficult to interpret ECI or WLCI for buildings with large unconditioned spaces. For instance, if the unconditioned space is an area of lower EC and OC, such as a home's attached garage, a lower ECI or WLCI could result when compared to a building without a garage. In a policy application, if a WLCI threshold were set, a building could reach these thresholds more easily by increasing the amount of low-EC and low-OC unconditioned space via the inclusion of lower-WLC spaces, such as attached garages. Additionally, there are discrepancies in the definitions of gross floor area between organizations such as the US General Services Administration, the International Code Council, and others (GSA, 2023; ICC, 2021). Because no single method of characterizing floor area is necessarily 'correct' or formalized in a standard, the more important takeaway is to document floor area methodologies consistently and clearly when developing a benchmark.

In summary, it is clear that robust benchmarks require consistency, clear methodologies, and scope alignment to allow for robust comparisons and goal setting. Where possible, empirical benchmark efforts should align around similar methodological

choices. The intention of efforts such as those by the Athena Institute (Bowick et al., 2017; Connor & Bowick, Matt, 2022), One Click LCA (One Click LCA Ltd., 2021; Pasanen & Castro, 2019), and Röck et al. (Röck, Sørensen, Steinmann, et al., 2022; Röck, Sørensen, Tozan, et al., 2022) is to unify empirical benchmarking efforts in their respective regions. For theoretical benchmarking efforts, the most straightforward path to creating defensible benchmarks would be to use existing building archetypes commonly updated by a trusted source.

Further, it is the intention of this study to establish a common method of defining building archetypes for embodied carbon benchmarks based on a single reference building. The DOE prototype building models, developed in coordination between DOE and the Pacific Northwest National Laboratory (PNNL) are an established building archetype model that are a familiar representation of 'typical' buildings for energy analysis in the architecture, engineering, and construction (AEC) community. These models are incomplete in terms of providing a full quantity takeoff, and are missing critical information about building structural systems, which are responsible for the majority of embodied carbon emissions in most buildings. However, the prototype buildings' characteristics, defined by typology, building size, and climate zone, can provide a starting point for developing a more thorough quantity takeoff and a starting point for defining archetypes for LCA.

The DOE prototype models are not a perfect representation of typical buildings in the US, but nor is any other single archetype. It would be impossible to define a single building design that is representative of the various design and construction techniques used across a given geographic area larger than a neighborhood. However, the characteristics of the DOE prototype models are already familiar within the AEC, research, and policy communities (GA - HB355, 2021; Reyna et al., 2022; E. Wilson et al., 2022). The use of the DOE prototype building models for EC benchmarking will enable cross-sector analyses that account for interactive tradeoffs between embodied and operational carbon in applications such as building code analysis.

2.5 Research gaps and opportunities

Sections 2.2-2.4 summarize the current landscape of environmental benchmarks for buildings. Section 2.2 highlights how operational energy benchmarks have been leveraged to improve the environmental performance of buildings globally and in the US. Section 2.3 demonstrates a budding but not yet evolved landscape of EC emissions benchmarks. Although there is much to be learned from EC emissions benchmarks to date as described in Section 2.4, there are still many gaps and opportunities for contribution, particularly in establishing theoretical benchmarks of common building typologies in the US context.

To this end, the critical research gaps and challenges in the research of EC benchmarks for the US context are summarized as follows:

- **Research gap 1:** There is a lack of robust, theoretical EC and WLC benchmarks for building archetypes in the US.
    - **Corresponding questions:**
        - What are the EC emissions of representative archetypal buildings, particularly those representing the most commonly constructed buildings in the US (*i.e.*, single-family residential, multifamily residential, and medium and large commercial office buildings)?
        - How can existing building archetypes for operational energy modeling be used to define EC benchmarks in US buildings?
        - How will the proportion of EC to OC in 'typical' US buildings change over time, particularly as grid emission factors change?
- **Research gap 2:** Epistemic uncertainty due (1) to variations in MQs due to design choices and (2) uncertainty in EC coefficients (ECCs, $kgCO_2e/kg$) due to manufacturing processes and product LCA practices limit the establishment of EC benchmarks representative of a single building typology.

- **Corresponding questions**:
    - What are the materials and building assemblies that contribute most to whole-building material use intensity (MUI, kg/m^2) and ECI?
    - How can a theoretical benchmarking methodology account for uncertainty in MQs, particularly for those most influential materials and assemblies?
    - How can a theoretical benchmarking methodology account for uncertainty in ECCs, particularly for those most influential materials?

- **Research gap 3:** Inconsistent methodologies are used across LCA studies and popular EC benchmark studies, leading to many inconsistent EC and OC benchmarks that are unable to be compared with one another.
    - **Corresponding questions**:
        - What qualities must a theoretical benchmark model have to enable future analyses as building archetypes, LCA data, and uncertainty characterization evolve?
        - What methodological choices should be made clear and consistent to enable clear result interpretation and robust analysis?

2.6 Aims and objectives

This dissertation aims to answer the research questions identified in Section 2.5 toward establishing theoretical EC benchmarks for three building typologies. Chapter III develops theoretical EC benchmarks for single-family residential buildings based on the DOE prototype building models. First, MUIs and ECIs (LCA modules A1-A3) based on the prototype models are calculated. Second, Monte Carlo simulation is employed to establish a statistical distribution of expected ECI values. Chapter IV builds on Chapter III by establishing and implementing a methodology to account for LCA modules A-C, including OC emissions, resulting in a WLCI metric. Additionally, embodied, operational, and whole life energy are analyzed in Chapter IV. Chapter V applies these methodologies to derive MUI, ECI, OCI, and WLCI benchmarks for medium and large commercial office buildings. The study models uncertainty in the underlying ECC data using kernel density estimation (KDE) and Monte Carlo simulation. Chapter VI applies the methodology to establish MUI and ECI distributions for multifamily residential apartment buildings and considers not only the uncertainty in ECCs using KDE and Monte Carlo simulation, but also implements a parametric approach to obtaining statistical distributions of MQs by varying structural and building envelope design considerations. The output of Chapter VI is a theoretical EC benchmark for multifamily residential buildings that considers uncertainty and variability in both MQs *via* parametric design and ECCs *via* Monte Carlo and KDE. Altogether, these chapters establish and implement consistent methodologies for developing theoretical EC emissions benchmarks for the top three most constructed building typologies in the US. Researchers, policymakers, and practitioners can directly use the theoretical benchmarks derived in this dissertation EC emissions reductions by using the benchmarks to deliver more robust research, science-based EC reduction policies, and benchmark-based building design.

CHAPTER III

3. Embodied Carbon Benchmarks of Single-family Residential Buildings in the United States

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3.1 Introduction

The objective of this study is to define a methodology to establish theoretical material use intensity (MUI, kg/m^2) and embodied carbon intensity (ECI, kgCO_2e/m^2 benchmarks for single-family residential buildings in the United States based on archetypal reference buildings. Sixty-four building models that vary across 16 climate zones and 4 foundation types were defined using the prototype single-family residential building energy model defined by the United States Department of Energy (DOE) and the Pacific Northwest National Laboratory (PNNL). First, structural calculations and material quantity takeoffs were performed to provide theoretical estimates of MUI for each major material classification (e.g., concrete, wood, steel, glass) in the structure, enclosure, and foundation of each prototype building. Second, the MUIs for each prototype building were used to compute three estimates of ECI using life cycle assessment (LCA) data for modules A1-A3 from three well-known LCA software tools: Athena Impact Estimator for Buildings (Athena), Tally, and One Click LCA (One Click). Fourth, Monte Carlo simulation was implemented to elucidate any statistical differences in ECI across all climate zones and foundation types. Biogenic carbon storage for each of the prototype buildings was calculated and reported separately.

This work is a critical first step in defining theoretical embodied carbon (EC) benchmarks for buildings in the United States, and the methods introduced herein will be built upon in Chapters IV-VI. The results of this work can be used by building designers, policymakers, legislators, and others who seek to adopt EC benchmarks for single-family

residential buildings in the United States. The methodology introduced in this study is geographically agnostic and could be applied to any existing building energy models.

3.2 Computational Methods

3.2.1 DOE Single-family Prototype Building Model

The single-family prototype residential building energy models defined by PNNL and the US DOE were used as the basis for this analysis (EERE, US DOE, n.d.). The models comply with the 2021 International Energy Conservation Code (IECC). Building geometry data (see **Table 3-1**) were extracted from the EnergyPlus model input (.idf) files (EERE, US DOE, n.d.) using an OpenStudio plugin for Sketchup (Dan Macumber, 2021; OpenStudio Coalition, n.d.; *Sketchup Pro*, 2019). In total, 64 unique prototype buildings were defined based on the 16 climate zones (*i.e.*, 1A, 2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8) and 4 foundation types (*i.e.*, slab-on-grade (S), crawl space (CS), heated basement (HB), unheated basement (UB)) defined in the DOE single-family residential prototype building models (EERE, US DOE, n.d.). The geometric characteristics that varied per foundation type are shown in **Table 3-2.**

Table 3-1. *Geometric characteristics of the single-family residential prototype building model.*

Geometric characteristic	Value
Footprint dimensions (m)	12.1 x 9.1
Footprint area (m^2)	110.4
Number of stories above grade	2.0
Window area (m^2)	33.0
Roof area (m^2)	115.3
Window-to-wall ratio	12%
Interior wall area (m^2)	366.4

Table 3-2. *Foundation-dependent geometric characteristics of the single-family residential prototype building model.*

Foundation type		Building height above grade (m)	Building height below grade (m)	Wall area above grade (m^2)	Wall area below grade (m^2)	Conditioned floor area (m^2)
Slab	(S)	6.7	0.0	284.1	0.0	220.8
Crawl space	(CS)	6.5	0.6	278.0	25.9	220.8
Heated basement	(HB)	6.7	2.1	284.5	90.6	331.2
Unheated basement	(UB)	6.7	2.1	284.5	90.6	220.8

Total conditioned floor area was utilized to normalize MUI and ECI rather than gross floor area. More specifically, the results for buildings with a heated basement foundation were normalized over a greater usable floor area (*i.e.*, two stories above grade with a usable basement) than the other foundation types (*i.e.*, two stories only). While gross floor area is often used to calculate the EUI for a commercial building, the EUI for a single-family residential building may be calculated using conditioned or gross floor area, depending on the application and referenced standard (Peterson, 2010). Given that total conditioned floor area was utilized in the normalization in this study, only the unheated basement building typology is affected, as its conditioned floor area (220.8 m^2) differs from its gross floor area (331.2 m^2).

While most of the materials and assemblies in the DOE reference buildings align with typical building construction in the United States, some modifications were made to reflect common practice. First, the layer of gypsum board/drywall that was included on the interior side of the gable was removed, because the attics in these buildings are unconditioned spaces. All exterior stucco was assumed to be synthetic (*i.e.,* an exterior insulation and finish system) rather than traditional portland cement-based stucco, as the original EnergyPlus input file defined 90-95% of all exterior surfaces with a layer of synthetic stucco. A layer of aggregate (*i.e.*, crushed stone) was included underneath the

slab-on-grade, heated basement, and unheated basement foundations to align with common structural engineering practices. Interior walls, which are not defined in the DOE models were added and included in this analysis per the methods discussed in **Section 2.2.2**. Structural systems, which are also not fully defined in the DOE models, were designed in accordance with the methods discussed in **Section 2.2.3**. The design of structural systems is variable and dependent on regional practices. Since regional structural design practices are not well documented, these designs were based on engineering judgment and simplicity of design. All structural design assumptions are listed in **Appendix A**. The DOE prototype buildings were not designed to represent all single-family residential construction practices in the United States, so the building prototypes (and resultant benchmarks) should be interpreted with recognition of the characteristics of the DOE prototype buildings and the assumptions of this analysis.

3.2.2 Material use intensity calculations

Bills of material quantities were calculated for (1) non-structural materials, (2) interior walls, and (3) structural materials, as presented in the following sections. Each mass quantity was calculated by computing the volume (m^3) and multiplying volume by density (kg/m^3) to yield a material quantity in mass units (kg). These material quantities were then normalized by dividing the calculated material mass by the total conditioned floor area of each prototype building (m^2) (see **Table 3-2**), resulting in an MUI (kg/m^2) for each material in the 64 prototypical single-family residential buildings.

The physical scope of this analysis includes the foundation, structure, core and shell, and interior walls for each prototype building. The foundation and structure include all concrete, steel (including steel reinforcement), dimensional lumber, and wood sheathing products (*i.e.*, OSB and plywood) necessary to support the structural loads discussed in **Section 2.2.3**. The core and shell include the wall assemblies (drywall, fiberglass batt insulation, any non-structural sheathing, and synthetic stucco), roof assemblies (drywall,

fiberglass insulation, felt underlayment, and shingles), windows, doors, and any insulation associated with the foundation (*e.g.*, perimeter insulation for a slab foundation or fiberglass batt insulation between an unheated basement and the first floor). The interior walls consist of drywall and non-structural dimensional lumber. Fasteners (*e.g.*, nails and adhesives), sound insulation, finish materials (*e.g.*, such as paint and carpet), appliances (*e.g.*, HVAC equipment), and other building service equipment (*e.g.*, wiring, piping) were not considered within the scope of the LCA. In addition, construction waste factors were not accounted for. All foam board insulation was assumed to be extruded polystyrene (XPS), even though expanded polystyrene (EPS), Polyisocyanurate (Polyiso), and other foam types with differing material properties may also be used in residential construction. Additionally, all engineered wood panels were assumed to be plywood in this study. In a typical single-family residential building, oriented strand board (OSB) panels may be used in place of plywood for wall or roof sheathing applications, and the two materials have similar properties, resulting in minimal impacts to MUI and ECI estimates.

3.2.2.1 MUI of non-structural materials

The EnergyPlus model input files included information about the area, thickness, and density of non-structural materials. First, these data were extracted from the building models. Then, their physical geometries were converted to material volumes using Microsoft Excel for Mac (Version 16.78) and R Studio (Version 2022.12.0+353). To calculate an MUI for each material in an assembly, its volume (m^3) was multiplied by the surface area (m^2) and the thickness of the material (m). Total volume of any one material was calculated by taking the sum of all volumes corresponding to a given material over the entire building. Next, the densities were extracted from the EnergyPlus model input files. Densities that were not defined clearly in EnergyPlus were extracted from Athena (*AIE4B*, 2022). For the list of material densities used in this study, please see **Table A1** of **Appendix A**.

3.2.2.2 MUI of Interior Walls

Interior walls were not defined in the EnergyPlus model input files for the prototypical buildings. To approximate the volume of interior wall materials, the total length of interior walls in a typical single-family residential building was assumed to be 0.8 times the total length of exterior walls on each floor for each floor in the building. This estimate was derived by analyzing 31 floor plans for typical single-family residential buildings of similar size to the EnergyPlus models (see **Table A2** in **Appendix A**). The interior wall length was then multiplied by a wall height of 2.44 m (8 feet), which was calculated by subtracting an assumed floor assembly thickness of 0.15 m (6 inches) from the floor-to-floor height given for the prototype models (2.59 m or 8'6"). Only buildings with the heated basement foundation included interior walls below grade.

The composition of the interior wall materials is based on (1) the definition of "Interior Nonbearing Walls" per the 2018 International Residential Code (*Ch. 6 IRC*, 2018) and (2) the size of commonly available framing members in the United States. The interior wall assembly includes two layers of 5/8" gypsum drywall separated by 0.051 m x 0.089 m (2 in x 3.5 in) lumber framing spaced at 0.41 m (16 inches) on center. The volume of each component material was then computed based on total wall area and the assumed thicknesses for gypsum board and lumber. Densities of the interior wall materials were defined using the process described for non-structural materials (see **Section 2.2.1**).

3.2.2.3 MUI of structural materials

Structural walls, beams, columns, and other structural elements were not fully defined in the EnergyPlus model input files for the prototypical buildings. The information that was included was deemed insufficient to meet the structural building code requirements specified by IBC 2018 (ICC, 2017). As such, the authors did not include the structural materials that were defined in the EnergyPlus model input files and, instead, designed code-compliant structural assemblies for each residential building prototype.

A structural design and structural material quantity takeoff analysis was performed for each prototype building. Revit design software was used to detail the geometric layout of the building (*Revit 2020*, 2020). ClearCalcs was used to design structural beams and headers (*ClearCalcs*, 2022). Risa 2D was used to design the attic trusses (*RISA-2D*, 2022) for each prototype building. **Tables A3-A5** in **Appendix A** detail prototype-specific design criteria, structural member selection, and structural material quantity takeoffs. Densities of the structural materials were extracted from Athena (*AIE4B*, 2022).

3.2.3 Embodied carbon intensity calculations

The ECI ($kgCO_2e/m^2$) of each single-family residential prototype building was estimated by conducting a screening LCA in accordance with ISO 14040/14044 standards. The functional units of analysis were the 64 code-compliant single-family residential building prototypes. The system boundary included life cycle modules A1-A3, which is also referred to as a cradle-to-gate LCA. The scope of analysis included the building structure, envelope, and foundation, which aligns with the MUI calculations described above.

The MUIs defined in **Section 2.2** were multiplied by three different embodied carbon coefficients (ECCs) ($kgCO_2e/kg$) for each material. Those ECCs were defined by extracting the LCA data for global warming impact as a midpoint indicator, herein referred to as LCA data, from the three most common whole-building LCA tools employed in North America: Athena, Tally, and One Click LCA (*AIE4B*, 2022; Building Transparency et al., 2022; One Click LCA Ltd., 2022). Tally and Athena both utilize the US EPA's tool for the reduction and assessment of chemical and other environmental impacts (TRACI) life cycle impact assessment (LCIA) characterization scheme and methodology to report environmental impact (*AIE4B*, 2022; US EPA, 2022). One Click LCA utilizes both TRACI and the CML LCIA methodology, which is commonly used outside of North America (*CML-IA*, 2016; *Impact Assessment Categories (CML, TRACI and PEF)*, 2022). For each tool, methodological decisions were made to select US-specific values, limit scope to cradle-to-

gate emissions, make appropriate material choices for single-family residential buildings, and exclude biogenic carbon emissions (which are calculated separately). For One Click LCA, methodological choices also prioritized generic and/or industry-wide LCA data where were multiple options were available. The LCA data used in this study represent life cycle modules A1-A3 (cradle-to-gate) and are provided as 100-year global warming potential (GWP-100, $kgCO_2e$) values. To define the ECCs, each material in the prototype buildings was mapped to a corresponding material in each LCA tool. The results of the material mapping and ECCs are listed in **Table *3-3***. The complete material name from each LCA tool used in this analysis is listed in **Table A6** of **Appendix A**

Table 3-3. *Lognormal mean and standard deviation of embodied carbon coefficients (kgCO2e/kg) used in this analysis, excluding biogenic carbon storage.*

Material Name	Life Cycle Assessment Tool		
	Athena	**One Click**	**Tally**
Building paper	0.174 ± 0.246	3.586 ± 1.115	0.966 ± 0.578
Concrete	0.125 ± 0.188	0.120 ± 0.184	0.130 ± 0.192
Drywall	0.227 ± 0.280	0.360 ± 0.353	0.244 ± 0.291
Fiberglass batt	0.212 ± 0.271	2.020 ± 0.836	1.560 ± 0.735
Glazing	0.727 ± 0.454	2.700 ± 0.875	1.395 ± 0.629
Lumber	0.125 ± 0.208	0.137 ± 0.218	0.190 ± 0.257
Plywood	0.131 ± 0.213	0.453 ± 0.396	0.264 ± 0.302
Shingles	0.039 ± 0.116	0.402 ± 0.373	1.720 ± 0.772
Steel	1.008 ± 0.591	0.518 ± 0.424	1.900 ± 0.811
Stone	0.002 ± 0.028	0.003 ± 0.030	0.002 ± 0.028
Stucco	0.104 ± 0.190	0.724 ± 0.501	0.588 ± 0.451
XPS	2.388 ± 0.910	24.800 ± 2.931	3.250 ± 1.061

The ECI for each material in each prototype building was calculated according to:

$$ECI_i = MUI_i * ECC_i \quad \text{(Eq. 3-1)}$$

where ECI_i is the cradle-to-gate embodied carbon intensity ($kgCO_2e/m^2$) of material i, MUI_i is the material use intensity (kg/m^2) of material i, and ECC_i is the embodied carbon coefficient ($kgCO_2e$/kg-material) material i defined by one of the three LCA tools. Material-level ECIs were then summed for each building prototype according to:

$$ECI_{total} = \sum_{i=1}^{n} ECI_i \quad \text{(Eq. 3-2)}$$

The results of this LCA are limited by its goal, scope, and methodological choices. The ECI data used in this analysis are based upon cradle-to-gate data included in life cycle modules A1-A3 for all analyses in this paper. Assumptions regarding the physical scope of the LCA are described in **Section 2.2** and assumptions related to material choices are also applicable to the LCA (e.g., all foam board was assumed to be XPS and LCA calculations assumed the ECC of XPS).

3.2.4 Biogenic carbon storage intensity calculations

Biogenic carbon storage ($kgCO_2$), or the CO_2 stored in natural materials as a result of photosynthesis (Levasseur et al., 2013), was quantified for all wood products in this study (*i.e.,* lumber and plywood). The biogenic carbon storage was calculated as the theoretical maximum biogenic carbon storage for each material and propagated to the building scale. Biogenic carbon storage is calculated deterministically and reported as a single value. It is excluded from the uncertainty analysis, Monte Carlo simulation, and statistical similarity analysis conducted herein. Biogenic carbon storage is assumed to occur up front in life cycle module A1 with no decay. Calculations only account for the biogenic carbon storage potential in softwood lumber and plywood.

Biogenic carbon storage was calculated according to the physics-based method defined in EN 16449 (European Commission for Standards, 2014):

$$(kgCO_2)_{bio} = 0.5 \times m \times \left(1 + \frac{MC}{100}\right)^{-1} \left(\frac{44}{12}\right) \quad \text{(Eq. 3-3)}$$

where $(kgCO_2)_{bio}$ is the theoretical maximum mass of biogenic carbon ($kgCO_2$) physically stored in the wood product, m is the total mass of wood in the wood product (kg), and MC is the moisture content of the wood product (%). A value of MC = 12% is used, which assumes that wood is in equilibrium with average indoor conditions of 65% relative humidity and 21.1°C (70°F) and is representative of most regions in the United States (Breyer, 2015; Simpson & TenWolde, 1999). The multiplier 0.5 accounts for the average percent of elemental carbon in wood (~50%), and the multiplier 44/12 represents the molar ratio of CO_2 to elemental carbon. This calculation is considered a theoretical maximum because it does not account for the end-of-life emissions of stored biogenic CO_2 that occur due to end-of-life treatments (*i.e.*, decomposition or incineration).

Biogenic carbon accounting often uses a 0/0, -1/+1, or dynamic LCA accounting method. Although each method uses different temporal allocations for biogenic carbon emissions and storage, they are all based on the premise that carbon dioxide is stored *via* photosynthesis and greenhouse gases are released throughout and at the end of the

material's life. It is also often assumed that the given biological material (*e.g.*, wood) is harvested from a source that utilizes sustainable forest management practices. In the case of wood products, stored biogenic carbon is typically released due to oxidation during the product's use phase or by degradation at the end of life *via* landfilling, composting, digestion, or combustion (Hoxha et al., 2020).

For this study, the theoretical maximum biogenic carbon storage and net CO_2 emissions are calculated assuming full CO_2 uptake and storage and without accounting for the release of any biogenic carbon during the product's use phase or end-of-life treatment. In essence, this includes the CO_2 that might be modeled using the -1/+1 method, but does not account for the emission of greenhouse gases from the system boundary. If whole-life carbon emissions were being considered, the net biogenic carbon storage would have a lower magnitude than presented in this paper.

3.2.5 Net CO_2 emissions intensity calculations

Net CO_2 emissions were calculated for each prototype building by subtracting the total biogenic carbon storage ($kgCO_2$) from the total EC emissions ($kgCO_2e$). The resulting net CO_2 emissions calculation is given in units of $kgCO_2e$, as CO_2e accounts for the combined impact of many greenhouse gases, including CO_2. A net CO_2 emissions intensity value was calculated by dividing the result by the applicable conditioned floor area value (**Table 3-2)**. Negative net CO_2 emissions or emissions intensity values indicate net CO_2 storage, while positive values indicate net CO_2 emissions to the atmosphere. Because the biogenic carbon storage calculations do not account for use-phase or end-of-life emissions, the net CO_2 emissions results presented herein will be less than results that incorporate whole-life impacts.

3.2.6 Uncertainty analysis and Monte Carlo simulation

The computation of ECI described above results in deterministic ECIs for each of the 64 prototypical buildings. However, notable variability exists across and within LCA data

sources (E. Marsh et al., 2023). Therefore, a Monte Carlo simulation was performed to quantify the uncertainty in the LCA data and capture the variability of the ECI results. The statistical variation of each individual ECC was modeled using a lognormal distribution, which has been utilized in several studies to represent the distribution of ECCs (Kang et al., 2015; D. Lee et al., 2019; Shillaber et al., 2017). The mean, μ, of each distribution was defined as the deterministic ECC value listed in **Table 3-3**. The standard deviation, σ, of each distribution was derived using the Q Metadata value, a measure of variation based on product datapoint specificity, provided from One Click (One Click LCA Ltd., 2022; *Q Metadata Calculation Method*, 2022). It was assumed that the Q metadata variability multiplied by the deterministic ECC is interchangeable with statistical variance (Waldman et al., 2020).

Monte Carlo simulations (n = 100,000) were performed for each single-family residential prototype building to elucidate the expected variability in ECI. The simulation count was determined by increasing the number of simulations by an order of magnitude until the average variance in ECI across all models differed by <1% between Monte Carlo runs. A two-sample Kolmogorov-Smirnov (K-S) test was utilized to compare the statistical similarity of ECI distributions across climate zone and foundation type using a threshold of $p < 0.05$. The statistical significance of the ECI benchmark results were not compared across separate LCA data sources.

3.3 Results and Discussion

3.3.1 Material use intensity (MUI) benchmarks

The MUIs for all 64 single-family residential prototype buildings are shown in **Figure 3-1**. The results are presented by foundation type (*i.e.*, crawl space, heated basement, slab-on-grade, and unheated basement) and climate zone. Many single-family residential buildings with the same foundation type have an identical MUI, but small differences in MUI do exist across climate zones for buildings with the same foundation types.

Figure 3-1a shows the MUIs for all prototype buildings with a crawl space foundation. The MUIs for these buildings range from 185 to 195 kg/m^2, yielding a difference of 10 kg/m^2. The lowest MUI is attributed to climate zone 1A, a warm, humid climate zone, while the highest MUI is attributed to climate zones 7 and 8, which are cold-weather climate zones. This difference in MUI is expected, as buildings in cold-weather climates typically require more materiality in their building envelopes, namely more insulation and thicker wall cavities to hold that insulation. More specifically, the MUI differences across climate zones are primarily attributable to differences in the materiality of lumber, fiberglass batt insulation, and XPS across climate zones. The MUI of each of these materials increases as the climate zone increases (see **Figure 3-1a**). In the warmest climates (climate zones 1A, 2A, and 2B), the residential buildings contain 2x4 lumber walls with R-13 (RSI-2.29) and R-30 (RSI-5.28) fiberglass batt insulation in the walls and attic, respectively. Warm-climate buildings did not include any XPS insulation. Conversely, the residential buildings in the coldest climates (zones 7 and 8) are constructed using 2x6 walls with R-20 (RSI-3.52) fiberglass batt insulation, R-60 (RSI-10.57) fiberglass batt insulation in the attic, and R-5 (RSI-0.89) XPS sheathing insulation around the entire building. These results are consistent with the intent of the DOE benchmark models, as the United States building code has less stringent requirements for thermal insulation in warmer climates. The MUIs for insulation materials in climate zones 3A through 6B lie between those corresponding to the warmest and coldest climate zones.

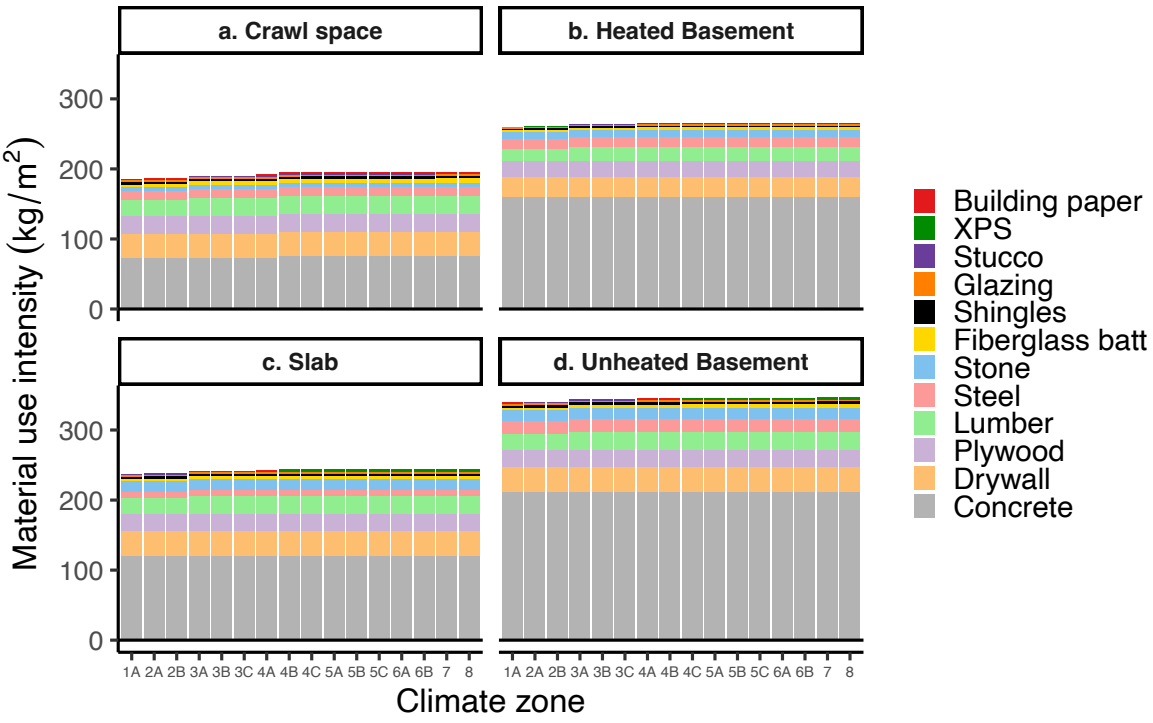

Figure 3-1. *MUIs of single-family residential prototype buildings with (a) crawl space, (b) heated basement, (c) slab-on-grade, or (d) unheated basement foundations by climate zone.*

Variations in concrete, drywall, and lumber quantities across climate zones are minor for buildings with a crawl space foundation (**Figure 3-1a**). Similar variations in MUI were evident for all other foundation types (**Figure 3-1b-d**). The magnitudes of the MUI differences between across climate zones are identical across all foundation types (**Figure 3-1a-d**). This result was expected, as the changes in wall thickness and insulation based on climate zone are consistent across all foundation types.

Figure 3-1 substantiates that foundation type has a greater effect on MUI than climate zone for each prototype building. Buildings with unheated basement foundations (**Figure 3-1d**) exhibit the highest MUIs across all foundation types, which range from 339 to 346 kg/m^2. This trend is anticipated, because (1) residential buildings with unheated concrete basement foundations require more material than buildings that have crawl space or slab-on-grade foundations and (2) the floor area used to calculate MUI was less than the floor area of the protype buildings with heated basements (see **Table 3-2**). Although buildings with a heated basement foundation type (**Figure 3-1b**) demonstrate higher total quantities of concrete, drywall, lumber, and insulation due to the finished interior walls of the basement, their higher conditioned floor areas result in lower MUIs than the unheated basement foundation type. Buildings with a crawl space (**Figure 3-1a**) and slab-on-grade foundation (**Figure 3-1c**) had the lowest and second lowest MUIs of all foundation types, respectively, primarily due to the lower quantities of concrete required to construct those foundations.

The greatest single-material contributor to the MUI of each single-family residential building is concrete, which accounts for 72 to 212 kg/m^2 (37 to 63% of total MUI) across all buildings. In most buildings, concrete contributes more mass than all other materials by a factor of more than two. Quantities of steel are identical across all buildings with the same foundation types because the primary function of steel in these buildings is to reinforce concrete foundations. Similar to concrete, the steel MUI is highest for the unheated basement foundation type (19 kg/m^2 or 5.6% of total MUI), but it is lowest for the slab-on-

grade foundation type (10 kg/m^2 or 4% of total MUI). This is an expected difference, as the buildings with slab-on-grade foundation types do not require the steel structural support columns that are found beneath the first story in the crawl space and basement designs. There were no differences in the quantity of paper, glass, plywood, shingles, or stucco across climate zones or foundation types, as all buildings have identical exteriors and superstructures.

The results in **Figure 3-1** are generally lower than other MUIs that have been reported in the literature. There are very little empirical data available about the MUI of single-family residential buildings globally, and any United States specific data are not granular enough for comparison with the MUI values derived in this study. However, a select number of studies have reported MUIs for single-family residential buildings of 600 to 1400 kg/m^2 (Arceo et al., 2021), 280 to 550 kg/m^2 (including an adjustment for different building footprints)(Gontia et al., 2018), and 660 ± 46 to 1700 ± 380 kg/m^2 (Arceo et al., 2023). These studies report much higher MUIs due to several key differences in scope. The inclusion of finish materials and physical scope additions can have a meaningful impact on MUI. Additionally, many of these buildings utilize high-density building envelope materials, such as brick and stone, which are substantially heavier than the wood framing and synthetic stucco siding that serve a similar functional purpose in the DOE model.

3.3.2 Embodied carbon intensity benchmarks

The ECIs for all 64 single-family residential buildings are shown in **Figure 3-2**. The ECI results are presented by foundation type (*i.e.*, crawl space, heated basement, slab-on-grade, and unheated basement), climate zone, and LCA data that was used to calculate the ECI. Many single-family residential buildings with the same foundation type have identical ECIs (**Figure 3-2**). However, as was the case for MUI, minor differences in ECI exist for buildings across climate zones.

Figure 3-2a contains all ECIs of single-family residential buildings with a crawl space foundation, as computed using the Athena LCA data . The ECIs range from 39 to 44 $kgCO_2e/m^2$ for climate zone 1-8, respectively. Minor differences in ECI across climate zones are directly attributable to the differences in lumber, XPS, and fiberglass batt MUIs presented in **Figure 3-1a**. Steel contributes the most to ECI for buildings **in Figure 3-2a** (32% of total ECI across all models). Although steel has a relatively small MUI (7% of total, on average), it has the second highest ECC of all materials (1.01 $kgCO_2e$/kg-material), leading to its relatively high contribution to ECI. Concrete and drywall contribute the second- and third-most most to ECI (22% and 19% of total ECI, respectively). Neither material has an abnormally high ECC (0.125 and 0.227 $kgCO_2e$/kg-material, respectively), but they are the two greatest contributors to building MUI (39% and 18%, respectively).

Similar trends in ECI are observed for single-family residential buildings with other foundation types. **Figure 3-2b-d** show the ECI results for single-family residential buildings with a heated basement, slab-on-grade, and unheated basement foundation, as calculated using Athena. The differences in ECI across climate zones are 48-50 $kgCO_2e/m^2$ for buildings with a heated basement, 41-46 $kgCO_2e/m^2$ for slab-on-grade, and 63-67 $kgCO_2e/m^2$ for unheated basement foundations. Again, these differences, are attributable to differences in lumber, XPS, and fiberglass batt MUIs per **Figure 3-1b-d**. Similarly, steel (21-34%), concrete (21-42%) and drywall (12-20%) remain the top contributors to ECI across all buildings. Concrete is the greatest contributor to ECI in buildings with heated basement (40%), slab-on-grade (34%), and unheated basement (41%) foundations.

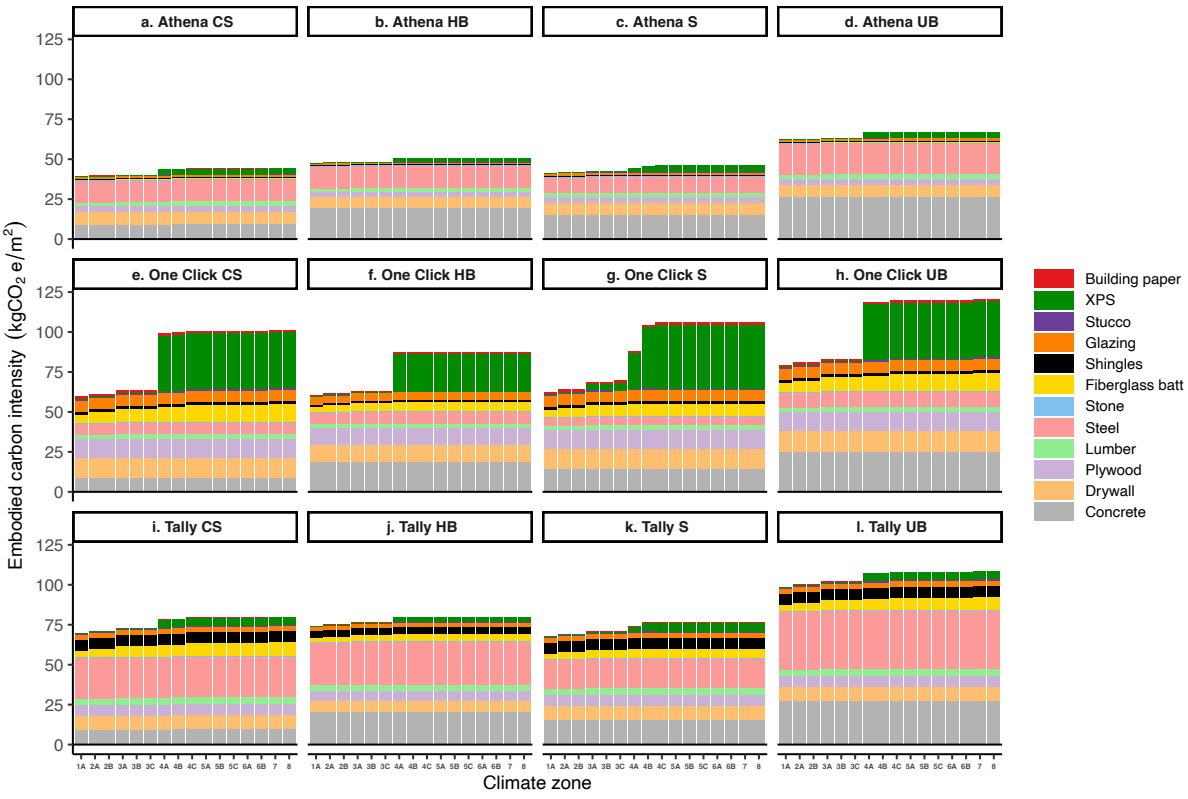

Figure 3-2. *ECIs of single-family residential prototype buildings organized by foundation type (i.e., CS, HB, S, and UB), LCA data source (i.e., Athena, OneClick, Tally), and climate zone.*

The trends in ECI across climate zone and foundation type remained consistent with each LCA data source. **Figure 3-2** shows that the ECIs for Athena span from 39-67 $kgCO_2e/m^2$, the ECIs for One Click range from 60-121 $kgCO_2e/m^2$, and those for Tally range from 68-109 $kgCO_2e/m^2$. Within a given foundation type, trends show an increase in ECI from climate zone 1A through climate zone 8, similar to the trends discussed for Athena, but with different magnitudes. Additionally, for each LCA data source, the crawl space foundation type has the lowest ECI for any given climate zone, followed by slab-on-grade, heated basement, and unheated basement.

The key differences between a material's contribution to MUI (**Figure 3-1)** and ECI (**Figure 3-2**) results from its ECC. This is evident by observing that for the Athena results (**Figure 3-2a-d)**, average concrete-related EC emissions are 34% of whole-building ECIs across all climate zones and foundation types, whereas concrete makes up 52% of the

building by mass, on average (**Figure 3-1)**. Conversely, steel-related EC emissions are approximately 28% of whole-building ECIs for Athena, while only 5% of the building mass is steel, on average. These marked differences in total contribution can be explained by the difference in ECC for concrete (0.125 $kgCO_2e$/kg-material) and steel (1.01 $kgCO_2e$/kg-material). Other materials for which ECC substantially affects contribution to MUI and ECI include XPS, lumber, fiberglass batt insulation, drywall, plywood, and glazing. **Figure 3-2** substantiates that the choice of LCA data has a pronounced effect on the resulting ECI.

There are also notable differences in ECCs across LCA data sources for some materials, which lead to considerable magnitude and contribution differences between LCA data. For any given foundation type and climate zone, Athena yields the lowest ECIs while One Click yields the highest ECIs. The average ECI across all foundation types and climate zones for each LCA data source characterize this well. The average ECI for Athena, One Click, and Tally are 50, 90, and 84 $kgCO_2e/m^2$, respectively.

The lowest ECI in the analysis, 39 $kgCO_2e/m^2$, is attributed to climate zone 1A, the crawl space foundation, and Athena. Buildings with crawl space foundations exhibit the lowest MUIs due to a lower quantity of structural, insulation, and finish materials relative to their gross square footage; climate zone 1A requires the lowest amount of insulation material across all buildings; and Athena exhibits lower ECCs than Tally and Athena on average. The highest ECI of 121 $kgCO_2e/m^2$ is associated with climate zones 7-8, the unheated basement foundation, and One Click. This trend is consistent with the fact that (1) the unheated basement foundation type exhibits the highest MUIs for each climate zone due to its quantities of structural, insulation, and drywall materials relative to its conditioned floor area; (2) climate zone 8 requires the greatest amount of insulation materials across all buildings; and (3) One Click exhibits higher ECCs than Tally and Athena on average.

Figure 3-3 compares the ECI results obtained herein with empirically derived ECIs from publicly available LCA studies of single-family residential buildings in North America.

In general, the theoretical ECI values reported in this study are more consistent but lower in magnitude than the empirical ECI values reported by the other studies. The buildings modeled in this study exhibited ECIs that range from 39 to 121 $kgCO_2e/m^2$, whereas the ECIs for the single-family residential buildings reported in a Carbon Leadership Forum (CLF) Benchmark Study range from 32.2 to 746.6 $kgCO_2e/m^2$ (Simonen, Rodriguez, Barrera, et al., 2017; Simonen, Rodriguez, McDade, et al., 2017). RMI reported residential ECIs that range from 44 to 561 $kgCO_2e/m^2$ (Magwood et al., 2023). The results reported herein are within the range of the values for the CLF Benchmark Study, and 90% of these results are within the range of values reported from RMI, but these results are on the low end of the researched ranges.

The lower ECI results reported herein are expected for several reasons. First, the RMI and CLF reports were limited in terms of the number and quality of the whole-building LCA (WBLCA) studies that were used to compute the benchmarks. Second, the scopes of the WBLCA data reported in CLF and RMI studies vary considerably compared with this work. Some of the WBLCAs included more LCA modules (*e.g.*, B1-B7 – use stage or C1-C4 – end of life stage) and/or included an expanded physical scope (*e.g.*, finish materials). Finally, the MUI and LCA data are not provided for the individual WBLCA studies, which means that the material quantities and ECC values used to compute those ECIs could vary widely, thereby introducing inconsistencies that were otherwise avoided by using an internally consistent MUI (*i.e.,* a prototypical building model) and LCA data source (*i.e.*, Athena, One Click, or Tally) for each benchmark value computed in the present study.

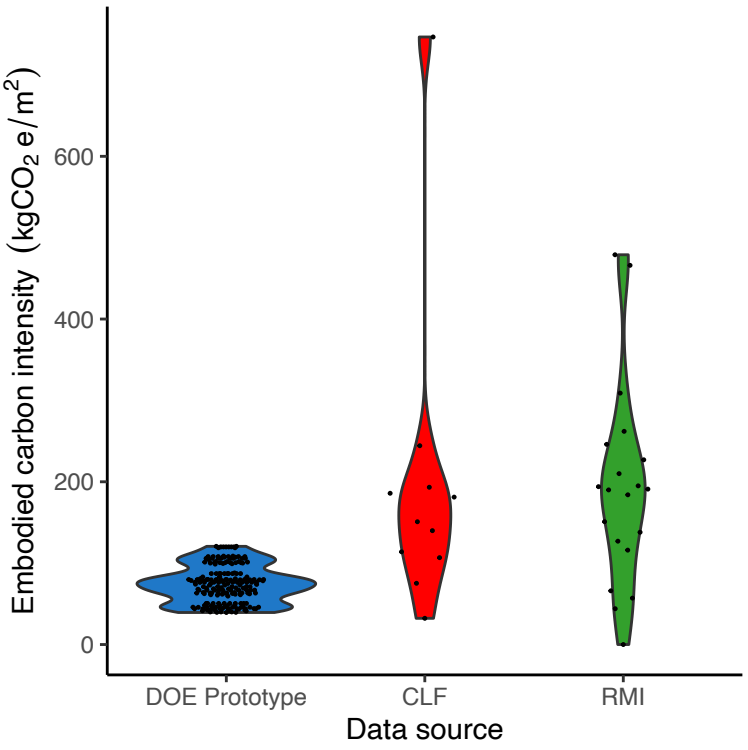

Figure 3-3. *Comparison of ECI values obtained in this study with empirical ECI data reported by the CLF and RMI for single-family residential buildings in North America.*

3.3.3 Biogenic carbon storage

Figure 3-4 shows the theoretical maximum biogenic carbon storage intensity ($kgCO_2/m^2$) and the net CO_2 emission intensity ($kgCO_2e/m^2$) for each climate zone and foundation type. According to this analysis, many building typologies are net-CO_2 storing, meaning that the magnitude of the biogenic carbon storage is higher than the initial EC emissions. For example, **Figure 3-4a** shows the ECI of residential buildings with a crawl space foundation as computed using the Athena LCA data, along with the theoretical estimates of biogenic carbon storage. The biogenic carbon storage ranges from 76 to 81 $kgCO_2/m^2$, depending on climate zone, whereas the ECIs range from 39 to 44 $kgCO_2e/m^2$. The net CO_2 emissions range from -37 to -41 $kgCO_2e/m^2$. The increase in the magnitude of biogenic carbon storage from climate zones 1A-2B (76 $kgCO_2e/m^2$) to climate zones 3A-8 (81

$kgCO_2e/m^2$) are due to the change from 2x4 to 2x6 wall construction. An increase in the quantity of wood results in an increase in the amount of stored biogenic carbon.

All net emissions intensities computed using the Athena LCA data are negative, indicating net-CO_2 storage across all climate zones. The foundation type exhibiting the greatest net-CO_2 storage is the crawl space foundation type, followed by slab-on-grade (-35 to -39 $kgCO_2e/m^2$), heated basement (-18 to -23 $kgCO_2e/m^2$), and unheated basement (-14 to -18 $kgCO_2e/m^2$). All foundation types have an identical quantity of biogenic carbon storage, except for the heated basement type, which has additional wood in the below-grade interior walls and a greater floor area over which emissions are normalized. Thus, the difference in net CO_2 storage across different foundation types is largely attributed to differences in cradle-to-gate EC emissions.

In contrast, the net emissions results for One Click (**Figure 3-4e-h**) and Tally (**Figure 3-4i-l**) illustrate that the magnitude of biogenic carbon storage does not necessarily offset all of the cradle-to-gate EC emissions. For ECIs computed using One Click, the unheated basement foundation type consistently exhibits positive net-CO_2 emissions. The crawl space, heated basement, and slab foundation type buildings in climate zones 1A-3C also demonstrate net CO_2 storage, but those in climate zones 4A-8 exhibit positive net CO_2 emissions as the result of higher cradle-to-gate ECIs. For Tally, net-negative CO_2 emissions (or CO_2 storage) were computed for all slab-on-grade and crawl space buildings and net-positive emissions for all heated basement and unheated basement buildings.

These results should be interpreted within the confines of this benchmark analysis. More specifically, the ECI for each residential building prototype are computed in accordance with the goal, scope, and system boundary assumptions outlined in **Section 3.2**. In addition, the calculation of biogenic carbon storage computed in this work considers the physical biogenic carbon stored during photosynthesis and does not consider use-phase or end-of-life emissions. The results would differ, for example, if the LCA scope and system

boundary were expanded to include additional materials (*e.g.*, finish materials such as wood flooring) and/or the emission of biogenic CO_2 that occurs during end-of-life disposal scenarios (*e.g.*, landfilling or incineration). Including additional net-emitting materials and accounting for end-of-life disposal would reduce overall carbon storage, raising the net emissions across the board. Nevertheless, the results presented in **Figure 3-4** can be used to compare results from other WBLCAs conducted in accordance with the scope and system boundary used herein.

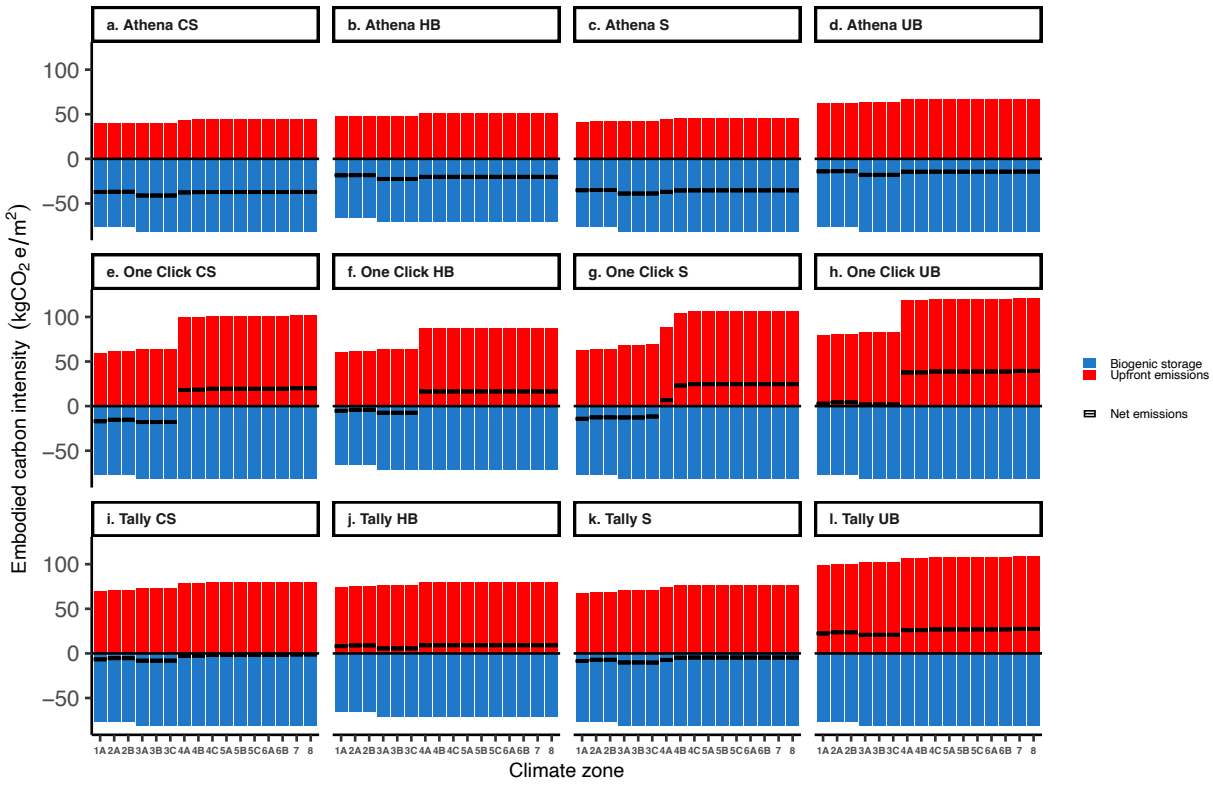

Figure 3-4. *Cradle-to-gate embodied carbon emissions, theoretical maximum biogenic carbon storage from wood products and net-CO_2 emissions of all residential building prototypes by LCA data source, climate zone, and foundation type.*

3.3.4 Probabilistic ECI Distributions

Figure 3-5 shows the probabilistic ECI distributions obtained using Monte Carlo simulation. The ECI results in **Figure 3-5** follow lognormal distributions, and the magnitudes of their medians tend to follow the same trends shown in **Figure 3-2.** For example, the distribution for climate zone 1A in **Figure 3-5a** ranges from 7 to 873 $kgCO_2e/m^2$ (both values are considered outliers, and thus, they are not pictured in **Figure 3-5a**), with a median ECI of 35 $kgCO_2e/m^2$, which is similar to the deterministic ECI of 39 $kgCO_2e/m^2$ presented in **Figure 3-2a**. Across all climate zones, the median ECI distribution is less than the corresponding deterministic ECIs shown **Figure 3-2** by 4-16%. It is known that for lognormal distributions, the median values are consistently lower than the mean values of that distribution. This is an expected result, because the ECC distributions that were used as an input into this analysis follow a lognormal distribution. The other trends observed in **Figure 3-5**, such as increasing ECI across climate zone, align with the results of the deterministic ECI analysis (**Figure 3-2**).

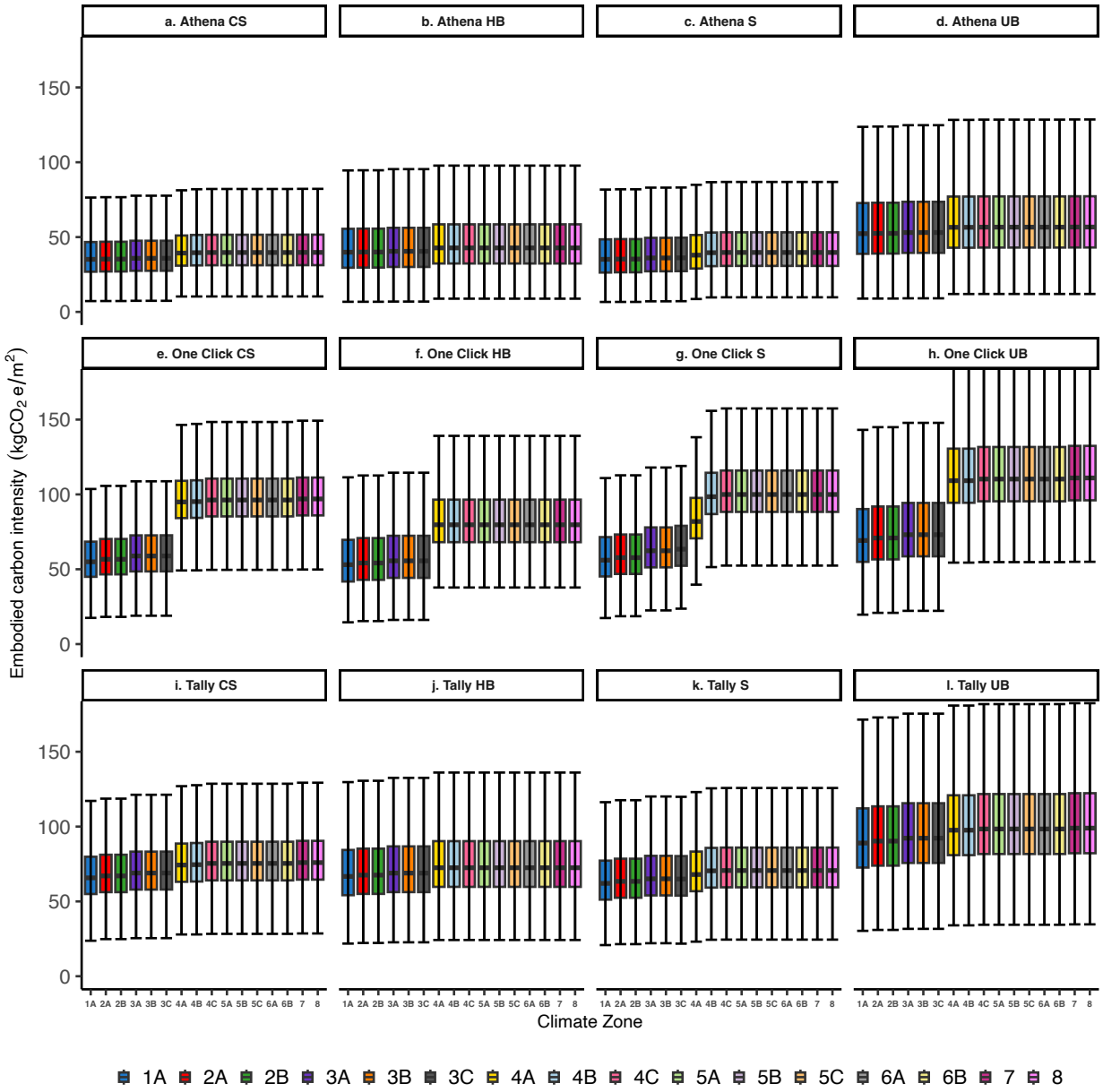

Figure 3-5. *Probabilistic ECI distributions for all 64 single-family prototype buildings across all foundation types and LCA data sources. Outlier datapoints were omitted to preserve readability.*

According to the results of a two-sided K-S test, the ECIs of residential buildings in climate zones 1A, 2A, 2B (Group 1), climate zones 3A, 3B, 3C (Group 2), and climate zones 4A-8 (Group 3) are statistically similar if (a) the buildings have the same foundation type and (b) the ECIs are computed using the same LCA data. There are no ECI distributions that are statistically similar across different foundation types. This statistical similarity

means that the analysis can be condensed from 192 unique distributions to 36 unique distributions (or 64 physical building models to 12). Reducing the number of unique distributions and benchmarks can markedly reduce computational intensity in future analyses. In addition, a lower number of unique distributions could also simplify the benchmarking process, given that the same benchmark for new residential buildings in the United States can be defined for multiple climate zones.

3.3.5 Significance and Limitations

This is the first known study to establish *theoretical, science-based* ECI benchmarks for single-family residential buildings in the United States. There have been attempts to establish empirical benchmarks in the United States, but with varied LCA scopes and limited datapoints (Simonen, Rodriguez, McDade, et al., 2017). A theoretical, science-based approach lays the foundation for the government and private companies to estimate the EC emissions of their building portfolios, establish reduction strategies, and enact codes, policies, or corporate goals aimed at reducing these impacts. Further, theoretical benchmarks could inform the standard-making process *via* organizations such as the Association Of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), which has existing efforts to incorporate EC in the standards that are ultimately adopted as codes (ASHRAE Task Force for Building Decarbonization, 2021; Association of Heating and Air-Conditioning Engineers (ASHRAE), 2023). Finally, these benchmarks could inspire new scientific literature that incorporates additional scope, modifies the prototypical building designs, or extrapolates these results to large portfolios of buildings.

The results of this analysis should be interpreted with the understanding that the DOE prototype buildings were not designed to represent all single-family residential construction practices in the United States. The results herein represent common construction practices for wood-frame houses built on top of four common foundation types and may be interpreted as benchmarks for buildings matching the physical description of

the DOE prototype buildings. These results would not be appropriate benchmarks for markedly different residential structural designs, such as buildings with concrete block walls.

3.4 Conclusions

This study defined theoretical EC benchmarks by formulating and implementing a methodology to compute the MUI and ECI of 64 prototypical single-family residential buildings, representative of code-compliant buildings across 16 climate zones and 4 foundation types. The MUI and ECI were computed, and distributions of ECI values were developed for each of the 64 prototypical buildings and each of 3 LCA data sources, with ranges of 185 to 346 kg/m^2 and 39 to 121 kgCO_2e/m^2, respectively.

Results indicate that the choice of LCA data has a notable impact on the ECI results for each of the 64 buildings, and that these results are sensitive to LCA data source. In this analysis, LCA results using Athena were lowest, results using One Click were highest, and Tally results were between those. Consistently, the MUI and ECIs of the crawl space foundation type were lowest, followed by slab-on-grade, heated basement, and unheated basement. When calculating net CO_2 emissions and the impacts of theoretical maximum biogenic CO_2 storage, the difference between a net-emitting and net-storing building is highly dependent on the choice of LCA data. ECI results calculated using the Athena LCA data were all net-CO_2 storing, while only 28% of those using One Click and 50% of those using Tally were net-CO_2 storing. If the effects of end-of-life disposal were accounted for, biogenic CO_2 storage would decrease, and net CO_2 emissions would increase across all scenarios. Additionally, a statistical similarity test indicates that some models with the same foundation type and using the same LCA data can be considered statistically similar and organized into three distinct groups of ECI based on climate zone, reducing the total number of distinct building models from 64 to twelve. The results presented herein provide a simple characterization of uncertainty, but further research is needed to better quantify

uncertainty and harmonize LCA approaches (including data and methodological choices) across tools.

The results of this study build on several empirical benchmarks to establish the first known theoretical EC benchmarks for single-family residential buildings in the United States. These theoretical benchmarks can inform code, policy, and goal-setting efforts to reduce EC emissions in buildings, and they also provide key information that could help streamline and simplify future analyses.

3.5 Data Repository

https://doi.org/10.6084/m9.figshare.24451948

CHAPTER IV

4. Whole-Life Carbon and Energy Benchmarks of Single-family Residential Buildings in the United States

4.1 Introduction

This study formulates and implements a methodology to define theoretical, science-based benchmarks for the whole-life energy intensity (WLEI, MJ/m^2) and whole-life carbon intensity (WLCI, $kgCO_2e/m^2$) of single-family residential buildings in the US. The methodology includes (1) estimating the operational and embodied energy consumption and (2) calculating the corresponding operational and embodied carbon (EC) emissions of prototypical, single-family residential buildings. Embodied impacts will be estimated using life cycle assessment (LCA), while operational impacts will be estimated using building energy modeling in combination with grid emission factors. WLCI is calculated by combining estimates of embodied carbon intensity (ECI, $kgCO_2e/m^2$) with estimates of operational carbon intensity (OCI, $kgCO_2e/m^2$). Similarly, WLEI is calculated by combining estimates of embodied energy intensity (EEI, MJ/m^2) with estimates of operational energy use intensity (EUI, kWh/m^2) (see **Figure 4-1**).

This study builds on Chapter III by expanding the scope to include LCA modules A4-A5, B, and C. In addition to EC, embodied energy is also evaluated. The scope includes LCA module B6, which represents the emissions and energy associated with operational energy consumption. Biogenic carbon storage is not computed in this chapter, as it is analyzed for the same building typology in Chapter III. Altogether, the expansion in scope enables the establishment of theoretical WLCI and WLEI benchmarks for the single-family residential prototype building models.

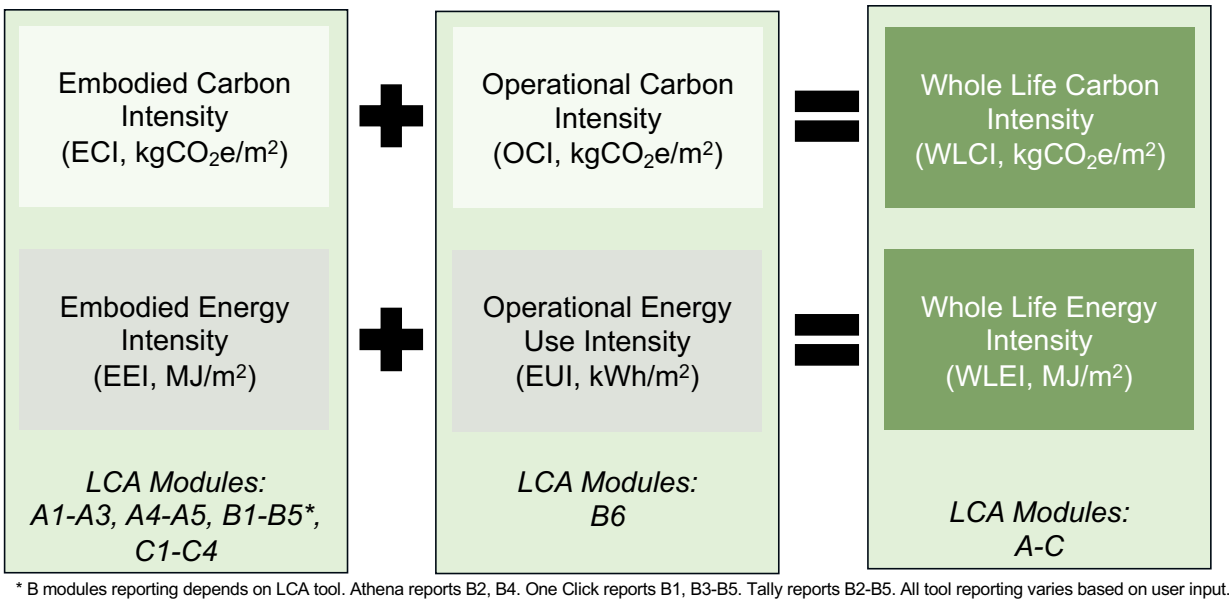

Figure 4-1. *A summary of the LCA modules comprising whole-life impacts as they are calculated in this chapter.*

4.2 Computational methods

4.2.1 DOE single-family prototype building and material use intensity

This study utilizes the prototype building energy models defined by the Pacific Northwest National Laboratory (PNNL) and the US Department of Energy (DOE) to represent archetypal single-family residential buildings, referred to hereafter as the DOE prototype buildings. These models contain information about building geometry and envelope materials. However, they lack some information necessary to perform a robust LCA, including physical characterizations of structural systems and interior walls. The models, provided as EnergyPlus input (.idf) files, can be used directly to calculate operational energy performance. Calculating embodied impacts requires a quantity takeoff of key building assemblies, including the structure. In Chapter III, bills of material quantities were created from these models, resulting in a material use intensity (MUI, kg/m^2) for each material in each DOE prototype building. The MUIs computed in Chapter III are summarized in **Table 4-1.**

Table 4-1. *MUIs (kg/m²) of single-family residential prototype buildings separated by foundation type, climate zone, and material.*

Foundation Type	Crawl space																Heated basement															
Climate Zone	*1A[1]*	*2A[2]*	*2B*	*3A[3]*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*	*1A[1]*	*2A[2]*	*2B*	*3A[3]*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*
Material																																
Building paper	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Concrete	72.4	72.4	72.4	72.4	72.4	72.4	72.4	75.2	75.2	75.2	75.2	75.2	75.2	75.2	75.2	75.2	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159	159
Drywall	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
Fiberglass batt	2.8	3.6	3.6	4.5	4.5	4.5	5.0	4.9	5.5	5.5	5.5	5.5	5.5	5.5	5.8	5.8	1.8	2.4	2.4	2.9	2.9	2.9	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Lumber	21.9	21.9	21.9	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	17.6	17.6	17.6	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5
Glazing	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Plywood	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4	23.4
Shingles	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Steel	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Stucco	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
XPS	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Foundation Type	Slab																Unheated basement															
Climate Zone	*1A[1]*	*2A[2]*	*2B*	*3A[3]*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*	*1A[1]*	*2A[2]*	*2B*	*3A[3]*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*
Material																																
Building paper	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Concrete	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	212	212	212	212	212	212	212	212	212	212	212	212	212	212	212	212
Drywall	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8
Fiberglass batt	2.3	3.1	3.1	3.6	3.6	3.6	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	2.8	3.6	3.6	4.5	4.5	4.5	4.9	4.9	5.5	5.5	5.5	5.5	5.5	5.5	5.8	5.8
Lumber	21.9	21.9	21.9	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	21.9	21.9	21.9	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8
Glazing	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Plywood	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6	25.6
Shingles	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Steel	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Stucco	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
XPS	0.0	0.0	0.0	0.1	0.1	0.1	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

[1] *Climate zones 1AWH, 1AWHT, and 1AWHTs are physically identical to climate zone 1A as represented in this table*
[2] *Climate zone 2AWH is physically identical to climate zone 2A as represented in this table*
[3] *Climate zone 3AWH is physically identical to climate zone 3A as represented in this table*

DOE prototype buildings representing 16 climate zones (*i.e.*, 1A, 2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8), four foundation types (*i.e.*, slab (S), crawl space (CS), heated basement (HB), unheated basement (UB)), and four heating system types (*i.e.*, electric resistance, electric heat pump, gas furnace, oil furnace) were defined in this analysis. The footprint of each DOE prototype building is identical across all climate zones, foundation types, and heating systems.

Table 4-2 and **Table 4-3** report key geometric characteristics of the DOE prototype buildings.

Table 4-2. *Geometric characteristics of the single-family residential prototype building.*

Geometric characteristic	Value
Footprint dimensions (m)	12.1 x 9.1
Footprint area (m^2)	110.4
Number of stories above grade	2.0
Window area (m^2)	33.0
Roof area (m^2)	115.3
Window-to-wall ratio	12%
Interior wall area (m^2)	366.4

Table 4-3. *Foundation-dependent geometric characteristics of the single-family residential prototype building.*

Foundation type		Building height above grade (m)	Building height below grade (m)	Wall area above grade (m^2)	Wall area below grade (m^2)	Conditioned floor area (m^2)
Slab	(S)	6.7	0.0	284.1	0.0	220.8
Crawl space	(CS)	6.5	0.6	278.0	25.9	220.8
Heated basement	(HB)	6.7	2.1	284.5	90.6	331.2
Unheated basement	(UB)	6.7	2.1	284.5	90.6	220.8

4.2.2 Embodied Impact Calculations

The EEI (MJ/m^2) and ECI (kgCO$_2$e/m^2) were computed using a screening LCA meeting ISO 14040/14044 standards. The functional units of analysis were the 72 distinct LCA models characterizing single-family residential buildings across 16 climate zones and four foundation types. The LCA models are identical across the four previously mentioned heating system types, as building services (including heating systems) were not included in the scope of this analysis. The physical scope of the study consists of the building structure, envelope, and foundation, which aligns with the physical scope of the MUIs. The system boundary for this LCA includes life cycle modules A1-A5, B2-B6, and C1-C4. Module B6 (operational energy) was calculated based on the methodology outlined in **Section 4.2.3**. Both the EEI and ECI are calculated for each material by life cycle module according to:

$$EEI_{i,j} = MUI_i * EEC_{i,j} \quad \text{(Eq. 4-1)}$$

$$ECI_{i,j} = MUI_i * ECC_{i,j} \quad \text{(Eq. 4-2)}$$

where $EEI_{i,j}$ is the embodied energy intensity (MJ/m^2) of material i for life cycle module j, MUI_i is the material use intensity (kg/m^2) of material i, and $EEC_{i,j}$ is the embodied energy coefficient (MJ/kg-material) defined by the applicable LCA data. Similarly, $ECI_{i,j}$ is the embodied carbon intensity of material i for life cycle module j and $ECC_{i,j}$ is the embodied carbon coefficient (kgCO$_2$e/kg-material) material i and life cycle module j defined by the applicable LCA data source. EEIs and ECIs can be summed across materials and LCA scopes for each prototype building according to:

$$EEI_{total} = \sum_{i=1}^{n} \sum_{j=1}^{n} EEI_{i,j} \quad \text{(Eq. 4-3)}$$

$$ECI_{total} = \sum_{i=1}^{n} \sum_{j=1}^{n} ECI_{i,j} \quad \text{(Eq. 4-4)}$$

where EEI_{total} and ECI_{total} represent the embodied energy intensity (MJ/m^2) and embodied carbon intensity (kgCO$_2$e/m^2) of a whole building for all of the life cycle modules included in this analysis (*i.e.,* A1-A5, B1-B5, C1-C4).

The embodied energy and embodied carbon coefficients were extracted from the Athena Impact Estimator for Buildings (Athena), One Click LCA (One Click), and Tally and

are summarized below in **Table 4-4** and **Table 4-5**, respectively (*AIE4B*, 2022; Building Transparency et al., 2022; One Click LCA Ltd., 2023). One coefficient is presented for each combination of LCA data source (i.e., Athena, One Click, and Tally) and life cycle module grouping (*i.e.,* A1-A3, A4-A5, B1-B5, and C1-C4). Default assumptions were used to characterize the building materials and LCA modules reported for each tool.

Table 4-4. *Embodied energy coefficients (MJ/kg) separated by LCA data source, life cycle module, and material.*

LCA Data	**Athena**				**One Click**				**Tally**			
LCA Scope	*A1-A3*	*A4-A5*	*B1-B5*	*C1-C4*	*A1-A3*	*A4-A5*	*B1-B5*	*C1-C4*	*A1-A3*	*A4-A5*	*B1-B5*	*C1-C4*
Building paper	10.537	1.599	24.320	0.034	77.756	0.240	0.000	4.017	37.000	0.137	0.000	0.732
Concrete	0.777	0.229	0.000	0.154	1.044	0.257	0.000	0.001	1.135	0.019	0.000	0.339
Drywall	3.688	1.008	0.000	0.107	4.561	0.142	0.000	0.649	3.960	0.137	4.851	0.754
Fiberglass batt	7.265	0.786	0.000	0.112	14.908	0.142	0.000	0.122	32.800	0.137	0.000	0.754
Glazing	7.822	0.214	16.180	0.039	29.065	0.142	0.000	1.097	20.427	0.732	21.912	0.754
Lumber	6.258	0.685	0.000	0.503	13.570	0.392	0.000	0.235	20.700	0.304	0.000	0.605
Plywood	7.714	0.774	0.000	0.518	13.799	0.392	0.000	0.235	18.100	0.372	19.077	0.605
Shingles	3.065	0.226	6.859	0.029	5.642	0.240	0.122	0.000	64.400	0.137	136.353	3.640
Steel	17.379	0.831	0.000	0.293	9.266	0.403	0.000	1.149	23.900	0.342	0.000	0.226
Stone	0.081	0.088	0.000	0.059	0.041	0.042	0.000	0.000	0.041	0.054	0.000	0.339
Stucco	0.634	0.251	0.000	0.107	32.316	4.538	0.000	0.111	56.352	0.510	77.431	0.744
XPS	45.968	3.680	0.000	0.112	37.550	0.240	0.000	4.017	94.300	1.031	0.000	0.754

Table 4-5. *Embodied carbon coefficients ($kgCO_2e/kg$) separated by LCA data source, life cycle module, and material. Excludes biogenic carbon storage.*

LCA Data	**Athena**				**One Click**				**Tally**			
LCA Scope	*A1-A3*	*A4-A5*	*B1-B5*	*C1-C4*	*A1-A3*	*A4-A5*	*B1-B5*	*C1-C4*	*A1-A3*	*A4-A5*	*B1-B5*	*C1-C4*
Building paper	0.174	0.033	0.417	0.002	2.456	0.008	0.000	2.069	0.966	0.009	0.000	0.043
Concrete	0.125	0.019	0.000	0.010	0.093	0.017	0.000	0.003	0.130	0.001	0.000	0.040
Drywall	0.227	0.067	0.000	0.007	0.307	0.005	0.000	0.023	0.244	0.009	0.298	0.045
Fiberglass batt	0.212	0.039	0.000	0.008	0.792	0.005	0.000	0.006	1.560	0.009	0.000	0.045
Glazing	0.727	0.015	1.486	0.003	1.922	0.005	0.000	0.039	1.395	0.050	1.490	0.045
Lumber	0.125	0.023	0.000	0.034	0.200	0.014	0.000	0.017	0.190	0.021	0.000	0.520
Plywood	0.131	0.033	0.000	0.035	0.599	0.014	0.000	0.017	0.264	0.025	0.809	0.520
Shingles	0.039	0.007	0.098	0.002	0.243	0.008	0.000	0.006	1.720	0.009	3.891	0.216
Steel	0.892	0.054	0.000	0.020	0.570	0.014	0.000	0.040	1.900	0.024	0.000	0.013
Stone	0.006	0.006	0.000	0.004	0.003	0.001	0.000	0.000	0.002	0.004	0.000	0.040
Stucco	0.104	0.023	0.000	0.007	1.728	0.219	0.000	0.005	2.050	0.035	3.076	0.043
XPS	2.388	0.214	0.000	0.008	3.124	0.008	0.000	2.069	3.250	0.071	0.000	0.045

All LCA results are limited by their respective goals, scopes, and other methodological choices. The EEC and ECC data used in this analysis inclusive of all reported life cycle modules from the given LCA data source, and no assumptions were made about modules that were not reported. The physical scope of this LCA excludes finish materials (*e.g.,* paint and carpet), fasteners (*e.g.*, adhesives and nails), sound insulation, appliances (*e.g.*, HVAC equipment), and other building services (*e.g.*, wiring, piping). Extruded polystyrene (XPS) and expanded polystyrene (EPS), two types of foam insulation, were combined into one category for this analysis and were assumed to have the ECC of XPS. In this study, all engineered wood panels were assumed to be plywood. In a typical single-family residential building, plywood and oriented strand board (OSB) panels can both be used for wall or roof sheathing applications as long as they are designed to withstand applicable loads. The two materials have similar material properties and embodied impacts to one another, so total MUI and ECI results would not be impacted substantially by this choice of material. Construction waste was not accounted for in this analysis.

4.2.3 Operational impact calculations

Operational energy consumption was simulated using EnergyPlus Version 9.5.0 for each of the 288 prototype buildings (NREL & LBNL, 2019, 2021). The cities used to characterize annual weather patterns in each climate zone are listed in **Table 4-6**. In this study, annual operational energy consumption data were mined from the simulation result files using Python (version 3.12). This simulation and data mining process results in a collection of operational EUI (kWh/m^2-yr) values for each fuel type (*i.e.,* electricity, gas, and fuel oil) and each prototype energy model.

Table 4-6. *Selected city for weather file, generation and emission assessment (GEA) region, grid emission rates, heating degree days, and cooling degree days for each climate zone. The average annual grid emission rate from 2025-2085 indicates the average rate for the 60-year RSP.*

Climate Zone	Weather File City, State	GEA Region	2025 projected grid emission factor ($kgCO_2e$/kWh**)	Average annual grid emission factor from 2025-2085 ($kgCO_2e$/kWh**)	Heating degree days	Cooling degree days
1AWH	Miami, FL	FRCC	0.50	0.32	200	4198
1AWHT/S	Honolulu, HI	HIMS*	N/A	N/A	0	4474
2AWH	Tampa, FL	FRCC	0.50	0.32	725	3427
2B	Tucson, AZ	WestConnect_South	0.28	0.20	1678	2954
3A	Atlanta, GA	SERTP	0.67	0.22	2991	1667
3AWH	Montgomery, AL	SERTP	0.67	0.22	2224	2212
3B	El Paso, TX	WestConnect_South	0.28	0.20	2708	2094
3C	San Diego, CA	CAISO	0.25	0.05	1256	984
4A	New York, NY	NYISO	0.34	0.05	5027	921
4B	Albuquerque, NM	WestConnect_South	0.28	0.20	4425	1244
4C	Seattle, WA	NorthernGrid_West	0.10	0.04	4908	190
5A	Buffalo, NY	NYISO	0.34	0.05	6747	477
5B	Denver, CO	WestConnect_North	0.54	0.17	6020	679
5C	Port Angeles, WA	NorthernGrid_West	0.10	0.04	5719	28
6A	Rochester, MN	MISO_North	0.47	0.15	7646	409
6B	Great Falls, MT	NorthernGrid_East	0.28	0.23	7741	388
7	International Falls, MN	MISO_North	0.47	0.15	10478	249
8	Fairbanks, AK	GVEA*	N/A	N/A	13940	84

*The NREL Cambium dataset excludes data from Alaska. As a result, Climate Zone 8 is not analyzed as part of the OCI or WLCI analysis.
**Indicates end-use electricity consumption

The fuel-specific EUIs can be added together, as demonstrated by:

$$EUI_{total} = EUI_{elec} + EUI_{gas} + EUI_{oil} \quad \text{(Eq. 4-5)}$$

where EUI_{total} is the EUI (kWh/m^2-yr) across all fuels, and EUI_{elec}, EUI_{gas}, and EUI_{oil} are the energy use intensities (kWh/m^2-yr) for electricity, natural gas, and fuel oil, respectively. In some cases, EUI_{gas} or EUI_{oil} are equal to 0, as some prototype energy models do not utilize fossil fuels.

Heating degree days (HDD) and cooling degree days (CDD) are valuable tools for understanding heating and cooling demand for a given climate zone based on the weather in that location. HDDs are calculated by subtracting the average daily temperature from the reference temperature of 65°F when the temperature is below the reference temperature, and those values are summed over the year. CDDs are calculated by subtracting 65°F from the average daily temperature when the temperature is above the reference temperature and then totaled over the year. The HDDs and CDDs for each simulation city were calculated based on the EnergyPlus weather (.epw) files used for this study and reported in **Table 4-6.**

Operational carbon (OC) emissions are calculated by multiplying the EUI for each fuel type by an appropriate emission rate (kgCO_2e/kWh). The emission rate for electricity varies based on the utility grid in a given locale and the power generation sources on which the local grid depends. This can vary substantially over time – not just on an annual basis, but on an hourly basis, as certain sources of power ramp up or ramp down to meet demand. The NREL Cambium dataset analyzes emission rates over time by analyzing recent data and projecting multiple grid demand and emission scenarios into the future (*Cambium*, n.d.; Gagnon et al., 2024, 2024). For the purposes of this study, annual Cambium data will be used, and the "mid case" scenario, which most closely resembles a "business-as-usual" operation of the grid, will be assumed. The mid case scenario accounts for changes in grid emissions over time, using the median inputs for grid decarbonization, demand growth, and other factors in the Cambium model. As a result, some generation and emission assessment

(GEA) regions will fully decarbonize by 2050, while others may increase in emissions due to increased demand growth and a lack of decarbonization plans.

Grid emission factors were extracted from the Cambium tool for every five-year interval up to 2050. Between the five-year intervals for which data was collected, the emission factors were interpolated. Beyond 2050, emission factors were assumed not to change from 2050 to 2085 (year 60) for each scenario, given that the Cambium dataset does not project beyond the year 2050. The emission factors for the year 2025 and an average for the 60-year RSP are summarized in **Table 4-6.** The GEA regions for each climate zone in this study were chosen based on the simulation city used to represent each climate zone in the prototype models. Fossil fuel emission rates were assumed to be constant over time and identical across the United States. The emission rates for natural gas (ER = 52.91 $kgCO_2e/MMBtu$ or 0.18 $kgCO_2e/kWh$) and fuel oil (ER = 75.09 $kgCO_2e/MMBtu$ or 0.26 $kgCO_2e/kWh$) are assumed to be identical across the United States (US EIA, 2023b).

The OCI ($kgCO_2e/m^2$-yr) is calculated as follows:

$$OCI_a = EUI_{elec} \times ER_{elec,a} + EUI_{gas} \times ER_{gas} + EUI_{oil} \times ER_{oil} \quad \text{(Eq. 4-6)}$$

where OCI_a represents the annualized operational carbon intensity ($kgCO_2e/m^2$-yr) of a given building energy model in year a, EUI_{elec}, EUI_{gas}, and EUI_{oil} are the energy use intensities (kWh/m^2-yr) for electricity, natural gas, and fuel oil, respectively, and $ER_{elec,a}$, ER_{gas}, and ER_{oil} are the emission rates ($kgCO_2e/kWh$) for electricity in year a, natural gas, and fuel oil, respectively. The total OCI over the 60-year RSP is calculated by summing the OCI for years 1-60.

4.2.4 Whole-life impact calculations

WLEI (MJ/m^2) and WLCI ($kgCO_2e/m^2$) are calculated by totaling the respective embodied and operational impacts associated with each metric. For example, WLEI is calculated by adding the EEI (MJ/m^2) (life cycle modules A1-A5, B1-B5, C1-C4) to the operational EUI (kWh/m^2, converted to MJ/m^2) (B6) for a given building. Correspondingly, WLCI is calculated by adding the ECI ($kgCO_2e/m^2$) (A1-A5, B1-B5, C1-C4) to the OCI ($kgCO_2e/m^2$) (B6). In this study, WLEI and WLCI account for total impacts over the life of the building.

A reference study period (RSP) of 60 years is assumed based on the review of residential carbon emissions benchmark studies in Chapter II of this dissertation. Many existing residential benchmark studies assume a 60-year RSP for single-family residential buildings (Hu, 2023; One Click LCA Ltd., 2021; Rasmussen et al., 2022; Röck, Sørensen, Tozan, et al., 2022; SIA, 2017; Simonen, Rodriguez, Barrera, et al., 2017). A 2012 study noted that RSP is often arbitrarily assigned in LCA studies, and its analysis of American Housing Survey data showed that the average residential building life was approximately 61 years in 2009 and that average life has a linearly increasing trend (Aktas & Bilec, 2012). A theoretical study of building life notes that the average age of a single-family residential building at the time of demolition could be between 102 and 130 years, but the study caveats these results and does not provide a recommended lifespan to use (Ianchenko et al., 2020). It is beyond the scope of this study to evaluate the lifespan of residential buildings, their influence on RSP, and their effect on WLCI calculations (Aktas & Bilec, 2012).

4.3 Results

4.3.1 Embodied energy intensity benchmarks

The EEI (GJ/m^2) values for all 72 LCA models are shown in **Figure 4-2** and **Figure 4-3**. In **Figure 4-2**, EEI is categorized by foundation type, LCA data source, climate zone, and material. In **Figure 4-3**, EEI is broken down by foundation type, LCA data source, climate zone, and LCA module.

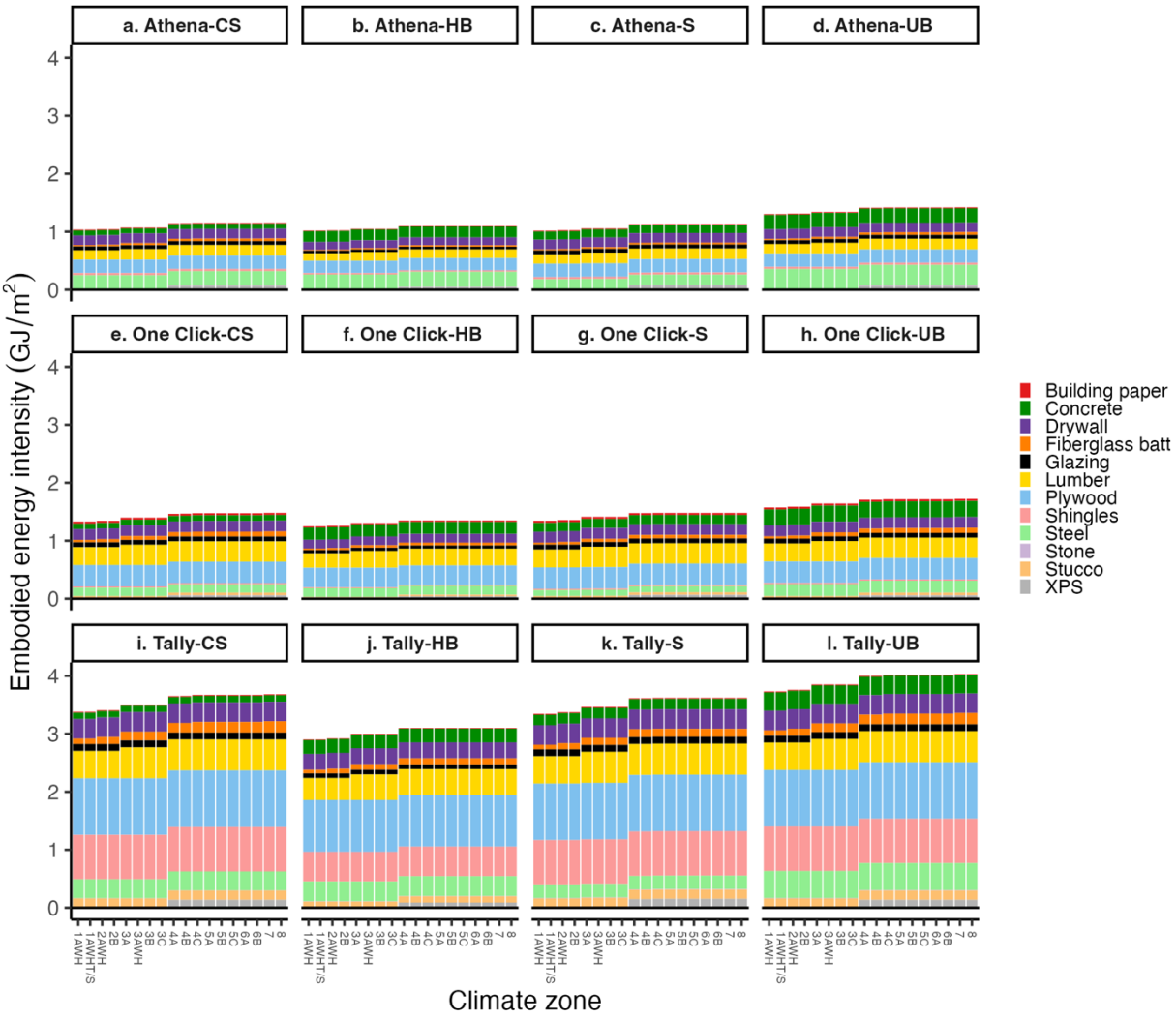

Figure 4-2. *EEIs of single-family residential prototype buildings, organized by climate zone and foundation type.*

Figure 4-2a shows the EEI values for all buildings with a crawl space foundation evaluated using Athena data. The EEIs range from 1.04 to 1.16 GJ/m^2 for climate zones 1AWH to 8, respectively. There is a slight difference in EEI across climate zones due to a requirement for more XPS, lumber, and fiberglass batt insulation in the cooler climate zones (i.e., the higher-numbered climate zones) to meet code requirements. This difference is enumerated in **Table 4-1**. From **Figure 4-2a**, it is evident that steel (a category mainly comprised of reinforcing steel) contributes the most to EEI (24%), followed by plywood (22%), lumber (16%), drywall (16%), and concrete (8%). These contributions to MUI differ from the total contribution to MUI for the crawl space foundation type, where the top contributing materials are concrete (38%), drywall (19%), plywood (14%), lumber (12%), and steel (7.2%). The reasons for this difference are that (1) steel has a higher EEC (18.5 MJ/kg) than the average material (14.2 MJ/kg) for Athena, (2) concrete has a lower EEC (1.2 MJ/kg), and (3) plywood, lumber, and drywall all have EECs between those values (9.0, 7.4, and 4.8 MJ/kg, respectively). These EECs indicate that steel is more energy-intensive to produce, maintain, and dispose of per unit mass than the other materials listed for Athena, which is consistent with the energy-intensive processes required to make structural steel elements (Gursel et al., 2023; Holtzhausen, 2007). Although concrete has the third-lowest EEC of all materials included in this analysis, it has the fifth-highest EEI by material due to the substantial mass of concrete required to construct a slab in single-family residential buildings.

Figure 4-2b-2d shows similar trends for buildings with heated basement, slab, and unheated basement foundation types utilizing Athena LCA data. The range of EEIs across climate zones is 1.02 to 1.10 GJ/m^2 for buildings with a heated basement, 1.02 to 1.13 GJ/m^2 for slab, and 1.30 to 1.42 GJ/m^2 for unheated basement. Similar to **Figure 4-2a**, the variations across climate zones in **Figure 4-2b-2d** can be attributed to differences in material quantities for XPS, lumber, and fiberglass batt insulation, while steel, plywood, lumber, drywall, and concrete remain the top contributors to both EEI and MUI. Steel

remains the leading contributor to EEI for heated basement (24%) and unheated basement (26%) foundation types, but plywood is the top contributor at 21% of total EEI for the slab foundation. Concrete also contributes more greatly to EEI for the heated basement (17%, third highest contributor) and unheated basement (18%, second highest contributor) foundation types than to the others. This result is consistent with the increase in concrete MUI for these foundation types, which require large concrete sub-structures compared with the other foundation types. Concrete remains the highest contributor to MUI for all foundation types.

The results across One Click (**Figure 4-2e-h**) and Tally (**Figure 4-2i-l**) show similar trends to Athena (**Figure 4-2a-d**) but with different relative magnitudes. The EEIs span from 1.02 to 1.42 GJ/m^2 for Athena, 1.25 to 1.72 GJ/m^2 for One Click, and 2.90 to 4.03 GJ/m^2 for Tally, with the lowest value for each LCA data source associated with climate zone 1AWH and 1AWHT/S, and the highest value associated with climate zones 7-8. For each LCA data source, the heated basement foundation type demonstrates the lowest EEI, and the unheated basement demonstrates the highest EEI. Although the heated basement foundation type has the highest gross whole-life embodied energy, its greater conditioned floor area leads to a lower EEI. The lowest EEI in the analysis, 1.02 GJ/m^2, is attributed to climate zone 1A, the slab foundation, and Athena. The highest EEI of 4.03 kgCO_2e/m^2 is associated with climate zones 7-8, the unheated basement foundation, and Tally. This trend is consistent with the fact that (1) Tally exhibits higher average EECs than One Click and Athena; (2) the unheated basement foundation type exhibits the highest MUIs for each climate zone due to its quantities of structural, insulation, and drywall materials relative to its conditioned floor area; and (3) climate zones 7-8 require more substantial quantities of insulation materials across all buildings, due to their colder climates.

Variations in EECs for certain materials lead to notable disparities in reported EEIs for Athena, One Click, and Tally. For any given foundation type and climate zone, Athena yields the lowest EEIs, followed by One Click and Tally, with average EEIs of 1.16 GJ/m^2,

1.46 GJ/m^2, and 3.51 GJ/m^2, respectively. This is due to differences in the EECs across LCA data sources, particularly for the materials representing the most mass within each building (i.e., concrete, plywood, lumber, drywall, and steel). For instance, the concrete EECs for Athena, One Click, and Tally are 1.16, 1.30, and 1.49 MJ/kg, respectively, and the drywall EECs are 4.80, 5.35, and 9.70 MJ/kg, respectively. The EEC of a given material is highest from Tally and lowest from Athena on average. However, that is not always the case – for steel, the lowest EEC (10.81 MJ/kg) is associated with One Click, but the highest EEC is still associated with Tally (24.47 MJ/kg).

The EEI data are also organized by LCA module in **Figure 4-3**. In addition to the findings discussed above, **Figure 4-3** indicates that the majority of EEI for all buildings is associated with LCA modules A1-A3 (cradle-to-gate embodied energy). LCA modules A1-A3 make up 76-79% of total EEI using Athena (**Figure 4-3a-d**), 90-92% using One Click (**Figure 4-3e-h**), and 56-62% using Tally (**Figure 4-3i-l**). Beyond LCA modules A1-A3, each LCA data source includes assumptions and exclusions that can lead to substantial differences in total EEI for each building. Most notably, Tally makes assumptions about the replacement and maintenance of many materials (e.g., asphalt shingles), which effectively doubles or triples the EEC for materials where LCA modules B1-B5 were included. Conversely, One Click does not assume any replacement or maintenance unless specified by the user. Athena includes replacement emissions for a smaller number of materials than Tally. As a result, LCA modules B1-B5 account for 1.02 to 1.32 GJ/m^2 (33-39% of total EEI) for Tally, but only 0.08 GJ/m^2 (5-8%) for Athena (and effectively 0% for One Click). LCA modules A4-A5 comprise 0.1 to 0.15 GJ/m^2 (10-11%) of EEI for Athena, 0.06 to 0.1 GJ/m^2 (4-6%) for One Click, and 0.03 GJ/m^2 (1%) for Tally, and modules C1-C4 comprise 0.04 to 0.07 GJ/m^2 (4-5%) for Athena, 0.05 to 0.07 GJ/m^2 (4%) for One Click, and 0.1 to 0.16 GJ/m^2 (3-4%) for Tally. These variations indicate the underlying assumptions and data utilized by each LCA data source.

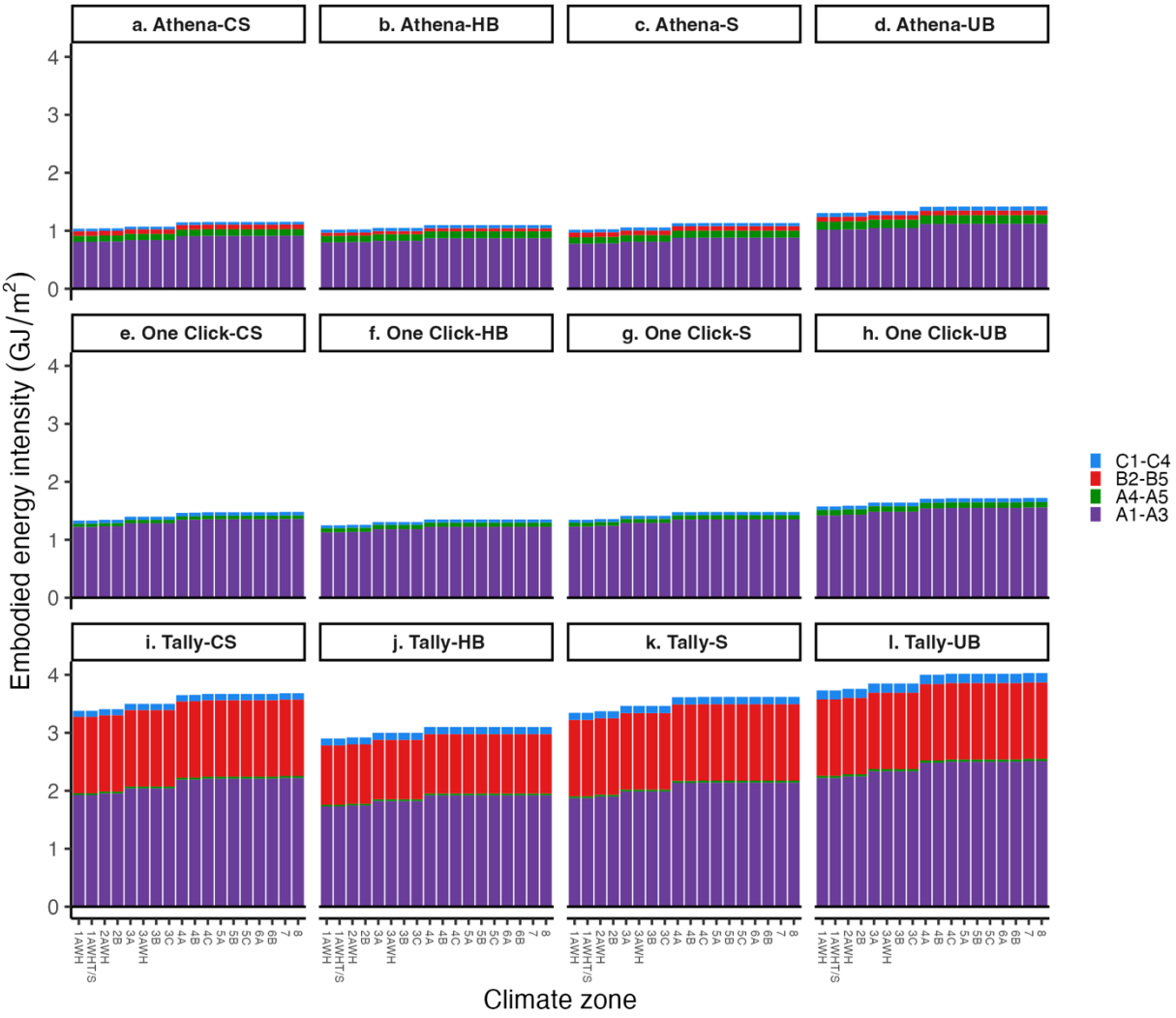

Figure 4-3. *EEIs of single-family residential prototype buildings, organized by climate zone and foundation type, with stacked bars delineating the contributing LCA modules.*

The EEI results demonstrate that choosing an LCA data source is crucial when analyzing and interpreting embodied energy data. This analysis found that, on average, EEIs from Tally were 67% higher than those for Athena and 59% higher than for One Click. Each tool's assumptions about the repair, maintenance, replacement, construction, and end-of-life treatment of building materials affect the results. For instance, Tally indicates the most substantial EEC contribution from replacement and maintenance when compared with the other LCA tools, which is evident in the EEIs related to module B. Future efforts could address disparities in these assumptions, to align the assumptions used to calculate module B and C impacts in these tools. Still, the cradle-to-gate embodied energy emissions (LCA modules A1-A3) alone show that results are highest with Tally and lowest with Athena.

The results also indicate that the trends across climate zones remain consistent with those in the MUI and ECI results of Chapter III. This consistency is an expected result, as EEIs are calculated directly from MUIs, multiplying the MUI of each material by its respective EEC.

4.3.2 Operational energy benchmarks

The EUIs for all 288 single-family residential buildings are shown in **Figure 4-4** and organized by foundation type, climate zone, and heating system type. **Figure 4-4a** presents the EUIs of single-family residential buildings with a crawl space foundation and an electric resistance heating system. These EUIs range from 68 kWh/m^2-yr (climate zone 3C) to 201 kWh/m^2-yr (climate zone 8). Unlike the relative upward trend in EEI from climate zone 1A to climate zone 8, there is more fluctuation in EUI from climate zone to climate zone. The lowest values are associated with more moderate climates (e.g., climate zone 3C). This result is expected, as energy consumption is dominated by the heating and cooling energy consumption of each prototype building, and heating and cooling demand are at their lowest in moderate climates. In all models, energy consumption due to lighting and

most plug loads are constant. However, heating, cooling, water heating, and cooking energy consumption, and thus, EUI, vary due to fuel types, system efficiencies, and the average hourly outdoor air temperatures for the city used in each simulation.

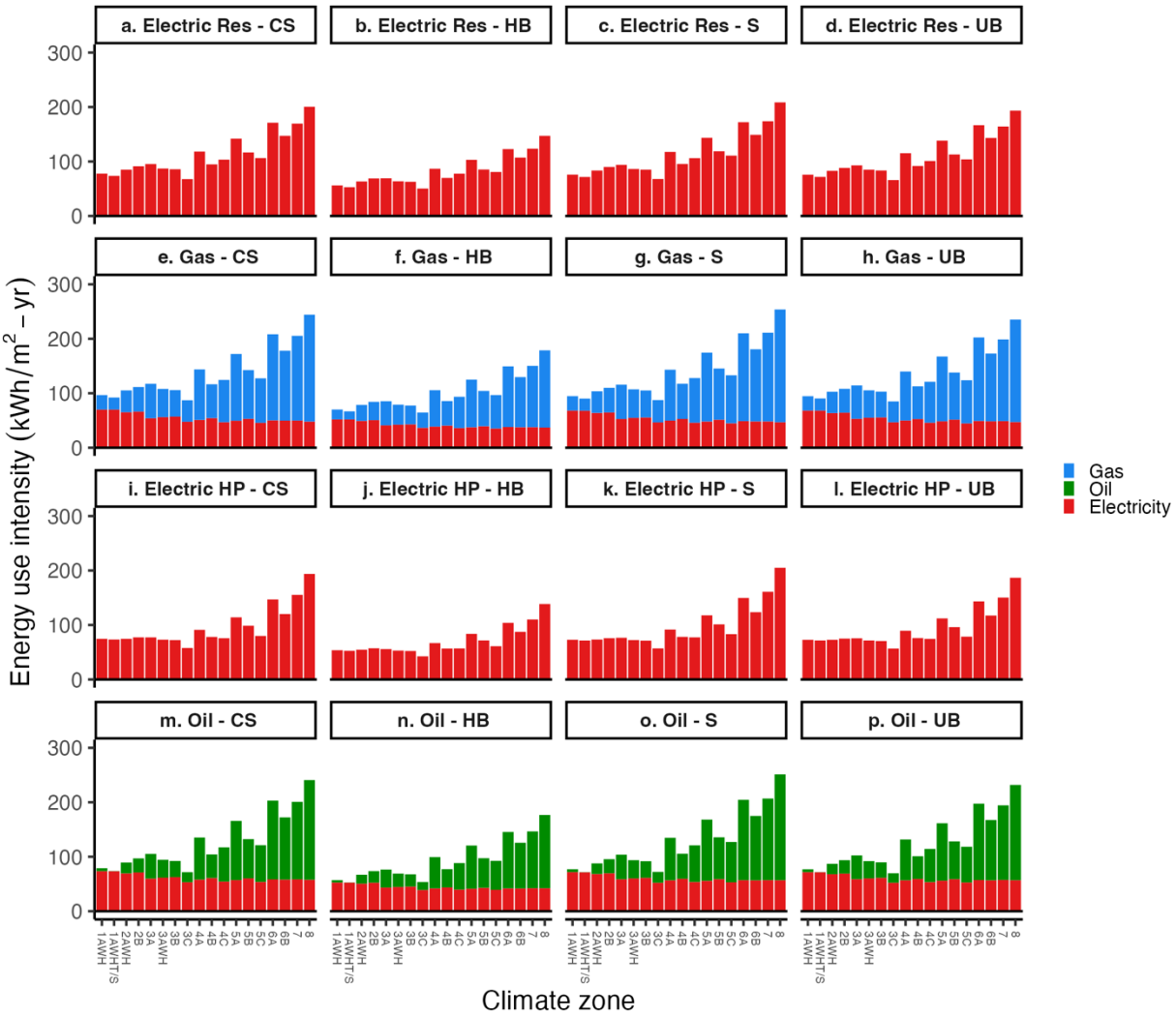

Figure 4-4. *EUIs for all operational energy models, broken down by climate zone, foundation type, and heating system.*

A building's demand for heating and cooling can be approximated by considering the number of HDDs and CDDs (as summarized in **Table 4-6)**. Although HDDs and CDDs do not consider heating or cooling system efficiency, they can help to explain differences in energy consumption across identical models in different locations, such as those in **Figure 4-4a**. The lowest EUI in **Figure 4-4A**, exhibited by climate zone 3C, is partially explained by the relatively low number of total degree days experienced in San Diego, CA, a city with a relatively mild climate compared with the others in this analysis. Total degree days are not an accurate predictor of relative EUI values since degree days do not consider the operational efficiency of heating and cooling systems or other whole-system energy effects (e.g., passive solar heating). For example, climate zone 4B (Albuquerque, NM) has a lower EUI than climate zone 4C (Seattle, WA) but a greater number of degree days (5669 vs. 5098 degree days). This disparity exists because the electric resistance heating modeled in EnergyPlus has a nominal efficiency of 100%, meaning that every 1 kWh of the electrical energy consumed for electric resistance heating is converted to 1 kWh of heat. In contrast, the cooling system has a rated coefficient of performance of 3.23, meaning that 3.23 kWh of heat is removed from the building for every 1 kWh of electrical energy consumed, on average. Additionally, Albuquerque, NM has higher annual solar exposure than Seattle, WA (average solar radiation of 6.48 kWh/m^2-day for Albuquerque compared with 4.12 kWh/m^2-day for Seattle) (*Solar Energy and Solar Power in Albuquerque, NM*, n.d.; *Solar Energy and Solar Power in Seattle, WA*, n.d.). That is to say, degree days partially explain the patterns observed in **Figure 4-4**, but other energy effects also play a role in these calculations.

Similar EUI trends are observed across all buildings with electric resistance heating, as shown in **Figure 4-1b-d**. EUIs range from 50 to 147 kWh /m^2-yr for heated basement foundation types, 68 to 209 kWh/m^2-yr for slab foundations, and 66 to 193 kWh/m^2-yr for unheated basement foundations. For all foundation types, climate zone 3C represents the minimum EUI, and climate zone 8 represents the maximum EUI. The

differences in EUI across foundation types are due to two key factors. The heated basement foundation type has a lower EUI than the other foundation types since it utilizes a greater conditioned floor area for calculating EUI. The heated basement buildings also have a slightly higher total operational energy consumption than the other foundation types. However, this increase is minor due to the insulative nature of the soil surrounding basement walls and the relatively low plug loads in the basements as they are modeled. Additionally, there are minor differences in total energy consumption across the foundation types due to the manner in which each foundation is uniquely insulated. Although the above-grade insulation is identical for each building, the placement and quantity of insulation varies for the different foundation types in a given climate zone.

Notable differences in EUIs exist across heating system types. **Figure 4-2a-p** shows that, for electric resistance, gas, electric heat pump, and oil heating, EUIs span from 50 to 209 kWh/m^2-yr, 65 to 254 kWh/m^2-yr, 42 to 205 kWh/m^2-yr, and 54 to 251 kWh/m^2-yr, respectively. These differences are due primarily to the efficiency of each heating system and secondarily to the water heating and cooling systems utilized in each model. The DOE prototype buildings assume a nominal efficiency of 100% for electric resistance heating, 80% for a gas furnace, and 78% for an oil furnace, with an assumed coefficient of performance of 3.69 for the electric heat pump. The electric heat pump system also has electric resistance backup heat, which is utilized when outdoor air temperatures are extremely low. Additionally, the cooling system (i.e., air conditioning) has a coefficient of performance of 3.23 for the electric resistance, gas furnace, and oil furnace buildings and a slightly more efficient coefficient of performance of 3.30 for the heat pump buildings. The electric resistance, heat pump, and oil furnace buildings have electric heat pump water heaters and electric stoves, while the gas furnace buildings have gas water heaters and gas stoves. Given that space heating is the most substantial load across most climate zones, the efficiency of the heating system drives the trend in EUIs, but the differences in efficiencies and fuel types account for other slight differences in EUI.

These results highlight that the choice of weather file can meaningfully impact the EUI results for a given climate zone. Different weather stations will report different HDDs and CDDs, thus resulting in different simulated EUIs within one climate zone or city. In this study, the weather files used by the DOE for each energy model were assumed, but a separate analysis could be conducted to consider the representativeness of these weather files across each climate zone. The DOE did not document the selection of representative cities for each weather file, so it is difficult to understand all the parameters considered in selecting these cities. Representativeness could be re-established based on one of many conditions, including the average weather conditions across the entire climate zone, the city with the greatest population in the climate zone, or the city with a high concentration of the studied building type (in this case, single-family residential buildings) for a given climate zone. City selection might depend on the intent of the analysis and how the results would be used. While the cities selected for some of these climate zones are the most populated cities in that climate zone (e.g., New York, NY for climate zone 4A), other climate zones have multiple options for populous cities (e.g., Los Angeles is the most populous city in climate zone 3C, where San Diego is the simulated city).

The operational energy analysis also illustrates that the relative differences in EUI across climate zones follow a different but expected pattern compared to the EEI patterns revealed in **Figure 4-3** and **Figure 4-4**. While the EEI generally increased from the hottest climate zones (e.g., climate zone 1AWH) to the coldest climate zones (e.g., climate zone 8), the EUI fluctuated across the climate zones, with minimum values occurring for climate zone 3C and maximum values for climate zone 8 across all combinations of foundation and heating system types. This is an expected result because climate zone 3C is the most moderate climate in terms of heating and cooling demand as it has the fewest total degree days (see **Table 4-6**), and climate zone 8 has the greatest heating demand and the greatest number of total degree days. Because the base energy loads in all buildings are relatively consistent, HVAC energy consumption fluctuates the most from model to model, and

heating systems are less efficient than cooling systems in general; we can expect climate zone 8 to exhibit the greatest total EUI.

4.3.3 Whole-life energy intensity benchmarks

Figure 4-5, Figure 4-6, and **Figure 4-7** show the WLEI (GJ/m^2) for each climate zone, heating system, and foundation type for the Athena, One Click, and Tally data, respectively. The operational EUI is identical for a given climate zone, heating system, and foundation type across all three figures, as the LCA data source is used to calculate EEIs and not EUIs.

Figure 4-5a presents the WLEI results for buildings with a crawl space foundation and electric resistance heating using Athena data. The range of WLEIs is 15.7 to 44.5GJ/m^2, with the lowest value associated with climate zone 3C and the heated basement foundation, and the highest with climate zone 8 and the slab foundation. Given that operational impacts dominate the WLEIs, trends in WLEI can be explained by the same trends underlying **Figure 4-4**. The proportion of embodied to total impacts (shown in **Table 4-7**) for the crawl space foundation, electric resistance heating, and Athena spans from 3% to 7%, with the lowest proportion associated with the highest WLEI and vice versa. Across **Figure 4-5a-d**, the WLEIs for all electric resistance buildings using Athena span from 11.9 GJ/m^2 (9% embodied impacts) for the electric resistance heating type, the heated basement foundation, and climate zone 3C to 46.2 GJ/m^2 (3% embodied impacts) for the slab foundation and climate zone 8. Considering all values in **Figure 4-5a-p** (all buildings analyzed using Athena), the lowest WLEI of 10.2 GJ/m^2 (10% embodied impacts) is for the prototype building in climate zone 3C with a heated basement and an electric heat pump, while the maximum WLEI of 55.9 GJ/m^2 (2% embodied impacts) is for the building in climate zone 8 with a slab foundation and gas furnace.

Figure 4-6 and **Figure 4-7** exhibit similar trends but different relative magnitudes. For One Click (**Figure 4-6**), the WLEI ranges from 10.5 GJ/m^2 (climate zone 3C, heated

basement, electric heat pump) to 56.2 GJ/m^2 (climate zone 8, slab, gas furnace) with EEI representing 3 to 12% of WLEI (see **Table 4-7**). Tally EEI results range from 12.1 (climate zone 3C, heated basement, electric heat pump) to 58.4 GJ/m^2 (climate zone 8, slab, gas furnace), with EEI representing 6% to 25% of WLEI (per **Table 4-7**). These results are expected, as the trends largely follow the operational EUI trends, which comprise the majority of WLEI for every building. Unsurprisingly, the highest WLEI is associated with a building in climate zone 8 with a gas furnace. It has already been established that climate zone 8 has the greatest number of total degree days and that buildings in climate zone 8 are the most materially intensive compared to other climate zones. Although the oil furnace has a lower efficiency (78%) than the gas furnace (80%), the buildings with gas furnaces also have gas water heaters, which have a lower efficiency (92% thermal efficiency) compared with the heat pump water heaters (COP = 3.0) included in buildings with oil heat. The variations in WLEI between buildings with oil and gas heat are relatively minor (<1% difference).

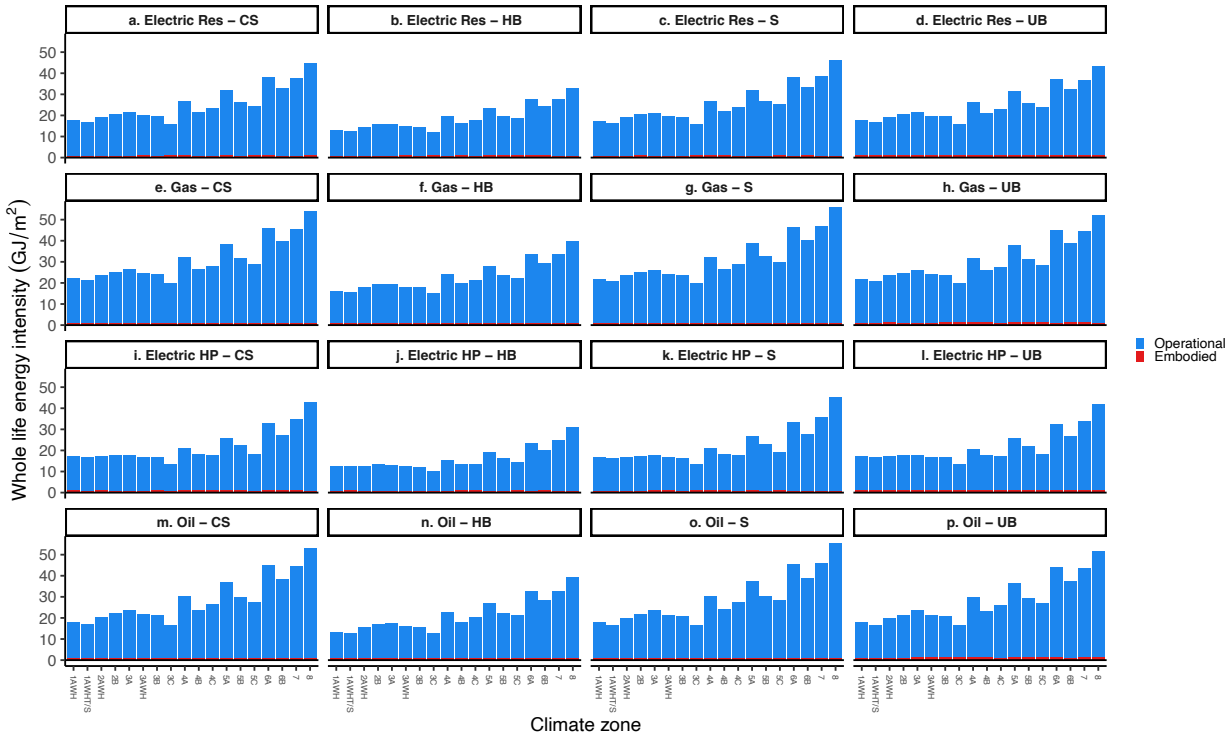

Figure 4-5. *WLEIs assuming a 60-year RSP for buildings that utilized Athena for EEI calculations.*

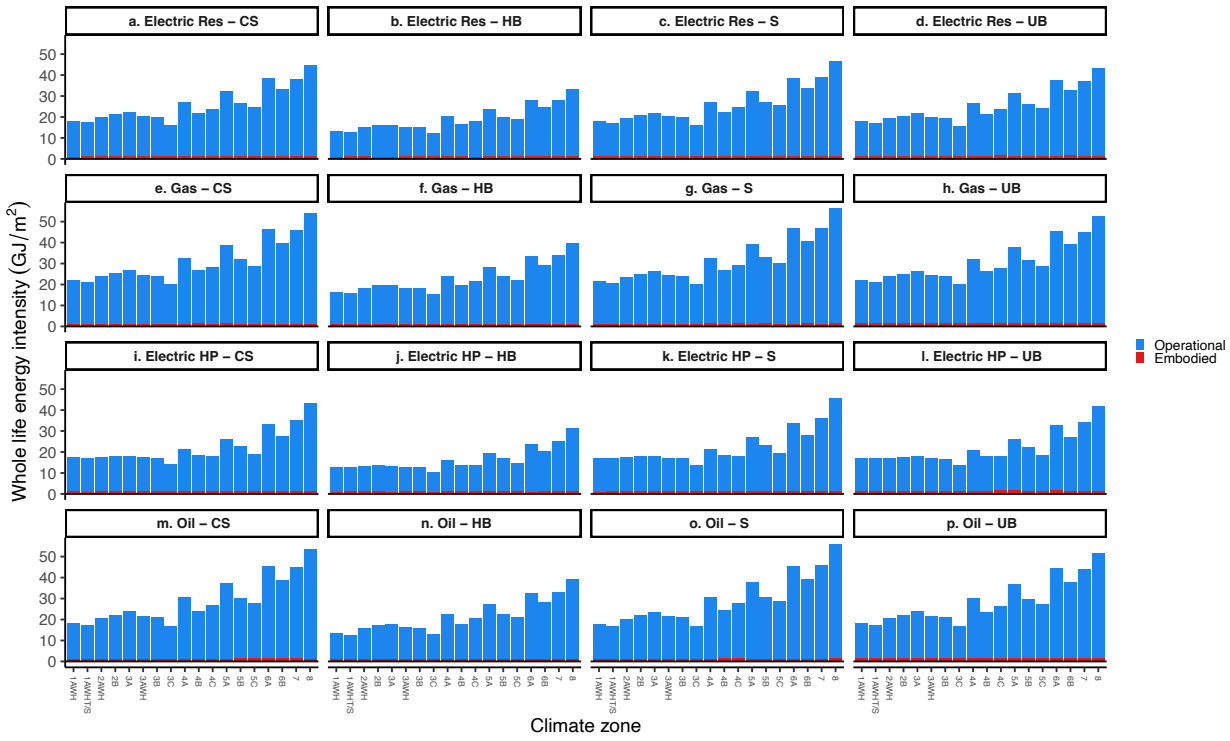

Figure 4-6. *WLEIs assuming a 60-year RSP for buildings that utilized One Click for EEI calculations.*

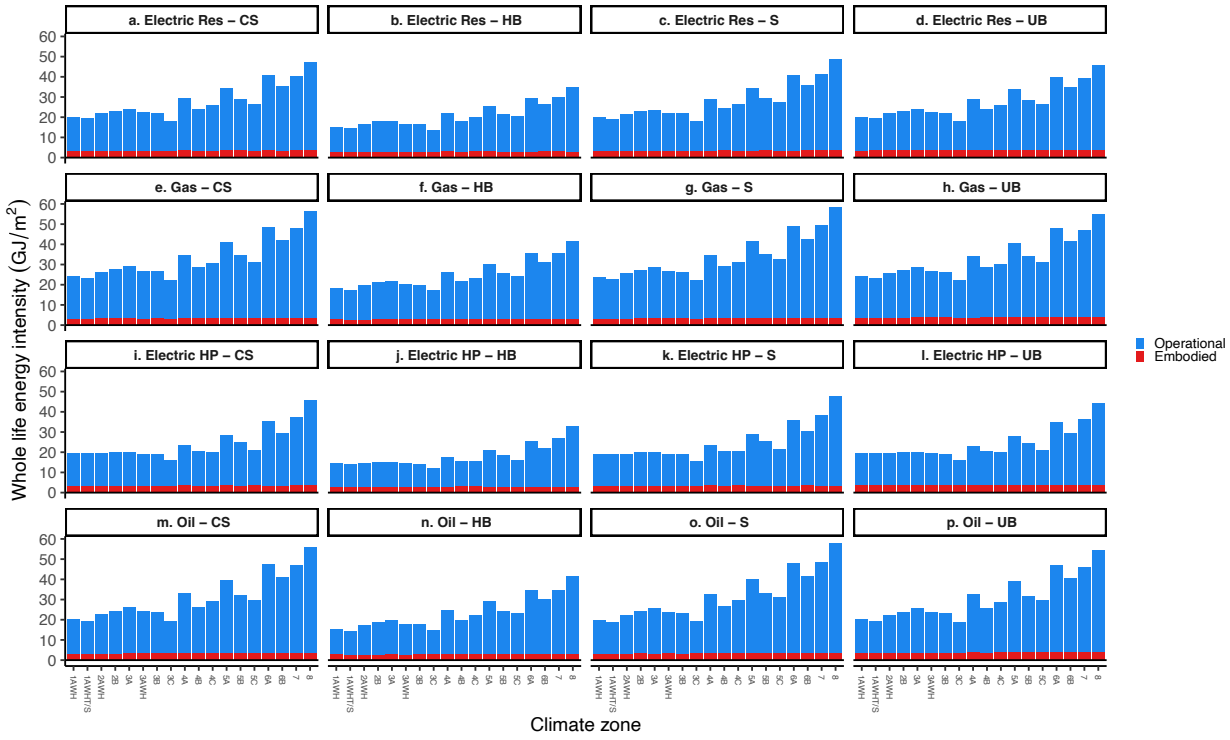

Figure 4-7. *WLEIs assuming a 60-year RSP for buildings that utilized Tally for EEI calculations.*

Table 4-7. *EEI expressed as a percent of WLEI for each building.*

LCA Data	Foundation Type	Crawlspace																	Heated basement														
	Climate Zone	*1AWH*	*2AWH*	*2B*	*3A*	*3AWH*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*	*1AWH*	*2AWH*	*2B*	*3A*	*3AWH*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*
	Heating System																																	
Athena	Electric resistance	6%	6%	5%	5%	5%	5%	5%	7%	4%	5%	5%	4%	4%	5%	3%	3%	3%	3%	8%	8%	7%	6%	7%	7%	7%	9%	6%	7%	6%	5%	6%	6%	4%	5%	4%	3%
	Gas furnace	5%	5%	4%	4%	4%	4%	4%	5%	4%	4%	4%	3%	4%	4%	2%	3%	3%	2%	6%	7%	6%	5%	5%	6%	6%	7%	5%	6%	5%	4%	5%	5%	3%	4%	3%	3%
	Heat pump	6%	6%	6%	6%	6%	6%	6%	8%	5%	6%	7%	4%	5%	6%	4%	4%	3%	3%	8%	8%	8%	8%	8%	8%	9%	10%	7%	8%	8%	6%	7%	8%	5%	5%	4%	4%
	Oil furnace	6%	6%	5%	5%	4%	5%	5%	6%	4%	5%	4%	3%	4%	4%	3%	3%	3%	2%	8%	8%	7%	6%	6%	7%	7%	8%	5%	6%	5%	4%	5%	5%	3%	4%	3%	3%
One click	Electric resistance	7%	8%	7%	6%	6%	7%	7%	9%	5%	7%	6%	5%	6%	6%	4%	4%	4%	3%	9%	10%	8%	8%	8%	9%	9%	11%	7%	8%	7%	6%	7%	7%	5%	6%	5%	4%
	Gas furnace	6%	6%	6%	5%	5%	6%	6%	7%	5%	6%	5%	4%	5%	5%	3%	4%	3%	3%	8%	8%	7%	6%	7%	7%	7%	9%	6%	7%	6%	5%	6%	6%	4%	5%	4%	3%
	Heat pump	8%	8%	8%	7%	8%	8%	8%	10%	7%	8%	8%	6%	6%	8%	4%	5%	4%	3%	10%	10%	10%	9%	10%	10%	10%	12%	9%	10%	10%	7%	8%	9%	6%	7%	5%	4%
	Oil furnace	7%	8%	7%	6%	6%	6%	7%	8%	5%	6%	6%	4%	5%	5%	3%	4%	3%	3%	9%	10%	8%	7%	7%	8%	8%	10%	6%	7%	7%	5%	6%	6%	4%	5%	4%	3%
Tally	Electric resistance	17%	18%	16%	15%	15%	16%	16%	19%	13%	15%	14%	11%	13%	14%	9%	10%	9%	8%	19%	20%	18%	16%	17%	18%	18%	22%	14%	17%	16%	12%	14%	15%	10%	12%	10%	9%
	Gas furnace	14%	15%	13%	12%	12%	13%	13%	16%	11%	13%	12%	9%	11%	12%	8%	9%	8%	7%	16%	17%	15%	14%	14%	15%	15%	18%	12%	14%	13%	10%	12%	13%	9%	10%	9%	7%
	Heat pump	17%	18%	17%	17%	17%	18%	18%	22%	16%	18%	18%	13%	15%	18%	10%	12%	10%	8%	20%	20%	20%	19%	20%	21%	21%	25%	18%	20%	20%	15%	17%	19%	12%	14%	12%	9%
	Oil furnace	17%	18%	15%	14%	13%	15%	15%	18%	11%	14%	13%	9%	11%	12%	8%	9%	8%	7%	19%	20%	17%	16%	15%	17%	17%	21%	13%	16%	14%	11%	13%	13%	9%	10%	9%	8%

LCA Data	Foundation Type	Slab																	Unheated basement																
	Climate Zone	*1AWH*	*2AWH*	*2B*	*3A*	*3AWH*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*	*1AWH*	*2AWH*	*2B*	*3A*	*3AWH*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*8*
	Heating System																																	
Athena	Electric resistance	6%	6%	5%	5%	5%	5%	5%	7%	4%	5%	5%	4%	4%	5%	3%	3%	3%	2%	7%	8%	7%	6%	6%	7%	7%	9%	5%	7%	6%	5%	5%	6%	4%	4%	4%	3%
	Gas furnace	5%	5%	4%	4%	4%	4%	4%	5%	4%	4%	4%	3%	3%	4%	2%	3%	2%	2%	6%	6%	6%	5%	5%	6%	6%	7%	4%	5%	5%	4%	5%	5%	3%	4%	3%	3%
	Heat pump	6%	6%	6%	6%	6%	6%	6%	8%	5%	6%	6%	4%	5%	6%	3%	4%	3%	2%	8%	8%	8%	7%	8%	8%	8%	10%	7%	8%	8%	6%	6%	8%	4%	5%	4%	3%
	Oil furnace	6%	6%	5%	5%	5%	5%	5%	6%	4%	5%	4%	3%	4%	4%	3%	3%	2%	2%	7%	8%	7%	6%	6%	6%	6%	8%	5%	6%	5%	4%	5%	5%	3%	4%	3%	3%
One click	Electric resistance	8%	8%	7%	7%	7%	7%	7%	9%	5%	7%	6%	5%	5%	6%	4%	4%	4%	3%	9%	9%	8%	8%	8%	8%	8%	10%	6%	8%	7%	5%	7%	7%	5%	5%	5%	4%
	Gas furnace	6%	6%	6%	5%	5%	6%	6%	7%	5%	6%	5%	4%	4%	5%	3%	4%	3%	3%	7%	7%	7%	6%	6%	7%	7%	8%	5%	7%	6%	5%	5%	6%	4%	4%	4%	3%
	Heat pump	8%	8%	8%	8%	8%	8%	8%	10%	7%	8%	8%	5%	6%	8%	4%	5%	4%	3%	9%	9%	9%	9%	9%	10%	10%	12%	8%	9%	10%	7%	8%	9%	5%	6%	5%	4%
	Oil furnace	7%	8%	7%	6%	6%	7%	7%	8%	5%	6%	5%	4%	5%	5%	3%	4%	3%	3%	9%	9%	8%	7%	7%	8%	8%	10%	6%	7%	6%	5%	6%	6%	4%	5%	4%	3%
Tally	Electric resistance	17%	18%	16%	15%	15%	16%	16%	19%	12%	15%	14%	10%	12%	13%	9%	10%	9%	7%	19%	19%	17%	16%	16%	17%	18%	21%	14%	17%	16%	12%	14%	15%	10%	12%	10%	9%
	Gas furnace	14%	15%	13%	12%	12%	13%	13%	16%	10%	12%	12%	9%	10%	11%	7%	8%	7%	6%	15%	16%	14%	14%	13%	14%	15%	17%	12%	14%	13%	10%	12%	13%	8%	10%	9%	7%
	Heat pump	18%	18%	18%	17%	17%	18%	18%	22%	15%	18%	18%	12%	14%	17%	10%	12%	9%	8%	19%	19%	19%	19%	19%	20%	20%	24%	17%	20%	20%	14%	16%	19%	11%	14%	11%	9%
	Oil furnace	17%	18%	15%	14%	13%	15%	15%	18%	11%	14%	12%	9%	11%	12%	8%	9%	7%	6%	18%	19%	17%	16%	15%	16%	17%	20%	12%	16%	14%	10%	13%	14%	9%	10%	9%	7%

84

4.3.4 Embodied carbon intensity benchmarks

The ECIs for all 72 LCA models are presented in **Figure 4-8**. **Figure 4-8a** shows the ECIs for buildings with a crawl space foundation using Athena, which range from 51.4 to 56.8 $kgCO_2e/m^2$ between climate zones 1AWH and 8, respectively. The variations in ECI across climate zones can be explained by the need for higher quantities of XPS, lumber, and fiberglass batt insulation to meet the energy code in the cooler climate zones. The top contributors to ECI in **Figure 4-8a**, on average, are steel (including steel reinforcement, 24% of total ECI on average), concrete (21%), drywall (19%), glazing (11%), plywood (9%), and lumber (8%). Much like the trends for EEI, the ECI of steel is highest due to its above-average ECC (0.97 $kgCO_2e/kg$ for Athena, compared with the average of 0.65 $kgCO_2e/kg$), despite its relatively low mass (7% of total MUI for buildings in **Figure 4-8a**). Similarly, glazing only comprises 1.4% of MUI, but it represents 10.9% of ECI in **Figure 4-8a** due to its high ECC (2.23 $kgCO_2e/kg$). Concrete is a top contributor in **Figure 4-8a** despite its lower ECC (0.15 $kgCO_2e/kg$) due to its high relative mass (38.5% of total MUI).

Similar trends are apparent across all foundation types for Athena (**Figures 8b-8d)**. Across all climate zones, ECIs range from 59.7 to 63.1 $kgCO_2e/m^2$ for the heated basement foundation type (**Figure 4-8b)**, 55.0 to 60.2 $kgCO_2e/m^2$ for slab (**Figure 4-8c**), and 78.5 to 83.5 $kgCO_2e/m^2$ for unheated basement (**Figure 4-8d**). The top six contributors to ECI remain steel, concrete, drywall, glazing, plywood, and lumber, but concrete is the leading contributor to ECI for the heated basement, slab, and unheated basement foundation types. The relative contributions of the other materials shift due to the different structural and building envelope designs of the prototype buildings. For example, the top contributors for the slab foundation type are concrete (32% of total ECI for **Figure 4-8c**), drywall (18%), steel (16%), glazing (10%), plywood (9%), and lumber (8%).

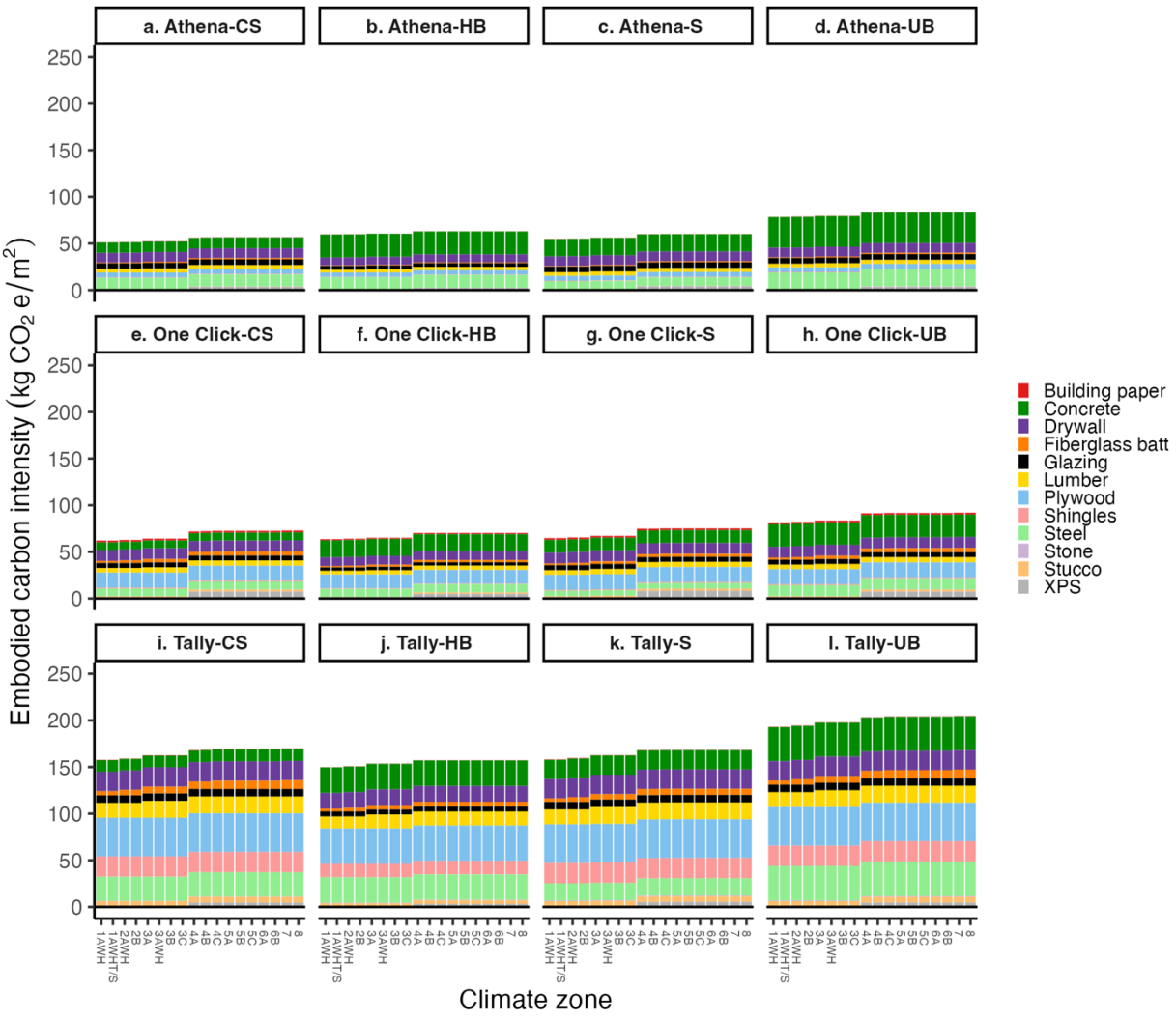

Figure 4-8. *ECIs of single-family residential prototype buildings, organized by climate zone and foundation type, with stacked bars delineating the contributing materials.*

Figure 4-8e-h (One Click) and **Figure 4-8i-l** (Tally) portray similar trends to **Figure 4-8a-d** (Athena) but with different magnitudes. Similar to the Athena ECI results, the One Click and Tally ECIs are lowest for climate zone 1AWH and highest for climate zone 8 across each foundation type. The ECIs range from 51.4 to 83.5 $kgCO_2e/m^2$ for Athena, 62.1 to 92.0 $kgCO_2e/m^2$ for One Click, and 149.9 to 204.8 $kgCO_2e/m^2$ for Tally. The crawl space foundation type has the lowest ECI value for Athena and One Click, while the heated basement is the lowest for Tally. For all LCA data sources, the highest values are

associated with the unheated basement foundation type. These results are consistent with the relative EEI results in **Figure 4-2** and **Figure 4-3**.

Another consistent trend between the EEI and ECI results is the effect that the applicable LCA tool has on the results. Tally reports the highest ECIs, with an average ECI of 171.4 $kgCO_2e/m^2$, One Click reports the next highest, with an average ECI of 73.7 $kgCO_2e/m^2$, and Athena reports the lowest, with an average ECI of 64.0 $kgCO_2e/m^2$. This finding is a direct result of the average ECCs reported for each LCA data source – the average ECC used in this study is 0.65 $kgCO_2e/kg$ for Athena, 1.39 $kgCO_2e/kg$ for One Click, and 2.09 $kgCO_2e/kg$ for Tally. All three LCA tools report similar ECCs for some materials, like concrete (0.15, 0.11, and 0.17 $kgCO_2e/kg$ for Athena, One Click, and Tally, respectively); however, there are noteworthy disparities in ECC for other commonly used materials such as plywood (0.20 $kgCO_2e/kg$ for Athena, 0.63 $kgCO_2e/kg$ for One Click, and 1.62 $kgCO_2e/kg$ for Tally. This disparity leads to an ECI for plywood approximately 8 times higher for Tally than Athena.

Figure 4-9 illustrates that these differences are also due to differences in ECCs by LCA module between Athena, Tally, and One Click. Similar to the EEI results, cradle-to-gate impacts (LCA modules A1-A3) account for the majority of the ECI for Athena (73-78% of total ECI) and One Click (86-90%). LCA modules A1-A3 are the greatest contributors for Tally, representing 44-54% of total ECI. Tally includes the most substantial allowance for maintenance and replacement emissions (B1-B5), accounting for use-stage emissions for drywall, glazing, plywood, shingles, and stucco. Athena includes B1-B5 emissions for glazing and shingles, while One Click does not include any emissions in LCA module B by default. Tally also includes a greater allocation of end-of-life emissions, primarily due to a relatively high ECC for C1-C4 emissions of wood products (0.52 $kgCO_2e/kg$) compared with One Click (0.017 $kgCO_2e/kg$) and Athena (0.035 $kgCO_2e/kg$).

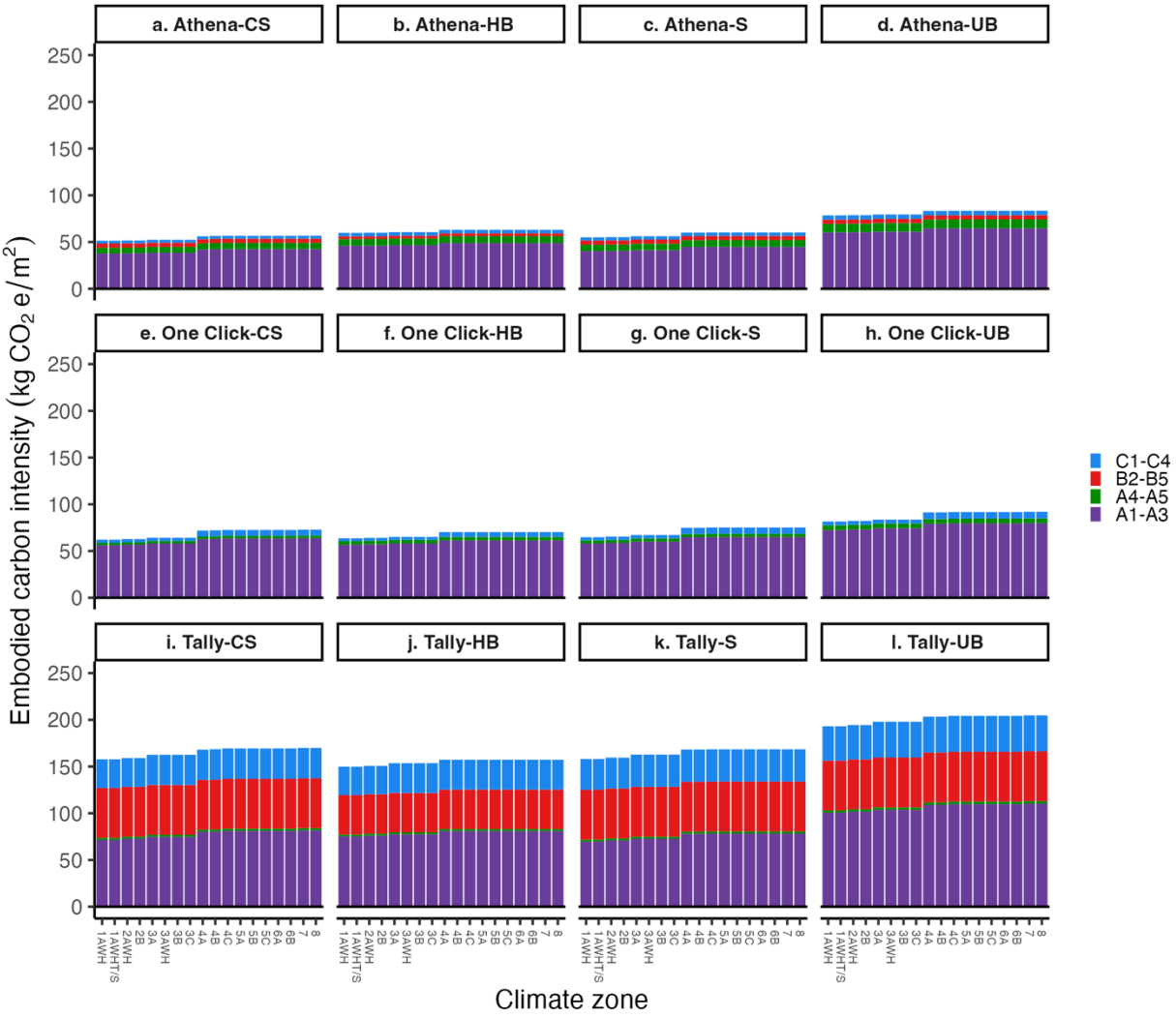

Figure 4-9. *ECIs of single-family residential prototype buildings, organized by climate zone and foundation type, with stacked bars delineating the contributing LCA modules.*

The key takeaways related to ECI mirror those discussed for EEI. The choice of LCA data remains very important when analyzing and interpreting the results of any LCA. Tally reports the highest ECI values, and Athena reports the lowest. Again, it is clear that replacement and maintenance emissions are accounted for much more heavily in Tally than the other LCA tools due to substantial module B emissions. The underlying assumptions cause some of the disparity in LCA results between the three tools – particularly for the higher-than-average values reported by Tally. The relative differences between the LCA

tools are not consistent with Chapter III. In Chapter III, the lowest values are reported for Athena (like in this chapter), but the highest values are reported for One Click. Since the development of Chapter III, there has been an update to the underlying LCA data in One Click, which reduced several ECCs, most notably the ECC for XPS insulation. In Chapter III, the ECC of XPS for LCA modules A1-A3 was 24.8 $kgCO_2e/kg$ (One Click LCA version 0.2.2 accessed February 7, 2022), and in Chapter IV, the EC of XPS for modules A1-A3 was 3.1 $kgCO_2e/kg$ (One Click LCA Version 0.23.0, Database version: 7.6, accessed December 20, 2023). This is likely due to the impact related to different blowing agents in the production of XPS, and how they were accounted for in the two versions of One Click LCA. There were other small changes in LCA data for One Click that did not substantially change the relative ECIs.

4.3.5 Operational carbon emissions intensity benchmarks

The OCI results for all 288 energy models are shown in **Figure 4-10**. The values in **Figure 4-10a**, signifying the crawl space foundation and electric resistance heating, range from a low of 4.1 $kgCO_2e/m^2$-yr for climate zone 3C to a high of 32.4 $kgCO_2e/m^2$-yr for climate zone 6B. The low value is expected, as San Diego, CA (climate zone 3C) has the lowest EUI in **Figure 4-2a**, and CAISO, the GEA region associated with San Diego, has an aggressive decarbonization plan. Conversely, Great Falls, MT (Climate Zone 6B) has one of the highest EUIs given its cold climate, and its grid emission rate does not decrease substantially over time. OCIs are not directly correlated to EUI, as the grid emissions projections in the Cambium dataset have a major impact on the electric emissions over time.

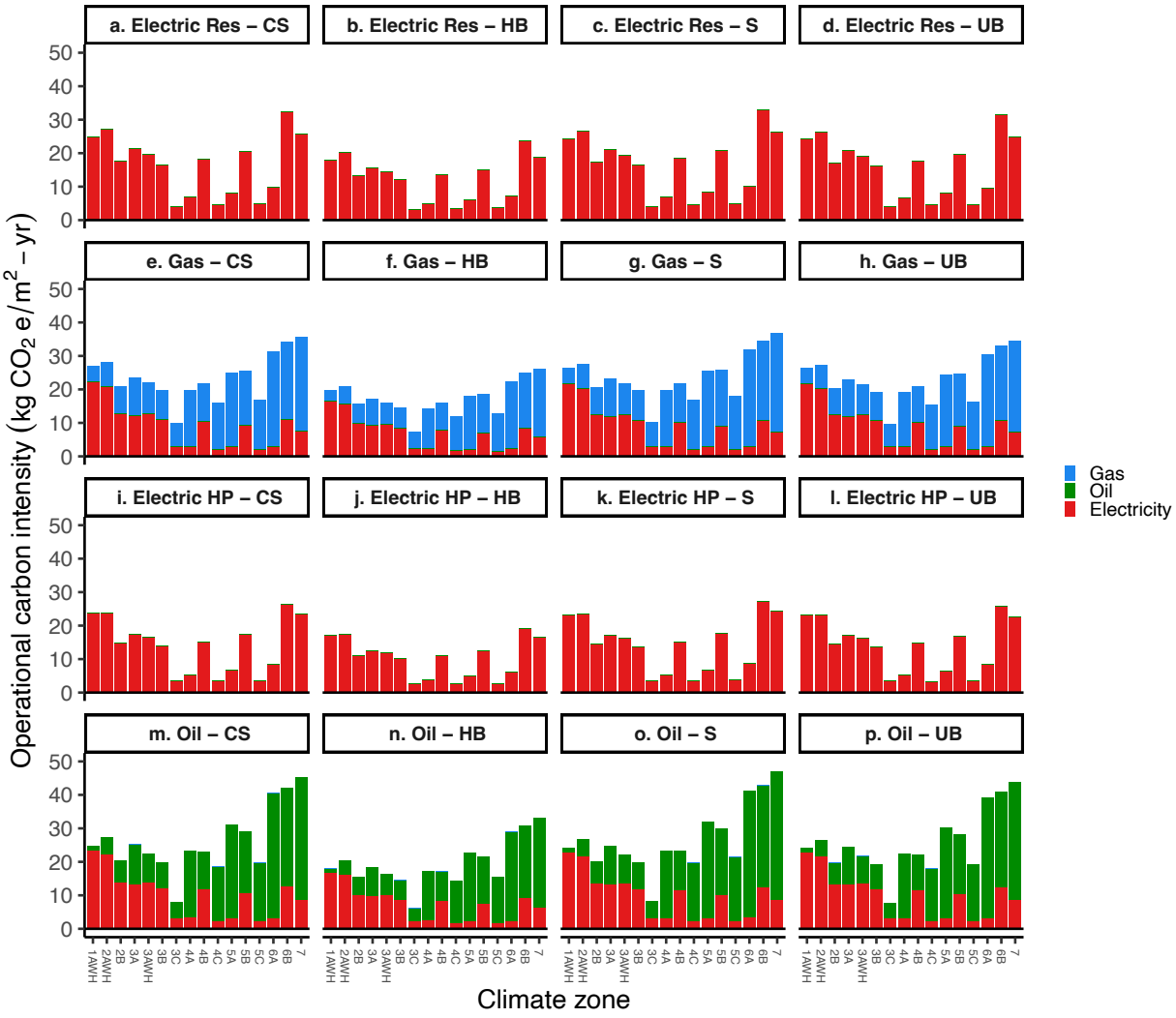

Figure 4-10. *OCIs for all 288 buildings, broken down by climate zone, foundation type, and heating system.*

Considering **Figure 4-10a-d**, the same relative ranking of OCIs across climate zones is observed for each foundation type and electric resistance heating. Climate zone 3C has the consistently lowest OCI, and climate zone 6B has the consistently highest OCI for buildings with electric resistance heating, with OCI ranges of 3.05 to 23.6 $kgCO_2e/m^2$ for the heated basement foundation type, 4.12 to 32.8 $kgCO_2e/m^2$ for the slab foundation type, and 4.0 to 31.6 $kgCO_2e/m^2$ for the unheated basement foundation type. The heated basement foundation tends to have the lowest OCI values, and the slab foundation has the highest.

The magnitude of OCI changes across different heating system types due primarily to the difference in emission rates between electricity, natural gas, and oil, but many emission patterns remain the same across climate zones. For instance, in **Figure 4-10e** (gas furnace, crawl space), the lowest OCI is attributed to climate zone 3C (10.0 $kgCO_2e/m^2$), and the highest OCI is attributed to climate zone 7 (35.6 $kgCO_2e/m^2$), followed by climate zone 6B. The differences in OCI between **Figures 10a and 10e** are most apparent for climate zones with very low grid emission rates or high heating loads. Most EUI values are primarily driven by heating and cooling loads, with some variation due to HVAC system efficiencies. Most notably, the OCI for climate zone 5C is 300% higher in **Figure 4-10e** (gas furnace) than **10a** (electric resistance), as climate zone 5C has a very low grid emission rate over time (between 0.024-0.1 $kgCO_2e/kWh$) compared with the natural gas emission rate (0.180 $kgCO_2e/kWh$). **Figure 4-10e-h** exhibits similar patterns across the gas heating system type, with climate zone 3C consistently reporting the lowest OCI across climate zones for a given foundation type and climate zone 8 consistently reporting the highest values, with OCIs between 7.3 to 26.0 $kgCO_2e/m^2$ for the heated basement foundation type, 10.2 to 36.7 $kgCO_2e/m^2$ for slab, and 9.7 to 34.5 $kgCO_2e/m^2$ for unheated basement.

Figure 4-10i-l (electric heat pump) demonstrates similar relative OCIs to **Figure 4-10a-d** (electric resistance), because the electric heat pump buildings rely on the same fuel

(grid electricity), identical water heating systems, identical base electric loads, and similar air conditioning systems. However, the electric heat pump buildings have lower relative OCIs than the electric resistance buildings due to the higher efficiency of the heat pump system, which has a coefficient of performance of 3.69 (compared with the nominal efficiency of 1.0 for the electric resistance heating system). As a result, the minimum OCI in **Figure 4-10i** is 3.4 $kgCO_2e/m^2$ for climate zone 3C, and the maximum OCI is 26.5 $kgCO_2e/m^2$ for climate zone 6B. Across **Figure 4-10j-10l**, the OCIs similarly mirror **Figure 4-10b-10d**, but with slightly lower OCIs. The OCIs for the electric heat pump buildings range from 2.5 to 19.3 $kgCO_2e/m^2$ for heated basement buildings, 3.5 to 27.2 $kgCO_2e/m^2$ for slab, and 3.3 to 25.9 for unheated basement. In extremely cold conditions, the electric heat pump system is modeled to utilize electric resistance backup heating, effectively reducing its efficiency from a COP of 3.69 to a nominal efficiency of 1.00. The heat pump buildings rely on backup heating most often in the coldest climates (e.g., climate zones 7 and 8), leading to greater energy consumption and, thus, greater OCI.

Figure 4-10m mirrors **Figure 4-10e**, with similar trends in OCI but higher OCI values primarily due to the higher emission rate for fuel oil (0.075 $kgCO_2e/kbtu$ or 0.26 $kgCO_2e/kWh$) compared with gas (0.053 $kgCO_2e/kbtu$ or 0.18 $kgCO_2e/kWh$), but also due to its reliance on an electric heat pump water heater, which is more efficient than gas heat, but utilizes electricity, which has a higher emission rate than gas in most climate zones. Oil furnaces are also modeled with a lower efficiency (78%) than gas furnaces (80%). Those comparative trends are valid across all buildings with oil furnace heating, where the lowest OCI is attributed to climate zone 3C, and the highest is attributed to climate zone 7. OCIs span 8.0 to 45.3 $kgCO_2e/m^2$ for crawl space foundations, 6.1 to 33.1 $kgCO_2e/m^2$ for heated basement, 8.3 to 47.0 $kgCO_2e/m^2$ for slab, and 7.6 to 43.8 $kgCO_2e/m^2$ for unheated basement.

4.3.6 Whole-life carbon intensity

The WLCIs of the building models are summarized in **Figure 4-11, Figure 4-12**, and **Figure 4-13**, separated by LCA tool, climate zone, heating system, and foundation type. The OCI is identical for each climate zone, heating system, and foundation type, while the ECI varies.

The WLCI results for buildings with a crawl space foundation and electric resistance heating calculated using Athena are presented in **Figure 4-11a**. The range of WLCIs is from 299 to 2003 $kgCO_2e/m^2$, with the lowest value associated with climate zone 3C and the highest with climate zone 6B. These trends are directly tied to the trends demonstrated in **Figure 4-10a**, as OCI represents the majority of WLCI. The proportion of ECI to WLCI for the buildings in **Figure 4-11a** spans from 4% to 18%. The contribution of ECI to WLCI across all scenarios is summarized in **Figure 4-8**. Across all buildings analyzed using Athena, the lowest WLCI of 215 $kgCO_2e/m^2$ is associated with the electric heat pump, heated basement, and climate zone 3C. This is expected, as the electric heat pump buildings have higher energy efficiency, climate zone 3C has a mild climate and a low 60-year emission rate, and the heated basement foundation type has the largest area over which emissions can be normalized. Conversely, the highest WLCI for Athena, 2718 $kgCO_2e/m^2$, is associated with oil heat, climate zone 7, and the crawl space foundation. This outcome aligns with the characteristics of this scenario, as oil has the highest emission factor of any heating fuels, climate zone 7 has high heating demand, and the slab foundation type features a higher ECI and OCI than the other foundation types.

The WLCIs computed using One Click and Tally exhibit similar trends but with different magnitudes of WLCI. Across **Figure 4-12,** WLCIs computed using One Click range from 220 to 2894 $kgCO_2e/m^2$, and the ECI as a proportion of WLCI ranges from 3 to 31%. The Tally WLCIs reported in **Figure 4-13** range from 308 to 2987 $kgCO_2e/m^2$, and the ECI as a proportion of WLCI ranges from 6 to 51%. Although the proportion of ECI to WLCI can grow to 51%, it is 11% on average across all tools. The 51% proportion is

associated with climate zone 4C, the heat pump, Tally, and the heated basement, where grid emissions are low, the climate is mild, the heating source is highly efficient, and the Tally ECIs are higher than other sources. For all three LCA data sources, the lowest WLCI is associated with electric heat pump, climate zone 3C, and the heated basement, and the highest WLCI with oil heat, climate zone 7, and the slab foundation. This aligns with the findings for **Figure 4-11** and the WLEI analysis above.

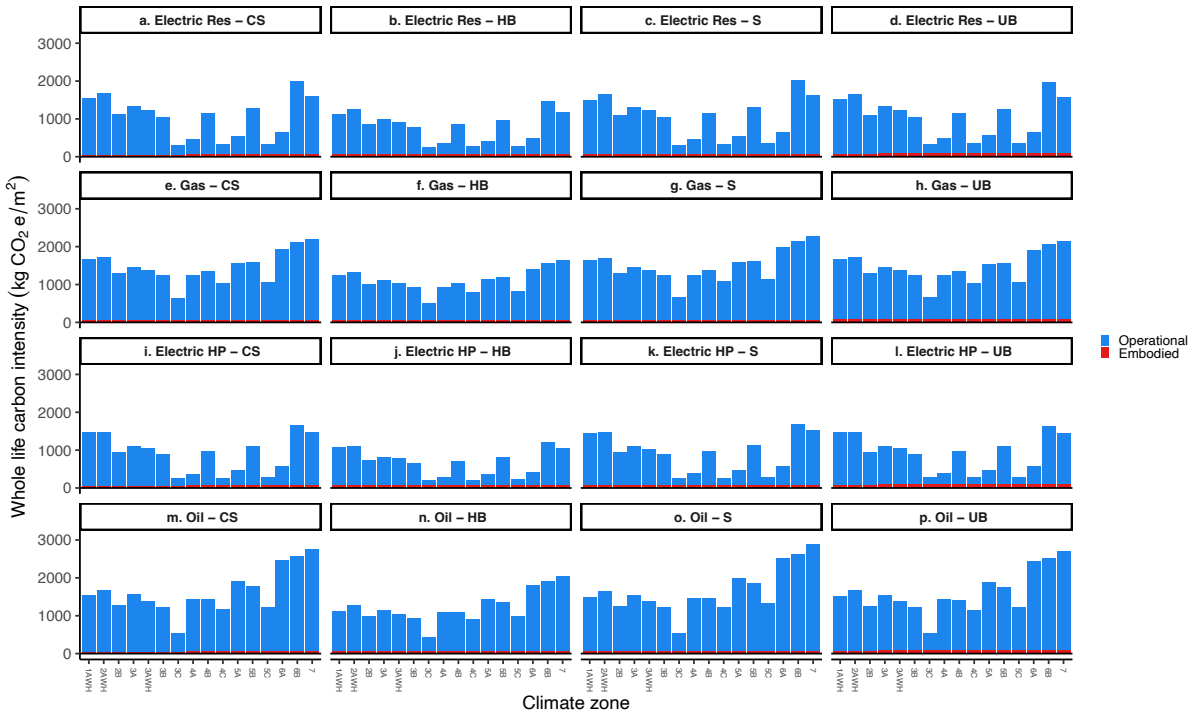

Figure 4-11. *WLCIs assuming a 60-year RSP for buildings that utilized Athena for ECI calculations.*

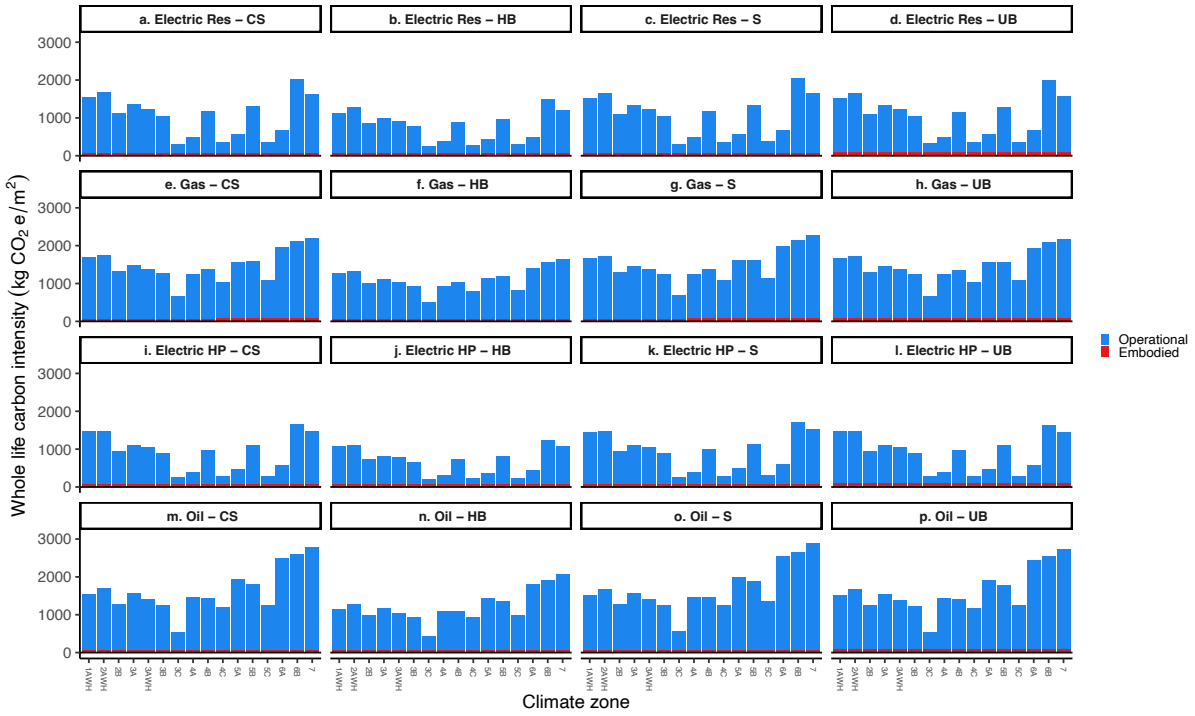

Figure 4-12. *WLCIs assuming a 60-year RSP for buildings that utilized One Click for ECI calculations.*

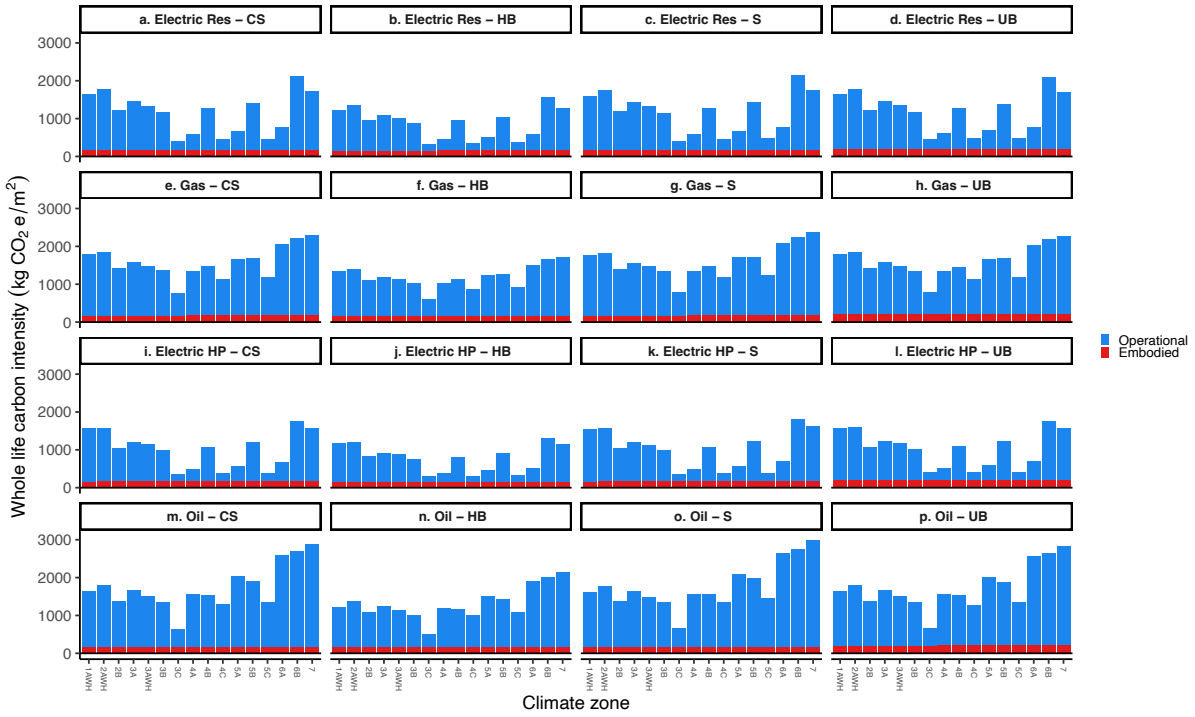

Figure 4-13. *WLCIs assuming a 60-year RSP for buildings that utilized Tally for ECI calculations.*

Table 4-8. *ECI expressed as a percent of total WLCI (excluding biogenic carbon storage) for each building.*

LCA Data	Foundation Type	Crawlspace															Heated basement														
	Climate Zone	*1AWH*	*2AWH*	*2B*	*3A*	*3AWH*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*1AWH*	*2AWH*	*2B*	*3A*	*3AWH*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*
	Heating System																																
Athena	Electric resistance	3%	3%	5%	4%	4%	5%	18%	12%	5%	17%	10%	4%	17%	9%	3%	4%	5%	5%	7%	6%	7%	8%	25%	17%	7%	23%	15%	7%	23%	13%	4%	5%
	Gas furnace	3%	3%	4%	4%	4%	4%	8%	5%	4%	6%	4%	4%	5%	3%	3%	3%	5%	5%	6%	6%	6%	6%	12%	7%	6%	8%	6%	5%	8%	5%	4%	4%
	Heat pump	3%	3%	5%	5%	5%	6%	20%	15%	6%	22%	13%	5%	21%	10%	3%	4%	6%	5%	8%	7%	8%	9%	28%	21%	9%	29%	18%	8%	28%	15%	5%	6%
	Oil furnace	3%	3%	4%	3%	4%	4%	10%	4%	4%	5%	3%	3%	5%	2%	2%	2%	5%	5%	6%	5%	6%	7%	14%	6%	6%	7%	4%	5%	6%	4%	3%	3%
One click	Electric resistance	4%	4%	6%	5%	5%	6%	21%	15%	6%	21%	13%	6%	20%	11%	4%	5%	6%	5%	7%	7%	7%	8%	26%	19%	8%	25%	16%	7%	24%	14%	5%	6%
	Gas furnace	4%	4%	5%	4%	5%	5%	10%	6%	5%	7%	5%	5%	7%	4%	3%	3%	5%	5%	6%	6%	6%	7%	13%	8%	7%	9%	6%	6%	8%	5%	4%	4%
	Heat pump	4%	4%	7%	6%	6%	7%	23%	18%	7%	26%	15%	7%	25%	12%	4%	5%	6%	6%	9%	8%	8%	10%	30%	23%	10%	31%	19%	9%	30%	16%	6%	7%
	Oil furnace	4%	4%	5%	4%	5%	5%	12%	5%	5%	6%	4%	4%	6%	3%	3%	3%	6%	5%	6%	6%	6%	7%	15%	6%	6%	8%	5%	5%	7%	4%	4%	3%
Tally	Electric resistance	10%	9%	13%	11%	12%	14%	40%	29%	13%	38%	26%	12%	37%	22%	8%	10%	12%	11%	16%	14%	15%	17%	46%	34%	16%	43%	30%	15%	42%	27%	10%	12%
	Gas furnace	9%	9%	11%	10%	11%	12%	21%	12%	11%	15%	10%	10%	14%	8%	8%	7%	11%	11%	14%	13%	14%	15%	26%	15%	14%	18%	13%	12%	17%	11%	10%	9%
	Heat pump	10%	10%	15%	13%	14%	16%	44%	35%	16%	45%	30%	14%	44%	25%	10%	11%	13%	13%	19%	17%	18%	20%	50%	40%	19%	51%	35%	17%	49%	30%	12%	14%
	Oil furnace	10%	9%	12%	10%	11%	12%	25%	11%	11%	13%	8%	9%	13%	7%	6%	6%	12%	11%	14%	12%	14%	15%	30%	13%	13%	16%	10%	11%	15%	8%	8%	7%

LCA Data	Foundation Type	Slab															Unheated basement														
	Climate Zone	*1AWH*	*2AWH*	*2B*	*3A*	*3AWH*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*	*1AWH*	*2AWH*	*2B*	*3A*	*3AWH*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*5C*	*6A*	*6B*	*7*
	Heating System																																
Athena	Electric resistance	4%	3%	5%	4%	5%	5%	19%	13%	5%	17%	11%	5%	17%	9%	3%	4%	5%	5%	7%	6%	6%	8%	25%	17%	7%	24%	15%	7%	23%	13%	4%	5%
	Gas furnace	3%	3%	4%	4%	4%	5%	8%	5%	4%	6%	4%	4%	5%	3%	3%	3%	5%	5%	6%	5%	6%	6%	12%	7%	6%	8%	5%	5%	8%	4%	4%	4%
	Heat pump	4%	4%	6%	5%	5%	6%	21%	16%	6%	22%	13%	5%	21%	10%	4%	4%	5%	5%	8%	7%	8%	9%	28%	21%	9%	29%	18%	8%	28%	14%	5%	6%
	Oil furnace	4%	3%	4%	4%	4%	5%	10%	4%	4%	5%	3%	3%	4%	2%	2%	2%	5%	5%	6%	5%	6%	6%	15%	6%	6%	7%	4%	5%	7%	3%	3%	3%
One click	Electric resistance	4%	4%	6%	5%	5%	6%	21%	15%	6%	21%	13%	6%	20%	11%	4%	5%	5%	5%	7%	6%	7%	8%	26%	19%	8%	25%	16%	7%	25%	14%	5%	6%
	Gas furnace	4%	4%	5%	5%	5%	5%	10%	6%	5%	7%	5%	5%	7%	4%	4%	3%	5%	5%	6%	6%	6%	7%	13%	7%	7%	9%	6%	6%	9%	5%	4%	4%
	Heat pump	4%	4%	7%	6%	6%	8%	24%	19%	8%	27%	16%	7%	25%	13%	4%	5%	6%	6%	9%	8%	8%	9%	29%	23%	9%	31%	19%	8%	30%	16%	6%	6%
	Oil furnace	4%	4%	5%	4%	5%	5%	12%	5%	5%	6%	4%	4%	6%	3%	3%	3%	5%	5%	7%	5%	6%	7%	15%	6%	6%	8%	5%	5%	7%	4%	4%	3%
Tally	Electric resistance	10%	9%	13%	11%	12%	14%	40%	29%	13%	37%	25%	12%	36%	22%	8%	10%	12%	11%	16%	14%	15%	17%	45%	34%	16%	43%	30%	15%	42%	26%	10%	12%
	Gas furnace	9%	9%	11%	10%	11%	12%	21%	12%	11%	14%	10%	10%	14%	8%	8%	7%	11%	11%	14%	13%	13%	15%	25%	15%	14%	18%	12%	12%	17%	10%	9%	9%
	Heat pump	10%	10%	15%	14%	14%	16%	44%	35%	16%	45%	29%	14%	43%	24%	9%	10%	12%	12%	18%	16%	17%	19%	49%	40%	19%	50%	34%	17%	49%	29%	12%	13%
	Oil furnace	10%	9%	12%	10%	11%	12%	25%	11%	11%	13%	8%	9%	12%	6%	6%	6%	12%	11%	14%	12%	13%	15%	30%	13%	13%	16%	10%	11%	15%	8%	8%	7%

4.4 Discussion

4.4.1 Key Takeaways

Sections 4.3.3 and **4.3.6** substantiate that operational impacts dominate the contribution to WLEI and WLCI across all climate zones, heating systems, and foundation types. This dominance is attributed to 60 years of operational impacts that are considerably higher than A-C embodied impacts for each scenario analyzed herein. The proportion of EEI to WLEI is 9% on average, and the proportion of ECI to WLCI is 11% on average. This finding signifies that operational impacts dictate the patterns across climate zones and heating systems, and the choice of LCA tool will have little effect on the total WLEI and WLCI values.

A future study could consider the impact of RSP on WLEI and WLCI for these benchmarks. Previous studies have shown what typical ages of single-family residential buildings might be expected in the United States, but they have also explored the effect of RSP on life cycle impacts (Aktas & Bilec, 2012; Ianchenko et al., 2020). An RSP longer than 60 years would result in more years of operational impacts due to ongoing energy consumption in the building. However, it would also trigger additional emissions in LCA module B, including repair, replacement, and refurbishment of materials that may reach the end of their useful life after 60 years. An RSP shorter than 60 years would reduce lifetime OCI, and it may reduce the few LCA module B emissions reported in this analysis.

Several other factors can substantially shift the relative contributions of embodied and operational impacts to WLEI and WLCI. Improvements in building efficiency over time will decrease operational emissions at the building scale, assuming that the emission rates of grid electricity in the US continue to decline. Over time, the expected reductions in grid emissions will impact both OCI and ECI beyond what is modeled in this chapter (IEA, 2023a; US EIA, 2023a). Although cleaner grid emissions are typically associated with operational energy consumption, a cleaner grid would also impact the EC emissions of any

material produced using US grid electricity. Improvements in energy efficiency may also increase EC emissions. Additionally, Building materials that are often used in highly efficient single-family residential buildings (*e.g.,* foam insulation products) are often higher-emitting than traditional materials that are used to achieve minimum code compliance (e.g., fiberglass batt insulation) (Chastas et al., 2016; S. J. Hong et al., 2020). However, more products are becoming available that can achieve higher operational performance levels while reducing EC emissions (e.g., bio-based insulation products) (Arehart, Nelson, et al., 2020).

The proportion of embodied impacts to total impacts would also increase if the scope of this LCA were expanded. This study excludes several categories of materials – most notably, finish materials (e.g., flooring), which can be very energy- and carbon-intensive to produce, are used in high quantities, and often have shorter replacement cycles due to longevity and the change in aesthetic preferences. Additionally, including building services, such as appliances, wiring, piping, and ducts, would similarly increase the quantity and proportion of embodied impacts when compared with total impacts.

The results in **Figure 4-10** illustrate the substantial impact of grid and fuel emission rates on OC emissions. Natural gas has a lower emission rate than 14 of the 16 GEA regions in this study for the year 2025, and 8 of the 16 regions for the life of the building. This means that in heating-dominated climates within those GEA regions, natural gas-heated buildings will have lower OCIs under the mid case scenario. Fortunately, the mid case scenario is not a path that GEA regions in the US are tied to, and it is quite possible that grid emission factors drop more precipitously than they are modeled in the mid case.

OCIs are anticipated to decrease in the future across all climate zones. Regardless of the emission rates, appliances, including heating systems, continue to become more efficient, and efficient technologies continue to become more affordable, increasing their adoption across the US. Emission rates will likely decrease in most (if not all) GEA regions

due to a shift away from fossil fuel energy sources and toward clean, renewable energy sources, such as solar photovoltaics and wind power, paired with energy storage (IEA, 2023a; US EIA, 2023a).

The regions listed in **Table 4-6** could be more deeply analyzed to consider which GEA region or regions would best characterize each ASHRAE climate zone. The selection of a simulation city can impact the emissions due to grid emission rates and climate. Although this study looks at all 18 ASHRAE climate zones commonly referenced in the US, only 9 of the 18 total GEA regions are analyzed. Some ASHRAE climate zones encompass multiple GEA regions and vice versa. In this study, GEA region was chosen based on the simulation city used by the DOE for EnergyPlus simulations. Another approach could be assigning each ASHRAE climate zone a weighted emission rate based on the GEA region(s) within that climate zone.

4.4.2 Significance and Limitations

This is the first known study to establish *theoretical, science-based* WLEI and WLCI benchmarks for single-family residential buildings in the United States. This analysis expands on the cradle-to-gate EC emissions benchmarks established in Chapter III. A science-based approach allows researchers to better characterize typical building energy and emissions impacts for comparative analyses or building stock modeling. Further, theoretical carbon and energy benchmarks could inform the development of standards, codes, policies, or corporate goals toward limiting US energy consumption and carbon emissions.

These results should be interpreted within the confines of this benchmark analysis. More specifically, the EUI, EEI, OCI, and ECI for each residential building prototype is calculated in alignment with the goal, scope, and system boundary assumptions outlined in **Section 4.2**. The results would differ if other assumptions were used in considering end-of-life disposal scenarios or if the LCA scope and system boundary were expanded to include

additional materials (*e.g.*, finishes). Nevertheless, the results presented herein can be compared with results from other WBLCAs conducted per the scope and system boundary used herein.

This study included the following additional assumptions. All material, energy, and carbon intensity calculations, including MUI, ECI, EUI, and WLCI, are normalized based on conditioned floor area rather than gross floor area, which is consistent with the approach utilized in Chapter III. Additionally, the MUIs were used directly from Chapter III, as the bills of materials would be identical despite expansions in the LCA scope of this analysis. The limitations and assumptions related to MUI calculations in Chapter III also apply to the results in this chapter.

4.5 Conclusions

Chapter IV of this dissertation establishes novel whole-life energy and carbon intensity benchmarks for 288 prototypical single-family residential buildings, utilizing 3 LCA data sources. Building on the MUI and cradle-to-gate ECI calculations performed in Chapter III, this study includes the computation of operational energy, OC, and embodied energy and an expansion of LCA scope to include modules A4-A5, B, and C. WLEI values span from 10.2 to 58.4 $GJ/m^{2,}$ and total WLCI (excluding biogenic carbon) values range from 215 to 2987 $kgCO_2e/m^2$. Athena reported the lowest EEIs and ECIs, while Tally reported the highest values. These results can be used as a whole-life energy benchmark for single-family residential buildings in the United States based on the DOE prototype buildings, and they build on the EC emissions benchmark established in Chapter III. The results reinforce several of the conclusions from Chapter III, including the importance of selecting appropriate LCA data, given the disparity in reported embodied impacts across Athena, Tally, and One Click.

This study highlights the difference in relative impact due to embodied and operational impacts. For WLEI, embodied energy represents only 2-25% (9% on average) of

total WLEI over the 60-year RSP for all three LCA tools. For WLCI, EC emissions represent 2-51% (11% on average) of WLCI over the 60-year RSP for all three LCA tools. This proportion is expected to shift substantially over time as the climate changes, grid emission factors improve, buildings become more efficient, and the embodied impacts of materials decrease. Future efforts should consider the impact of city selection on energy and emissions results, more deeply consider the LCA assumptions related to LCA modules A4-A5, B, and C, and update this analysis based on changes in energy-efficient appliances, grid emission rates, and the embodied impacts of materials.

CHAPTER V

5. Theoretical embodied and operational carbon benchmarks of commercial office reference buildings in the United States

5.1 Introduction

The objective of this study is to establish theoretical, science-based benchmarks for the material use intensity (MUI, kg/m^2), embodied carbon intensity (ECI, kgCO_2e/m^2), and operational carbon intensity OCI (kgCO_2e/m^2) of medium and large commercial office buildings in the United States (US). This study utilizes the medium and large office prototype building models established by the US Department of Energy (DOE) as the basis of analysis. This chapter's objective will be achieved by (1) developing bills of materials by interpreting energy models and using structural design to obtain material quantities, (2) computing A1-A3 and A-C EC emissions using life cycle assessment, and (3) simulating OC emissions using whole-building energy simulation. Whole-life carbon intensity (WLCI, kgCO_2e/m^2) will be calculated by summing ECI and OCI. Biogenic carbon storage will be quantified for the building designs that include wood. Uncertainty will be characterized using probabilistic life cycle assessment (LCA).

This study builds on the methods and results of Chapters III and IV in several ways. First, it generates theoretical EC benchmarks for an additional, prominent building typology in the US – commercial office buildings. Second, it incorporates a more detailed structural analysis to capture design variety related to structural materials and lateral loading conditions for three different structural systems: reinforced concrete, steel, and wood. Finally, this study will take a more sophisticated approach to uncertainty modeling by conducting a probabilistic LCA using kernel density estimation (KDE) to fit probabilistic distributions of embodied carbon coefficients (ECCs, kgCO_2e/kg) obtained from environmental product declarations (EPDs). The methods utilized in this chapter are intended to define more accurate and robust theoretical EC benchmarks and provide

additional tools for researchers and practitioners who may use these benchmarks. The methods defined herein are a critical factor to the reproducibility and future usability of the theoretical benchmark results.

5.2 Computational Methods

5.2.1 DOE commercial prototype buildings

The prototype commercial building energy models developed by the US DOE and the Pacific Northwest National Laboratory (PNNL) are used as the basis of building design for the OC analysis and LCA performed herein (US DOE, 2018). In this study, the medium and large office DOE prototype buildings, pictured in **Figure 5-1**, are analyzed across 16 ASHRAE climate zones representative of climatic conditions across the US. Climate zones reported by the DOE for cities outside of the US were omitted from this study. Each climate zone represents different regional climatic conditions, which affect building envelope design (e.g., insulation quantities), heating, ventilation, and air conditioning (HVAC) system design, and OCI calculations due to different heating and cooling demands. The geometric characteristics of the medium and large office buildings, as defined by DOE and PNNL, are summarized in **Table 5-1**. All prototype buildings comply with ASHRAE Standard 90.1 – 2019, a standard adopted as a commercial building energy efficiency code in many state and local jurisdictions across the US (*ASHRAE 90.1-2019*, 2019).

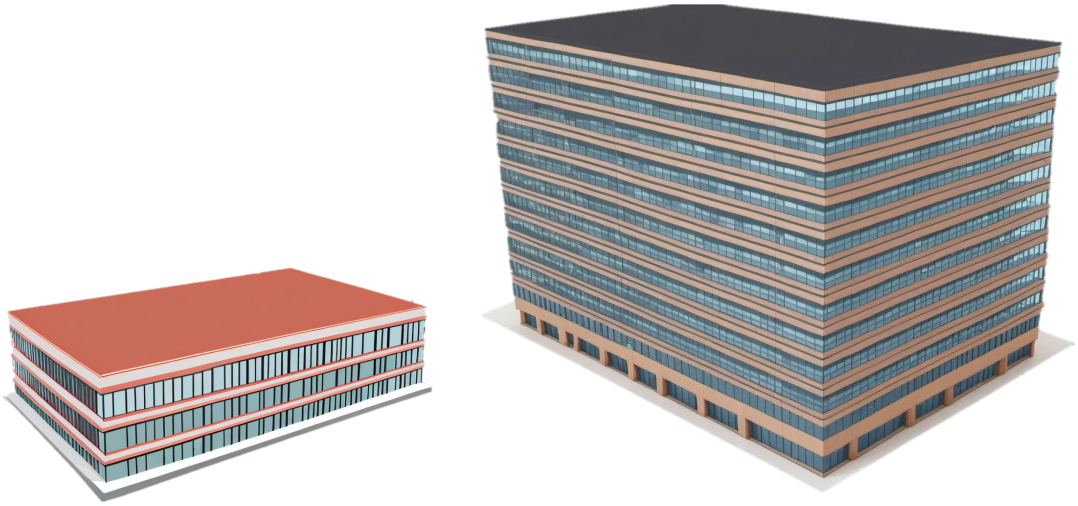

Figure 5-1. *Renderings of the medium (left) and large (right) DOE prototype office building models generated using Google Sketchup and AI for editing (OpenArt AI, 2024; Sketchup Pro, 2019).*

Table 5-1. *Geometric characteristics of the medium and large commercial office prototype buildings.*

Geometric characteristic	Medium office	Large office
Footprint dimensions (m)	50 x 33	73 x 49
Footprint area (m^2)	1660	3563
Gross conditioned floor area (m^2)	4982	46320
Number of stories above grade	3	12
Number of stories below grade	0	1
Window area (m^2)	593	3477
Roof area (m^2)	1660	3563
Floor-to-floor height (m)	4	4
Building height above grade (m)	12	48
Building height below grade (m)	0	2.5
Wall area above grade (m^2)	1978	11590
Wall area below grade (m^2)	0	594
Above-ground window-to-wall ratio	30%	28.5%

Each DOE prototype building model has identical exterior geometries across all climate zones, though there are differences in the quantities and characteristics of building envelope materials such as insulation and glazing across climate zones. **Table 5-2** details the differences in non-structural materials, including wall insulation, roof insulation, and window properties across climate zones for buildings studied. The required thermal resistance (R-value) for insulation materials, window U-factor, and window solar heat gain coefficients (SHGCs) necessary to meet the requirements of ASHRAE 90.1 are different for each climate zone. Climate zone 1A represents the hottest climate zone included in this study (represented by Miami, FL), on average, while climate zone 8 represents the coldest (represented by Fairbanks, AK).

The thermal properties of the windows and roofs of large office buildings are identical to those of medium offices. However, the thermal resistance for wall insulation is lower for large offices than for medium offices, because the energy consumption of larger office buildings is typically more load-dominated than the more envelope-dominated medium office buildings. In other words, larger office buildings typically have a smaller surface area-to-volume ratio, so heat transfer in the building is dominated by internal loads (e.g., appliances, people), while heat transfer in smaller buildings is more reliant on the building envelope design (e.g., insulation, air sealing, windows).

Table 5-2. *Building envelope properties for the medium and large commercial office prototype buildings in each climate zone (ASHRAE 90.1-2022, 2022; US DOE, 2018).*

Climate Zone	Medium Office				Large Office			
	Wall Thermal Resistance (RSI, m^2-K/W)	Roof Thermal Resistance (RSI, m^2-K/W)	Window U-Factor (W/m^2-K)	Window Solar Heat Gain Coefficient	Wall Thermal Resistance (RSI, m^2-K/W)	Roof Thermal Resistance (RSI, m^2-K/W)	Window U-Factor (W/m^2-K)	Window Solar Heat Gain Coefficient
1A	0.53	3.47	2.86	0.23	0.03	3.47	2.86	0.23
2A	0.77	4.32	2.58	0.25	0.55	4.32	2.58	0.25
2B	0.77	4.32	2.58	0.25	0.55	4.32	2.58	0.25
3A	0.82	4.32	2.41	0.25	0.68	4.32	2.41	0.25
3B	0.82	4.32	2.41	0.25	0.68	4.32	2.41	0.25
3C	0.82	4.32	2.41	0.25	0.68	4.32	2.41	0.25
4A	1.46	5.31	2.06	0.36	0.93	5.31	2.06	0.36
4B	1.46	5.31	2.06	0.36	0.93	5.31	2.06	0.36
4C	1.46	5.31	2.06	0.36	0.93	5.31	2.06	0.36
5A	1.65	5.31	2.06	0.38	1.07	5.31	2.06	0.38
5B	1.65	5.31	2.06	0.38	1.07	5.31	2.06	0.38
5C	1.65	5.31	2.06	0.38	1.07	5.31	2.06	0.38
6A	1.80	5.31	1.94	0.38	1.19	5.31	1.94	0.38
6B	1.80	5.31	1.94	0.38	1.19	5.31	1.94	0.38
7	1.80	6.09	1.66	0.40	1.32	6.09	1.66	0.40
8	2.19	6.09	1.49	0.40	1.76	6.09	1.49	0.40

5.2.2 Material quantity takeoffs and material use intensity

Material quantities were calculated for non-structural materials and structural materials separately. For each material, the mass quantity (kg) was calculated by either multiplying the volume (m^3) of the material by density (kg/m^3) or by multiplying the surface area of a material (m^2) by a surface area density (kg/m^2). The material quantity (kg) was then area-normalized by dividing the calculated mass by the total conditioned floor area of the applicable prototype building (m^2) (see **Table 5-1**), yielding an MUI (kg/m^2) for each material in each prototype building. MUI was calculated for non-structural materials across 32 scenarios, representing 16 climate zones and two building sizes, and for structural materials, it was calculated across 50 scenarios, representing five primary structural materials, five loading conditions, and two building sizes. These scenarios combine to represent 800 physical building models.

5.2.2.1 MUI of non-structural materials

The MUI of non-structural materials was derived from the 32 DOE prototype building models for medium and large office buildings across 16 climate zones. These models are available as EnergyPlus model input files (.idf files) from the DOE Building Energy Codes Program (EERE, US DOE, n.d.). Each .idf file contains information about the geometry and density of non-structural materials, including insulation and select finish materials. The geometry of each surface in each prototype building was extracted from the .idf files using a modified version of the Python package 'pyidf,' which can output surface areas (m^2) and thicknesses (m) for every building surface included in the original prototype building, as well as assumed volumetric densities (kg/m^3) or area densities (kg/m^2) for the materials (Buffat, 2014/2023; *Python*, 2024). Most densities were extracted from EnergyPlus, and any missing values were extracted from One Click LCA (One Click) (One Click LCA Ltd., 2023). The extracted geometric and density values were used to calculate volume (m^3) and mass (kg) for each non-structural material.

The thermal resistance (RSI, m^2-K/W) of insulation and the U-factor and SHGC of windows were extracted from the EnergyPlus models for each climate zone (see **Table 5-2**). However, insulation materials were not explicitly identified in the initial prototype energy models, so the densities of these materials were not available in EnergyPlus. All insulation in wall assemblies was assumed to be mineral wool batt insulation, as mineral wool batts are commonly used as wall insulation in midrise commercial buildings in the US. All roof insulation was assumed to be polyisocyanurate foam, which is a common rigid foam board used as the insulative layer in built-up roofing systems that are typically specified in the design of medium and large office buildings. The extracted thermal resistance and U-factor data from EnergyPlus were combined with volumetric and area densities for mineral wool batt and polyisocyanurate insulation from One Click LCA to compute insulation volumes and masses across each building assembly.

Once the mass of each non-structural material was calculated, MUI was calculated by dividing each material's mass by the total conditioned floor area of the respective prototype building. Assembly- and building-level MUIs were then calculated by summing the MUIs of each material by assembly and across all assemblies, respectively. This analysis resulted in 32 unique non-structural designs, resulting in 32 MUI values across 16 climate zones and two building sizes.

5.2.2.2 MUI of structural materials

The EnergyPlus input files for the prototypical buildings did not include details regarding the structural walls, beams, columns, and other elements. As such, a full structural analysis was performed to design code-compliant structural assemblies for each commercial prototype building and the criteria described in **Appendix B-1**, referencing structural building code requirements specified by the 2018 International Building Code (IBC) and loading criteria from ASCE 7-16 (American Society of Civil Engineers, 2017; ICC, 2017). Specific design standards used in this analysis include ACI 318-19 for reinforced

concrete designs (American Concrete Institute, 2019), the AISC Steel Construction Manual and AISC 360 for steel designs (AISC, 2022, 2023), and the 2018 National Design Specification (NDS) for Wood Construction Manual for mass timber designs (AWC, 2018). The structural models are based on three primary designs: reinforced concrete with a post-tensioned (PT) concrete slab, steel with a composite deck, and mass timber with a cross-laminated timber (CLT) deck. Reinforced concrete and steel braced-frame structures are two of the most common choices for medium and large-sized office buildings in the US (Abed et al., 2022; McKinsey & Company, 2022). Mass timber designs were also analyzed, as mass timber is an emerging, low-embodied-carbon alternative to steel and concrete as a structural material (Abed et al., 2022; McKinsey & Company, 2022).

Five lateral loading scenarios were considered in the design of the medium and large office prototype buildings. The five scenarios are meant to span a range of expected lateral loading conditions, including baseline (low hazard), moderate earthquake, high earthquake, moderate wind, and high wind. The lateral design parameters were selected to be representative (but not exhaustive) of the conditions experienced across the US (American Society of Civil Engineers, 2017, 2023). These parameters are detailed in **Appendix B-1**. The five loading scenarios were applied to every climate zone included in this analysis because wind and seismic conditions can vary across single ASHRAE climate zones.

Gravity members were designed according to the LRFD load case 1.2D + 1.6L (American Society of Civil Engineers, 2017). Building foundations were designed as spread footings for the medium office and mat foundations with thickened portions under the lateral system for the large office for each loading scenario. The most materially efficient foundation option is defined as the option that requires the smallest amount of concrete and reinforcing steel in the foundation to meet the structural criteria of the given loading scenario and structural material choice. Base reactions used for foundation design were produced by combining analysis results from ETABS with the gravity analysis. Punching

shear for the spread footings and mat foundation were computed according to ACI 318-19 (*ACI 318-14 and ACI 318R-14*, 2014).

Once the appropriate loads for each scenario were determined, lateral force resisting systems were designed using reinforced concrete shear walls for the concrete and mass timber buildings, steel braced frames for the steel and mass timber buildings, and a CLT rocking wall for the mass timber buildings. These five primary structural materials were applied to each of the five loading conditions for each of the two building sizes (medium and large), resulting in 50 separate structural designs that could be applied to the 16 climate zones and 3 LCA datasets modeled in this study. For the purposes of this study, a combination of primary structural material, loading condition, and size (e.g., a large office building made from concrete in the baseline loading scenario) is referred to as a 'structural design.' The lateral force-resisting system of each building was designed using ETABS software (Version 21.1.0), utilizing the geometry of each DOE prototype building as described in **Table 5-1** (ETABS, 2023). Dead loads and superimposed dead loads were modeled as an area mass applied on each floor. The lateral system was conservatively sized to safely resist 100% of the lateral load in each respective scenario. Additional information is included in the appendix, including structural details and assumptions (**Appendix B-1**), floor layout and grid spacing diagrams (**Appendix B-2**), and ETABS output reports for steel and concrete designs (**Appendix B-3**).

5.2.3 LCA and embodied carbon intensity

The ECI of each prototype building was evaluated by conducting a screening LCA in accordance with ISO 14040/14044 standards (ISO, 2006a, 2006b). The functional units were the 800 building models for which MUI was calculated. The LCA scope includes life cycle modules A1-A5, B2-B6, and C1-C4 per **Figure 2-1**, unless otherwise noted**.** LCA module B6 (operational energy) will be reported separately. Biogenic carbon storage was calculated separately and is not included in the ECI calculations. The physical scope of the study

includes the building foundation, structure, core, and shell. Select finish materials such as carpets and acoustic ceiling tiles are included in the analysis since they were included in the DOE prototype buildings. The LCA data used to compute ECIs for each material were extracted from three of the most commonly used LCA tools in North America – Athena Impact Estimator for Buildings (Athena), One Click LCA (One Click), and Tally (*AIE4B*, 2022; Building Transparency et al., 2022; One Click LCA Ltd., 2023). The ECI is calculated according to the following:

$$ECI_i = MUI_i * ECC_i \quad \text{(Eq. 5-1)}$$

where ECI_i is the embodied carbon intensity of material i, MUI_i is the material use intensity (kg/m^2) of material i, and ECC_i is the embodied carbon coefficient (kgCO_2e/kg) material i for the given LCA data source. The ECCs for each material per life cycle module are detailed in **Table 5-3**. The simplified material names are used to categorize and graph the MUI and ECI results.

Table 5-3. *Embodied carbon coefficients (ECC, $kgCO_2e/kg$-material) for Athena, One Click, and Tally, organized by life cycle module and material. Excludes biogenic carbon storage.*

Material	Simplified Material Name	Athena ECC ($kgCO_2e/kg$)				One Click ECC ($kgCO_2e/kg$)				Tally ECC ($kgCO_2e/kg$)			
		A1-A3	A4-A5	B1-B5	C1-C4	A1-A3	A4-A5	B1-B5	C1-C4	A1-A3	A4-A5	B1-B5	C1-C4
Concrete - 4 ksi	Concrete	0.12	0.02	-	0.01	0.14	0.02	-	0.00	0.15	0.00	-	0.04
Concrete - 5 ksi	Concrete	0.14	0.02	-	0.01	0.17	0.02	-	0.00	0.18	0.00	-	0.04
Concrete - 6 ksi	Concrete	0.14	0.02	-	0.01	0.18	0.02	-	0.00	0.18	0.00	-	0.04
Concrete - 8 ksi	Concrete	0.17	0.02	-	0.01	0.21	0.02	-	0.00	0.21	0.00	-	0.04
Normal weight concrete floor	Concrete	0.16	0.02	-	0.01	0.12	0.00	-	0.00	0.13	0.00	-	0.04
Lightweight Concrete - 3 ksi	Concrete	0.12	0.02	-	0.01	0.14	0.02	-	0.00	0.25	0.00	-	0.04
Door	Door	4.89	0.08	-	0.57	1.95	0.01	-	0.04	1.69	0.05	1.68	0.04
Window	Glazing	1.73	0.02	1.73	-	2.48	0.02	-	0.04	1.34	0.05	1.44	0.04
Mineral wool insulation	Insulation	0.84	0.15	-	0.01	1.36	0.00	-	0.01	1.79	0.01	-	0.04
Polyisocyanurate Insulation	Insulation	2.37	0.19	-	0.01	6.12	0.01	-	2.07	2.58	0.01	-	0.04
Acoustic ceiling	Acoustic ceiling	0.42	0.09	-	0.01	0.32	0.00	-	0.02	1.36	0.01	1.41	0.04
Carpet	Carpet	4.02	0.42	-	0.01	4.03	0.02	-	2.07	5.27	0.09	29.25	0.49
Gypsum board	Drywall	0.36	0.09	-	0.01	0.31	0.00	-	0.02	0.20	0.01	0.26	0.04
Built-up asphalt roof	Roof	0.84	0.03	2.60	0.00	3.39	0.01	-	2.07	0.40	0.01	0.42	0.04
HSS Section	Structural steel	0.96	0.15	-	0.15	2.11	0.09	-	0.04	2.45	0.02	-	0.00
Plate steel	Structural steel	2.23	0.13	-	0.15	2.82	0.01	-	0.04	2.58	0.02	-	0.01
PT Reinforcing	Structural steel	1.70	0.1	-	0.22	1.12	0.02	-	0.08	1.70	0.04	-	0.00
Rebar	Structural steel	0.85	0.05	-	0.11	0.56	0.01	-	0.04	0.85	0.02	-	0.01
Steel - W Beam	Structural steel	0.96	0.15	-	0.15	2.11	0.09	-	0.04	0.97	0.02	-	0.00
Steel deck	Structural steel	2.23	0.13	-	0.15	2.82	0.01	-	0.04	2.58	0.02	-	0.01
Steel rod	Structural steel	0.85	0.05	-	0.11	0.56	0.01	-	0.04	1.91	0.02	-	0.01
Stucco	Stucco	0.11	0.03	0.03	0.01	1.73	0.22	-	0.01	3.32	0.03	-	0.05
Cross-laminated timber	Wood	0.43	0.16	-	0.04	0.52	0.01	-	0.02	0.37	0.03	-	0.50
Glued laminated timber	Wood	0.24	0.04	-	0.04	0.38	0.01	-	0.02	0.25	0.05	-	0.50

ECIs can be summed across materials for each prototype building according to:

$$ECI_{building} = \sum_{i=1}^{n} ECI_i \quad \text{(Eq. 5-2)}$$

where $ECI_{building}$ represents the whole-building embodied carbon intensity ($kgCO_2e/m^2$) of a given prototype building, and n represents the total number of materials in the building. A total of 2400 ECIs was computed by applying ECCs from 3 tools to 800 unique MUIs.

5.2.4 Biogenic carbon storage calculations

The biogenic carbon stored in wood products was quantified as part of this study. Biogenic carbon storage ($kgCO_2$) refers to the CO_2 stored in natural materials as a result of photosynthesis (Levasseur et al., 2013). Biogenic carbon storage is reported separately from ECI in this analysis, as the biogenic carbon storage calculation utilized is a scientifically derived theoretical maximum storage calculation that does not account for use-phase emissions or the end-of-life treatment of wood products, including the release of greenhouse gases to the atmosphere that results from the incineration, landfilling, or composting of wood products. If use-phase and end-of-life emissions were being considered, the net biogenic carbon storage would have a lower magnitude than presented in this paper.

Biogenic carbon storage was calculated according to the physics-based method defined in EN 16449 (European Commission for Standards, 2014):

$$(kgCO_2)_{bio} = 0.5 \times m_w \times \left(1 + \frac{MC}{100}\right)^{-1} \left(\frac{44}{12}\right) \quad \text{(Eq. 5-3)}$$

where $(kgCO_2)_{bio}$ is the theoretical maximum mass of biogenic carbon ($kgCO_2$) physically stored in the wood product, m_w is the total mass of wood in the wood product (kg), and MC is the moisture content of the wood product (%). A value of MC = 12% is used, which assumes that wood is in equilibrium with average indoor conditions of 65% relative humidity and 21.1°C (70°F) and is representative of most regions in the United States (Breyer, 2015; Simpson & TenWolde, 1999). The multiplier 0.5 accounts for the average

percent of elemental carbon in wood (~50%), and the multiplier 44/12 represents the molar ratio of CO_2 to elemental carbon.

The theoretical maximum biogenic carbon storage is calculated deterministically and reported as a single value. It is excluded from the uncertainty analysis, Monte Carlo simulation, statistical similarity analysis, and WLCI analysis conducted herein. Biogenic carbon storage is assumed to occur in LCA module A1 with no decay. Because of the limitations of this analysis, the theoretical maximum biogenic carbon storage results are reported separately from ECI results. Calculations only account for the biogenic carbon storage potential in CLT and glued laminated timber (glulam) products, although there may be minor amounts of biogenic carbon stored in other materials. The biogenic carbon storage and idealized net CO_2 storage calculations should be taken for reference only, and not used directly as part of a whole-building benchmark.

5.2.5 Operational energy and carbon intensity calculations

Operational energy consumption was simulated using EnergyPlus Version 9.5.0 for each of the 32 DOE prototype building energy models (NREL & LBNL, 2019, 2021). The cities used to characterize annual weather patterns in each climate zone are listed in **Table 5-4**. For this study, annual operational energy consumption data were simulated using EnergyPlus and extracted from the simulation result files using Python (version 3.12). This simulation and data mining process results in a collection of operational EUI (kWh/m^2-yr) values for each fuel type (*i.e.,* electricity, gas, and fuel oil) and each prototype building.

Table 5-4. *Selected city for weather file, generation and emission assessment (GEA) region, and grid emission factor for each climate zone included in the analysis.*

Climate zone	Weather file city, state	GEA Region	2025 projected grid emission factor ($kgCO_2e/MWh$**)
1A	Miami, FL	FRCC	500.4
2A	Tampa, FL	FRCC	500.4
2B	Tucson, AZ	WestConnect_South	282.8
3A	Atlanta, GA	SERTP	666.5
3B	El Paso, TX	WestConnect_South	282.8
3C	San Diego, CA	CAISO	253.8
4A	New York, NY	NYISO	339.8
4B	Albuquerque, NM	WestConnect_South	282.8
4C	Seattle, WA	NorthernGrid_West	100.2
5A	Buffalo, NY	NYISO	339.8
5B	Denver, CO	WestConnect_North	539.2
5C	Port Angeles, WA	NorthernGrid_West	100.2
6A	Rochester, MN	MISO_North	467.4
6B	Great Falls, MT	NorthernGrid_East	282.1
7	International Falls, MN	MISO_North	467.4
8	Fairbanks, AK	GVEA*	N/A

*The NREL Cambium dataset excludes data from Alaska. As a result, Climate Zone 8 is not analyzed as part of the OCI or WLCI analysis.
**Indicates end-use electricity consumption

The fuel-specific EUIs can be added together to calculate whole-building EUI across all fuel types:

$$EUI_{total} = EUI_{elec} + EUI_{gas} \quad \text{(Eq. 5-4)}$$

where EUI_{total} is the EUI (kWh/m^2-yr) across all fuels, and EUI_{elec} and EUI_{gas} are the energy use intensities (kWh/m^2-yr) for electricity and natural gas, respectively.

OC emissions are calculated by multiplying the EUI for each fuel type by an appropriate emission factor. The emission factor for electricity varies based on the utility grid in a given locale, the power generation sources that the local grid depends on, and the decarbonization of different utility grid regions in the United States. **Table 5-4** provides

the projected 2025 grid emission factor extracted from the National Renewable Energy Laboratory (NREL)'s Cambium dataset. The Cambium dataset projects the electric grid emissions across 18 distinct regions in the United States based on current grid emissions and several carbon reduction scenarios. Those scenarios are the "mid case" scenario, representing the middle of expected range inputs for technology costs, fuel prices, and demand growth; the "95% decarbonization by 2050" scenario, which includes nascent technologies excluded from the mid case scenario toward a 2050 emissions reduction goal; and the "100% decarbonization by 2035" scenario, which includes a more aggressive emissions reduction scheme toward a decarbonized utility grid in 2035 (*Cambium*, n.d.; Gagnon et al., 2024).

In this study, OCI is calculated for assumed reference study periods (RSPs) of 30, 45, and 60 years. The expected RSP can meaningfully affect OCI, ECI, and WLCI calculations. Additional years of RSP can have mixed impacts on WLCI. A longer RSP results in additional operational emissions due to energy consumption and additional EC emissions due to material maintenance and replacement; however, a longer RSP also results in lower EC emissions per year, as the majority of EC emissions are cradle-to-gate, and there is a longer period of time over which to normalize those emissions (Aktas & Bilec, 2012; Hasik et al., 2019; R. Marsh, 2017; Mequignon et al., 2013). To compute the 30-, 45-, and 60-year OCIs in this study, emission factors were extracted from the cambium tool for every five years out to the year 2050. Between the five-year intervals for which data was collected, the emission factors were interpolated. Beyond 2050, emission factors were assumed not to change from the 2050 values for each scenario.

The emission factors for natural gas (EF = 52.91 $kgCO_2e$/MMBtu or 0.18 $kgCO_2e$/kWh) and fuel oil (EF = 75.09 $kgCO_2e$/MMBtu or 0.26 $kgCO_2e$/kWh) are assumed to be identical across the United States and remain constant over time (US EIA, 2023b). Additionally, fossil fuel loads in the building models are not assumed to change over time,

so building electrification is not accounted for. The OCI ($kgCO_2e/m^2$-yr) is calculated as follows:

$$OCI_{annual,a} = EUI_{elec} \cdot EF_{elec,a} + EUI_{gas} \cdot EF_{gas} + EUI_{oil} \cdot EF_{oil} \quad \text{(Eq. 5-5)}$$

where $OCI_{total,a}$ represents the annualized operational carbon intensity ($kgCO_2e/m^2$-yr) of a given building energy model in year a, EUI_{elec}, EUI_{gas}, and EUI_{oil} are the energy use intensities (kWh/m^2-yr) for electricity, natural gas, and fuel oil, respectively, EF_{elec} is the emission factor ($kgCO_2e/kWh$) for electricity in year a, and EF_{gas} and EF_{oil} are the emission factors ($kgCO_2e/kWh$) for natural gas and fuel oil, respectively. The total OCI over the life of the building is calculated as the sum of the annual OCIs over the building's expected life.

5.2.6 Probabilistic LCA using KDE to characterize uncertainty

It is well established that LCA data are highly variable (E. Marsh et al., 2023). The ECI calculations described in section 5.2.3 result in deterministic, single-value ECIs for each of the 50 building designs and 3 LCA data sources. While these single-value ECIs are helpful for comparison when using those tools, they do not consider uncertainty in LCA. To address this, a probabilistic LCA was performed to characterize the variation in ECCs. This study leverages KDE to generate statistical distributions based on ECCs derived from environmental product declarations (EPDs). Those distributions are then used in a Monte Carlo simulation to generate ranges of potential whole-building LCA values for each of the models herein. This method of using KDE to produce probabilistic LCAs based on EPDs in a recent study by Torres and Srubar (in review), and is proven to better fit ECC datasets than fitting normal or lognormal distributions. It is anticipated that this will generate more realistic ECCs and ECIs than the uncertainty analysis performed using lognormal distributions in Chapter III.

ECC distributions were generated using KDE and the EPD data from the Embodied Carbon in Construction Calculator (EC3) database per Torres and Srubar (in review). Then, Monte Carlo simulations (n = 10,000) were performed for each commercial office building

design. In this study, 10,000 Monte Carlo simulations were run, and the number of simulations was selected by increasing the number of simulations until the average variance in ECI across all models differed by <1% between Monte Carlo runs. This resulted in 10,000 unique ECC values per material, which were then multiplied by the MUI for each building design and each Monte Carlo simulation run, resulting in 500,000 unique ECIs (when climate zone is not accounted for). A two-sample Kolmogorov-Smirnov (K-S) test was used to assess the statistical similarity of ECI distributions for different office building designs. A threshold of $p<0.05$ was used to assess statistical similarity. The statistical similarity of the ECI distributions was not compared across building sizes.

The scope of the probabilistic LCA will include only life cycle modules A1-A3, but the same physical scope described in Section 5.2.2. The LCA scope includes LCA modules A1-A3 because EPDs, the source of data for the probabilistic analysis, typically only report LCA modules A1-A3. The probabilistic LCA will only consider data from EC3 and not from the three LCA tools described in Section 5.2.3.

5.3 Results

5.3.1 Material use intensities

The MUIs (kg/m^2) for each of the 800 building models were computed and reported in **Appendix B-4.** The whole-building MUIs differ by less than 1% across all climate zones for a structural design. Therefore, the MUIs reported in this section are provided for only a single climate zone (climate zone 5B) to simplify reporting and discussion. The MUIs for the 50 prototypical building models designed for climate zone 5B are summarized in **Figure 5-2** and **Figure 5-3**. The MUIs are reported as both whole-building MUI values (**Figure 5-2**) and percent contribution per material (**Figure 5-3**). For both **Figure 5-2** and **Figure 5-3**, the MUI is reported for each structural design based on the five loading conditions (*i.e.,* baseline (low hazard), moderate wind, high wind, moderate earthquake, and high earthquake), five primary structural material choices (*i.e.,* steel braced frame, reinforced

concrete, mass timber with concrete shear wall, mass timber with steel braced frame, and mass timber with wood rocking wall designs), and two sizes (i.e., medium and large).

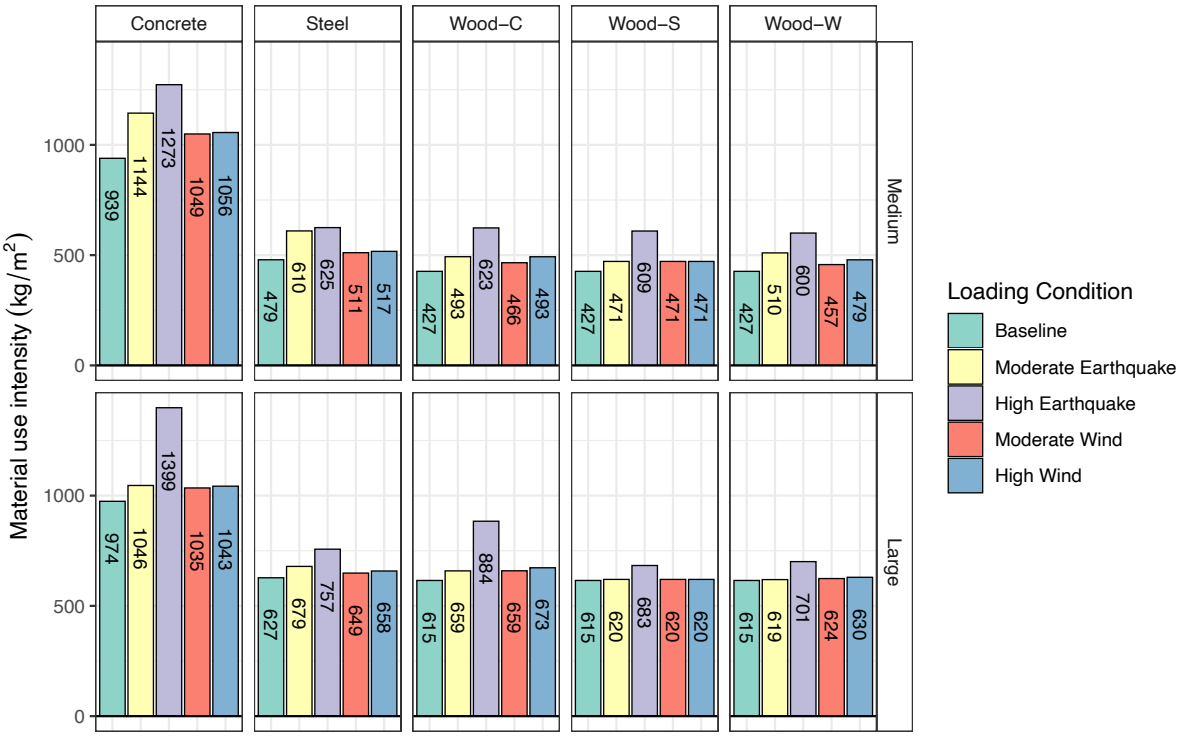

Figure 5-2. *Whole-building MUI for each structural design (primary structural material, loading scenario, and building size).*

Figure 5-2 reports whole-building MUIs across all building sizes, loading conditions, and primary structural materials. The three wood scenarios indicate the lateral force resisting system material, with Wood-C representing a wood building with a reinforced concrete shear wall, while Wood-S has a steel brace frame system and Wood-W has a CLT rocking wall. The top-left panel of **Figure 5-2** provides the MUI of all medium-sized buildings that were designed with reinforced concrete – these MUIs range from 939 kg/m^2 for the baseline loading condition to 1273 kg/m^2 for the high earthquake scenario. The moderate earthquake, high wind, and moderate wind scenarios fall between the baseline and high earthquake scenarios, with MUIs of 1144, 1049, and 1056 kg/m^2, respectively. The range of MUI for medium-sized buildings across all primary structural materials is 427-1273 kg/m^2. The range for steel braced-frame buildings is 479-625 kg/m^2, while the Wood-C scenario MUIs range from 427-623, the Wood-S scenario ranges from 427-609 kg/m^2, and Wood-W ranges from 427-600 kg/m^2. The MUIs for all baseline wood buildings are identical, as these buildings do not have the dedicated lateral force-resisting systems that differentiate each scenario. The MUIs for all large buildings range from 615 to 1399 kg/m^2. The differences between concrete, steel, and the three wood designs for large buildings are parallel to those featured in the medium buildings, with concrete having a higher range of MUI (974-1399 kg/m^2), while the steel and wood scenarios have lower, comparable MUIs (627-757 kg/m^2 for steel and 615-884 kg/m^2 across all wood scenarios). For large buildings, the baseline wood designs have the lowest MUI (615 kg/m^2). The range of MUIs across all medium and large buildings (i.e., all MUI results) spans from 427 to 1399 kg/m^2.

Table 5-5. *Percent difference in MUI from baseline loading conditions for each structural design.*

		Concrete	Steel	Wood-C	Wood-S	Wood-W
Medium	Moderate earthquake	22%	27%	16%	11%	20%
	High earthquake	36%	31%	46%	43%	41%
	Moderate wind	12%	7%	9%	11%	7%
	High wind	12%	8%	16%	11%	12%
Large	Moderate earthquake	7%	8%	7%	1%	1%
	High earthquake	44%	21%	44%	11%	14%
	Moderate wind	6%	3%	7%	1%	1%
	High wind	7%	5%	9%	1%	2%

Table 5-5 shows the percent difference in MUI between the baseline structural loading conditions and all other loading conditions for a given building size and primary structural material type. The percent difference between the baseline and another loading condition is greatest for the high earthquake scenario, which is expected due to the greater lateral force requirements (and therefore, a more massive lateral force-resisting system), at approximately 31-46% difference from the baseline for the medium buildings, and 11-44% for large buildings. The greatest differences in MUI for the high earthquake scenario are in the three wood building designs, as the lateral force resisting systems represent a greater proportion of total MUI in these buildings due to the lighter mass of the wood superstructure and foundations for these buildings when compared with steel and reinforced concrete designs. Typically, the next greatest percent difference is for the moderate earthquake scenario, followed by high wind and moderate wind. There is a minimal difference in MUI between the baseline scenario and moderate earthquake, moderate wind, and high wind for the Wood-S and Wood-W designs for large buildings. This result indicates that the baseline design includes enough shear resistance to resist most of the lateral forces associated with these mild conditions.

The trend of increasing MUI based on lateral design requirements from the low hazard scenario (lowest) to moderate wind, high wind, moderate earthquake, and finally, high earthquake (highest) is expected. The relatively higher MUIs for reinforced concrete

buildings over steel brace frame buildings for a given set of loading conditions are also expected, as steel brace frame design typically allows for more structurally efficient form factors, and steel members have higher compressive and flexural strengths per unit mass than reinforced concrete.

Figure 5-3 reports the contribution that each material has to the overall MUI of each structural design. For all of the buildings in the top-left panel (referring to medium concrete buildings), MUI is dominated by the mass of concrete (91-92% of total MUI) due to the total quantity of concrete required for the building's foundation; however, there is also an appreciable amount of rebar, which represents about 3-4% of whole-building MUI for these buildings. Each of the other materials contributes less than 2% of the total MUI. Considering all of the medium-sized buildings, concrete remains the dominant material contributing to the MUI, but the percent contribution is lower for wood and steel buildings than it is for concrete buildings. Across all medium building scenarios, concrete represents 65-92% of the total MUI. For the medium steel buildings, structural steel is the second most utilized material (7-8.5% of MUI), while for the three wood scenarios, the second most utilized material is engineered wood, representing 14.5-21.4% of total MUI.

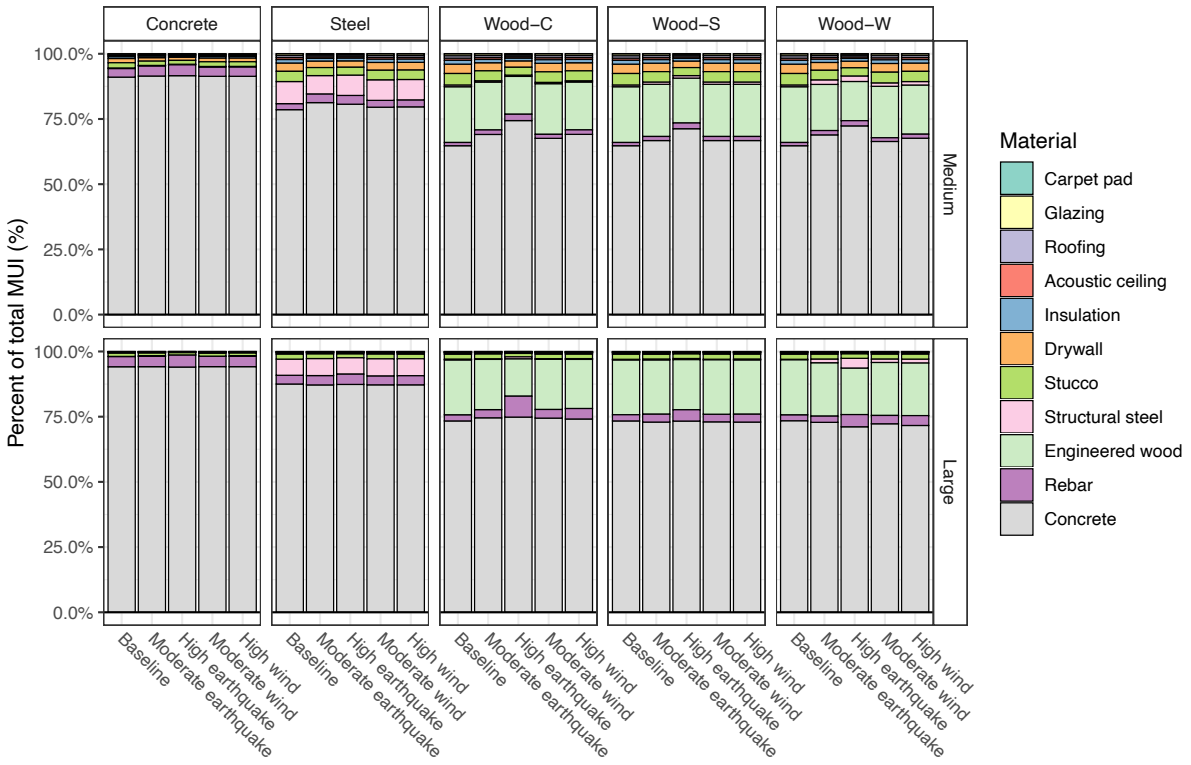

Figure 5-3. *Whole-building MUI and contribution of each material for each structural design.*

For large buildings, there are similar trends in the data, but with higher proportions of structural materials (i.e., concrete, rebar, structural steel, and engineered wood) to all other materials. Non-structural materials such as insulation, glazing, and stucco contribute less to the MUI of the large office building due to a lower surface area to volume ratio when compared with the medium buildings. The MUI of non-structural materials in large buildings is less than 2% per material. Across all large buildings, concrete represents 71-94% of MUI. In large concrete buildings, rebar has the second greatest contribution to MUI at 4-5%. In large steel buildings, structural steel has the second greatest contribution at 6-7% (followed by rebar at 3-4%). For large wood buildings, engineered wood is the second greatest contributor to MUI at 14-21% of MUI, followed by rebar at 2-8%. Stucco and drywall are also notable contributors to total MUI across all large buildings, representing 1-2% and 0.5% of MUI, respectively. Each other material represents less than 0.25% of MUI for each building.

5.3.2 Deterministic embodied carbon intensities

The ECIs for the 150 building models associated with climate zone 5B are calculated and reported in this section. Climate zone 5B is reported in alignment with **Section 5.3.1**.

5.3.2.1 Cradle-to-gate ECIs (A1-A3)

The cradle-to-gate ECIs for each building in climate zone 5B are reported in **Figure 5-4.** The range ECI for the medium concrete buildings analyzed using the Athena LCA data, shown in the top-left panel, is from 182-240 $kgCO_2e/m^2$. As expected, the lowest ECI is associated with the baseline loading condition (182 $kgCO_2e/m^2$), in which no additional lateral force resisting system is required, and the highest ECI is associated with the high earthquake loading scenario (240 $kgCO_2e/m^2$). This trend is consistent across all structural design and LCA tool combinations.

Cradle-to-gate ECIs across all structural designs and LCA tools range from 114 to 337 $kgCO_2e/m^2$. The lowest ECI (114 $kgCO_2e/m^2$) is associated with wood as the primary structural material, the baseline loading condition, the medium office building, and the Athena LCA data. This value is shared across all three wood designs. This is consistent with the general trends in MUI and ECC for wood buildings, which typically have lower masses than their concrete and steel counterparts. Additionally, the Athena ECCs for some materials, including glulam, concrete, and stucco, are notably lower than those for One Click and Tally. The highest ECI (337 $kgCO_2e/m^2$) is associated with the concrete primary structural material, the high earthquake loading condition, the medium office building, and the Tally LCA data. This is also in line with the trends in MUI reported in **Figure 5-2** and **Figure 5-3,** as well as the general trends in ECC. Tally consistently has the highest ECCs for concrete and structural steel compared with Athena and One Click, as shown in **Table 5-3**.

5.3.2.2 Whole-life ECIs (A-C)

Figure 5-5 reports the whole-life ECI for each building in climate zone 5B using three LCA data sources. The range of ECI for the concrete medium office buildings using the Athena LCA tool is shown in the upper-left panel of **Figure 5-5**. As with cradle-to-gate ECI, the lowest whole-life ECI is associated with the baseline loading condition (235 $kgCO_2e/m^2$), in which no additional lateral force resisting system is required, and the highest ECI is associated with the high earthquake loading scenario (306 $kgCO_2e/m^2$). This trend is consistent across all structural design and LCA tool combinations.

The same trends for cradle-to-gate ECI remain consistent for cradle-to-grave ECI. The whole-life ECIs across all structural designs and LCA tools range from 158 to 420 $kgCO_2e/m^2$, and those values are represented with wood as the primary structural material, the baseline loading condition, the medium office building, and the Athena LCA data for the low value, and the concrete primary structural material, the high earthquake loading condition, the medium office building, and the Tally LCA data for the high value.

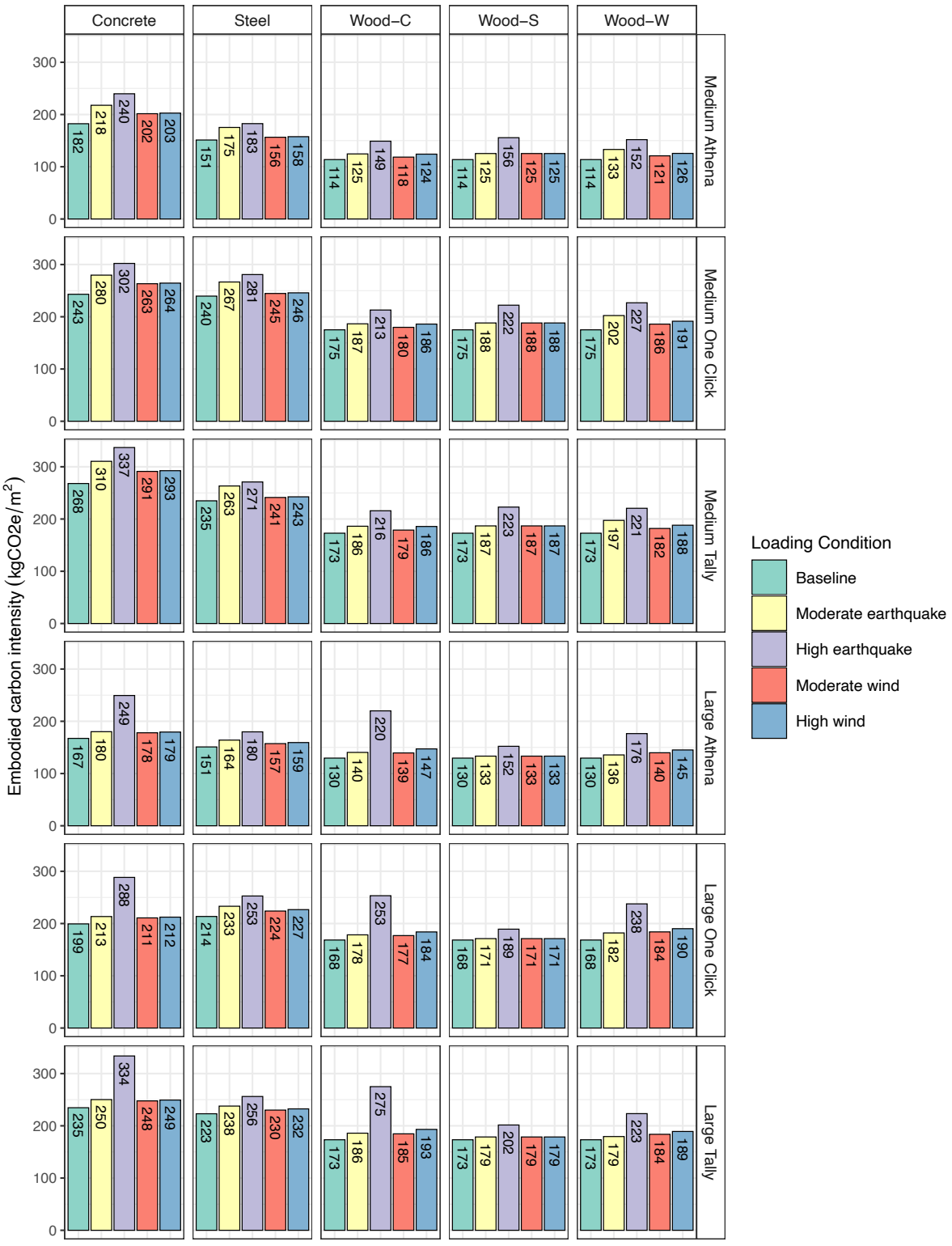

Figure 5-4. *Cradle-to-gate (A1-A3) ECI for each structural design (primary structural material, loading scenario, and building size) and LCA tool.*

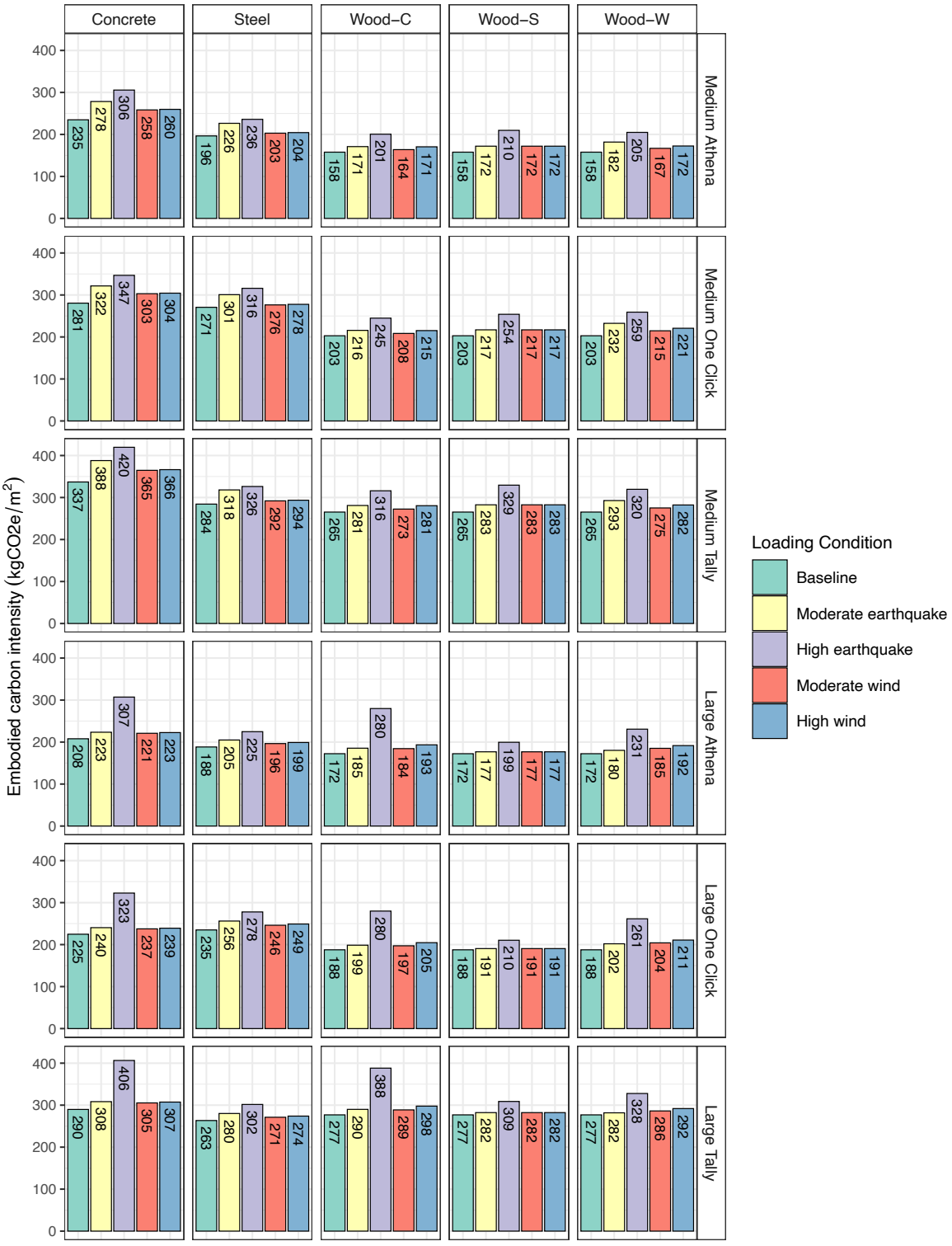

Figure 5-5. *Whole-life (A-C) ECI for each structural design (primary structural material, loading scenario, and building size) and LCA tool.*

Figure 5-6 details the percent contribution of each material to whole-life ECI across all structural designs and LCA datasets. Concrete dominates the ECI for medium concrete buildings in **Figure 5-6**, representing 53-64% of the total ECI. The second greatest contributor to ECI for medium-sized concrete buildings depends on the LCA tool. Using Athena, the second greatest ECI is attributed to steel rebar at 13-18%, followed by insulation and roofing at 4-6% each and glazing at 4% of total ECI. This is an expected result due to the relative magnitude of the Athena ECCs for concrete steel, insulation, roofing, and glazing in **Table 5-3** and the MUIs presented in **Figure 5-2** and **Figure 5-3**.

For medium concrete buildings using One Click, the second greatest ECI is attributed to stucco at 11-13%, followed by insulation at 10-12%, steel rebar at 7-10%, and roofing at 6-7%. For medium concrete buildings using Tally, the second greatest ECI is attributed to stucco at 15-19%, followed by steel rebar at 8-11%, carpet pad at 4-5%, and insulation at 3-4%. As expected, the ECIs of buildings with steel as a primary structural material include greater contributions from structural steel than concrete buildings**.** The contribution of structural steel to ECI spans 33 to 37% for Athena, 35 to 37% for One Click, and 22 to 24% for Tally for medium steel buildings**.** Steel is the greatest contributor to ECI for medium steel buildings evaluated using Athena, while concrete is the second greatest contributor (32 to 36%). For medium steel buildings evaluated using One Click, concrete represents 20 to 25% of ECI, and for Tally, concrete contributes more to ECI than steel at 29 to 33%. The contribution of engineered wood to the ECI of wood buildings spans from 23 to 30% for Athena, 17 to 22% for One Click, and 24 to 29% for Tally. Engineered wood is the second greatest contributor to ECI for all wood buildings, behind concrete, which contributes 31-40% of ECI for Athena, 19-30% for One Click, and 19-29% for Tally.

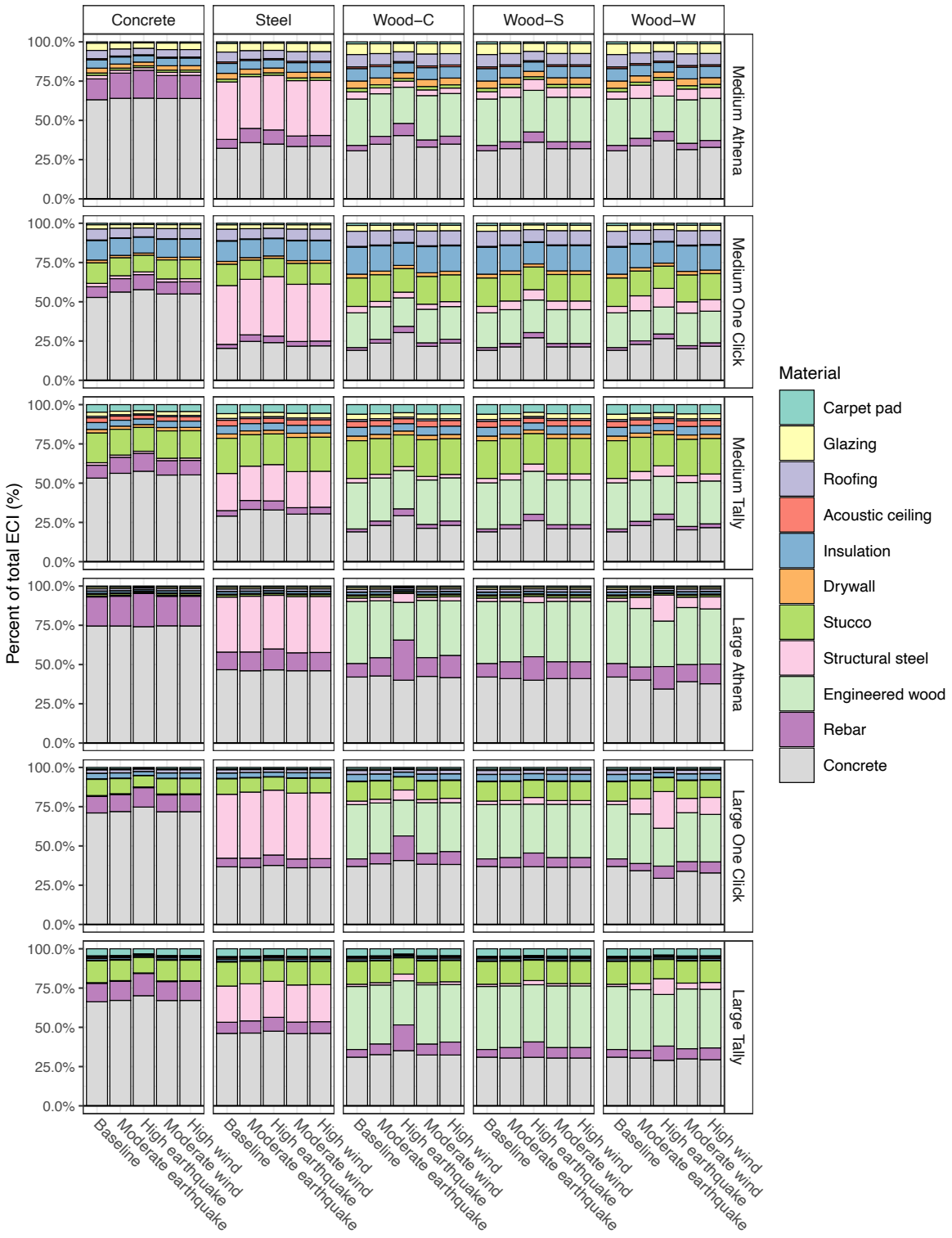

Figure 5-6. *Material contribution to whole-life ECI as a percent of total ECI for each structural design (primary structural material, loading scenario, and building size) and LCA tool.*

For large buildings, the contributions to ECI are similarly dominated by concrete and the respective primary structural materials of each structural design. For large concrete buildings, concrete represents 74% of ECI for Athena, 71-75% for One Click, and 66-70% of ECI for Tally. For large steel buildings, concrete represents 46% of ECI for Athena, 36-38% for One Click, and 46-48% for Tally, while structural steel represents 35-36% of ECI for Athena, 41-42% for One Click, and 23-24% for Tally. Across all large wood buildings, concrete represents 34-43% of ECI for Athena, 29-41% of ECI for One Click, and 29-35% of ECI for Tally, while engineered wood represents 24-40% of ECI for Athena, 22-35% for One Click, and 28-40% for Tally. Stucco and rebar remain major contributors to ECI across large buildings analyzed using all three LCA tools. Insulation, roofing, and glazing all have a lower relative impact due to the lower surface area to volume and surface area to floor area ratios for large buildings compared with medium buildings. All patterns exhibited in **Figure 5-6** are consistent for both cradle-to-gate and whole-life ECI.

Figure 5-7 shows the distribution of whole-life ECIs for each building size and LCA tool, where each distribution includes buildings comprised of different structural designs. The figure demonstrates that, in general, LCA results generated utilizing Tally have the greatest ECIs for the medium and large buildings studied herein, ranging from 265-420 $kgCO_2e/m^2$ for medium buildings and 263 to 406 $kgCO_2e/m^2$ for large buildings. One Click LCA typically reports the second greatest ECIs (203-347 $kgCO_2e/m^2$ for medium buildings and 188 to 323 $kgCO_2e/m^2$ for large buildings), and Athena reports the lowest ECIs (158-306 $kgCO_2e/m^2$ for medium buildings and 172 to 307 $kgCO_2e/m^2$ for large buildings). This represents a difference of up to 144 $kgCO_2e/m^2$ between buildings analyzed using Tally and those using Athena.

The distribution of data by structural design substantiates the data observed in **Figure 5-5**. For instance, in **Figure 5-7,** the greatest ECIs in each distribution are associated with buildings with concrete structures, and the high earthquake scenario has

the greatest ECI of all concrete buildings. Similarly, baseline steel and wood buildings are associated with the lowest ECI in each of the six distributions.

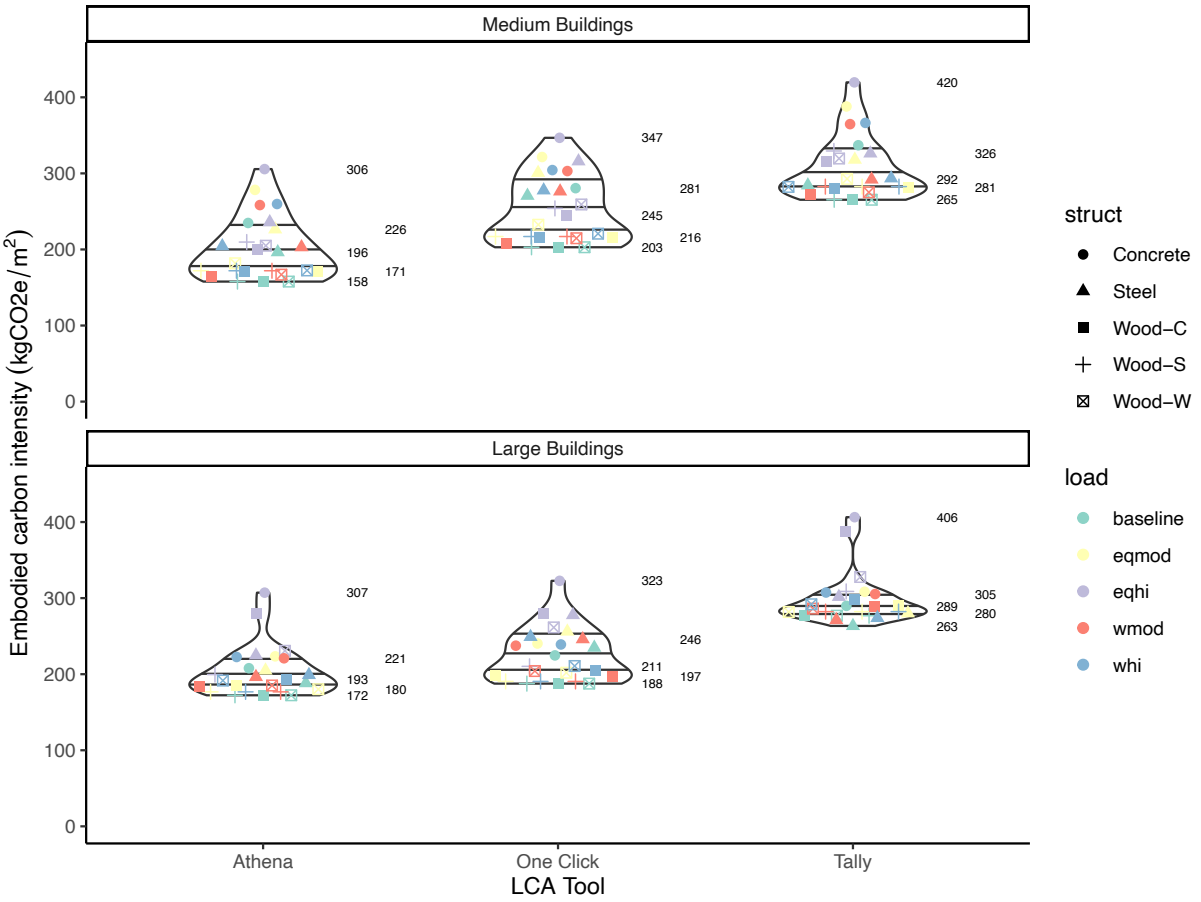

Figure 5-7. *Embodied carbon intensity presented based on the building size and LCA tool. The primary structural material and loading condition are indicated by the color and shape of each data point.*

5.3.3 Theoretical maximum biogenic carbon storage

The theoretical maximum biogenic carbon storage and cradle-to-gate (A1-A3) ECI are shown in **Figure 5-8** for each of the three wood building designs across two building sizes and five lateral loading conditions. The biogenic carbon storage for the top-left panel, indicating medium office buildings made from wood with concrete lateral systems, range from 146-147 $kgCO_2e/m^2$, indicating less than 1% difference from the lowest to highest values. There are similar trends for medium wood buildings with a steel lateral system, in which theoretical maximum biogenic carbon storage ranges from 145-147 $kgCO_2e/m^2$ (1.3% difference). Trends are also similar for large buildings, in which the biogenic carbon storage ranges from 204-211 $kgCO_2e/m^2$ for wood concrete shear wall, 208-211 $kgCO_2e/m^2$ for wood rocking wall, and 204-208 $kgCO_2e/m^2$ for wood steel braced frame buildings.

The medium wood rocking wall buildings exhibit the most notable difference across all five lateral loading scenarios, with a range of 147-169 $kgCO_2e/m^2$. The highest ECI of 169 $kgCO_2e/m^2$ is associated with the high earthquake scenario, which is expected, as a higher lateral loading scenario requires more material in the wood rocking wall than lower lateral load scenarios. For the wood rocking wall scenario, the lateral force-resisting system is made from CLT and structural steel, so the increase in CLT MUI directly increases the amount of biogenic carbon storage in this scenario. There is a similar effect for the large office, wood rocking wall, high earthquake scenario, but it is less pronounced, showing biogenic carbon storage of 211 $kgCO_2e/m^2$ for the high earthquake scenario and 208 $kgCO_2e/m^2$ for the other scenarios.

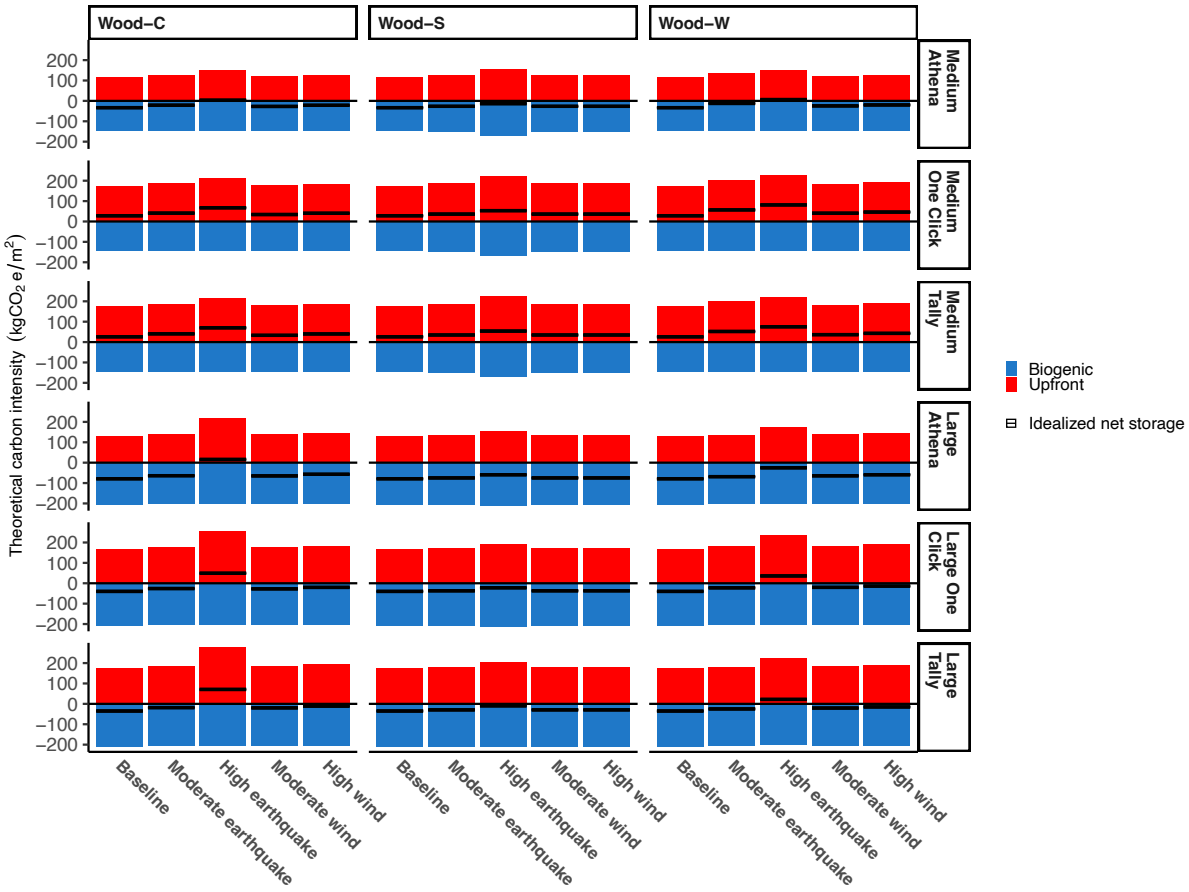

Figure 5-8. *Theoretical maximum biogenic carbon storage per unit area across three mass timber design scenarios for five lateral loading scenarios and two building sizes.*

The cradle-to-gate ECIs combined with the theoretical maximum biogenic carbon storage indicates there may be net carbon storage for 28% of all medium wood buildings and 89% of all large wood buildings analyzed. Net storage is donated by a horizontal black line below the horizontal axis (i.e., 0 $kgCO_2e/m^2$) in **Figure 5-8,** while net emissions is indicated by a black line above the horizontal axis. This result indicates that, in this idealized scenario, the physical biogenic carbon stored in wood is greater than the cradle-to-gate emissions in all of the included building materials. For medium buildings, the idealized net storage is highly dependent on LCA data. Due to the lower ECIs associated with Athena, all wood designs except for the "high earthquake" scenario buildings are net CO_2 storing. However, none of the medium wood building ECIs from One Click or Tally

show net storage. For large buildings, almost all are net CO_2 storing, with the exception of several high earthquake loading scenarios. This difference between medium and large buildings is understandable, as the large buildings have a much greater proportion of wood products – CLT and Glulam – to concrete and steel. The concrete and steel in the foundation of all buildings drives substantial EC emissions, while the wood products drive fewer emissions and substantial biogenic carbon storage. In the case of the medium building, there is less wood per unit mass of foundation, so the biogenic storage in the wood does not overcome the substantial amount of EC emissions associated with the concrete and steel foundations.

5.3.4 Operational carbon intensity

The OC emissions of all 32 unique prototype buildings were computed across three grid decarbonization scenarios. **Figure 5-9** shows the distribution of 30-, 45-, and 60-year OCIs across all climate zones studied, separated by building size and grid decarbonization scenario. The 30-year OCI of medium office buildings for the mid case grid decarbonization scenario, which ranges from 156 $kgCO_2e/m^2$ (climate zone 4C) to 878 $kgCO_2e/m^2$ (climate zone 1A). The remaining climate zones follow an expected pattern, with the highest OCIs in cooling-dominated climate zones with higher emission factors (e.g., climate zone 1A) and lower OCIs in mild climate zones with lower emission factors (e.g., climate zone 4C). In cases where a climate zone has a greater heating demand but a lower grid emission factor (e.g., climate zone 5A), results are mixed. Despite driving greater total energy consumption due to high heating demands, heating-dominated climate zones such as Climate Zone 7 also have mixed OCIs due to the relatively low emission factor of their natural gas heating sources compared with the higher emission factor of electricity, the main source of fuel for cooling.

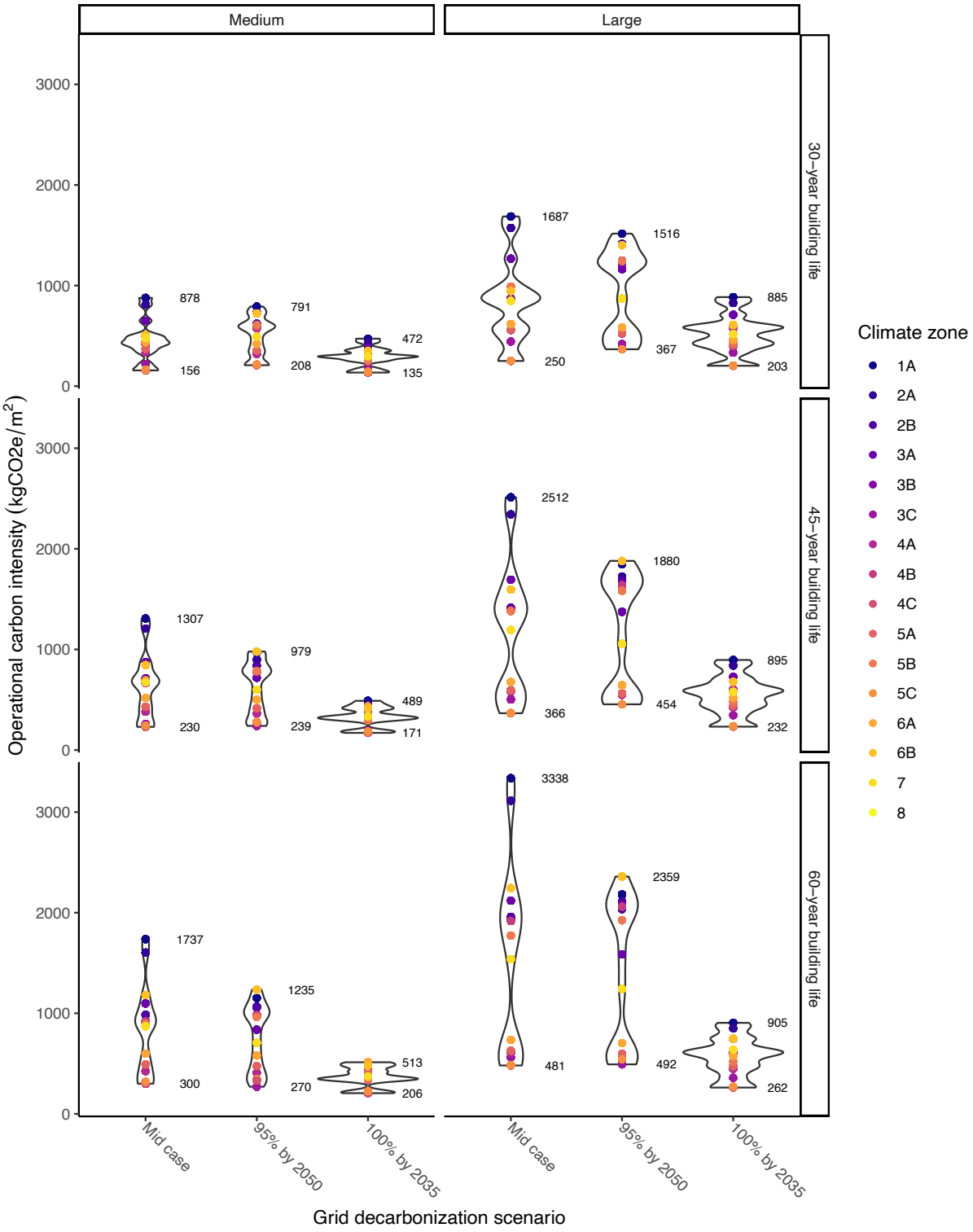

Figure 5-9. *Operational carbon intensity for each building design across 16 climate zones, three grid decarbonization scenarios, two building sizes, and three reference study periods.*

For the medium office, 30-year RSP, and 95% reduction by 2050 scenario, OCIs range from 208-791 $kgCO_2e/m^2$. This is expected, as the 95% reduction by 2050 scenario has mixed results when compared with the Mid case scenario for specific grids. For the 100% reduction by 2035 scenario, OCIs are expectedly much lower – ranging from 135-472 $kgCO_2e/m^2$.

For large office buildings, the OCIs are higher, as the EUIs for large office buildings are typically higher than those of medium office buildings. OCIs for large office buildings, a 30-year RSP, and the Mid case scenario range from 250-1687 $kgCO_2e/m^2$. For the 95% reduction by 2050 scenario, OCIs range from 467-1516 $kgCO_2e/m^2$, and for 100% by 2035, the range is 203-885 $kgCO_2e/m^2$.

With increasing RSP, the total, non-time-normalized OCI will always increase unless all energy sources in the building (including fossil fuels) are decarbonized. For the large Mid case scenario buildings, OCIs range from 250-1687 $kgCO_2e/m^2$ for a 30-year RSP, 366-2512 $kgCO_2e/m^2$ for a 45-year RSP, and 481-3338 $kgCO_2e/m^2$ for a 60-year RSP. The magnitude of the increase in OCI as RSP increases is reduced slightly for the 95% by 2050 scenario and reduced substantially for the 100% by 2035 scenario because the grid carbon emissions will be dramatically reduced beyond year 30 for these scenarios. For large buildings and the mid case scenario, the maximum OCI for a 60-year RSP is 98% higher than the maximum OCI for a 30-year RSP. For the 95% by 2050 scenario, that difference is only 56%, and for the 100% by 2035 scenario, that difference is only 2% because all grid emissions beyond year 30 are carbon-free. There are still emissions in those later years, as this model does not assume that fossil fuel loads are electrified.

5.3.5 Whole-life carbon intensity

The WLCI of the prototype building models assuming a 60-year RSP is shown in **Figure 5-10**. The WLCI of these buildings is most sensitive to the variables that affect OC emissions: Climate zone, generation and emission assessment (GEA) region (which varies by climate zone), and grid decarbonization scenario. It is clear that the greatest WLCIs are associated with the mid case scenario and climate zone 1A, with a median of 1997 $kgCO_2e/m^2$ for medium buildings and 3573 $kgCO_2e/m^2$ for large buildings. Climate zone 1A represents the highest median WLCI in most scenarios, except for the 95% by 2050 scenario, where climate zone 6B has a higher WLCI. The lowest WLCI across all scenarios is associated with climate zone 4C and the 100% by 2035 scenario, with a median of 466 $kgCO_2e/m^2$ for medium buildings and 497 $kgCO_2e/m^2$ for large buildings. The lowest WLCI by scenario and building size varies from case to case.

The clearest difference between the highest and lowest WLCIs concerns the mid case scenario, which most closely resembles a continuation of business as usual. For the mid case scenario and large buildings, the greatest median WLCI is associated with climate zone 1A (3573 $kgCO_2e/m^2$). The lowest is associated with climate zone 4C (716 $kgCO_2e/m^2$).

Although there is great variation across climate zones, there is a clear pattern of WLCI reduction from the mid case scenario to 95% by 2050 to 100% by 2035. The median WLCI across all climate zones and building sizes in the mid case is 1190 $kgCO_2e/m^2$, 1198 $kgCO_2e/m^2$ for the 95% by 2050 case, and 697 $kgCO_2e/m^2$ for the 100% by 2035 case.

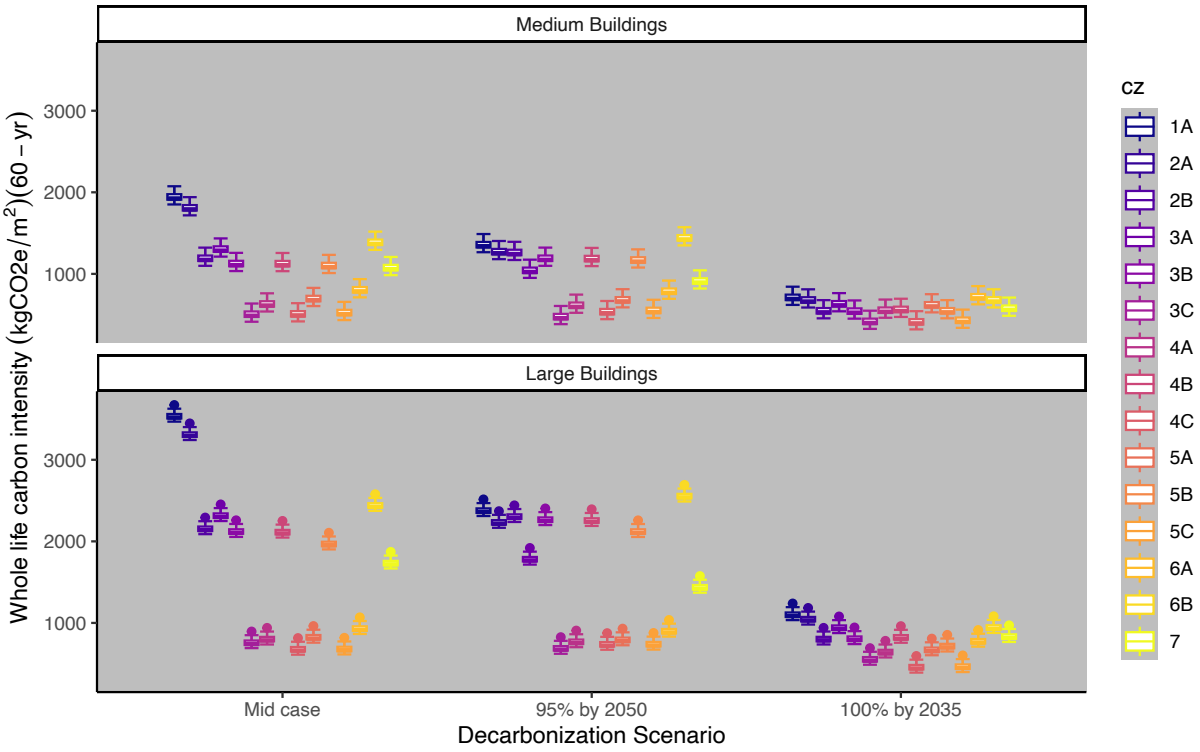

Figure 5-10. *Whole-life carbon intensity of all building designs separated by climate zone, size, and decarbonization scenario*

Across all scenarios, climate zones 3C, 4A, 4C, 5A, 5C, and 6A have dramatically lower WLCIs than all other climate zones. This is partially due to low grid emissions in some GEA regions, but existing grid decarbonization plans in certain locales have an outsized impact on other GEA regions. Currently, grid emissions are very low in the NorthernGrid_West GEA Region, representing Climate Zones 4C and 5C. Their emission factor of 100 $kgCO_2e/MWh$ is more than 2x lower than any other GEA region included in this study. In Climate Zone 3C, representing the CAISO region, grid emissions are projected to be 250 $kgCO_2e/MWh$ in 2025, but the state has aggressive decarbonization plans that are already committed to, so they are included in the Cambium projections for that region.

Figure 5-11 shows the relationship between ECI and OCI, considering 30-year, 45-year, and 60-year RSPs, with a line indicating where there is a 1:1 relationship between embodied and OCI over the life of the building. This figure elucidates the proportion of ECI

to OCI across the building models. In the 30-year RSP scenario, OC emissions are greater than EC emissions in 87% of building design and building decarbonization scenario combinations. Of those cases that fall 'below' the line, indicating that EC emissions are greater than OC emissions, most are associated with the 100 by 2035 grid decarbonization scenario. This result is expected, as the 100% by 2035 scenario results in the lowest overall OCIs, as shown in **Figure 5-9.** The trends are similar for the 45-year and 60-year building lives, which essentially just shift the OCI results higher for each scenario. For the 45-year RSP scenario, 92% of all cases have higher OCIs than ECIs, and for the 60-year RSP, 96% of all cases have higher OCIs than ECIs.

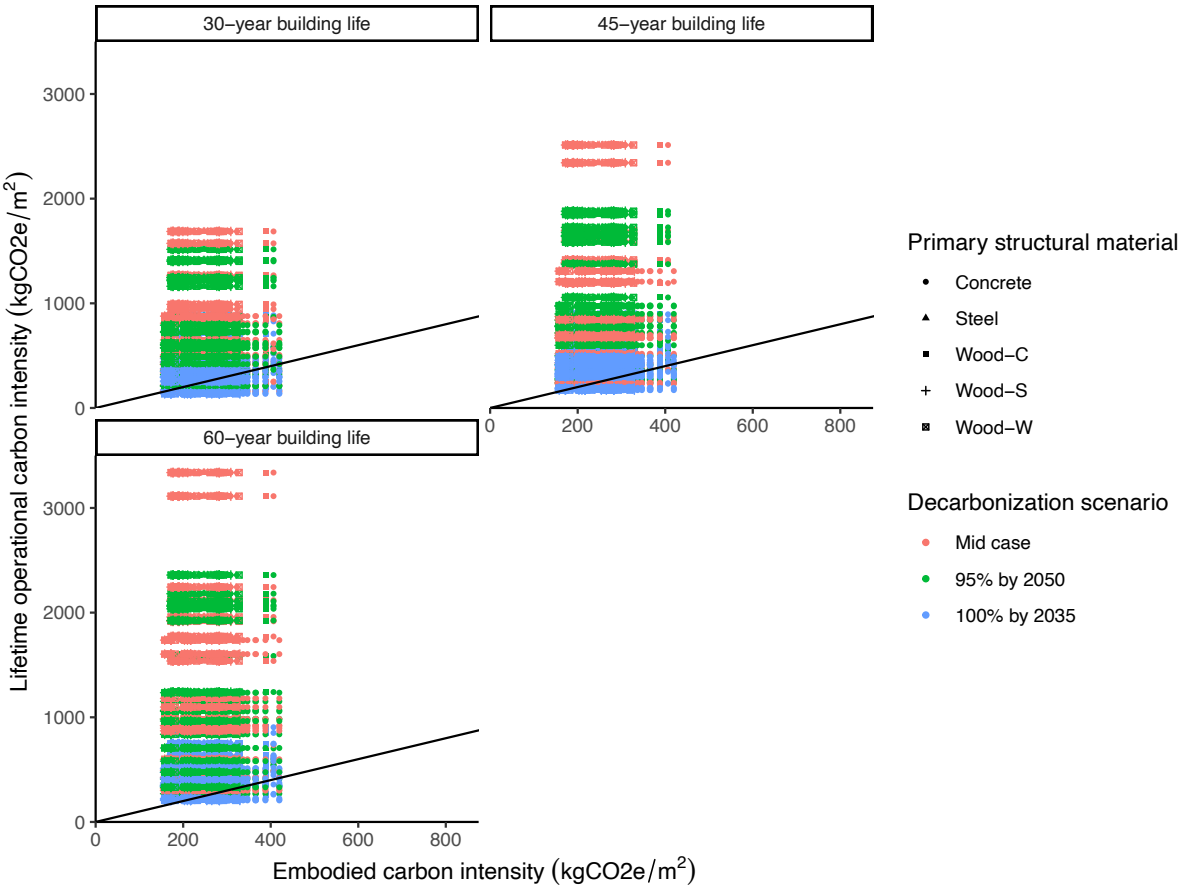

Figure 5-11. *Operational carbon intensity plotted against embodied carbon intensity for each structural design, operational carbon emission result, and RSP (30-, 45-, and 60-year).*

5.3.6 Probabilistic embodied carbon intensity

Figure 5-12 shows the range of ECIs for each structural design, lateral loading scenario, and building size, accounting for a probabilistic distribution of ECCs. As with MUI and ECI, this analysis is only applied to climate zone 5B due to the consistency in materiality across all climate zones. The median values show the same pattern described in **Figure 5-5,** with ECI increasing from the baseline to the high earthquake scenario, and with the highest ECIs associated with concrete and steel buildings, respectively. For instance, in the top-left panel, which represents medium-sized concrete buildings, the median values range from 231-237 $kgCO_2e/m^2$, with the lowest value associated with the baseline scenario, and the highest associated with the high earthquake scenario. The third quartile (Q3) values follow the same general pattern, with the lowest Q3 for medium concrete buildings of 318 $kgCO_2e/m^2$ associated with the baseline case, and the highest of 340 $kgCO_2e/m^2$ associated with high earthquake. The first quartile (Q1) values are relatively constant, with Q1 = 155 $kgCO_2e/m^2$ for the medium concrete building baseline case and 156 $kgCO_2e/m^2$ for all other medium concrete cases.

Across all medium buildings, the same patterns are maintained. The range of median values for steel buildings is 227-234 $kgCO_2e/m^2$, and the wood with concrete shear wall, steel brace frame, and wood rocking wall lateral systems have medians ranging from 191-202 $kgCO_2e/m^2$, 191-206 $kgCO_2e/m^2$, and 191-208 $kgCO_2e/m^2$, respectively.

For large office buildings, the median values follow similar patterns. The median ECIs for concrete and steel buildings span from 214-235 $kgCO_2e/m^2$ and 212-223 $kgCO_2e/m^2$, respectively. The medians of the wood buildings with concrete shear wall, steel brace frame, and wood rocking wall lateral force resisting systems are 182-212 $kgCO_2e/m^2$, 182-196 $kgCO_2e/m^2$, and 182-204 $kgCO_2e/m^2$, respectively.

A two-sample K-S test indicated that there are some statistically similar ECI distributions across the structural designs studied herein. Most notably, the concrete and steel medium building designs for moderate earthquake, moderate wind, and high wind

loading were all determined to have statistically similar distributions of ECI. The comparability within a structural material is an expected result, as the designs across moderate earthquake, moderate wind, and high wind loading were highly similar within a given structural material. However, the similarities in ECI between several steel and concrete designs for these more moderate loading scenarios are noteworthy. It is also expected that the baseline and high earthquake designs would be sufficiently different across materials based on the MUI results presented in Section 5.3.1.

There were additional similarities within structural material categories for large buildings. For instance, large steel buildings in the moderate wind, high wind, and moderate earthquake loading scenarios have statistically similar distributions of ECI. For large concrete buildings, ECIs for buildings designed for moderate earthquake and high wind are similar, and baseline and moderate wind are similar. For wood buildings, there were no similarities across unique designs (i.e., the baseline designs are identical for wood buildings) or with other structural materials.

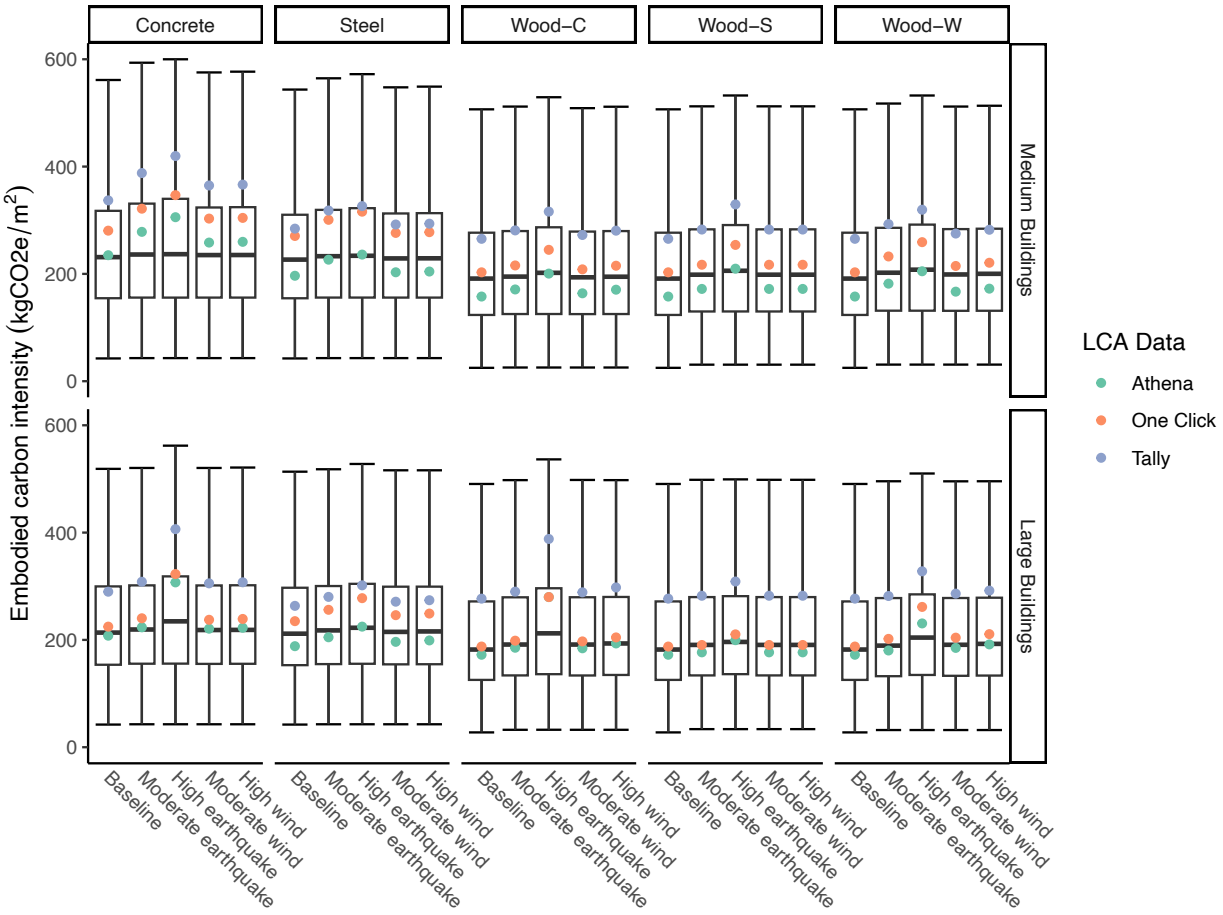

Figure 5-12. *Ranges of ECI for each of the distinct building models using KDE based on EC3 to develop probability distributions for each material.*

5.3.7 Toward establishing theoretical benchmarks for commercial office buildings

Figure 5-13 summarizes the distributions of MUI, cradle-to-gate ECI, and OCI across all of the structural and operational scenarios considered in this study, and the descriptive statistics are shown in **Table 5-6**. The MUI statistics included below provide useful references that could be used for comparison with other material quantity takeoffs, and the material-level MUI data could be leveraged to recreate this study. The range of deterministic and probabilistic ECIs have a great deal of overlap, and have median ECIs that are about 25% apart. The much wider array of values (as indicated by the Min and Max values) for the probabilistic ECIs leads to the wider IQR than for the deterministic ECIs. This result is expected, as the incorporation of uncertainty led to models that included relatively higher and lower cradle-to-gate ECIs than the deterministic results. Finally, the range of OCI values, in coordination with the data related to the grid decarbonization scenario and GEA region, could be used as points of comparison, or in the generation of an OCI benchmark.

Table 5-6. *Summary statistics for the distributions of MUI, ECI, and OCI computed in this study.*

	Size	**Min**	**Q1**	**Median**	**Q3**	**Max**
MUI (kg/m^2)	M	427	471	510	623	1273
	L	615	620	659	757	1399
Deterministic ECI (A1-A3) ($kgCO_2e/m^2$)	M	114	173	187	240	337
	L	130	168	180	223	334
Probabilistic ECI (A1-A3) ($kgCO_2e/m^2$)	M	25	151	238	380	1705
	L	28	151	227	373	1704
OCI ($kgCO_2e/m^2$)	M	135	313	432	718	1737
	L	203	518	676	1401	3338

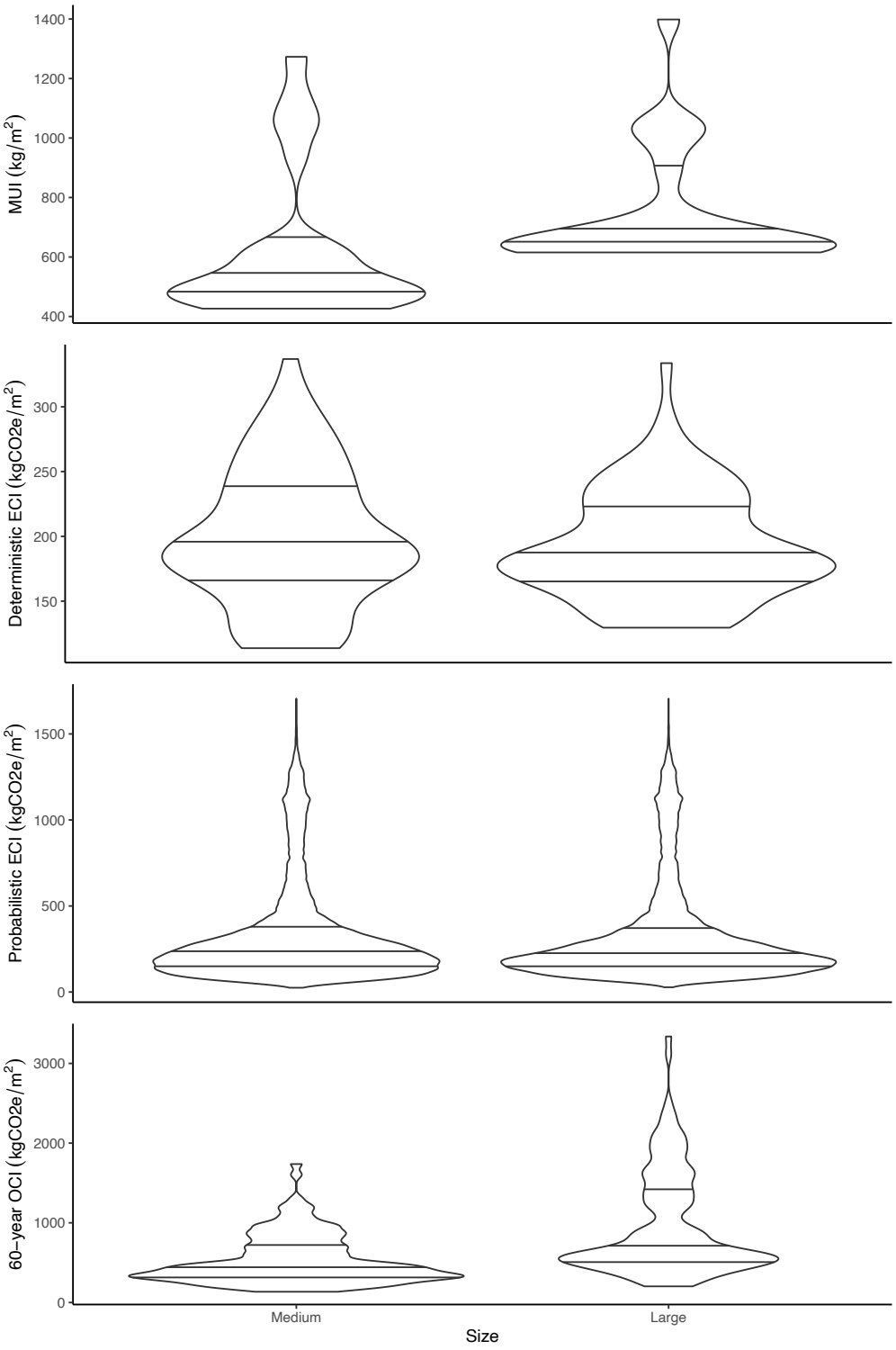

Figure 5-13. *MUI, deterministic cradle-to-gate ECI, probabilistic cradle-to-gate ECI, and 60-year OCI are plotted as a distribution for medium- and large-sized buildings.*

5.4 Discussion

5.4.1 Key Takeaways

The results presented in **Figure 5-3 and Figure 5-7** demonstrate that structural materials are responsible for the greatest contribution to MUI and ECI in all 800 commercial office building models. Concrete, engineered wood, and steel (including rebar and structural steel) are responsible for 88-99% of MUI across all models (94% on average) and 47-96% of ECI (74% on average). The sizeable contribution of structural materials across both MUI and ECI supports the fact that structural materials represent the majority of a building's materiality and EC emissions (Dimoudi & Tompa, 2008; Kaethner & Burridge, 2012). This finding also highlights structural materials as a substantial opportunity for reducing materiality and ECI in buildings. Because structural materials represent such a major contribution to each of these metrics, even small reductions in material quantities through more efficient design or reductions in ECCs through material substitution can yield notable improvements in the EC emissions of a given commercial office building. For instance, a 10% reduction in the ECC of all concrete mixes through the use of alternative concrete mixes would yield a 2-7% reduction in ECI across a whole building in this study.

Although non-structural materials represent smaller relative contributions to MUI and ECI, they are still responsible for substantial quantities of embodied energy and EC emissions for a single medium commercial office building. The EC emissions for insulation represent 5% of total ECI on average, which is equivalent to 20.5 $kgCO_2e/m^2$ for medium buildings or 4.5 $kgCO_2e/m^2$ for large buildings. The total EC emissions per building would be approximately 102,000 $kgCO_2e$ for a whole medium office building or 208,000 $kgCO_2e$ for a large office building, which are approximately 6x and 12x the total EC emissions of the theoretical single-family home benchmark for One Click presented in Jungclaus et al. (2024)**.** Thus, a very conservative 20% reduction in insulation emissions for a medium office

building would be the equivalent of eliminating the total carbon emissions of 1-2 single-family homes. Realistically, a reduction of at least 50% is possible using off-the-shelf technologies based on materials available today, and greater reductions (and net carbon storage) are possible with emerging natural insulation material options. Similarly, substantial opportunities for emissions reduction are possible by considering alternate roofing, siding, and interior finish materials.

This study showed that the ECI for certain steel and concrete buildings can be considered statistically similar. This means that, given the inputs to the KDE model, the ECIs of steel and concrete buildings with moderate earthquake, moderate wind, and high wind loads can be expected to have similar ECIs. This is unexpected, as concrete and steel buildings have very different MUIs, and steel and concrete have very different ECCs across the tools studied in this analysis. However, when uncertainty is taken into consideration, these building designs were determined to be highly similar. This conclusion is dependent on the specific ECC data used from EC3 for the KDE analysis and is likely to change as more EPDs are included in EC3 and as new low-carbon materials enter the market.

The choice of LCA data and structural design had meaningful impacts on the ECIs presented in this analysis. **Figure 5-12** demonstrated that, while there a wide range of potential values when uncertainty is considered, there is no clear agreement across the 3 LCA data sources. On average, LCA results were highest for Tally, second highest for One Click, and lowest for Athena. The Athena ECIs were always within the IQR of the probabilistic LCA. The One Click values were within the IQR for 48 out of 50 designs, and the Tally values were within the IQR for 21 out of 50, always trending higher than the medians.

The OCI of each building is highly dependent on the applicable GEA region as well as the grid decarbonization scenario pursued. Although climatic conditions did affect the EUI, and thus the OCI of each building, the grid emissions had an outsized effect on the ultimate OCI. For instance, the total site energy consumption for climate zone 5A (Buffalo,

NY) and climate zone 5B (Denver, CO) are highly similar – the EUI for the large office building is 155 kWh/m^2-yr for 5A and 168 kWh/m^2-yr (8% higher) for 5B. However, the 60-year OCI for climate zone 5A and the mid case scenario is 485 kgCO_2e/m^2, while it is 1772 kgCO_2e/m^2 (265% higher) for climate zone 5B. This disparity is due to the drastically different grid emission factors in the NYISO region when compared with the WestConnect_North region. The 2022 emission factor for NYISO is 340 kgCO_2e/MWh, while it is 540 kgCO_2e/kWh for WestConnect_North. Although both grid regions have decarbonization goals, the initial years of notably higher emission factors for WestConnect_North substantially shift the 60-year outlook when compared with NYISO.

The WLCI is primarily driven by OCI, and thus, the WLCI is highly dependent on the trajectory of grid emissions in each GEA region. **Figure 5-11** demonstrates that, even for the 60-year scenario, 87% of all OCIs modeled in this paper are greater than their corresponding deterministic ECIs. This emphasizes the continued importance of decarbonizing the utility grid and improving efficiency in buildings, as the impacts of OC are currently an order of magnitude greater than EC in commercial office buildings across most climate zones.

Mass timber buildings have lower embodied carbon emissions than steel and concrete buildings, regardless of whether biogenic carbon storage is accounted for. More analysis should be performed to fully understand the implications of biogenic carbon storage for the wood buildings studied in this chapter. Although the results shown in **Figure 5-8** demonstrated that the theoretical maximum biogenic carbon storage in mass timber buildings is substantial, this does not consider the regrowth cycle of trees harvested for lumber, the source of lumber, or the end-of-life treatment of the wood, all of which could have limiting effects on the biogenic carbon storage.

5.4.2 Broader Research Context

The results presented in this study are valuable data for establishing MUI, ECI, and OCI benchmarks for reference buildings based on the archetypal models established by the US DOE. These results could be used as benchmark values for cases where a whole building LCA is being conducted for buildings similar to the DOE prototype buildings, or where the scope of the embodied or operational carbon analysis is similar to this study. Although the DOE prototype buildings are meant to represent 'typical' designs for buildings of each typology defined (e.g., medium office), they will not be representative of all buildings of that type. For example, the medium office prototype building assumes the use of stucco as a cladding material, but another commercial office building might use steel, aluminum, fiber cement board, or a glazed curtain wall assembly for cladding. Changes to cladding could substantially change the MUI, ECI, EUI, and OCI. Similarly, this study assumed a 9.45m x 9.6m (31' x 31'6") bay size for medium office buildings with a concrete structure, while there are nearly infinite choices when it comes to sizing bays in commercial office buildings, which can have substantial impacts on the MUI and ECI of a building.

The MUI, ECI, EUI, and first-year OCI results are within an expected range based on a review of relevant literature. The MUI results presented in this study are between 421-1389 kg/m^2 for medium and large office buildings across all structural designs and loading scenarios. The RASMI dataset reports MUIs for nonresidential buildings with an interquartile range (IQR) of 314-1348 kg/m^2, which is very similar to the range of values reported herein (Fishman et al., 2024). The static ECIs in this study are between 125-430 kgCO_2e/m^2, while the IQR of the probabilistic ECIs range from 122-340 kgCO_2e/m^2. The North American values reported for office buildings in the 2017 CLF Benchmark study are between 32-1314 kgCO_2e/m^2, and a series of European sources for commercial office LCA results report ECIs between 11-780 kgCO_2e/m^2 (One Click LCA Ltd., 2021; Rasmussen et al., 2022; Röck, Sørensen, Tozan, et al., 2022; SIA, 2017). It is important to note that these data points come from studies with varying physical and LCA scopes. A study by Arehart et

al. (2020) reports ECIs between 50-105 $kgCO_2e/m^2$ for the DOE prototype buildings analyzed in this study, except the scope is limited to only non-structural materials included in the energy model.

To ensure that operational energy and carbon are in line with expected values, we can consider the EUI and first-year OCI for comparison with known values. The OCI values reported in this study are highly dependent on the grid decarbonization scenarios in Cambium, so taking the first-year OCI ensures comparability with past studies of annual OC emissions. Although the EUIs simulated for the DOE prototype buildings have been validated through a rigorous process run by PNNL, we can compare these EUIs with empirical data points (EERE, US DOE, n.d.; US DOE, 2018). For instance, the EPA Energy Star Portfolio Manager, which calculates median EUIs based on real building energy consumption, reports a median EUI of 166.8 kWh/m^2-yr (52.9 $kBtu/ft^2$-yr) for office buildings (US EPA, 2024a), while the range of values reported in this study is between 68-176 kWh/m^2-yr. It is expected that the Portfolio Manager EUI would be on the high end of the range of values reported in this study, as this study includes modeled values, which tend to be lower (higher-performing) than empirical EUIs. Additionally, this study is representative of the 2019 ASHRAE 90.1 standard, while buildings included in the Portfolio Manager dataset are older and were required to meet less energy-efficient versions of the building code. For OCI, the first-year OCI for all buildings analyzed in this study is between 8.4-102 $kgCO_2e/m^2$ for the mid case emissions scenario. To the author's knowledge, OCI estimates for commercial buildings in the US are not widely available. A study of an international reference building with an EUI of 54 kWh/m^2-yr (below the range of the EUI of the reference buildings included in this study) reports OCIs between approximately 8-53 $kgCO_2e/m^2$ (Frischknecht, Birgisdottir, et al., 2019). The lower range of OCIs when compared with the US reference building is expected due to the relatively small size of the reference building (2421 m^2) and the low EUI of that reference building. Additionally, many of the grid emission factors analyzed in that study are lower than those that exist for the

US grid. There are no known OCI benchmarks in the US with which the results of this study can be compared.

Establishing robust benchmarks that are representative of all office buildings would require a more parametric design methodology that represents many different structural and architectural design choices as well as many different site conditions. For this study, three structural materials were selected, and five lateral loading conditions were defined to represent conditions across the US. For each of these combinations, site properties such as soil type were assumed, and a single design was produced. In an ideal scenario, for each of the three structural materials, structural layouts and foundations would be varied and analyzed iteratively. Further, the lateral loading conditions could be iterated continuously (as opposed to discretely, considering only five scenarios) to represent every potential lateral loading condition in the US. Further, regional concerns could be iterated upon to consider different soil conditions, design styles, and material choices. Some of these conditions could be iterated parametrically – for instance, the bay spacing could be varied linearly within a range of reasonable values. Variation to capture regional design and material choices would be more difficult to capture, as there are no known studies or standards that capture these preferences holistically, and there is not a statistically representative database of structural and/or architectural designs that could be analyzed to consider regional preferences and conditions. This would be a valuable future use case for efforts like the Carbon Leadership Forum Benchmark Study V2 or the SE 2050 database, which seeks to analyze large sets of data regarding the material intensity and EC emissions of building structures (CLF, 2022; SE 2050, 2023; *SE2050*, n.d.).

5.4.3 Significance and Limitations

This study signifies the first known *theoretical, science-based* benchmarks for the MUI, ECI, and OCI of office buildings in the United States based on reference buildings. The development of building designs across 16 unique climate zones, two building sizes, five

load scenarios, and five primary structural materials enables the use of these benchmarks across a wide range of local conditions in the US. The theoretical, science-based approach utilized herein can enable better building design, robust goal-setting, and the enactment of codes and policies that aim to reduce embodied impacts across the building sector.

It is important to recognize the value of the MUIs analyzed for the commercial prototype buildings in this study. Although ECI, OCI, and WLCI are typically the most useful outputs, particularly when designing a building toward environmental goals, the MUIs provide a more valuable reference point for researchers using this analysis. As low-carbon materials enter the market, the MUIs calculated in this study could be applied to new ECCs or distributions of ECCs to understand the improvements that certain materials can have at the whole building scale. Similarly, these MUIs can be modified to account for specific design choices, such as the choice of insulation material or the addition of finish materials.

High EC emissions and OC emissions can be 'locked in' during building construction. Cradle-to-gate EC emissions, which represent more than 87% of total ECI based on this analysis, are locked in during building construction and cannot be mitigated in any meaningful way once the building has been constructed. Similarly, a building that is designed with operational inefficiencies will likely have high OC emissions for many years. Unlike with EC, OC can be reduced in buildings via building retrofits and grid decarbonization, but still, retrofits can be expensive, and grid decarbonization is largely out of the hands of building owners and developers.

It is also critical to understand the implications that some design choices can have on both OCI and ECI. For instance, petroleum-based foam insulation products can have an ECC that is 1.5-6x that of mineral wool or fiberglass batt insulation products but provide a greater thermal resistivity per inch of insulation. The same can be said about foam insulation products and natural products such as wood wool and hempcrete, which provide net carbon sequestration. Design decisions, such as which insulation product to use, can

result in mixed ECI and OCI tradeoffs. As such, it is critical to consider both operational and embodied emissions in building design.

The results presented herein should be considered within the context of the LCA goal and scope established in the methods of this study. Although the DOE prototype buildings were analyzed as reference buildings for energy consumption in offices, there are many different office design practices within the US, and the designs utilized herein may not align with certain regional practices, and they will certainly not align with more bespoke commercial office designs.

This study makes several key assumptions. First, this study assumes that all material and carbon intensity calculations, including MUI, ECI, OCI, and WLCI, are normalized based on conditioned floor area rather than gross floor area, which is consistent with the approach utilized in Jungclaus et al. (2024). Second, minor modifications to the bills of materials for the LCA models were made from the DOE prototype buildings to align with standard design practices, including the addition of stucco cladding in large office buildings, which did not include any cladding (this aligns with the use of stucco as cladding in the medium office buildings) and the use of mineral wool batt insulation where no type of insulation was specified. Those modifications are assumed not to impact operational energy simulations. Third, the emission factors for natural gas are considered uniform across the United States and were assumed to be consistent during the 30-60-year assumed RSP. Finally, uncertainty in material quantities was not considered in this analysis.

This analysis has several notable limitations. Emission rates for future years, based on the Cambium dataset, were only considered on an annual basis in 5-year increments. A more detailed analysis would consider hourly marginal emission rates projected by Cambium and integrate them with the hourly energy modeling analysis performed in this study. The analysis performed in this study is not necessarily less accurate, but it is less precise by not considering hourly marginal emission rates. The LCA conducted herein did not account for building services (such as HVAC and plumbing equipment), plug loads (such

as refrigerators and computers), and some finish materials (beyond acoustic ceiling tiles and carpet pads), such as workplace partitions, furniture, and paint, all of which could contribute meaningfully to the ECI of office buildings – particularly when maintenance and replacement are considered over time. This study did not parameterize structural design, nor did it consider more than one substructure design per building size, which limits the representativeness of the computed benchmark values across various commercial office designs. This study also only considered one building envelope/façade design based on the DOE models, which is not representative of the wide array of cladding and insulation materials and window-to-wall ratios used in commercial buildings. Finally, the theoretical maximum biogenic CO_2 storage signifies a more idealized biogenic CO_2 storage than would be actualized in a building project, as it does not account for the decay of wood products during their useful life or at the end of their useful lives. The idealized net biogenic carbon storage shown in **Figure 5-8** is for demonstration purposes and should not be used as an actual quantity of net biogenic storage that would be expected in practice.

5.5 Conclusions and future work

This study established theoretical EC benchmarks for 800 prototypical office building models based on DOE prototype buildings representing 16 climate zones, five primary structural materials, five lateral loading conditions, and two building sizes (3 and 12 stories). The MUI for each prototype building ranges from 427-1273 kg/m^2 for medium buildings and 615-1399 kg/m^2 for large buildings. The A1-A3 ECI based on Athena, Tally, and One Click ranges from 114 to 337 kgCO_2e/m^2 for medium buildings and 130 to 334 kgCO_2e/m^2 for large buildings, whole the A-C EC emissions ranges from 158 to 420 kgCO_2e/m^2 for medium buildings and 172 to 406 kgCO_2e/m^2 for large buildings. The probabilistic LCA results show median ECIs between 191-237 kgCO_2e/m^2 for medium buildings and 182-236 kgCO_2e/m^2 for large buildings. Additionally, OCI was computed across the 32 prototype building energy models, resulting in a range of 135-1737 kgCO_2e/m^2

for medium buildings and 203-3338 $kgCO_2e/m^2$ for large buildings, with notable variation based on climate zone, utility region, and grid decarbonization scenario.

Future research can build on these theoretical benchmark models by parameterizing material quantities. A robust parametric study would vary the structural design (e.g., bay sizes and concrete strength), the building envelope (e.g., insulation types), and finish materials (e.g., flooring type) to establish anticipated ranges of MUI and ECI for each structural design scenario. In combination with probabilistic LCA, a parametric structural model would result in a more robust set of potential ECIs for commercial office buildings that is more inclusive of a variety of structural designs. Additionally, future analysis should consider the whole-life implications of biogenic carbon storage, including end-of-life treatment and the impact of RSP on net carbon storage.

The theoretical benchmark results presented herein provide critical reference points for researchers, structural engineers, architects, policymakers, and other parties seeking to reduce embodied impacts in commercial office buildings. Engineers and architects can use these benchmarks as points of comparison for relevant buildings with similar geometries and similar reference cases. Establishing points of comparison is the first step toward designing lower EC structures. Policymakers can use this analysis to understand the impact of different materials, and how they might be targeted in future codes and policies. Researchers might improve these benchmarks and/or update them to match emerging energy and structural design practices, or to incorporate new and innovative materials. The theoretical ECI, OCI, and WLCI figures presented in this study can serve as an enabling factor for lower emissions in the US building stock.

CHAPTER VI

6. Theoretical embodied carbon benchmarks of multifamily residential apartment buildings in the United States

6.1 Introduction

This chapter proposes a methodology for establishing theoretical embodied carbon intensity (ECI, $kgCO_2e/m^2$) benchmarks for multifamily residential apartment buildings in the US based on the US Department of Energy (DOE) prototype building energy models. This chapter builds on simple structural designs in previous chapters by designing parametric structural designs for concrete-, steel-, and wood-frame buildings to generate ranges of material use intensity (MUI, kg/m^2) and ECI for the multifamily apartment building typology. The parametric analysis resulted in 24,000 unique, but functionally equivalent, structural designs across different structural systems. Structural design options include variations in primary structural material, span length, soil bearing pressure, foundation concrete strength, and floor system concrete strength (only for concrete floor systems) for both the mid-rise and high-rise apartment building models.

The structural analyses, life cycle assessments (LCAs), and uncertainty modeling were undertaken to establish theoretical, science-based benchmarks. First, material quantity (MQ) takeoffs were performed for each structural design to quantify MUI in the structure, foundation, and building envelope for each design. Second, the MUIs for each design were used to perform a deterministic LCA for each building design across three LCA software tools: Athena Impact Estimator for Buildings (Athena), Tally, and One Click LCA (One Click). Cradle-to-gate ECI (LCA modules A1-A3) was evaluated across these tools. Third, a probabilistic LCA was performed using Monte Carlo simulation and kernel density estimation (KDE) to model uncertainty in ECI across all building designs. Fourth, the theoretical maximum biogenic carbon storage for each building model was calculated.

6.2 Computational methods

6.2.1 DOE apartment prototype building

This analysis uses the prototype mid-rise and high-rise apartment building models developed by the US DOE and the Pacific Northwest National Laboratory (PNNL) as a reference building to develop theoretical benchmarks (US DOE, 2018). The prototype building models are intended as reference buildings for energy analysis. However, the prototype models are used in this study to represent a 'typical' manifestation of building geometry and building envelope material quantities. The mid-rise and high-rise apartment buildings, pictured in **Figure 6-1**, are analyzed across 16 ASHRAE climate zones defined for the prototype building models. The choice of climate zone affects the thermal resistance of materials in the walls and roof of each building. There are additional differences in the models related to operational energy consumption that are not in scope for this study.

The geometric characteristics of the two building sizes are summarized in **Table 6-1**, and the climate zone-specific characteristics of each building are summarized in **Table 6-2**. All prototype buildings comply with ASHRAE Standard 90.1 – 2022, a standard adopted as a commercial building energy efficiency code in many state and local jurisdictions across the US (*ASHRAE 90.1-2022*, 2022).

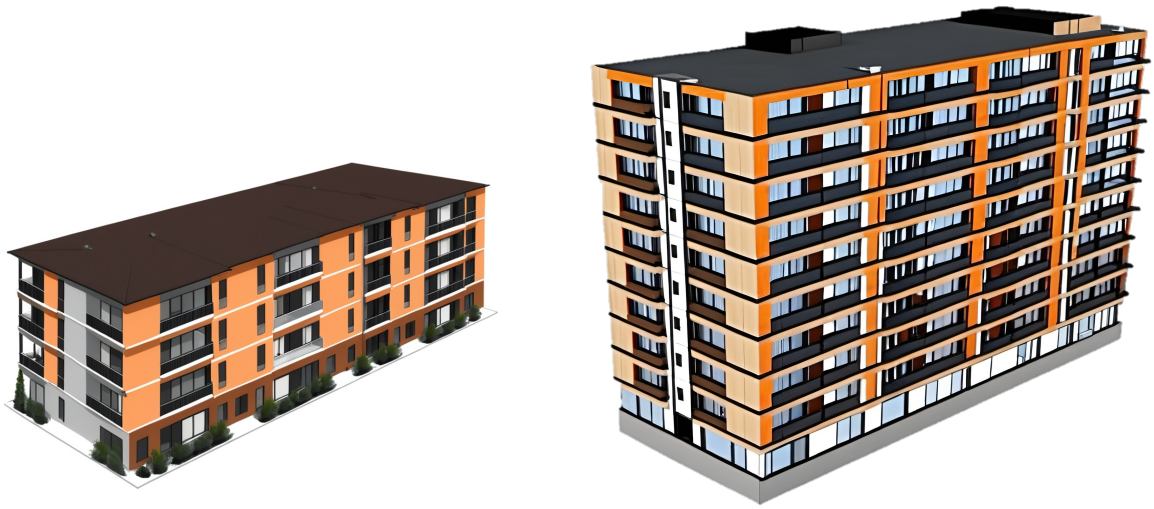

Figure 6-1. *Renderings of the mid-rise (left) and high-rise (right) DOE prototype multifamily apartment building models generated using Google Sketchup and AI for editing (OpenArt AI, 2024; Sketchup Pro, 2019).*

Table 6-1. *Geometric characteristics of the mid-rise and high-rise apartment prototype buildings.*

Geometric characteristic	Mid-rise apartment	High-rise apartment
Footprint dimensions (m)	46 x 17	46 x 17
Footprint area (m^2)	784	784
Gross conditioned floor area (m^2)	3135	7836
Number of stories (all above grade)	4	10
Window area (m^2)	307	1150
Roof area (m^2)	784	784
Floor-to-floor height (m)	3	3
Building height above grade (m)	12	30
Wall area above grade (m^2)	1542	3855
Above-ground window-to-wall ratio	20%	30%

Table 6-2. *Building envelope properties for the mid-rise and high-rise apartment prototype buildings in each climate zone (ASHRAE 90.1-2022, 2022; US DOE, 2018).*

			Mid-rise apartment				High-rise apartment			
			Exterior wall insulation			Roof insulation	Exterior wall insulation			Roof insulation
Climate zone	City	State	Ground	Mid	Top		Ground	Mid	Top	
1A	Miami	FL	0.47	0.45	0.31	4.32	0.95	0.94	0.60	4.32
2A	Tampa	FL	0.83	0.77	0.53	4.32	1.10	1.08	0.68	4.32
2B	Tucson	AZ	0.83	0.77	0.53	4.32	1.10	1.08	0.68	4.32
3A	Atlanta	GA	0.83	0.77	0.53	4.32	1.10	1.08	0.68	4.32
3B	El Paso	TX	0.83	0.77	0.53	4.32	1.10	1.08	0.68	4.32
3C	San Diego	CA	0.83	0.77	0.53	4.32	1.10	1.08	0.68	4.32
4A	New York	NY	1.36	1.33	1.06	5.31	1.10	1.08	0.68	5.31
4B	Albuquerque	NM	1.36	1.33	1.06	5.31	1.10	1.08	0.68	5.31
4C	Seattle	WA	1.36	1.33	1.06	5.31	1.22	1.20	0.74	5.31
5A	Buffalo	NY	1.53	1.50	1.18	5.31	1.22	1.20	0.74	5.31
5B	Denver	CO	1.53	1.50	1.18	5.31	1.22	1.20	0.74	5.31
5C	Port Angeles	WA	1.53	1.50	1.18	5.31	1.22	1.20	0.74	5.31
6A	Rochester	MN	1.66	1.63	1.26	5.31	1.31	1.29	0.78	5.31
6B	Great Falls	MT	1.66	1.63	1.26	5.31	1.31	1.29	0.78	5.31
7	International Falls	MN	1.84	1.80	1.38	6.09	1.43	1.41	0.84	6.09
8	Fairbanks	AK	1.99	1.95	1.47	6.09	1.53	1.50	0.88	6.09

6.2.2 Material use intensity

In this study, MQ takeoffs were obtained using distinct methodologies for structural and non-structural materials. Structural material quantities were computed using parametric structural models to evaluate different floor systems, primary structural materials, soil bearing pressures, and concrete strengths. Structural designs were based on the geometry of the DOE prototype buildings, but because the DOE prototype models do not contain code-compliant structural designs, structural analyses were necessary. Non-structural material quantities were directly inferred from the DOE prototype models. The MUI was calculated by dividing the material quantities of each material by the gross conditioned floor area of the applicable prototype building model (as reported in **Table 6-1**). Gross conditioned floor area is used for normalization in this study, as it is a common metric for normalizing energy consumption in buildings and a proxy for usable floor area. MUI was calculated for 32 non-structural building envelope material designs and 24,000 structural designs. These scenarios combine to represent 384,000 physical building models.

6.2.2.1 Parametric design to calculate structural material use intensity

This chapter takes a parametric approach to structural design to develop a range of representative material quantities. Chapters III-V established that structural systems typically have the greatest assembly-level contribution to MUIs and ECIs, and Chapter V specifically identifies parametric design as an improvement to the design approach taken in that chapter. In response, this chapter encompassed parametric structural models that evaluated different structural systems, concrete strengths, soil bearing pressures, and span lengths, as summarized in **Figure 6-2**.

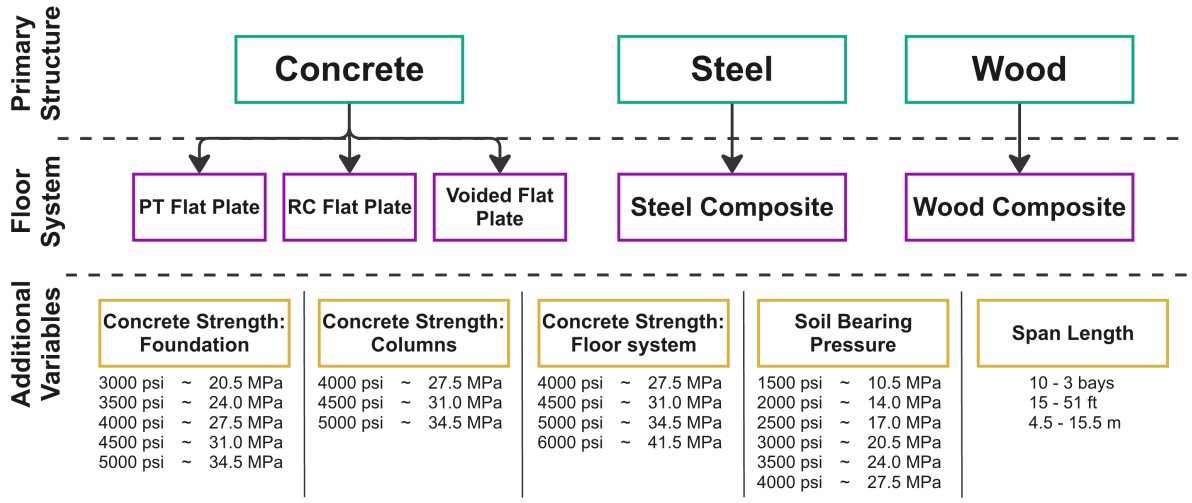

Figure 6-2. *Overview of parametric design options included in this analysis.*

In this study, building structural designs are classified based on the floor system utilized. The choice of floor system does not just dictate floor system design, but it also incorporates the material quantities for beams, girders, columns, and foundations. For example, the post-tensioned (PT) flat plate, reinforced concrete (RC) flat plate, and voided flat plate designs included concrete column and foundation designs. The steel composite design uses Grade 50 (50 ksi, or ~350 MPa) structural steel for columns, beams, and girders, and the wood composite uses cross-laminated timber (CLT) for columns, beams, and girders. Concrete and steel structural designs are two of the most common material choices for mid- and high-rise buildings in the US (Abed et al., 2022; McKinsey & Company, 2022). Mass timber design, including the wood composite design included herein, is a low-embodied-carbon alternative to steel and concrete as a structural material (Abed et al., 2022; McKinsey & Company, 2022).

The three concrete floor systems considered in this chapter are illustrated in **Figure 6-3**, and reflect common design choices made by structural designers in the US. RC flat plates are one of the most common floor system designs in the US due to their relative ease

of constructability compared with other designs, but PT and voided flat plate systems can offer benefits in terms of material consumption and, thus, embodied carbon (EC) emissions. For concrete floor systems, the strength of the concrete in the floor varies across four compressive strength classes (4 to 6 ksi or ~27.5-41.5 MPa) to reflect typical design strengths. The concrete floor systems modeled herein are designed based on the methods employed by Broyles et al. (2024).

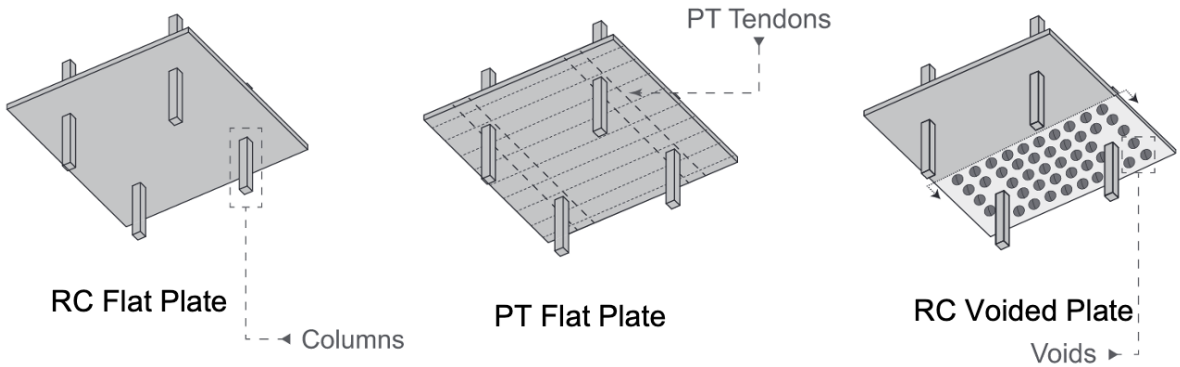

Figure 6-3. *Illustrations of the three floor systems modeled in this paper, as originally presented by Broyles et al. (2024).*

The parametric analysis captures variation in several parameters across all five structural systems: foundation concrete compressive strength is varied across five classes, spanning from 3000-5000 psi (~20.5-34.5 MPa); 8 bay sizes are considered, simulating between 3 and 10 bays; 6 soil bearing pressures are analyzed from 1500-4000 psi (~10.5-27.5 MPa); two building sizes are considered based on the details included in **Table 6-1**. Live load was assumed to be 40 psf (~2 kPa) uniform loads based on the International Building Code (ICC, 2021), and dead load was assumed to be 10 psf (~0.5 kPa). Short-term and long-term deflection limits were considered in this study, with the floor designs needing to satisfy a long-term deflection limit of L/360. The concrete, steel composite, and wood

composite floor systems are designed for a 2-hr fire rating per the International Building Code (ICC, 2021). Although the load values used in the present study may be comparable to building codes in other geographic regions, this paper focuses on North American building codes to accurately estimate EC emissions for the US. Future work will also include the evaluation of different building envelope configurations.

The parametric analysis resulted in 7,680 designs for each of the concrete floor systems, 480 design scenarios for the steel composite system, and 480 design scenarios for the wood composite/mass timber system. The material quantities were estimated for each design scenario to meet the strength and serviceability limit states according to ACI 318 (American Concrete Institute, 2019). Steel reinforcement was included in the structural design for the concrete floors and concrete columns in the concrete buildings, as well as in the foundations for all buildings. The steel and wood composite structural designs followed the American Institute for Steel Construction (AISC) Steel Construction Manual (2023) and the National Design Specification (NDS) for Wood Construction Manual developed by the American Wood Council (AWC) (2024). The foundation design for both systems followed the American Concrete Institute (ACI) 318 design code (2019, p. 318).

6.2.2.2 Non-structural material use intensity, including variable wall assemblies

Non-structural MQs were derived from the 32 prototype building models, representing mid- and high-rise apartment buildings across 16 climate zones. The MQs were derived from the EnergyPlus model input files (.idf files) developed for each prototype model per the DOE. The .idf files detail the geometry of non-structural building assemblies and provide enough information to derive MQs for insulation, drywall, cladding, doors, and windows. Most densities were extracted from EnergyPlus, and any missing values were extracted from One Click LCA (One Click) (One Click LCA Ltd., 2023). These data were used to ultimately calculate mass (kg) for each non-structural material except for insulation.

The mass of insulation materials was calculated by using the surface area of the exterior roof and wall assemblies in combination with the mass per unit area of insulation based on the required thermal resistance. The thermal resistance (RSI, m^2-K/W) of insulation is defined based on building assembly and climate zone in order to achieve compliance with ASHRAE 90.1-2022 (*ASHRAE 90.1-2022*, 2022). The thermal resistance data were extracted from EnergyPlus and summarized in **Table 6-2**. All insulation in wall assemblies was assumed to be mineral wool batt insulation, as mineral wool batts are commonly used as wall insulation in mid-rise buildings in the US. All roof insulation was assumed to be polyisocyanurate foam, which is a common rigid foam board used as the insulative layer in built-up roofing systems that are typically specified in the design of mid-rise and high-rise apartment buildings. The extracted thermal resistance and U-factor data from EnergyPlus were combined with volumetric and area densities for mineral wool batt and polyisocyanurate insulation from One Click LCA to compute insulation volumes and masses for each envelope assembly.

Once the mass of each non-structural material was calculated, MUI was calculated by dividing each material's mass by the total conditioned floor area of the respective prototype building. Assembly- and building-level MUIs were then calculated by summing the MUIs of each material by assembly and across all assemblies, respectively. This analysis resulted in 32 unique non-structural designs. Future work will account for different building envelope configurations, with a focus on different insulation and cladding options.

Differences in building envelope design across climate zones resulted in <1% difference in whole-building MUI for the multifamily apartment prototype buildings. As such, only two non-structural building envelope designs will be considered: one for the mid-rise building and one for the high-rise building. The building envelope design for climate zone 5B will be used as a proxy for all building envelope designs throughout the results section.

6.2.3 Deterministic life cycle assessment

The ECIs of each prototype were computed using LCA. A screening LCA was conducted for each building in accordance with ISO 14040/14044 standards (ISO, 2006a, 2006b). The functional units are the 24,000 functionally equivalent physical building models described in Section 6.2.2 above. The LCA is conducted for cradle-to-gate EC emissions, or LCA modules A1-A3 (see **Figure 2-1).** LCA module B6 (operational energy) is excluded from this analysis. Theoretical maximum biogenic carbon storage was calculated separately. The physical scope of the study includes the building foundation, structure, core, and shell, but excludes lateral systems.

The LCA data from three of the most commonly used LCA tools in North America – Athena Impact Estimator for Buildings (Athena), One Click LCA (One Click), and Tally (*AIE4B*, 2022; Building Transparency et al., 2022; One Click LCA Ltd., 2023) – were used to perform a deterministic LCA. A deterministic LCA, in this case, is one in which only one embodied carbon coefficient (ECC) is used per building material across all design scenarios. Because One Click does not provide one ECC per material, an order of priority was established, where industry-wide ECCs were selected for a given product if available; if not, a nation-wide value; if not, a generic value established by One Click; if not, a specific EPD was chosen.

The ECI is calculated according to the following:

$$ECI_i = MUI_i * ECC_i \quad \text{(Eq. 6-1)}$$

where ECI_i is the embodied carbon intensity of material i, MUI_i is the material use intensity (kg/m^2) of material i, and ECC_i is the embodied carbon coefficient (kgCO_2e/kg) material i for the given LCA data source. The ECCs for each material per life cycle module are detailed in **Table 6-3,** with the exception of the plastic void former. The void former EC is calculated based on a specific EPD that suits the function of the RC voided plate floor system as designed. ECC data for void formers is not available in Athena, Tally, or One Click. The

simplified material names in **Table 6-3** are used to categorize and graph the MUI and ECI results.

ECIs can be summed across materials for each prototype building in order to provide a building-level ECI. A total of 72,000 ECIs was computed by applying ECCs from three tools to 24,000 unique MUIs.

Table 6-3. *Embodied carbon coefficients (ECC, $kgCO_2e/kg$) for LCA modules A1-A3 from Athena, One Click, and Tally, organized by material. Excludes biogenic carbon storage. Excludes plastic for void former in RC voided plate.*

Material	Simplified Material Name	Athena ECC ($kgCO_2e/kg$)	One Click ECC ($kgCO_2e/kg$)	Tally ECC ($kgCO_2e/kg$)
Concrete – 3 ksi	Concrete	0.09	0.12	0.11
Concrete – 3.5 ksi	Concrete	0.11	0.13	0.13
Concrete - 4 ksi	Concrete	0.12	0.14	0.15
Concrete – 4.5 ksi	Concrete	0.13	0.16	0.17
Concrete - 5 ksi	Concrete	0.14	0.17	0.18
Concrete - 6 ksi	Concrete	0.14	0.18	0.18
Concrete - 8 ksi	Concrete	0.17	0.21	0.21
Normal weight concrete floor	Concrete	0.16	0.12	0.13
Door	Door	4.89	1.95	1.69
Window	Glazing	1.73	2.48	1.34
Mineral wool insulation	Insulation	0.84	1.36	1.79
Polyisocyanurate Insulation	Insulation	2.37	6.12	2.58
Gypsum board	Drywall	0.36	0.31	0.20
Built-up asphalt roof	Roof	0.84	3.39	0.40
PT Reinforcing	Structural steel	1.70	1.12	1.70
Rebar	Structural steel	0.85	0.56	0.85
Grade 50 Steel	Structural steel	0.96	2.11	0.97
Steel deck	Structural steel	2.23	2.82	2.58
Stucco	Stucco	0.11	1.73	3.32
Cross-laminated timber	Wood	0.43	0.52	0.37

6.2.4 Probabilistic LCA

Chapters III and V establish the value of performing probabilistic LCAs. Similar to Chapter V, this study will utilize the method of using kernel density estimation (KDE) to produce probabilistic LCAs based on EPDs per Torres and Srubar (in review) in an effort to generate an anticipated range of ECIs for each building design.

ECC distributions were generated using KDE and the EPD data from the Embodied Carbon in Construction Calculator (EC3) database per Torres and Srubar (in review). Then, Monte Carlo simulations (n = 10,000) were performed for each apartment building design. The resulting 10,000 ECC values simulated for each material were then multiplied by MUI to generate 10,000 unique ECIs for each building design. In total, this results in 240 million unique ECIs (not accounting for different climate zones). The scope of the probabilistic LCA includes life cycle modules A1-A3 and the same physical scope described in **Section 6.2.2**. The probabilistic LCA is based on data from EC3 and not from the three LCA tools described in **Section 6.2.3**.

6.2.5 Biogenic carbon storage calculations

Biogenic carbon storage ($kgCO_2$), the CO_2 stored in natural materials due to photosynthesis (Levasseur et al., 2013), naturally occurs in wood products and other natural building materials. The theoretical maximum biogenic carbon storage was calculated for all wood products in this study using the physics-based method defined in EN 16449 (European Commission for Standards, 2014). Theoretical maximum biogenic carbon storage is calculated as follows:

$$(kgCO_2)_{bio} = 0.5 \times m \times \left(1 + \frac{MC}{100}\right)^{-1} \left(\frac{44}{12}\right) \quad \text{(Eq. 6-2)}$$

where $(kgCO_2)_{bio}$ is the mass of biogenic carbon ($kgCO_2$) physically stored in the wood product, m is the mass of wood in the product (kg), and MC is the moisture content of the wood (%). MC = 12% is assumed, as it is representative of the conditions in most regions of the United States: wood that is in equilibrium with average indoor conditions of 65%

relative humidity and 21.1°C (70°F) (Breyer, 2015; Simpson & TenWolde, 1999). The multiplier 0.5 signifies the average percent of elemental carbon in wood (~50%), and 44/12 is the molar ratio of CO_2 to elemental carbon. The biogenic carbon storage calculation utilized in this study does not account for the emissions of stored biogenic CO_2 due to end-of-life treatments such as decomposition or incineration.

6.3 Results

6.3.1 Material use intensity

The whole-building MUIs for 24,000 apartment building models are summarized by floor system and building size in **Figure 6-4**. The PT flat plate MUIs have an inter-quartile range (IQR) of 715 to 962 kg/m^2, with a median of 768 kg/m^2. The RC flat plate has a higher median and quartiles, with an IQR of 1049-1635 kg/m^2 and a median of 1144 kg/m^2. This is expected based on the higher materiality of RC flat plate designs noted in the literature (Broyles et al., 2024; Broyles & Hopper, 2023). The RC voided plate design demonstrates MUIs between the first two designs, demonstrating an IQR of 849 to 1252 kg/m^2 and a median of 907 kg/m^2. This is expected since the void formers replace structurally-unnecessary concrete thereby minimizing MUI. However, post-tensioning a concrete system is a slightly more efficient strategy to minimize MUI because of the use of high-strength PT tendons.

The whole-building MUI for mid-rise apartments with steel composite structures is much lower than that of concrete floor systems. The MUIs range from 377 to 419 kg/m^2 with a median of 393 kg/m^2. This occurs for several expected reasons. First, steel is known to be more structurally efficient than concrete per unit mass. Chapter V demonstrates the same concept – that a steel building design will show a much lower MUI than a functionally equivalent concrete design. Second, the concrete floor systems have much more variability in MUI. The designs outlined in **Section 6.2.2.1** include variations for the floor system concrete strength and concrete column strength, while the steel buildings only include one

floor system and column design. This inherently leads to a narrower range of MUIs. The mid-rise wood composite buildings have a comparatively low median MUI, but a wider IQR. The IQR of mid-rise wood composite buildings is 377 to 808 kg/m^2 with a median of 471 kg/m^2. The wider IQR is due to the fact that wood composite systems are more sensitive to changes in span length.

For high-rise buildings, the patterns across floor systems are very similar, with the RC flat plate having the greatest median MUI (1199 kg/m^2) and the widest IQR (1089-1756 kg/m^2). The next greatest medians are for the RC voided plate and PT flat plate systems, similar to the mid-rise buildings. For high-rise buildings, the lowest median MUI is associated with the wood composite floor system, while the steel floor system had the lowest median MUI for the mid-rise buildings. The summary statistics for all buildings shown in **Figure 6-4** are shown in **Table 6-4.**

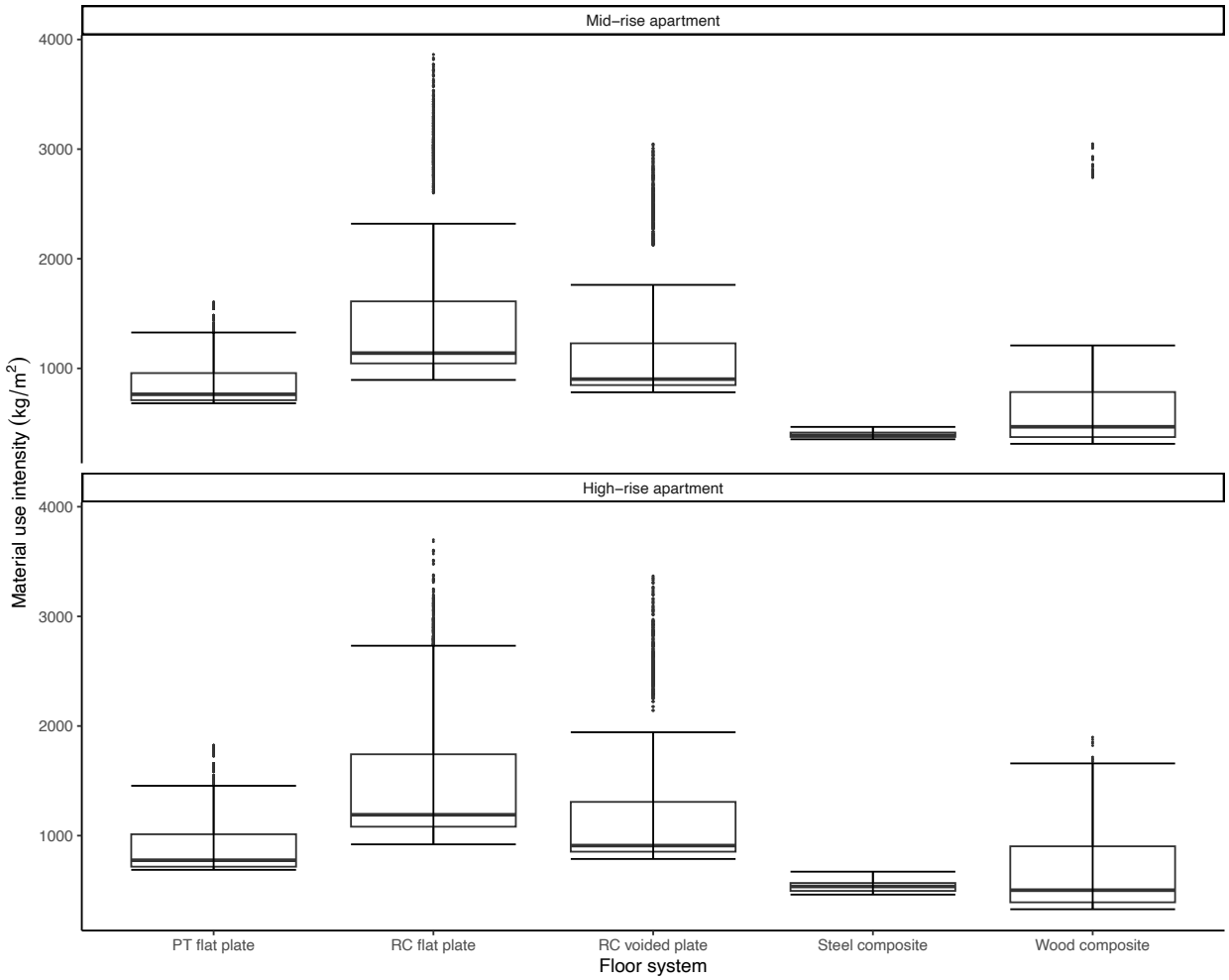

Figure 6-4. *Distributions of total material use intensity for all materials across five floor systems and two multifamily residential apartment building sizes.*

Table 6-4. *Summary statistics of MUI (kg/**m²**) for each size and floor system based on* ***Figure 6-4****.*

Size	Floor system	Min	Q1	Median	Q3	Max
Mid-rise apartment	PT flat plate	682	715	768	962	1651
	RC flat plate	894	1049	1144	1635	3946
	RC voided plate	782	849	907	1252	3098
	Steel composite	353	377	393	419	492
	Wood composite	312	377	471	808	3104
High-rise apartment	PT flat plate	686	721	787	1016	1892
	RC flat plate	916	1089	1199	1756	3776
	RC voided plate	787	857	916	1343	3443
	Steel composite	462	502	540	574	713
	Wood composite	328	394	513	936	1980

The MUIs of high- and mid-rise apartment buildings are similar but slightly higher for high-rise buildings across all structural systems. The mid- and high-rise buildings have identical floor system designs and horizontal layouts, but the high-rise building foundation is designed to withstand a greater gravity load due to a total of 10 stories as opposed to the four stories of the mid-rise building. As a result, the median MUIs for high-rise buildings are 1-4% higher than mid-rise MUIs for concrete floor systems, 8% higher for wood composite, and 38% higher for steel. This is expected, as the addition of 6 stories for the high-rise building requires more structural columns. The relative increase in mass for the additional steel columns is greater than that for concrete or wood structures.

The MUI for each building design is dominated by the contribution of structural materials. **Figure 6-6** shows the distribution of MUI associated with each major material category for each floor system and building size. Concrete floor systems alone represent 60-70% of MUI for both mid- and high-rise buildings. The wide range of MUIs for concrete in concrete systems is due to the wide array of design options for concrete floor systems. Not only are span length and foundation concrete strength varied, as they are for steel composite and wood composite structures, but concrete strength is also varied in columns and floor systems.

The material-level MUIs in steel composite floor systems are also dominated by concrete, but the range of potential MUIs for concrete systems is much narrower. While the maximum concrete MUI for the RC floor plate designs in mid-rise buildings is approximately 2410 kg/m^2, the maximum concrete MUI for the steel buildings is 220 kg/m^2. The MUI of steel in the steel composite buildings is much lower, with a maximum MUI of about 80 kg/m^2 for the mid-rise building. For wood composite buildings, there is a much narrower band of concrete MUIs (220 to 280 kg/m^2), and CLT is the dominant material (IQR of 50 to 250 kg/m^2). The relative patterns of MUI by material are similar for high-rise buildings.

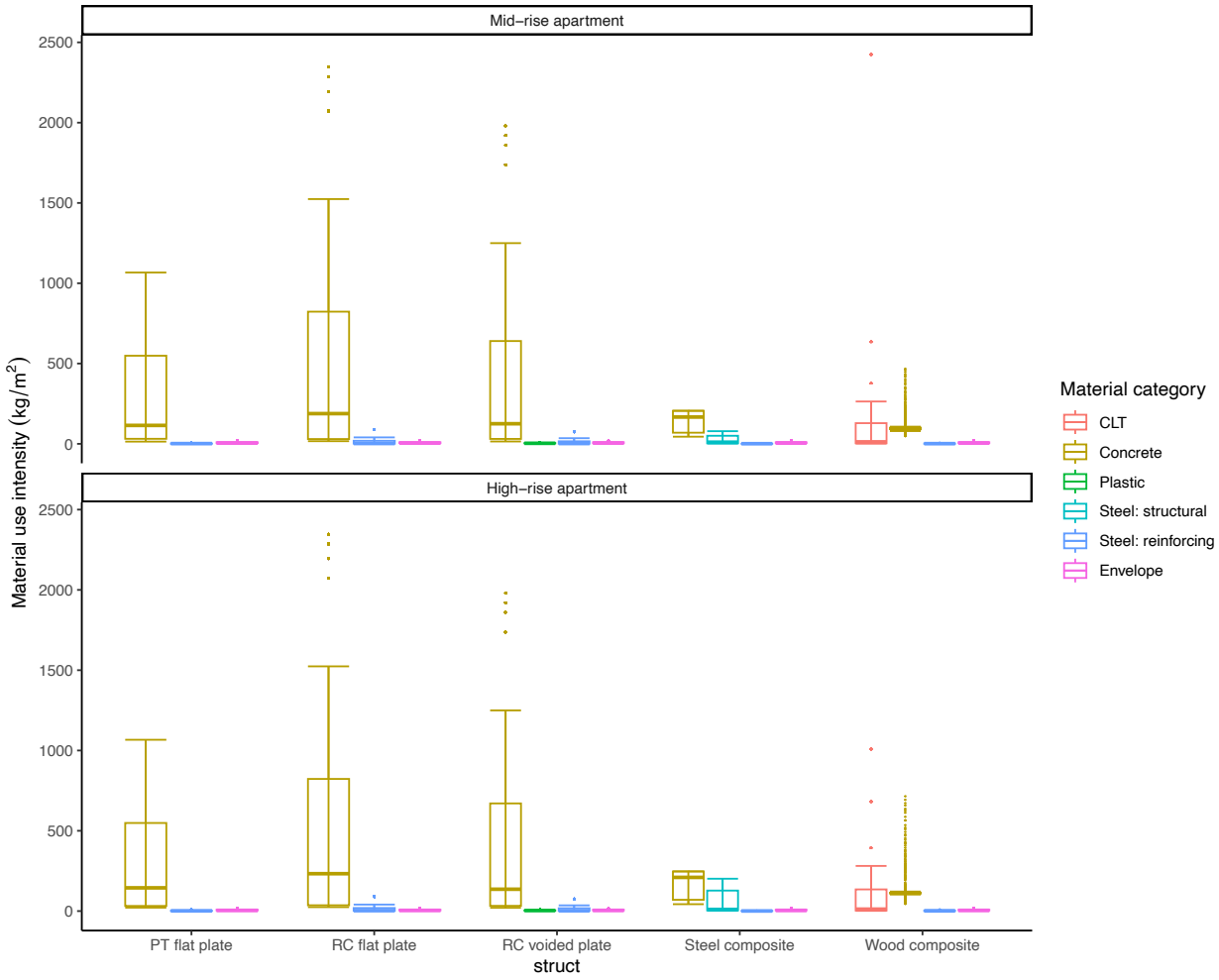

Figure 6-5. *MUI by material, with all structural materials listed, and all building envelope materials grouped together.*

The wide range of MUIs shown in **Figure 6-4** and **Figure 6-5** can be explained by the parameters included in the structural analysis (see **Figure 6-2).** The greatest single contributor to structural material quantity (SMQ) variability is the number of bays (and associated span length) for each structural design. **Figure 6-6** shows the influence of number of bays on the MUI for each structural system and building size. The MUI decreases with the increase in the number of bays modeled or decreasing span length. For the RC flat plate design in mid-rise apartments, the median MUI is 3050 kg/m^2 for three bays, and 950 kg/m^2 for ten. The MUI appears to increase exponentially as the number of bays is reduced for the RC flat plate, which has the highest MUIs across all designs. For the

PT flat plate, MUI ranges from approximately 1300 to 820 kg/m^{2,} for 3 to 10 bays, respectively, in mid-rise buildings. The PT flat plate has the lowest MUI of the concrete floor systems. For steel buildings, the MUIs are consistent across all bay options, with median MUI spanning from 376 to 405 kg/m^2 for mid-rise buildings. The median MUI for wood composite buildings spans from 337 to 2827 kg/m^2 for mid-rise buildings. Wood composite buildings with ten bays represent the lowest overall MUI, while RC flat plate buildings with three bays have the highest. Steel buildings have the smallest variation in MUI, and, thus, are least sensitive to changes in span.

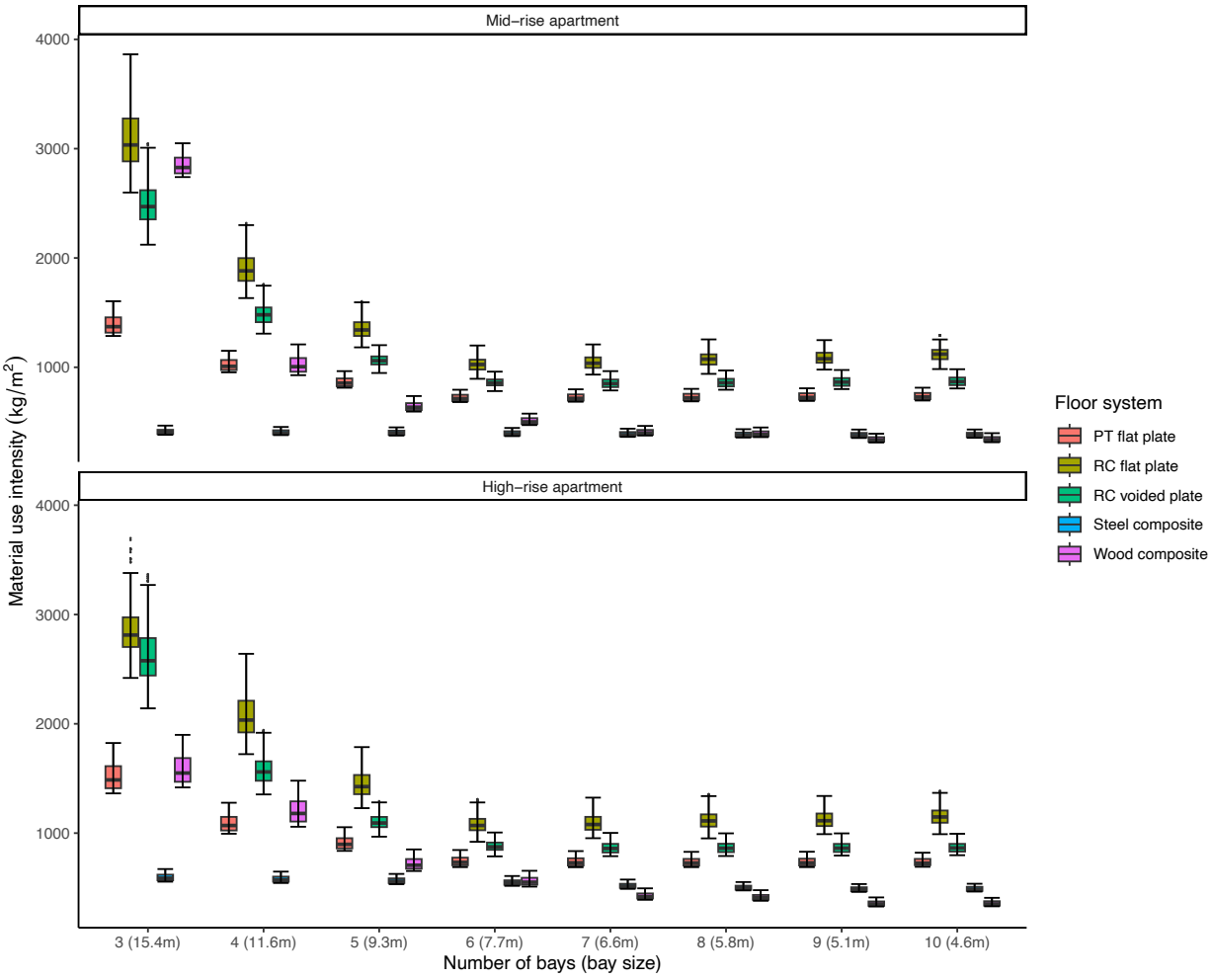

Figure 6-6. *MUI by floor system and span length for all multifamily apartment designs.*

A decrease in MUI with an increase in the number of bays (or a decrease in span length) is expected. Floor systems must increase materiality in order to resist deflection as span lengths become longer. This pattern is well documented in the literature (Broyles et al., 2024; D'Amico & Pomponi, 2020; Gan et al., 2017; Hawkins et al., 2020; Jayasinghe et al., 2021, 2022).

6.3.2 Embodied carbon intensity calculated via deterministic LCA

Figure 6-7 shows the range of ECIs across five floor systems, two building sizes, and three LCA tools for LCA modules A1-A3. The IQR and median ECI for each structural system are reported in **Table 6-5**. The ECIs for all PT flat plate structural designs in mid-rise apartment buildings are shown at the top-left of the figure – the associated ECI IQR for Athena is 120-150 $kgCO_2e/m^2$, One Click is 173-209 $kgCO_2e/m^2$, and Tally is 208-246 $kgCO_2e/m^2$. The IQR and medians for each structural design clearly indicate a pattern of the lowest ECI associated with Athena, followed by One Click and Tally for all mid-rise buildings. Across all mid-rise buildings, the lowest ECIs are associated with the PT Flat Plate (lowest median, at 127 $kgCO_2e/m^2$) and wood composite floor designs (lowest minimum, at 90 $kgCO_2e/m^2$) for the Athena LCA tool. The highest median ECIs are associated with steel composite structures using Tally, at 320 $kgCO_2e/m^2$, and the greatest maximum MUI is associated with wood composite structures using One Click at 1415 $kgCO_2e/m^2$.

The patterns are very similar for high-rise buildings, with a few exceptions. For high-rise buildings, the highest median ECI is associated with the steel buildings and One Click LCA, with a median of 595 $kgCO_2e/m^2$. The greatest maximum ECI is 830 $kgCO_2e/m^2$, which is associated with the RC Flat Plate and Tally. The lowest median is associated with the PT flat plate and Athena (126 $kgCO_2e/m^2$), and the lowest minimum is associated with wood composite and Athena (89 $kgCO_2e/m^2$). Across all structural designs, Athena maintains the lowest ECIs, while One click and Tally have mixed results.

The median steel composite ECIs for mid-rise apartment buildings are greater than those of the concrete floor systems but with a narrower IQR. This narrow ECI IQR tracks with the similarly narrow MUI IQR discussed in **Section 6.3.1**. The median and IQR of steel ECIs are high relative to concrete floor systems, even though the MUIs of steel floor systems were relatively low. This is due to the high magnitude of structural steel ECCs across all LCA tools when compared with concrete (see **Table 6-3**). This highlights the relatively high carbon intensity for steel production on a unit mass basis. This effect is more pronounced for high-rise buildings due to the more substantial gravity systems necessary to support ten stories.

Overall, PT flat plate and wood composite systems have the lowest ECIs – both in terms of median values and minimums. For some building designs, the PT system may have a lower ECI than a wood composite system – particularly where spans are long, and PT systems are much more materially efficient in resisting deflection than CLT floor systems. For shorter spans, wood composite buildings typically have lower ECIs.

ECIs calculated using LCA modules A-C were also computed and reported in **Appendix C**.

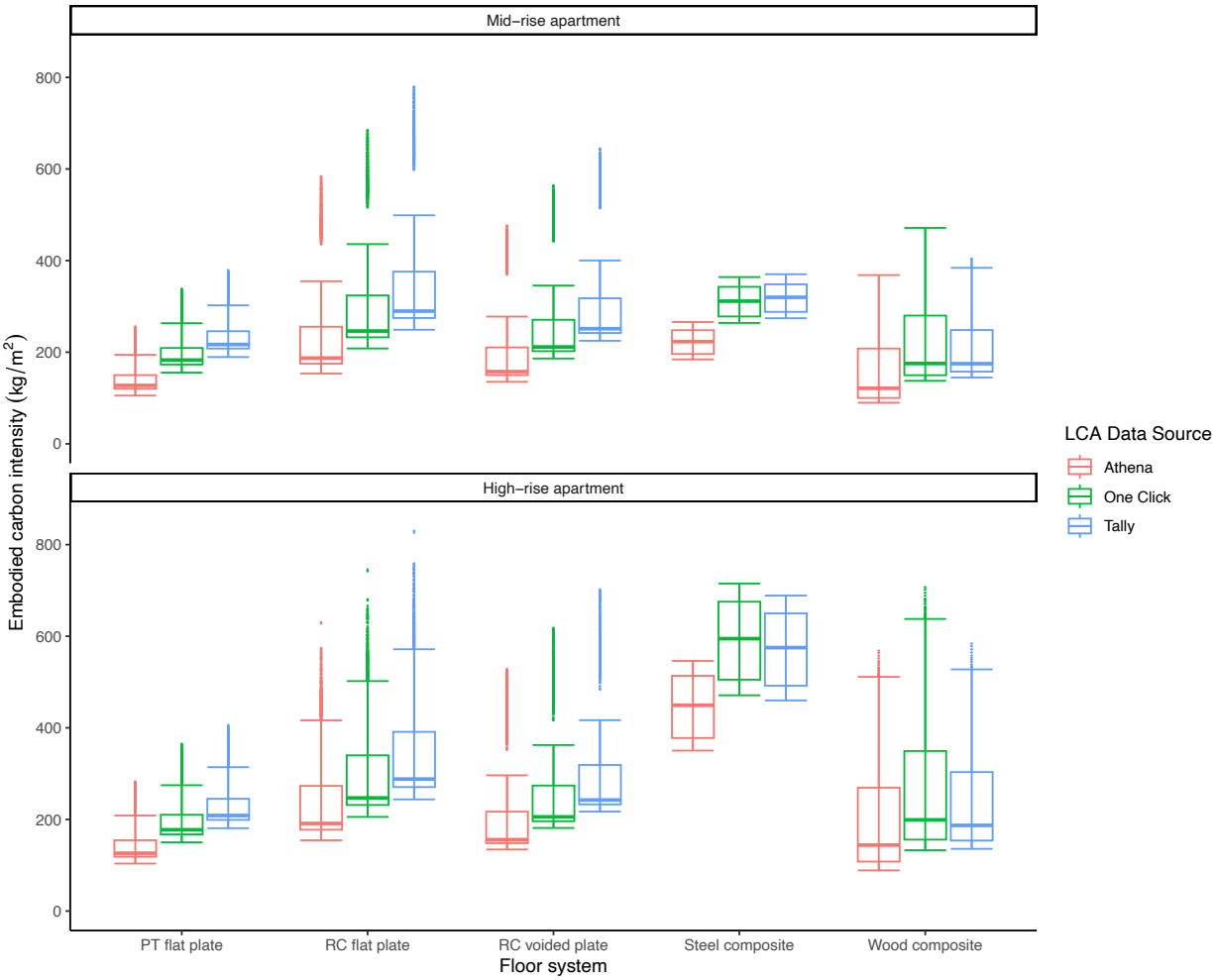

Figure 6-7. *Deterministic ECI for LCA modules A1-A3 using Athena, One Click, and Tally.*

Table 6-5. *Summary statistics for A1-A3 Deterministic ECIs (**kgCO₂e/m²**) for each floor system, size, and LCA tool, based on* ***Figure 6-7.***

Size	Floor system	LCA tool	Min	Q1	Median	Q3	Max
Mid-rise apartment	PT flat plate	Athena	105	120	127	150	256
		One click	155	173	183	209	338
		Tally	189	208	217	246	379
	RC flat plate	Athena	153	175	187	256	583
		One click	208	233	246	324	685
		Tally	249	275	290	376	780
	RC voided plate	Athena	135	150	158	211	477
		One click	186	202	211	271	564
		Tally	225	242	251	318	644
	Steel composite	Athena	184	196	223	248	266
		One click	264	278	311	343	364
		Tally	274	288	320	348	370
	Wood composite	Athena	90	109	143	252	368
		One click	138	160	201	332	471
		Tally	145	163	194	292	404
High-rise apartment	PT flat plate	Athena	104	119	126	155	283
		One click	150	167	178	210	365
		Tally	181	199	209	245	406
	RC flat plate	Athena	155	178	191	273	630
		One click	206	232	247	340	746
		Tally	244	271	288	391	830
	RC voided plate	Athena	134	148	156	217	528
		One click	181	196	206	274	618
		Tally	217	233	242	319	702
	Steel composite	Athena	350	378	449	514	546
		One click	471	505	595	675	715
		Tally	460	492	575	650	689
	Wood composite	Athena	89	108	144	269	569
		One click	133	156	199	349	707
		Tally	136	154	187	303	584

6.3.3 Embodied carbon intensity calculated via probabilistic LCA

The probabilistic LCA results for each structural system and building size is shown in **Figure 6-8**. Much like in previous sections, these results are presented as a range of cradle-to-gate (A1-A3) ECIs for each design. The ECIs computed using the three LCA tools above resulted in 72,000 ECIs based on 24,000 total physical designs. The probabilistic LCA resulted in 240 million total simulated ECIs, multiplying the 24,000 physical models by 10,000 simulated ECCs per material.

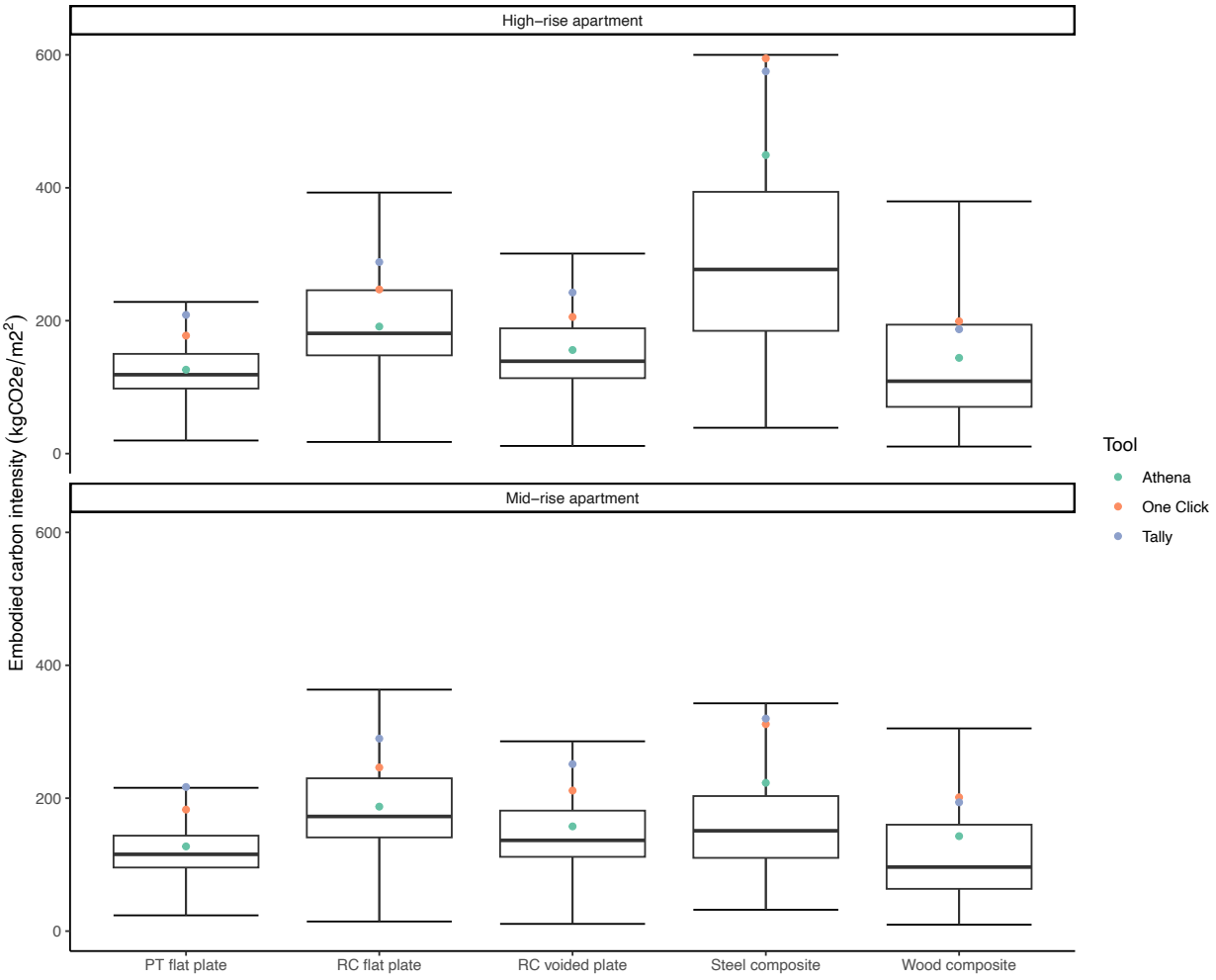

Figure 6-8. *Probabilistic distributions of cradle-to-gate (A1-A3) ECI for each structural system and building size. Dots indicate the median ECI associated with the three LCA tools used earlier in this chapter.*

The ECI distributions generated *via* probabilistic LCA indicate similar patterns to the deterministic results shown in **Figure 6-7** and **Table 6-5**, although the magnitude of median and quartile ECIs are generally lower than those reported for the deterministic LCA. For the mid-rise apartment building, median cradle-to-gate ECIs are 110, 180, 130, 150, and 100 $kgCO_2e/m^2$ for the PT flat plate, RC flat plate, RC voided plate, steel composite, and wood composite systems, respectively. These medians are lower than those reported in **Table 6-5**.

The Athena LCA tool results most closely match the medians presented for the probabilistic LCA. For 8 out of 10 cases shown in **Figure 6-8**, the median Athena ECI is within the IQR of the probabilistic LCA. Only two out of 10 medians are within the IQR for One Click, and none of the Tally medians are within the IQR. The distributions between the deterministic analysis using Athena and the probabilistic analysis are most similar for the concrete floor systems, indicating that the ECCs used for concrete in Athena most closely match the probabilistic distributions based on EC3.

6.3.4 Theoretical maximum biogenic carbon storage

The theoretical maximum biogenic carbon storage and cradle-to-gate ECI for the wood composite buildings are shown in **Figure 6-9** as ranges of carbon intensity for each building size and LCA tool. The mid-rise apartment buildings designed using wood composite structures have whole-building ECIs with IQRs ranging from 109 to 252 $kgCO_2e/m^2$ for Athena, 160 to 332 $kgCO_2e/m^2$ for One Click, and 163 to 292 $kgCO_2e/m^2$ for Tally. The IQR of theoretical maximum biogenic carbon storage associated with mid-rise wood composite buildings is approximately 267 $kgCO_2e/m^2$ to 450 $kgCO_2e/m^2$. This implies that the maximum biogenic carbon storage in each wood composite building is greater than the cradle-to-gate emissions for each building design.

The theoretical maximum biogenic carbon storage represents 110-200% of the cradle-to-gate ECI for each individual building design, confirming that each building

design, under idealized conditions, would be net carbon-storing, regardless of the source of LCA data. The highest proportion of biogenic carbon storage is associated with the building designs with the greatest MUI and ECI, as well as the greatest span length. These designs have the highest idealized net CO_2 storage, but at the cost of high materiality and high cradle-to-gate ECI. The theoretical maximum biogenic carbon storage cannot be achieved and maintained throughout the building's service life, so additional considerations must be made to estimate a realistic quantity of net CO_2 storage during the full life of the building.

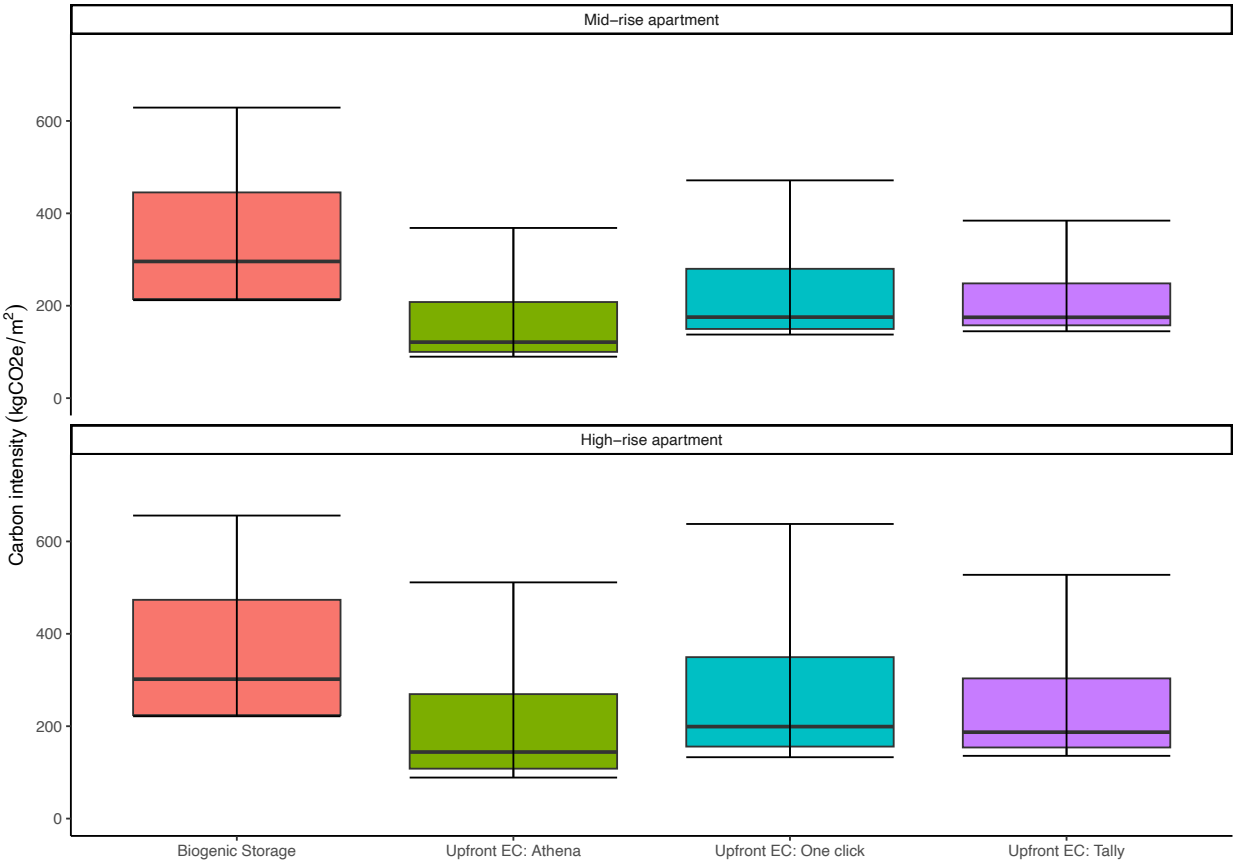

Figure 6-9. *Theoretical maximum biogenic carbon storage intensity in wood composite buildings as a range of possible intensity values, compared with the cradle-to-gate embodied carbon emissions, as computed for each of the LCA tools.*

6.4 Discussion

6.4.1 Key Takeaways

The MUIs analyzed herein show a clear pattern whereby the concrete floor systems have the greatest MUIs, and the wood composite and steel buildings have similar MUIs. The variability in MUI is lowest for steel structures. Similarly, steel buildings are least sensitive in terms of changes in MUI and changes in the number of structural bays. MUIs across all structural materials are most sensitive to bay size. As the bay size increases and the number of bays decreases, MUI increases across all structural systems. This is an expected result that is well documented in the literature. A study by D'Amico and Pomponi (2020) establishes SMQ equations for different structural materials with only one dependent variable: bay width (assuming a square bay). A study by Broyles et al. (2024) demonstrates an increase in MUI with an increase in span length for several concrete floor systems using a similar parametric design approach to this chapter.

The ECI ranges for each structural system lead to several findings. The range of ECI for wood composite buildings was quite wide, with an IQR spanning 89-584 $kgCO_2e/m^2$. This IQR encompasses the median ECIs for all buildings modeled with concrete floor systems. Most notably, the RC flat plate design, which has the highest MUIs of all designs, has considerable overlap with the IQR of the wood composite designs across all scenarios. Additionally, steel designs had the greatest median ECIs of any structural system despite having the lowest MUIs. This is expected due to the high ECCs for structural steel and is consistent with findings in Chapter V.

The overlap in ECI between wood composite building designs and concrete designs uncovers several important potential design tradeoffs. First, it indicates that there are designs in which a concrete floor system design has lower cradle-to-gate EC emissions than a wood composite design. In particular, a structurally efficient concrete floor design, such as a PT flat plate, would have a lower ECI for the longest spans considered in this study. This

conclusion may change with different LCA data. The inclusion of biogenic carbon storage in the LCA would change this conclusion, as the long-term storage of biogenic carbon could lead to lower ECIs for wood composite buildings, or even net carbon storage.

Higher net CO_2 storage is associated with higher material consumption for many buildings. This is made clear in **Figure 6-9**, where the highest cradle-to-gate ECIs are associated with the highest theoretical biogenic carbon storage. While substantial biogenic carbon storage is potentially beneficial in offsetting cradle-to-gate CO_2 emissions, materially intensive designs can offer drawbacks. The most materially intensive designs in this study involve long structural spans and, thus, higher materiality in floor systems. These systems may be costly and have constructability issues when compared with more MUI-efficient structures. Additionally, materially intensive wood designs could become an issue in the future if demand for US forest products substantially increases and supply is constrained. Consequently, more materially intensive wood designs should not be pursued solely to increase biogenic carbon storage, as there are several tradeoffs.

Across most structural systems, Athena reported the lowest whole-building ECIs, followed by One Click and then Tally (highest). This finding is consistent with the results reported in Chapters IV-V.

The probabilistic LCA demonstrates a much broader array of potential whole-building ECIs by accounting for uncertainty in ECC. The wider IQR for each structural system further blurs the boundaries between the ECI of particular designs, as all IQRs for a given building size overlap with one another. One way to decrease the breadth of results would be to specify certain EPDs or to filter to a more specific set of EPDs, reducing the uncertainty in a particular material's ECC.

6.4.2 Results in context

The MUIs and ECIs reported in this study are in line with other published values, although those values span very broad ranges. The Regional Assessment of Buildings' Material Intensities (RASMI) reports ranges of MUIs for eight construction materials in buildings by region, typology, and structural design. Although these eight materials are not all-encompassing, they include the majority of common structural materials, which typically represent the majority of MUI. The MUIs reported in RASMI for multifamily residential buildings in North America span an IQR of 708 to 1265 kg/m^2 for reinforced concrete buildings, 162 to 547 kg/m^2 for steel buildings, and 97 to 305 kg/m^2 for timber buildings. The concrete MUIs reported in this study overlap considerably with the RASMI data – spanning approximately 715 to 1756 kg/m^2 across all floor system designs. For steel buildings, this study reports an IQR of 375 to 415 kg/m^2 for mid-rise buildings and 496 to 568 kg/m^2 for high-rise buildings. These ranges are both within the IQR reported by RASMI. For timber buildings, this study reports 374-785 kg/m^2 for mid-rise buildings and 392 to 903 kg/m^{2}for high-rise buildings. These MUIs are much higher than those reported in RASMI, though they are more in line with the MUIs reported for mid- and high-rise commercial office buildings in Chapter V, which spanned from 427-884 kg/m^2. Given that the RASMI data for timber structures in multifamily buildings in the US is extrapolated from only four data points, that data may not be representative of all timber construction. The timber multifamily apartment buildings used to inform the RASMI analysis could, for example, include much less materially intensive buildings than a mid- or high-rise apartment, such as 2-story townhouses that utilize dimensional lumber rather than CLT.

The ECI results in this study vary by building size, structural design, LCA tool (including probabilistic LCA), and LCA scope, among other factors. Across all concrete designs and LCA tools, the IQR for A1-A3 ECI spans from 119 to 376 kgCO_2e/m^2, for composite steel buildings, 196 to 675 kgCO_2e/m^2, and the wood composite buildings from 108 to 349 kgCO_2e/m^2. There are no direct comparisons for ECI by structural system, but a

few empirical data points are available. In the CLF benchmark study, which includes variable LCA scopes, multifamily residential buildings in North America have an IQR of ECIs between 246-530 $kgCO_2e/m^2$ (n=21), while the global range is 248-538 $kgCO_2e/m^2$ (n=65). Across several European case studies, ECIs are reported between 100-675 $kgCO_2e/m^2$. Two aggregate studies report ranges between 120-675 (Rasmussen et al., 2022) and 450-750 (Röck, Sørensen, Tozan, et al., 2022). A study of theoretical multifamily prototypes reports ECIs between 340-840 $kgCO_2e/m^2$ (Lavagna et al., 2018).

It is promising that the MUIs and ECIs for this study fall within an expected range of values. However, these ranges are quite broad due to the wide variety of potential designs, scopes, system boundaries, and LCA data used for analysis. Additionally, even though sources such as RASMI can categorize results by structural system type, more information about the structural design would be needed to truly inform a fair comparison. For instance, comparing the MUI of a 10-story multifamily apartment building which utilizes CLT and glulam as primary structural materials with the MUI of a 2-story townhome primarily built from dimensional lumber would not be a fair comparison due to the different use cases, ECCs, and material properties.

6.4.3 Future work

Future work will include additional variations in building envelope design and structural design. Most notably, different wall assembly designs should be evaluated in terms of EC emissions, operational carbon performance, and their impact on structural design. The DOE prototype building models include a building wall assembly made from drywall, steel studs, insulation (assumed to be mineral wool), and stucco. A future study should vary the cladding material to consider options such as fiber cement, metal, and composite wood siding products. Fiberglass batt insulation and emerging alternative insulation products should be evaluated. Additionally, wood studs or concrete block walls

could be analyzed. These variations would also require a structural analysis that considers the different masses of these building envelope materials.

The probabilistic LCA could be modified to better represent a specific population of materials. For instance, when creating a probability density function of ECCs *via* KDE, the EPDs used as inputs to this analysis can be filtered based on their properties and geographic representativeness. This could include the inclusion or omission of materials with specific physical properties, such as the number of glass panes in a window assembly. This could also include materials that are representative of a specific region (e.g., state in the US) or a particular manufacturer's products. Instead, this analysis considered the full population of US-based EPDs in the EC3 tool.

Further, the probabilistic LCA data should be evaluated to more deeply understand similarities, differences, and dependencies between ECI and different building designs. The results in **Figure 6-8** show a simple distribution of ECI by building size and structural design, but these distributions could be compared for statistical similarity. Further statistical comparison may indicate whether or not there are significant differences between the distribution of ECIs reported for different design scenarios. The similarity analysis could also consider whether soil bearing pressure, foundation concrete strength, and other parameters have significant impacts on the ECI of different buildings. Finally, a regression and feature importance analysis would enable the creation of new equations for estimating ECI based on the results of the analysis, much like the SMQ equations proposed for different structural designs by D'Amico and Pomponi (2020).

6.4.4 Significance and Limitations

This chapter establishes a parametrically derived theoretical benchmark for the MUI and ECI of multifamily residential apartment buildings in the US. The parameterization of structural design for concrete, steel, and wood composite floor systems resulted in 24,000 unique physical building models, which represent a wide variety of building design strategies that are employed across the US. This approach and the MUIs and ECIs generated herein can be directly used or filtered to best represent regional design differences, or to quantify the tradeoffs in structural design choices such as span length or foundation concrete strength.

The MUIs computed for each scenario provide an incredibly valuable reference point for researchers using this analysis in the future. Although the range of ECIs presented is a valuable reference point for current practice, the MUIs can be combined with new ECC data in the future. As low-carbon materials enter the market, new ECCs could be utilized to compute new ECIs and to compare those designs with the designs and materials used in this study. Similarly, these MUIs can be modified to account for specific design choices, such as the choice of insulation material or the addition of finish materials.

The results presented in this chapter should be considered within the context of the LCA goal and scope established in the methods of this study. Although the DOE prototype buildings were analyzed as reference buildings for energy consumption in apartment buildings, there are many different apartment building design practices within the US, and the designs analyzed in this chapter may not align with specific regional practices or new emerging practices.

This study makes several key assumptions. This study assumes that all material and carbon intensity calculations are normalized based on conditioned floor area rather than gross floor area, which is consistent with the approach utilized in previous chapters. Second, minor modifications to the bills of materials for the LCA models were made for the DOE prototype buildings to align with standard design practices, including the use of

mineral wool batt insulation where no type of insulation was specified. Finally, uncertainty in material quantities and ECC were not considered in this analysis.

This analysis has several notable limitations. The LCA conducted herein did not account for building services (such as HVAC and plumbing equipment), plug loads (such as refrigerators and computers), and finish materials, such as carpet and paint, which could contribute appreciably to the ECI of apartment buildings – particularly when maintenance and replacement are considered over time. Additionally, construction waste was not considered for any aspect of the building design. Construction waste can be crudely estimated using factors from tools such as Athena, One Click, and Tally, but such estimates do not always align with one another. As such, the MUIs and ECIs in this analysis are lower than values that incorporate waste. This analysis also did not consider objectives such as constructability, cost, or acoustic performance, as evaluations of other parameters were outside the scope of this study. A multi-objective analysis would make this work more useful for practitioners.

There are several additional limitations related to the parametric structural design. The three concrete floors were designed and analyzed following the direct design method (DDM). Since PT systems cannot be effectively designed using DDM, a modified DDM approach was used (Broyles & Hopper, 2023), though the modified coefficients are conservative compared to typical DDM coefficients. A minimum slab thickness of ~125 mm (5 in) was used to obtain a 2 hr. fire rating. This assumption governs the EC of floors with low spans and lighter loading scenarios, as other fire ratings (i.e., 1-hr, 3hr) have alternative slab thickness requirements. No maximum thickness requirement was specified. A maximum pre-compression limit of 2.07 MPa (300 psi) was set for the PT systems, which is a common design limit used in industry. However, there may be certain cases where more PT could be used, further reducing the amount of concrete material needed.

The theoretical maximum biogenic CO_2 storage reported herein is a physics-based calculation of biogenic CO_2 stored in wood. The calculation represents physical storage, not net cradle-to-gate emissions, which would include wood process emissions and the decay of wood products at the end of their useful lives.

6.5 Conclusions

This study established theoretical MUI and ECI benchmarks based on 24,000 multifamily apartment building designs. The MUI IQRs reported herein span from 377 to 1756 kg/m^2. The deterministic ECI IQRs span from approximately 108 to 675 kgCO_2e/m^2 across all structural designs and LCA tools. Probabilistic analysis based on data from EC3 showed a range of results that trended lower than the three LCA tools, with an overall ECI IQR of 112 to 194 kgCO_2e/m^2 across all designs. Analysis of the theoretical maximum biogenic carbon storage of wood composite buildings indicated that biogenic carbon storage can be substantial in wood composite buildings, but that the buildings with the greatest net biogenic carbon storage may not be the most materially efficient designs.

Establishing theoretical EC benchmarks for residential apartment buildings represents a critical step toward decarbonizing the built environment. This study provides a robust framework for quantifying and contextualizing EC emissions in these buildings, which can be used by researchers to further scientific discovery, policymakers to set EC limits, and practitioners as a point of comparison with their building designs. By quantifying material quantities and ECIs, this study can empower more meaningful work toward reducing EC emissions in multifamily residential apartment buildings.

CHAPTER VII

7. Conclusion

7.1 Summary

This dissertation establishes a methodology for calculating theoretical, science-based embodied carbon (EC) emissions benchmarks for single-family residential, apartment (*i.e.,* multifamily residential), and commercial office buildings in the US. Chapter II elucidated the fundamental research gap: a lack of science-based, theoretical benchmarks in the literature. Chapter III established a methodology for calculating theoretical cradle-to-gate EC benchmarks for single-family residential buildings in the US based on the DOE prototype building models and life cycle assessment (LCA) data from Athena, Tally, and One Click LCA. A simple uncertainty model defined the range of potential embodied carbon intensity (ECI, $kgCO_2e/m^2$) values for each single-family residential building model in Chapter III. Chapter IV built on Chapter III by evaluating whole-life energy and CO_2 emissions for single-family residential buildings and by expanding the scope to include LCA modules A-C, operational energy, embodied energy, and operational carbon (OC) emissions. Chapter V established a methodology for calculating the cradle-to-gate and whole-life CO_2 emissions benchmarks for commercial office buildings designed to meet varying structural loads representative of conditions across the US. Chapter V also used an emerging probabilistic life cycle assessment approach to model uncertainty in embodied carbon coefficients (ECCs, $kgCO_2e/kg$). Chapter VI employed parametric structural design and probabilistic LCA to develop theoretical EC benchmarks for multifamily residential apartment buildings, resulting in a more robust range of potential ECIs that accounts for uncertainty in both material quantity and ECC. Together, these studies build on one another by expanding LCA scope, improving methods, and addressing different building typologies in each successive study.

7.2 Findings and Contributions

The key contributions of this dissertation support the development of theoretical, science-based benchmarks. The contributions as they relate to the research gaps identified in **Chapter II** are summarized in **Table 7-1**.

Table 7-1. *Summary of the key findings and contributions of this dissertation as they relate to the identified research gaps.*

Research gap	**Results and Findings***	**Contribution**
How can existing building archetypes for operational energy modeling be used to define EC benchmarks in US buildings?	DOE prototype building models lack details about structure, foundation, finish materials, and other building assemblies. Developing material quantity (MQ) takeoffs based on the DOE prototype models requires additional structural analysis to represent a functional building. The approach to computing these MQ takeoffs can be deterministic (Chapters III-V), but parametric models (Chapter VI) help to model variability in MQs. LCA can also be deterministic, but a probabilistic approach is necessary to model the uncertainty and variability in ECCs.	Single-design and parametric design methodologies for converting DOE prototype building models to MQ takeoffs. Deterministic and probabilistic methodologies for performing LCA based on these MQ takeoffs.
What are the EC emissions of representative archetypal buildings in the US?	Chapters III-VI detail the deterministic and probabilistic ranges of ECI for the applicable DOE prototype models. The range of deterministic values is reported as follows:	Deterministic theoretical EC emissions benchmarks for single-family, multifamily residential apartment, and commercial office buildings in the US using the DOE prototype building models for reference.

Research gap	Results and Findings*	Contribution
	Single-family residential *Chapters III, IV* $ECI_{A1\text{-}A3}$: 39 to 121 $kgCO_2e/m^2$ $ECI_{A\text{-}C}$: 51 to 205 $kgCO_2e/m^2$ **Commercial Office** *Chapter V* $ECI_{A1\text{-}A3}$: 114 to 337 $kgCO_2e/m^2$ $ECI_{A\text{-}C}$: 158 to 420 $kgCO_2e/m^2$ **Apartment (multifamily residential)** *Chapter VI, excluding outliers* $ECI_{A1\text{-}A3}$: 89 to 715 $kgCO_2e/m^2$ $ECI_{A\text{-}C}$: 122 to 842 $kgCO_2e/m^2$	
How will the proportion of EC to OC in 'typical' US buildings change over time, particularly as grid emission factors change?	The ratio of EC and OC emissions depends on the building typology, the reference study period (RSP), the grid region, and the decarbonization of that grid. OCI represents a greater proportion of WLCI on average, but ECI can be a greater proportion of WLCI when grid emission factors are low. RSP has a greater impact on the OCI for the mid case than the 95% by 2050 or 100% by 2035 scenarios due to higher grid emissions. The analysis of three grid decarbonization scenarios shows that the current grid emissions and future grid decarbonization scenarios have a substantial impact on both OCI and WLCI results. The ratio of ECI to whole-life carbon intensity (WLCI) emissions, where WLCI = ECI + OCI,	Ranges of ECI, OCI, and WLCI for typical single-family residential and commercial office buildings in the US, using business-as-usual grid emission projections. Comparison of OCI and WLCI across three grid decarbonization scenarios and three RSPs for commercial office buildings.

Research gap	Results and Findings*	Contribution
	for single-family and commercial office buildings is as follows: **Single-family residential** *Chapter IV* ECI / WLCI: 2-50% **Commercial Office** *Chapter V* ECI / WLCI, 30-year RSP: Mid case: 7 to 68% 95% by 2050: 8 to 62% 100% by 2035: 13 to 71% ECI / WLCI, 45-year RSP: Mid case: 5 to 59% 95% by 2050: 6 to 58% 100% by 2035: 13 to 66% ECI / WLCI, 60-year RSP: Mid case: 4 to 53% 95% by 2050: 5 to 56% 100% by 2035: 13 to 62%	
What are the materials and building assemblies that contribute most to whole-building material use intensity (MUI, kg/m^2) and ECI?	The top contributors to MUI across all building models are structural materials, which is expected and substantiated by previous studies. The relative contributions of different building materials vary considerably across building	MUIs for each design option across all typologies. MUIs are one of the most valuable contributions from this analysis. The MUIs from each chapter can be used to model shifts in ECI contribution as material ECCs change over time. MUIs can be filtered for desired building design

Research gap	Results and Findings*	Contribution
	typologies, building sizes, structural designs, loading scenarios, and other parameters. Insulation and finish materials can notably contribute to total ECI, particularly in single-family residential buildings. Clear breakdowns can be seen in: **Single-family residential** *Chapters III, IV* Figure 3-1 **Commercial Office** *Chapter V* Figure 5-3 **Apartment (multifamily residential)** *Chapter VI* Figure 6-5	characteristics, particularly from the parametric study (Chapter VI).
How can a theoretical benchmarking methodology account for uncertainty in MQs, particularly for those most influential materials and assemblies?	The probabilistic LCAs computed provided an extensive range of potential ECIs that are difficult to interpret, but their medians and IQRs follow expected values based on deterministic values. The wide range of probabilistic ECIs highlights a need to reduce uncertainty in ECC in order to narrow the range of likely ECIs for a given building design The probabilistic, cradle-to-gate ECIs are reported as IQRs for each typology here:	Distributions of ECIs by typology and design scenario. These are valuable contributions to future research focused on analyzing the probabilistic range of ECIs based on variations in MQs and ECCs. Chapter V adds depth to simplified uncertainty modeling methods by implementing KDE for ECC uncertainty. Chapter VI combines the KDE methodology with parametric design, which accounts for additional uncertainty in SMQs.

Research gap	Results and Findings*	Contribution
	Single-family residential *Chapters III, IV* *Lognormal ECC distributions* $ECI_{A1\text{-}A3}$: 48 to 93 $kgCO_2e/m^2$ **Commercial Office** *Chapter V* *KDE ECC distributions* $ECI_{A1\text{-}A3}$: 151 to 376 $kgCO_2e/m^2$ **Apartment (multifamily residential)** *Chapter VI, excluding outliers* *KDE ECC distributions* $ECI_{A1\text{-}A3}$: 112 to 194 $kgCO_2e/m^2$	The MUIs computed in each chapter can be applied to future probabilistic LCAs in which the ECC differs from this analysis.

* All findings should be considered within the goal and scope of respective LCAs and material quantity takeoffs.

7.3 Limitations

The central limitation of this work is that any reference building – in this case, the Department of Energy (DOE) prototype building models – is not representative of all buildings of a given typology. This dissertation sought to partially address this limitation by varying foundation designs (Chapters III, IV), lateral loading conditions (Chapter V), structural materials (Chapters V, VI), concrete strengths (Chapter VI), bay sizes (Chapter VI), and other design elements. Ideally, all design options would be parameterized or otherwise varied to best represent the array of design choices for each building typology in the US. Ultimately, the DOE prototype buildings are not very detailed, so much of the material quantification required generalized assumptions and some scope was limited.

All studies that utilize LCA to characterize environmental impacts are limited by goal and scope. The scope of each chapter was intentionally limited to the physical materials present in each DOE prototype model, a functional structure (defined differently in each chapter), and any other materials necessary to provide adequate structural support or enclosure. This definition was necessary to constrain the problem space, but does not account for a variable amount of additional materiality and EC emissions related to building systems that are not in scope (e.g., building services). Within the building systems included, such as structures, there are missing minor details that would also add to the materiality and ECI of these buildings, including fasteners and secondary framing.

The LCA modules reported from Athena, One Click, and Tally rely on many assumptions. The difference in methodology between tools leads to the greatest variability in LCA modules B and C. For instance, One Click does not account for any module B emissions, which are namely due to repair and replacement. However, Tally includes substantial material replacement and maintenance emissions, which can account for up to 50% of module A-C ECI in some cases (see **Figure 4-3**).

The theoretical maximum biogenic carbon storage computations performed in Chapters III, V, and VI are idealized and simplified. This theoretical maximum biogenic CO_2 storage metric does not account for the decay of biogenic CO_2 during the service life or end-of-life treatment of buildings. It offers a snapshot of carbon emissions and storage before building construction, but does not account for biogenic carbon leaving the product system as specified in ISO 21930 (ACLCA, 2019; ISO, 2017). As a result, it is reported separately from the ECI benchmark results.

7.4 Future work

This dissertation lays the foundation for many impactful future investigations. Largely, the scope of this research could be expanded to make theoretical EC benchmarks more robust and applicable to a broader range of building designs and typologies. This scope expansion could take many forms:

- **Performing parametric analysis for a wider variety of building systems.** Varying building envelope designs would enable a unique consideration of EC and OC tradeoffs when changing cladding, insulation, or other commonly varied materials. Other design choices, such as finish materials, building services, or shading strategies, could also be included and varied to add breadth to the analysis.
- **Refining kernel density estimation (KDE) parameters.** The KDE method can specifically include or remove particular EPDs based on technical characteristics (e.g., thermal performance), manufacturer, regionality, and other variables. Filtering or specifying EPDs for certain materials will narrow the ECC uncertainty for a given material, thereby reducing the range of potential ECIs for a given benchmark (Torres & Srubar III, in review).
- **Applying regionally-specific ECCs**. Regionally-specific ECCs would make benchmarks more specific to use cases such as building stock level analyses that include regional variations in ECC or state and local policy analysis.

- **Expanding the physical system boundary**. Modeling finish materials, building services, HVAC equipment, and other building assemblies would broaden the applicability of benchmark values for designers, researchers, and policymakers. A great deal of EPD data is available for certain finish materials, but many materials or assemblies are currently lacking in data. However, the landscape is expanding as industry commitments and federal funding support the production of more EPDs across more product categories, such as HVAC and building services (*MEP 2040*, 2024; US EPA, 2023b, 2024c).
- **Considering future grid emissions in the calculation of ECCs over time.** The analysis of electric grid emissions scenarios in Chapter V elucidated the substantial impact grid emission projections can have on OCI. These grid emission factors could be used to project ECC over time, as many product ECCs depend on electricity consumption and grid emissions.
- **Modeling building stock emissions using benchmarks**. Building stock modeling would require EC benchmarks for more typologies and scope alignment across benchmarks. There are sufficient data from the US Energy Information Administration to combine such benchmarks with floor area projections by typology (US EIA, 2018a, 2018b, 2020, 2023a).
- **Analyzing emissions reductions due to specific code and policy proposals**. The Pacific Northwest National Laboratory currently uses the DOE prototype models to estimate the energy and demand reductions due to code improvements at the building and stock scales (Tyler et al., 2023). Using the building stock analysis proposed above, a related study could evaluate the EC reduction implications of different code and policy proposals.
- **Analyzing ECI for more building typologies**. An enabling next step for stock modeling is to compute ECI benchmarks for a wider variety of building typologies,

starting with more commonly constructed typologies such as warehouses and retail buildings.

- **Applying detailed biogenic carbon accounting**. Future analyses should consider realistic whole-life biogenic carbon accounting methods that consider the decay of biogenic CO_2 in natural materials across a building's life cycle. Studying the various end-of-life treatment options for natural materials across the US could lead to better end-of-life CO_2 emission and storage models.

7.5 Closing remarks

Theoretical embodied carbon emissions benchmarks provide a crucial foundation for decarbonizing the built environment. Researchers, practitioners, and policymakers can immediately apply these benchmarks to drive impactful change. For researchers, these benchmarks offer a valuable point of reference that can guide methodological choices in evaluating whole-building ECIs and assessing the effects of code and policy changes at the building stock level. Practitioners can leverage these benchmarks to compare with whole-building LCAs or to estimate the impacts of specific EC reduction strategies for 'typical' buildings similar to the DOE prototype models. Policymakers can utilize these benchmarks to set ambitious, yet achievable science-based reduction targets for EC emissions in residential and commercial buildings. Collectively, these efforts can foster a more comprehensive and informed approach to reducing EC emissions in residential and commercial buildings, reinforcing the potential for this dissertation to contribute meaningfully to the decarbonization of our built environment.

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Appendices

Appendix A. Single-family residential building supplementary information

Table A1. Material Densities

Project Material Name	Density (kg/m3)	Source/Additional Info
Concrete	2293.0	Athena
Drywall	800.9	EnergyPlus
Fiberglass batt	10.8	EnergyPlus
Foam insulation*	49.2	Athena
Glazing	N/A**	Spec sheet for typical window
Lumber	423.1	Athena
Building paper	1431.0	Athena
Shingles	1121.3	EnergyPlus
Steel	82.7	Density of rebar per m3 of reinforced concrete
Synthetic Stucco	400.0	EnergyPlus
OSB	544.6	EnergyPlus
Plywood	544.7	EnergyPlus
Stone	N/A**	Athena

* All foam insulation was assumed to be extruded polystyrene (XPS), as it is much more commonly used in applications as exterior sheathing and foundation insulation, which are the two uses noted in the DOE prototype model.
****** Custom calculation used to calculate the total quantity of this material that did not utilize volume and density.

Table A2. Interior wall length-to-perimeter (IWL-P) ratio

Name of Floor Plan	Total area (ft^2)	Number of Floors	Interior Wall Length (ft)	Exterior Perimeter (ft)	Interior wall length to perimeter (IWL-P) ratio	Link to Source	Accessed
2000-Square-Ft-Small-House-Plan	2000	1	182.0	177.8	1.02	Civic Concepts	8/30/23
2373-Square-Feet-House-Plan-1	2373	1	272.5	284.8	0.96	Civic Concepts	8/30/23
2500-Square-Feet-Simple-House-Plan	2500	1	150.0	204.5	0.73	Civic Concepts	8/30/23
2750-Square-Ft-House-Plan	2750	1	181.0	207.3	0.87	Civic Concepts	8/30/23
ADC1	2192	1	191.0	222.3	0.86	American Design Concepts	8/30/23
Asher Homes-Tucson	2564	2	299.0	333.5	0.9	Asher Homes	8/30/23
Burlington III	2517	1	231.0	233.8	0.99	Stock Development	8/30/23
Generic Bldg 1	2304	2	221.0	305.0	0.72	Renovation Headquarters	8/30/23
Generic Bldg 2	2716	2	272.5	260.5	1.05	Renovation Headquarters	8/30/23
Generic Bldg 3	1866	2	177.0	250.3	0.71	Renovation Headquarters	8/30/23
Generic Bldg 4	2100	2	201.0	260.0	0.77	Renovation Headquarters	8/30/23
Generic Bldg 5	2520	3*	246.0	348.0	0.71	Renovation Headquarters	8/30/23
Generic Bldg 6	2640	3*	266.0	381.0	0.7	Renovation Headquarters	8/30/23
Generic Bldg 7	2082	3*	284.0	387.3	0.73	Renovation Headquarters	8/30/23
Habitat For Humanity Portland	1728	2	172.0	240.0	0.72	Habitat for Humanity	8/30/23
NIST	4227	3*	309.0	439.0	0.7	NIST	8/30/23
WonderlandHomes-Abeline	2730	2*	267.0	343.0	0.78	Wonderland Homes	8/30/23
WonderlandHomes-Aspen	1842	3**	216.0	294.8	0.73	Wonderland Homes	8/30/23
WonderlandHomes-Azalea	2850	2*	287.0	360.0	0.8	Wonderland Homes	8/30/23
WonderlandHomes-Birch	3370	2	377.0	423.3	0.89	Wonderland Homes	8/30/23
WonderlandHomes-Blossom	2657	3*	256.0	426.8	0.6	Wonderland Homes	8/30/23
WonderlandHomes-Cascade	2750	3*	273.0	459.0	0.59	Wonderland Homes	8/30/23
WonderlandHomes-Clover	2122	3**	208.5	311.0	0.67	Wonderland Homes	8/30/23
WonderlandHomes-Daphne	2111	3**	250.0	288.5	0.87	Wonderland Homes	8/30/23
WonderlandHomes-Laurel	2167	3**	246.3	339.3	0.73	Wonderland Homes	8/30/23
WonderlandHomes-Olive	2232	2**	238.0	344.8	0.69	Wonderland Homes	8/30/23
WonderlandHomes-Poplar	2714	2**	284.0	330.8	0.86	Wonderland Homes	8/30/23
WonderlandHomes-Prairie	2560	2**	302.0	325.0	0.93	Wonderland Homes	8/30/23
WonderlandHomes-Rosemary	1772	3**	221.0	256.0	0.86	Wonderland Homes	8/30/23
WonderlandHomes-Spruce	2754	2**	333.0	353.5	0.94	Wonderland Homes	8/30/23

Average IWL-P Ratio:	0.80

* Floor plan and IWL-P ratio include finished basement
** Floor plan includes unfinished basement, but basement is not included in calculating the IWL-P ratio.

Table A3. Building-specific structural material quantities

Foundation type	Climate zone	Material	Volume (m^3)	Mass (kg)	MUI (kg/m^2)	Elements Included
CS	All	Concrete	6.94	15919.96	72.09	footers, stem walls
CS	All	Engineered Wood	10.36	5645.39	25.56	roof and wall sheathing, joists
CS	All	Softwood Lumber	2.23	942.71	4.27	trusses, headers
CS	All	Steel	0.27	2098.29	9.50	rebar, structural beams and columns
HB	All	Concrete	22.58	51782.09	156.32	footers, basement walls, basement slab
HB	All	Engineered Wood	10.36	5645.39	17.04	roof and wall sheathing, joists
HB	All	Softwood Lumber	2.23	942.71	2.85	trusses, headers
HB	All	Steel	0.58	4570.22	13.80	rebar, structural beams and columns
S	All	Concrete	11.55	26483.23	119.92	footers, slab
S	All	Engineered Wood	10.36	5645.39	25.56	roof and wall sheathing, joists
S	All	Softwood Lumber	2.23	942.71	4.27	trusses, headers
S	All	Steel	0.38	2948.11	13.35	rebar, structural beams and columns
UB	All	Concrete	20.00	45866.69	207.69	footers, basement walls, basement slab
UB	All	Engineered Wood	10.36	5645.39	25.56	roof and wall sheathing, joists
UB	All	Softwood Lumber	2.23	942.71	4.27	trusses, headers
UB	All	Steel	0.53	4148.72	18.79	rebar, structural beams and columns

*Excludes material quantity for 2x6 stud walls, as their material quantities were calculated separately.

Figure A4. Structural drawings of common dimensions across all foundation types

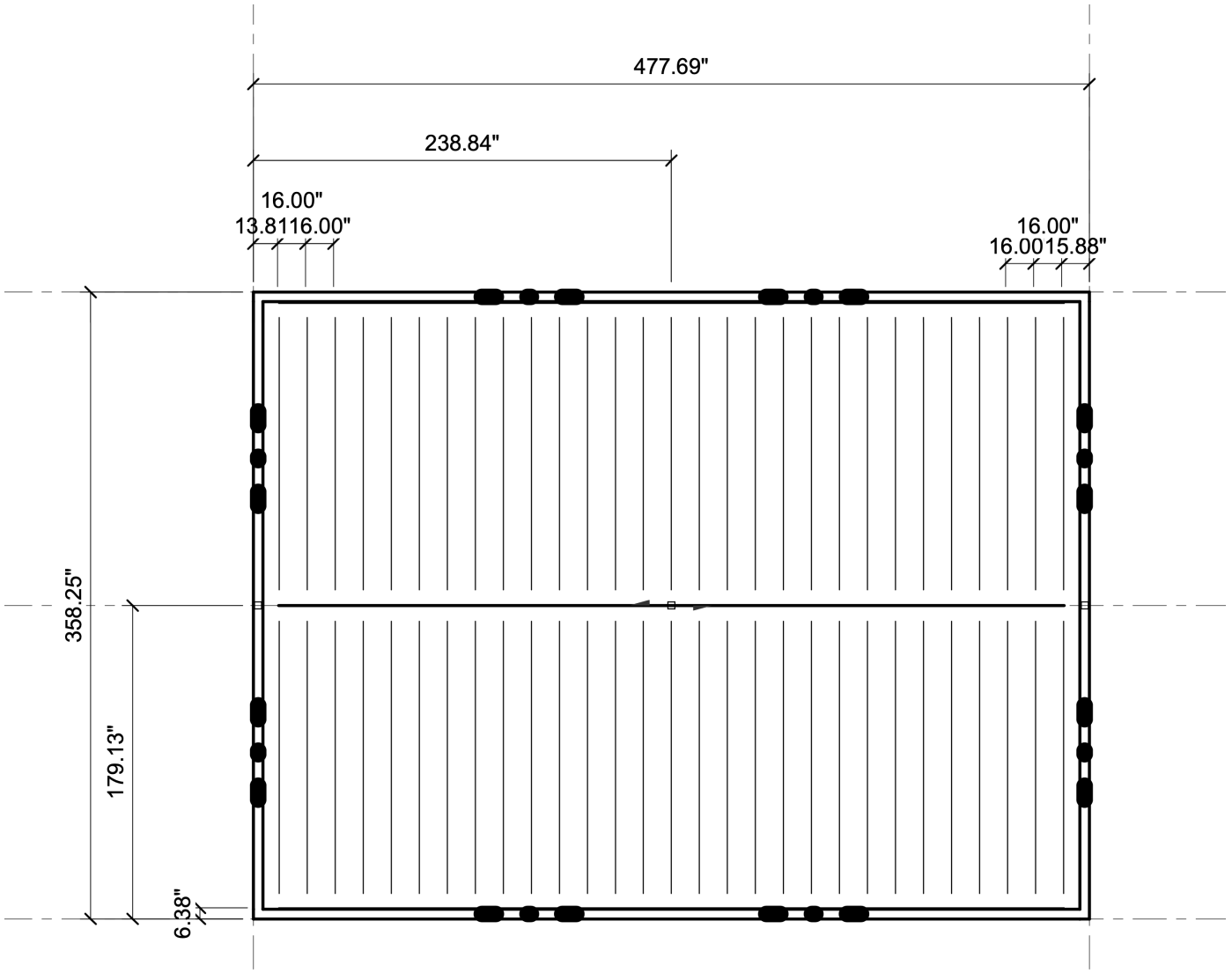


Figure A4.1. Floor Member Spacing

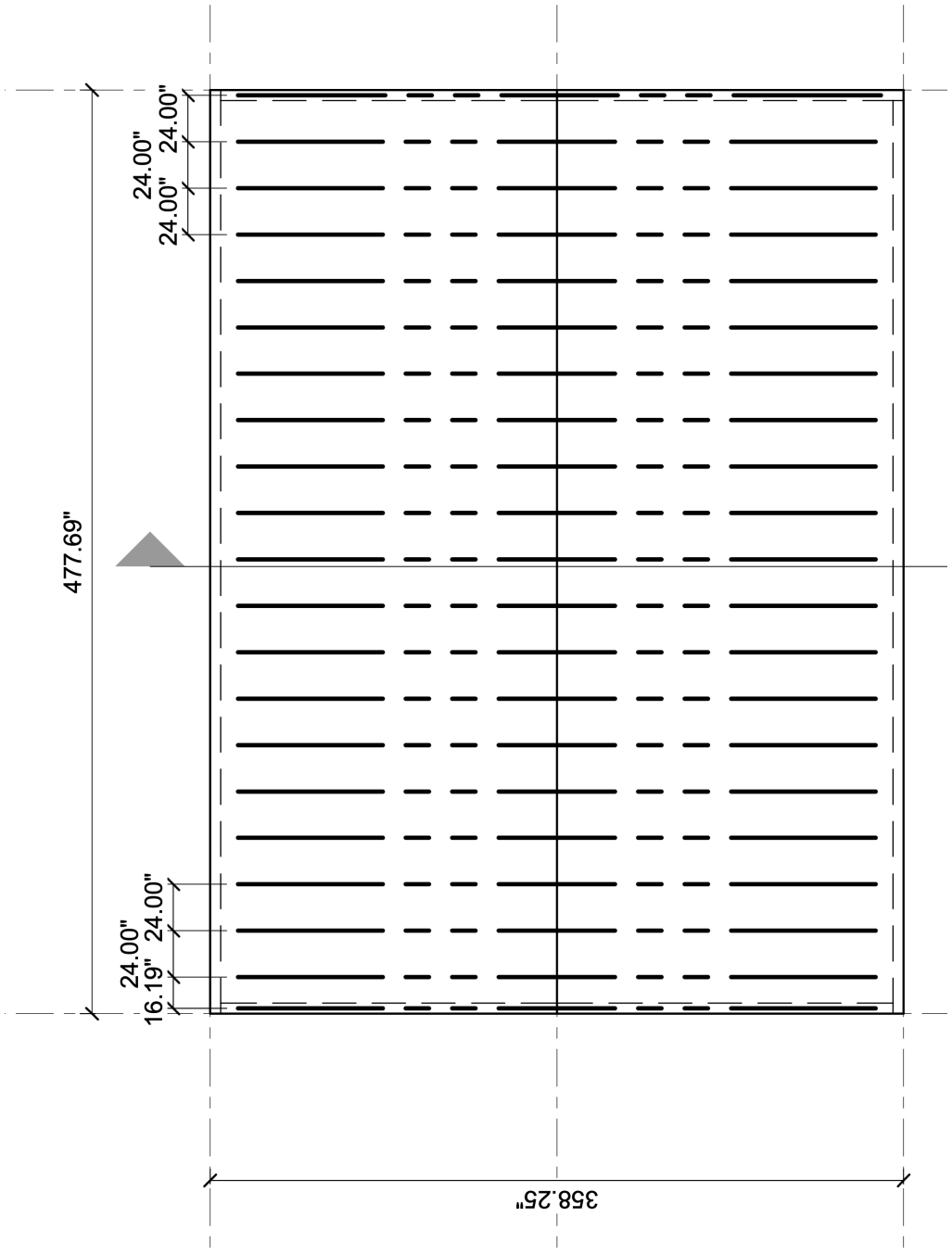


Figure A4.2. Roof Truss Spacing

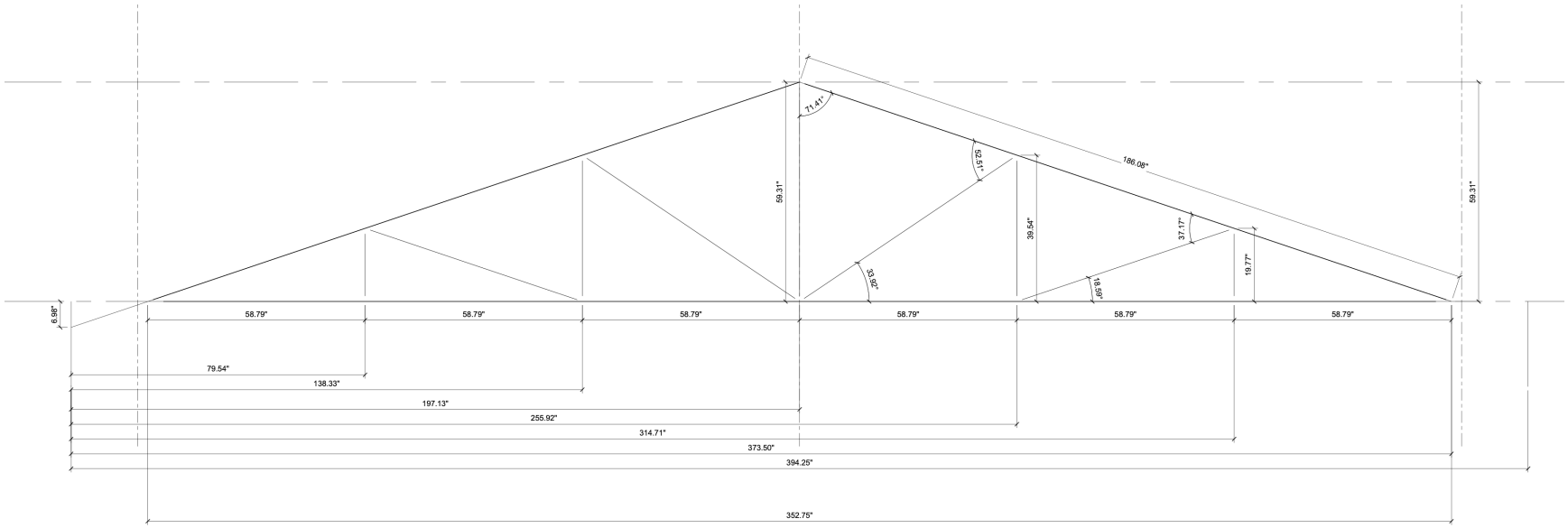
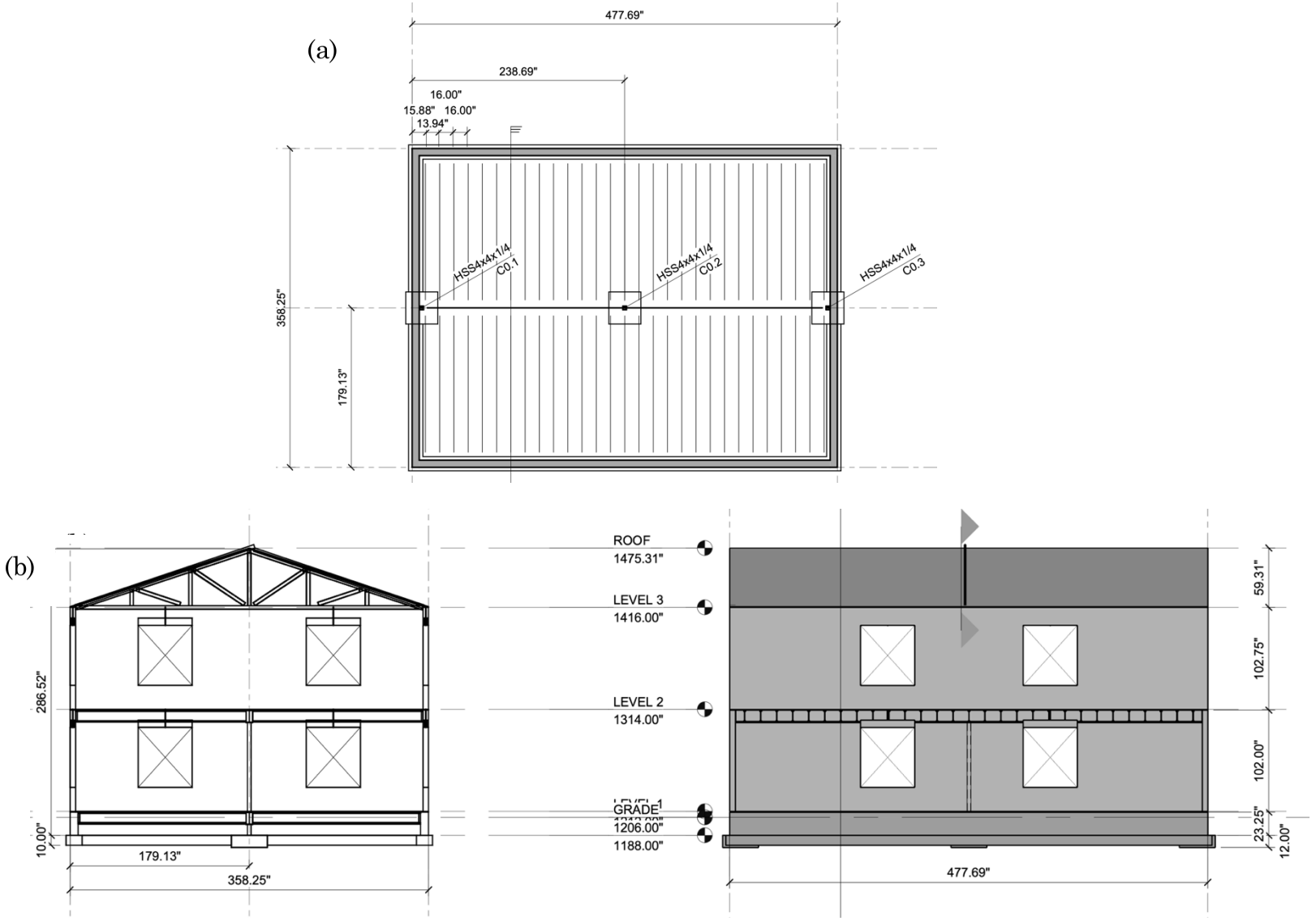
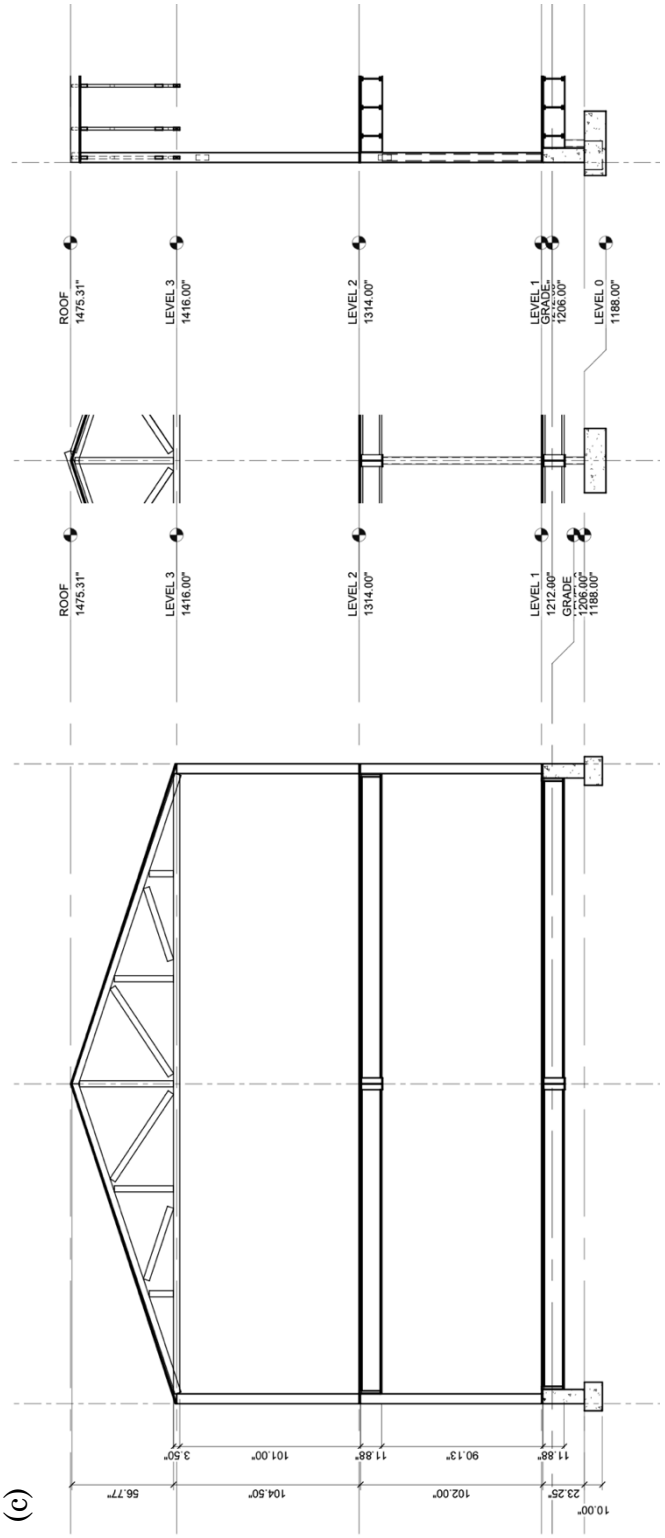


Figure A4.3. Roof Truss Dimensions

Figure A5. Structural drawings of uncommon dimensions for each foundation type

Figure A5.1. Crawl space foundation type drawings: (a) foundation plans, (b) elevations, (c) wall plans

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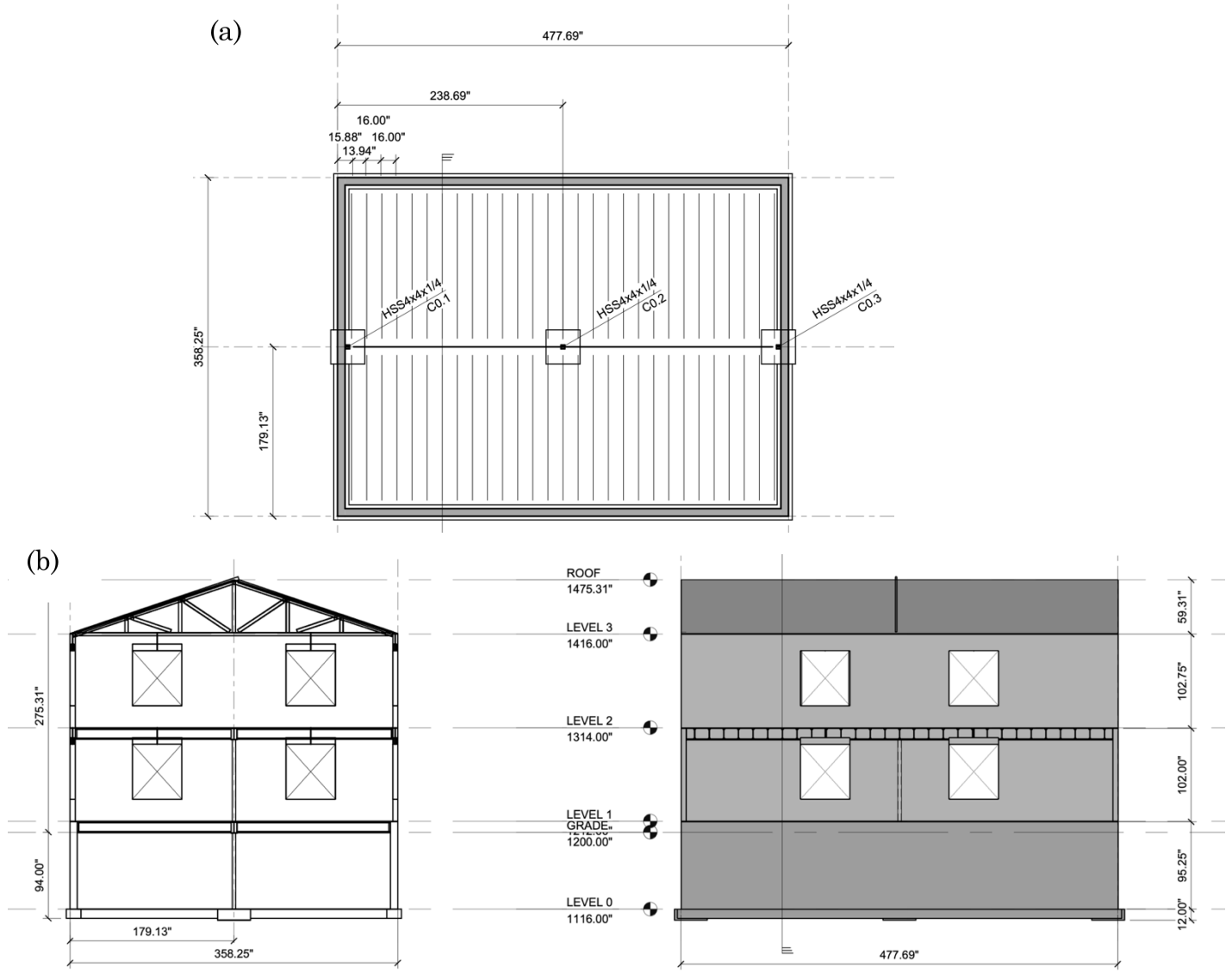
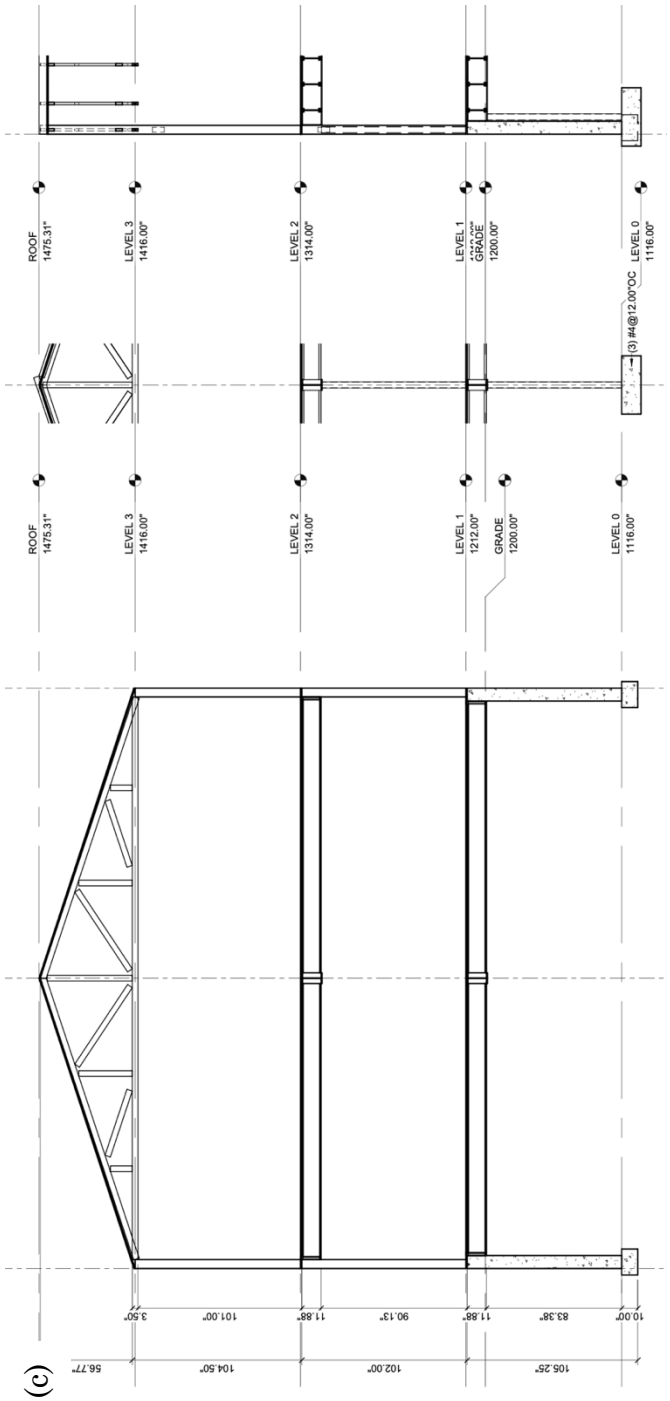
1475.31"
LEVEL 3
1416.00"
LEVEL 2
1314.00"
LEVEL 1
1212.00"
GRADE
1206.00"
LEVEL 0
1188.00"
56.77"
104.50"
102.00"
23.25"
10.00"
3.50"
101.00"
11.88"
90.13"
11.88"

(c)

Figure A5.2. Heated basement foundation type drawings: (a) foundation plans, (b) elevations, (c) wall plans




ROOF
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56.77"
3.50"
104.50"
101.00"
102.00"
11.88"
90.13"
105.25"
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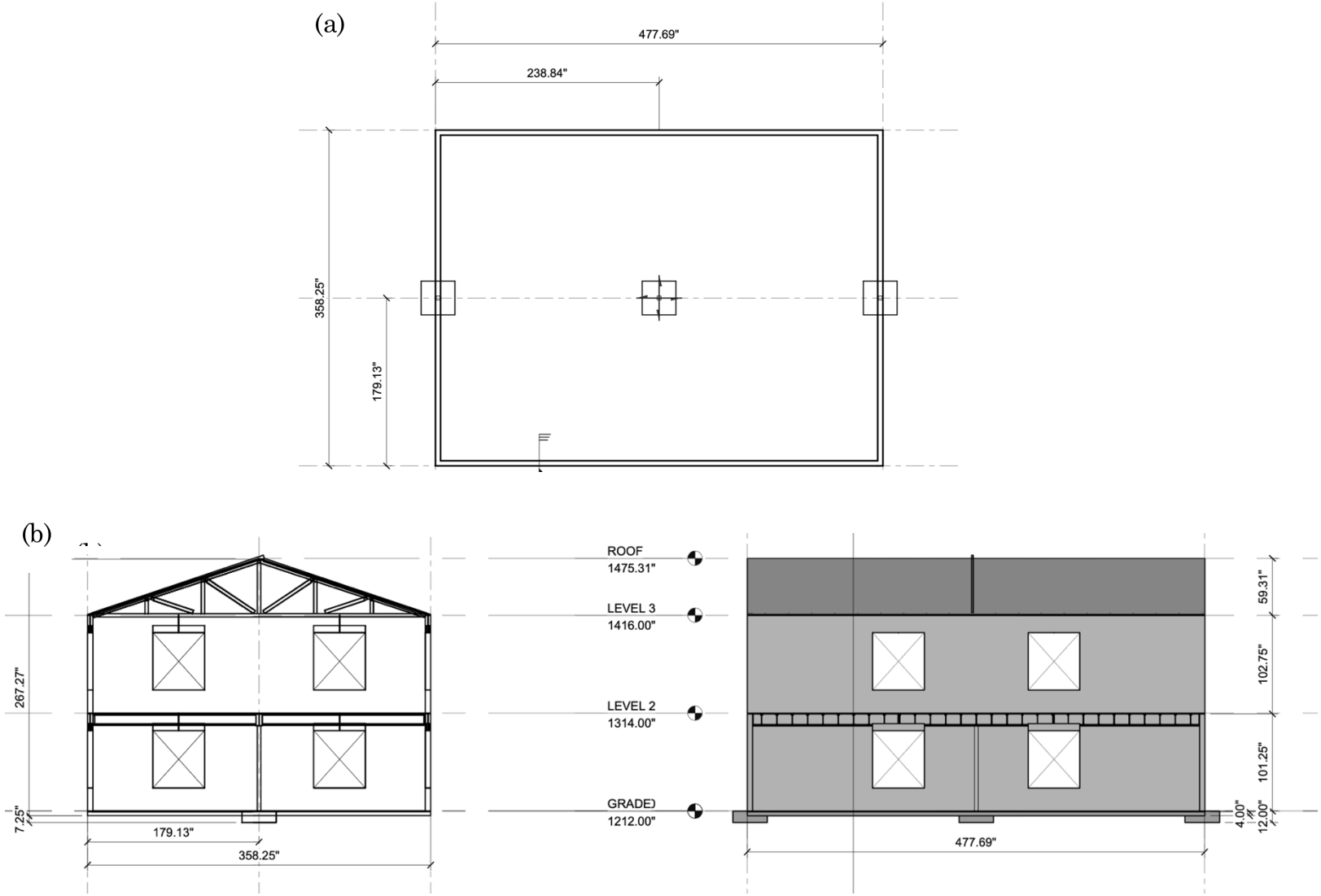
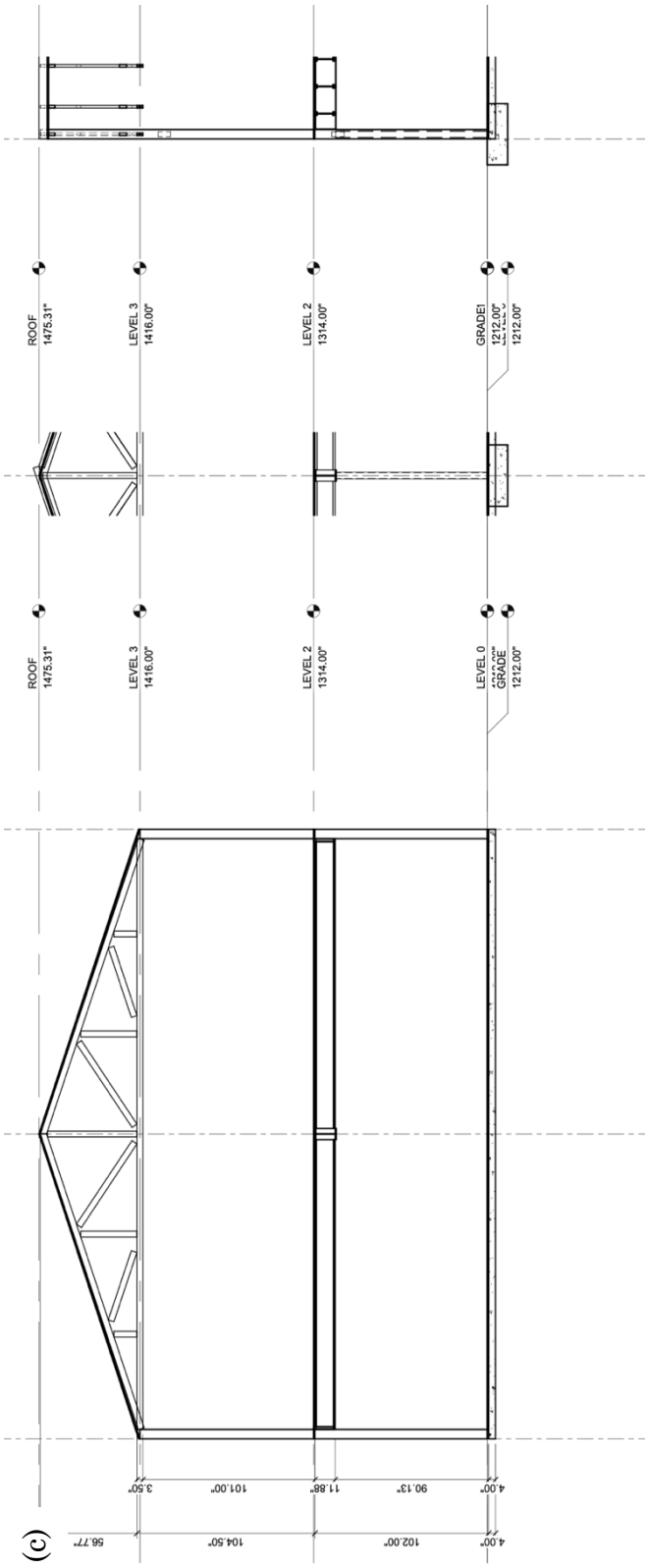
83.38"
10.00"

(c)

Figure A5.3. Slab foundation type drawings: (a) foundation plans, (b) elevations, (c) wall plans

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GRADE
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ROOF
1475.31'
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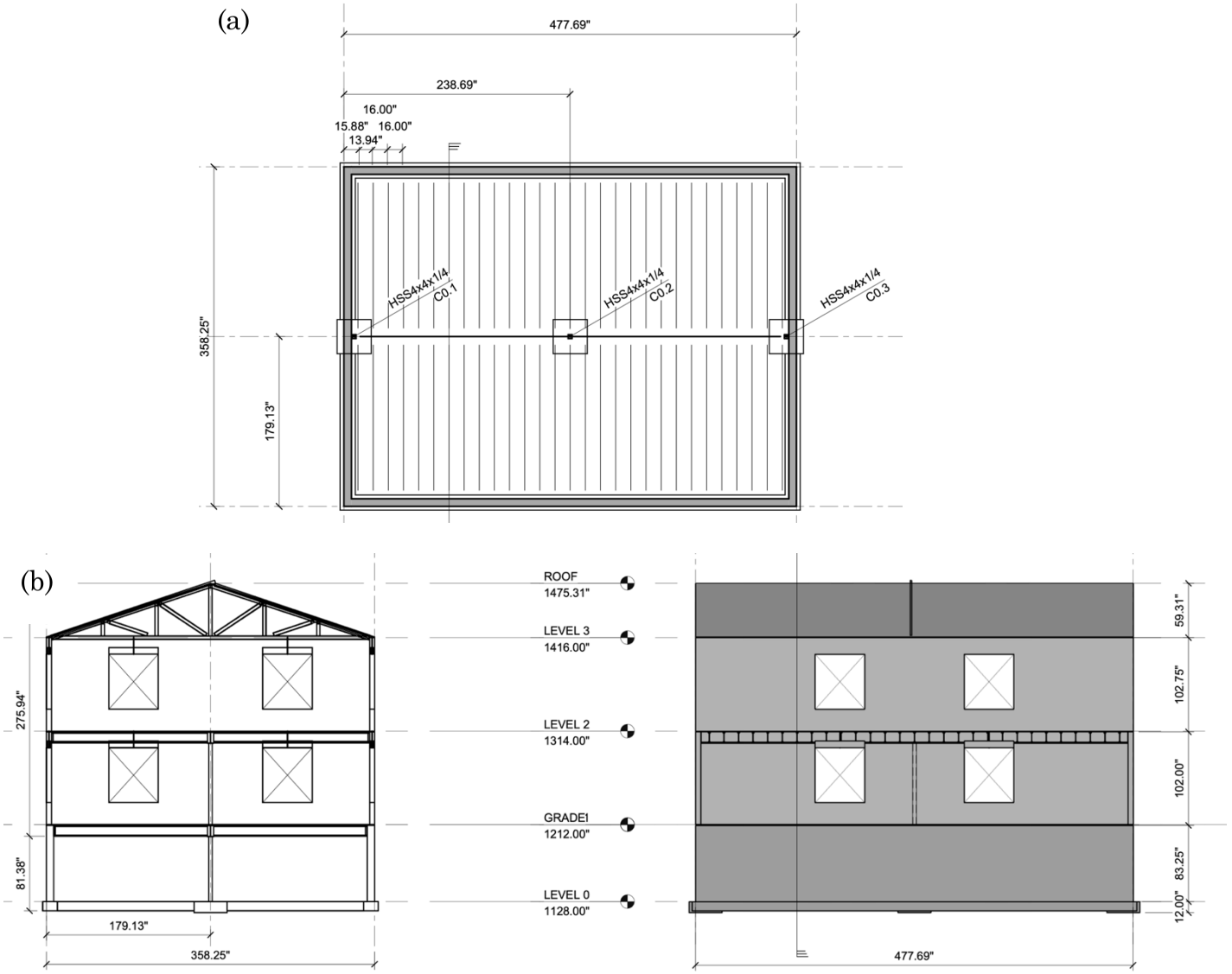
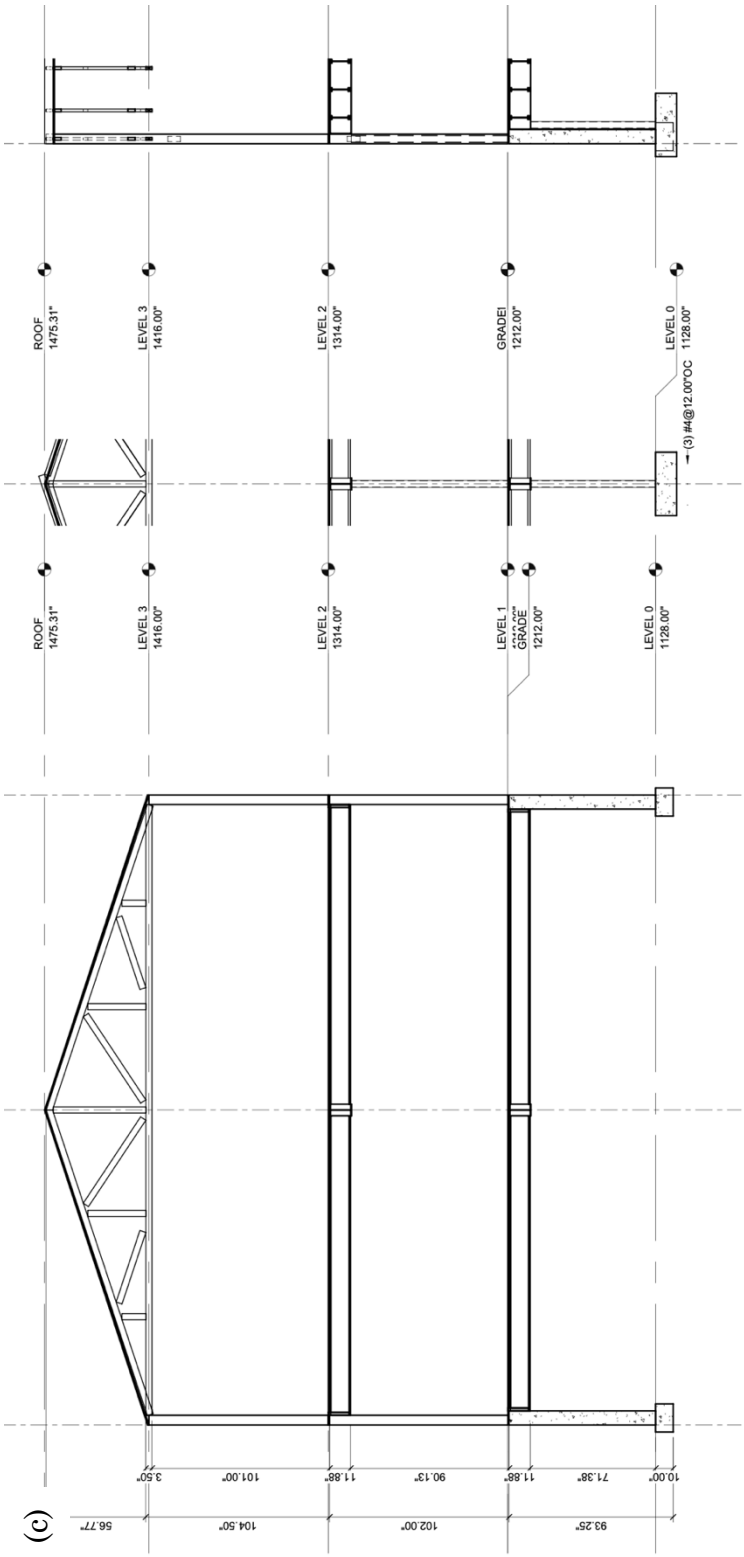
1416.00'
LEVEL 2
1314.00'
LEVEL 0
GRADE
1212.00'
3.50"
101.00"
11.88"
90.13"
4.00"
56.77"
104.50"
102.00"
4.00"
(c)

Figure A5.4. Unheated basement foundation type drawings: (a) foundation plans, (b) elevations, (c) wall plans

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ROOF
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1416.00"
LEVEL 2
1314.00"
LEVEL 1
GRADE
1212.00"
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1128.00"
3.50"
101.00"
11.88"
90.13"
11.88"
71.38"
10.00"
56.77"
104.50"
102.00"
93.25"

(c)

Table A6. Material name mapping across tools utilized in this study: EnergyPlus, Athena, Tally, and OneClick

Project (simplified)	EnergyPlus	Athena	Tally	OneClick
Building paper	Bldg_paper_felt	#15 Organic Felt	Asphalt felt sheet	Geotextile, generic, 312 g/m^2 (1.02 oz/ft2), Composition: PP net, non-woven PE felt
Concrete	Concrete_4in	Concrete Benchmark USA 3000 psi	Concrete 3000 PSI national avg no steel	NOT SPECIFIED - USED ONECLICK AVERAGE VALUE
Concrete	N/A - not included	Concrete Benchmark USA 3000 psi	Concrete 3000 PSI national avg no steel	Concrete, ready mix, 2501 - 3000 psi (C18/20), 3000-20-FA (NRMCA)
Drywall	Drywall_1/2in	1/2" Regular Gypsum Board	Wall board, gypsum	Drywall (mixed gypsum), 0.37in
Fiberglass batt	ceil_consol_layer (1 of 2)	FG Batt R50	Glass wool, batt or blown	Fiberglass batt insulation, 9.65 in
Fiberglass batt	floor_consol_layer (1 pf 2)	FG Batt R20	Glass wool, batt or blown	Fiberglass batt insulation, 9.65 in
Fiberglass batt	wall_consol_layer (1 of 2)	FG Batt R20	Glass wool, batt or blown	Fiberglass batt insulation, 9.65 in
Fiberglass batt	Fiberglass Batt	FG Batt R50	Glass wool, batt or blown	Fiberglass batt insulation, 9.65 in
Foam Insulation	sheathing_consol_layer	Expanded Polystyrene	Expanded polystyrene (EPS), board	XPS insulation (extruded polystyrene), 1.02in
Foam Insulation	XPS	Expanded Polystyrene	Asphalt felt sheet	XPS insulation (extruded polystyrene), 1.02in
Glazing	Glass	Double Glazed No Coating Air	Glazing, double pane IGU Window frame, vinyl	Double Pane IGU
Lumber	ceil_consol_layer (2 of 2)	Small Dimension Softwood Lumber, kiln-dried	Heavy timber	Softwood lumber, kiln-dried and planed, 19 mm, 460 kg/m3, 15% moisture content
Lumber	door_const	Small Dimension Softwood Lumber, kiln-dried	Door, exterior, wood, solid core	Exterior door w/ IGU, 86x36x1.34in
Lumber	floor_consol_layer (2 of 2)	Small Dimension Softwood Lumber, kiln-dried	Heavy timber	Softwood lumber, kiln-dried and planed, 19 mm, 460 kg/m3, 15% moisture content
Lumber	Lumber_2x4	Small Dimension Softwood Lumber, kiln-dried	Wood framing	Softwood lumber, kiln-dried and planed, 19 mm, 460 kg/m3, 15% moisture content
Lumber	Std Wood 6inch	FG Batt R20	Wood framing	Softwood lumber, kiln-dried and planed, 19 mm, 460 kg/m3, 15% moisture content
Lumber	wall_consol_layer (2 of 2)	Small Dimension Softwood Lumber, kiln-dried	Wood framing	Softwood lumber, kiln-dried and planed, 19 mm, 460 kg/m3, 15% moisture content
Lumber	N/A - not included	Small Dimension Softwood Lumber, kiln-dried	Wood framing	Softwood lumber, kiln-dried and planed, 19 mm, 460 kg/m3, 15% moisture content
Lumber	2x4 framing interior	Small Dimension Softwood Lumber, kiln-dried	Wood framing	Softwood lumber, kiln-dried and planed, 19 mm, 460 kg/m3, 15% moisture content
OSB	OSB_1/2in	Oriented Strand Board	Oriented strandboard (OSB)	Oriented strand board (OSB), 9.5 mm, 620 kg/m3, 7% moisture content (American Wood Council, Canadian Wood Council)
OSB	OSB_5/8in	Oriented Strand Board	Oriented strandboard (OSB)	Oriented strand board (OSB), 9.5 mm, 620 kg/m3, 7% moisture content (American Wood Council, Canadian Wood Council)
OSB	OSB_7/16in	Oriented Strand Board	Oriented strandboard (OSB)	Oriented strand board (OSB), 9.5 mm, 620 kg/m3, 7% moisture content (American Wood Council, Canadian Wood Council)
Plywood	Plywood_3/4in	Softwood Plywood	Plywood, interior grade	Softwood plywood, 9.5 mm, 484 kg/m3, 7% moisture content
Shingles	Asphalt_shingle	Glass Based shingles 20yr	Asphalt roofing shingles, no adhesive	Asphalt Shingle Roofing System Industry Average EPD
Steel	N/A - not included	Rebar, Rod, Light Sections	Steel reinforcement only	Reinforcement steel (rebar), generic, 97% recycled content (typical), A615
Stone	N/A - not included	Ballast (aggregate stone)	Coarse aggregate	Aggregate (crushed gravel), generic, dry bulk density, 1600 kg/m3
Stucco	syn_stucco	EPDM Membrane (white, 60 mil)	EPDM Membrane (white, 60 mil)	Plastic (Stucco) cement, 2.5% clinker kiln dust

Appendix B. Commercial office building supplementary information

Appendix B-1 Structural Design Criteria and Assumptions

The structural sub-systems considered include:

- Gravity Framing (e.g., gravity beams, gravity columns, etc.)
- Gravity Foundations (e.g., spread footings at gravity columns)
- Lateral Force-Resisting System (e.g., steel braced frames)
- Lateral Force-Resisting System Foundations (e.g., strip footings at steel braced frames)

For each building prototype (medium and large office), for each material considered (steel, concrete, and timber) the structural sub-systems can be designed. The prototype building for any site of any material can then be aggregated from the appropriate sub-systems.

Gravity Loads

Live loads

At grade floor:	100 psf live
Above grade floors:	80 psf live (reducible per International Building Code)
Roof:	20 psf roof live (see also snow loads)

Superimposed Dead Loads

The dead loads considered in addition the structure's self-weight include:

Floor:	15 psf dead per floor area (comprised of floor finishes, MEPF and ceiling)
Roof:	15 psf dead per roof area (comprised of roofing, MEPF and ceiling)
Exterior Enclosure:	10 psf dead per wall area, assume 4ft parapets

Deflection and Vibration Criteria

Deflection and vibration criteria, not strength, can control the design of floor framing. The following criteria from Table 1604.3 of the International Building Code (IBC) was used for all structural material types.

Component	L or Lr	S or W	D + L
Roof members	l/240	l/240	l/180
Floor Members	l/360 (IBC) l/640 (vibration*)		l/240

Natural Hazard Criteria

The DOE prototype buildings are located in 16 cities in the United States, selected based on their climatic conditions. These 16 cities also represent a range of natural hazards impacting structural design, particularly snow, wind and seismic.

Seismic

For seismic design, ASCE 7-16 is used assuming Risk Category II structures and Site Class D (known site conditions, not default).

The seismic hazard levels include:

- Moderate Seismic (Seismic Design Category C): El Paso, TX
  - S_S = 0.323 and S_{DS} = 0.332
  - S_1 = 0.106 and S_{D1} = 0.169
- High Seismic (Seismic Design Category D): San Diego, CA
  - S_S = 1.491 and S_{DS} = 0.994
  - S_1 = 0.503 and S_{D1} = 0.604*

* Note that, for San Diego, further amplification of S_{D1} by 1.5x in accordance with the exception of ASCE 7-16 Section 11.4.8 is required when calculating seismic forces.

Wind

For wind design, ASCE 7-16 is used assuming Exposure Category B.

The design wind speeds include:

- Moderate Wind: International Falls, MN
  - V = 106mph
- High Wind: Tampa, FL
  - V = 141mph

Snow; Rain and Ice

Not included in this study.

Foundation Design

Shallow spread, strip and mat foundations are used with the following geotechnical criteria:

- 3,000psf allowable under dead plus live
- One-third increase for allowable load combinations involving wind or seismic

Basement walls for the large office prototype are designed for the following geotechnical criteria:

- 55pcf equivalent fluid pressure (allowable load)

Appendix B-2 Grid spacing and Floor Plans

The grid spacing for each building design option is listed in **Table B-2.1** and illustrated in **Figures B-2.1-B-2.4** below.

Table B-2.1. Grid spacing for the medium and large office prototype buildings.

Primary structural material	Medium Office (m)	Large Office (m)
Steel	10.9 x 9.9	9.6x9.1
Concrete	9.6x9.5	8.9x8.8

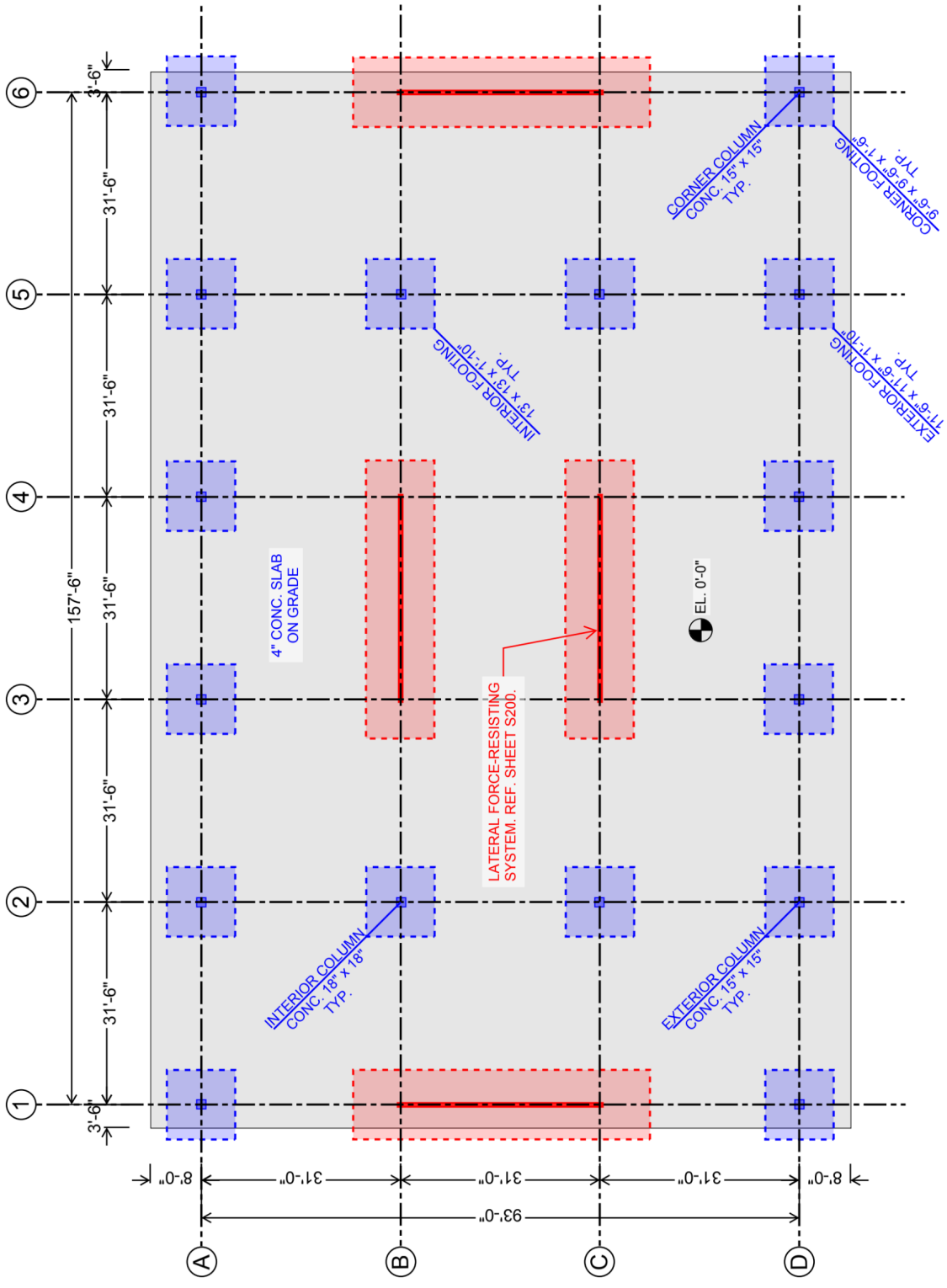

Figure B-2.1: Medium office, concrete: Foundation and Level 1 plan

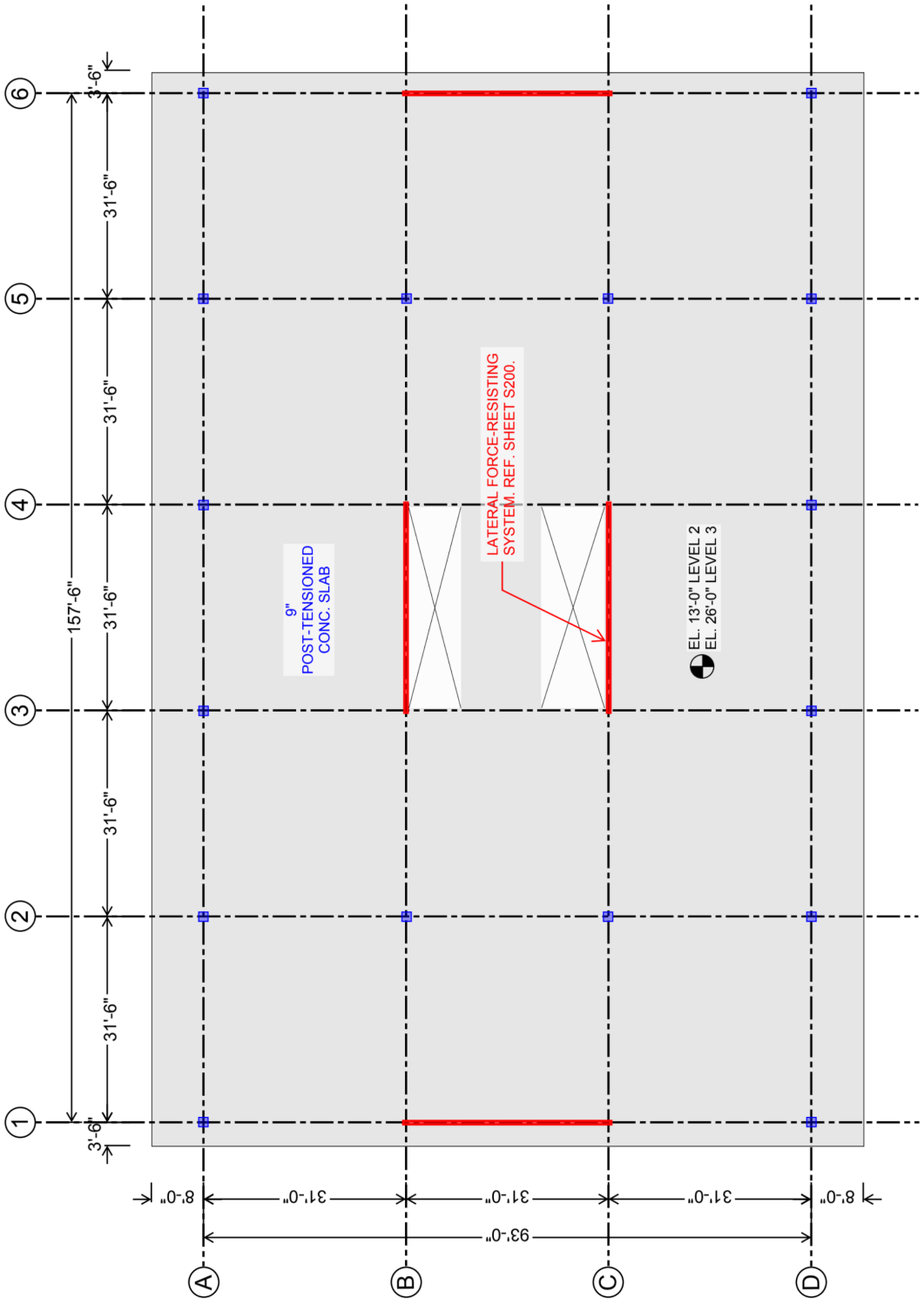

Figure B-2.2: Medium office, concrete: Level 2-3 plan

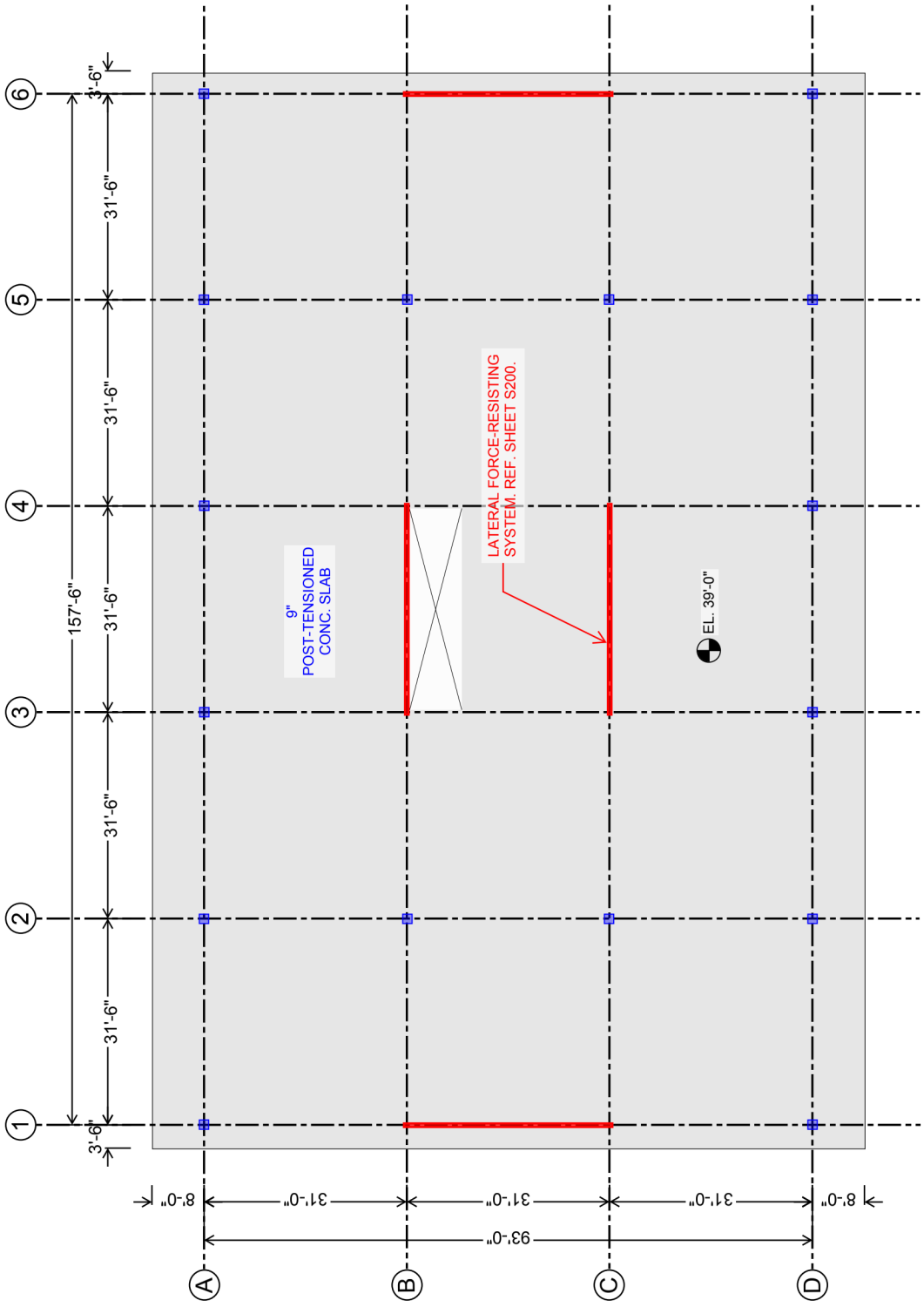

Figure B-2.3: Medium office, concrete: Roof plan

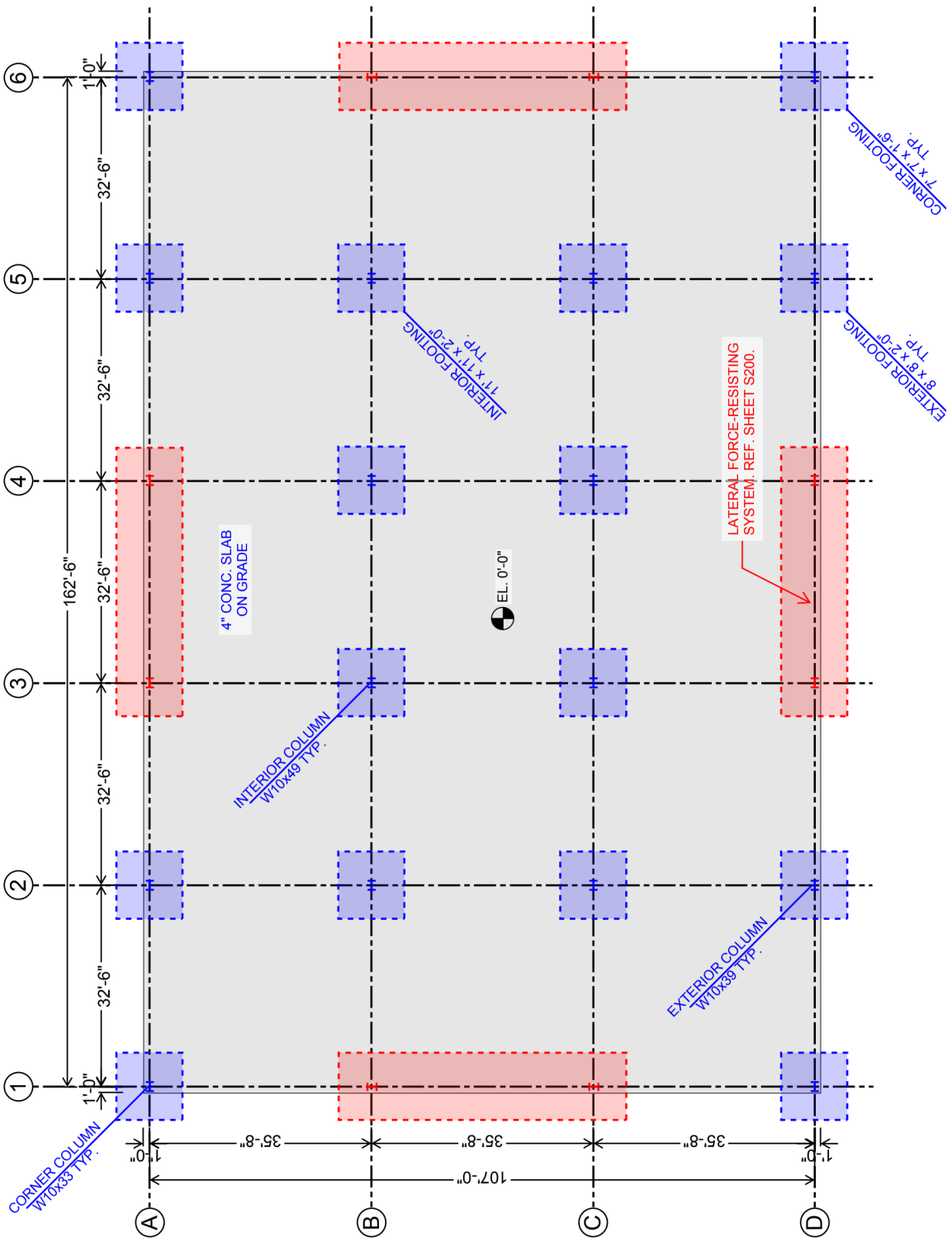

Figure B-2.4: Medium office, steel: Foundation and level 1 plan

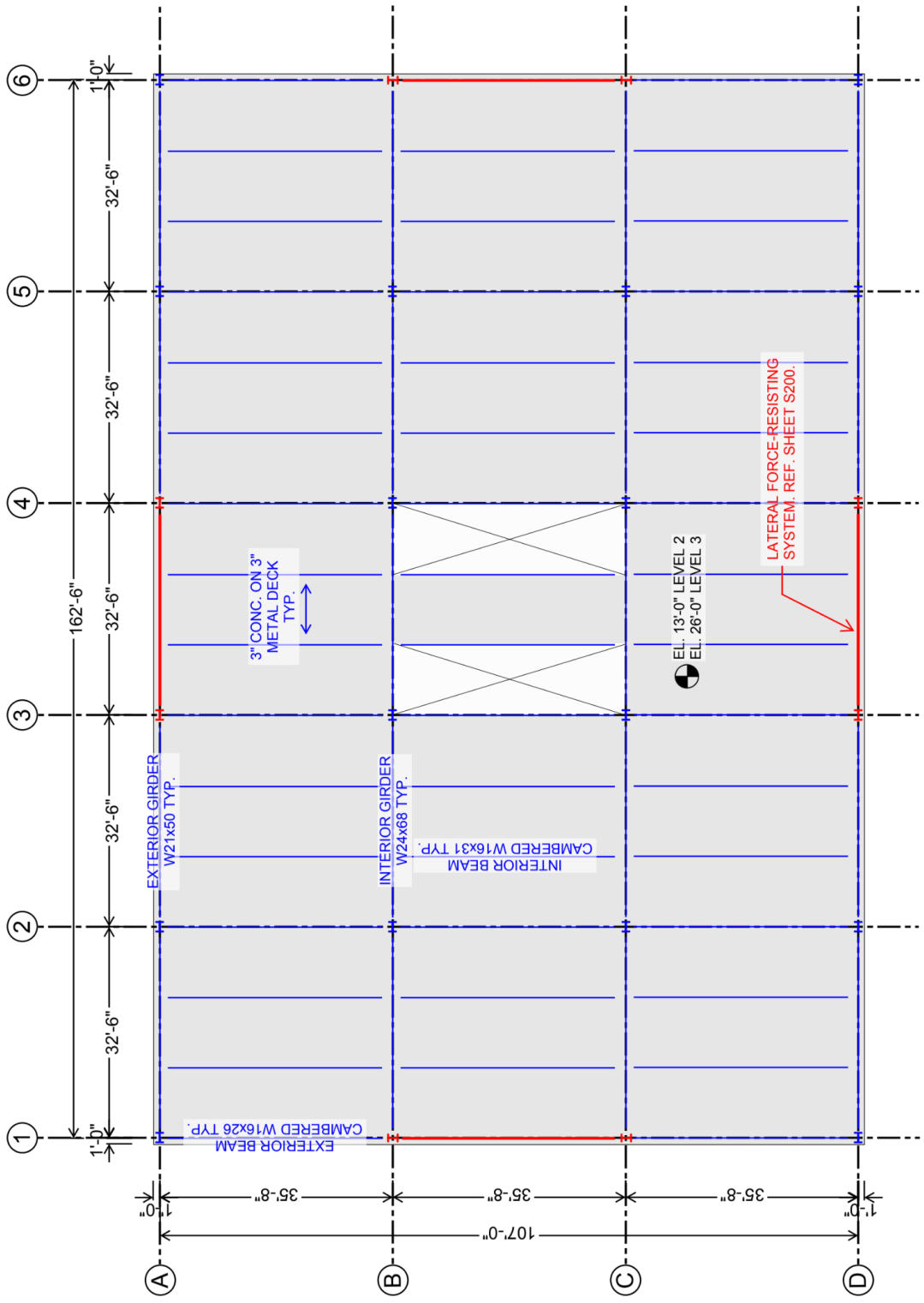

Figure B-2.5: Medium office, steel: Level 2-3 plan

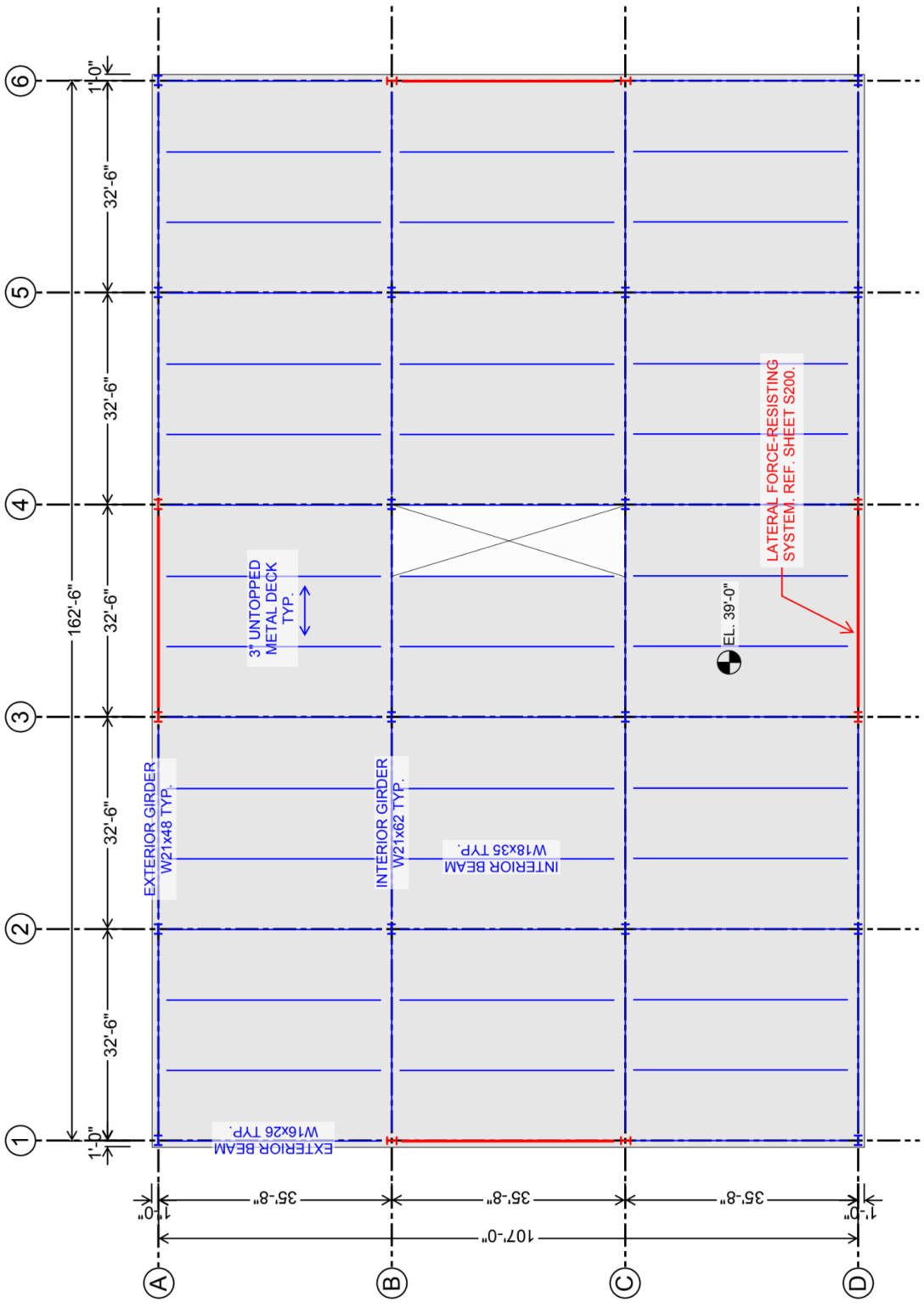

Figure B-2.6: Medium office, steel: Roof plan (50 psf roof load)

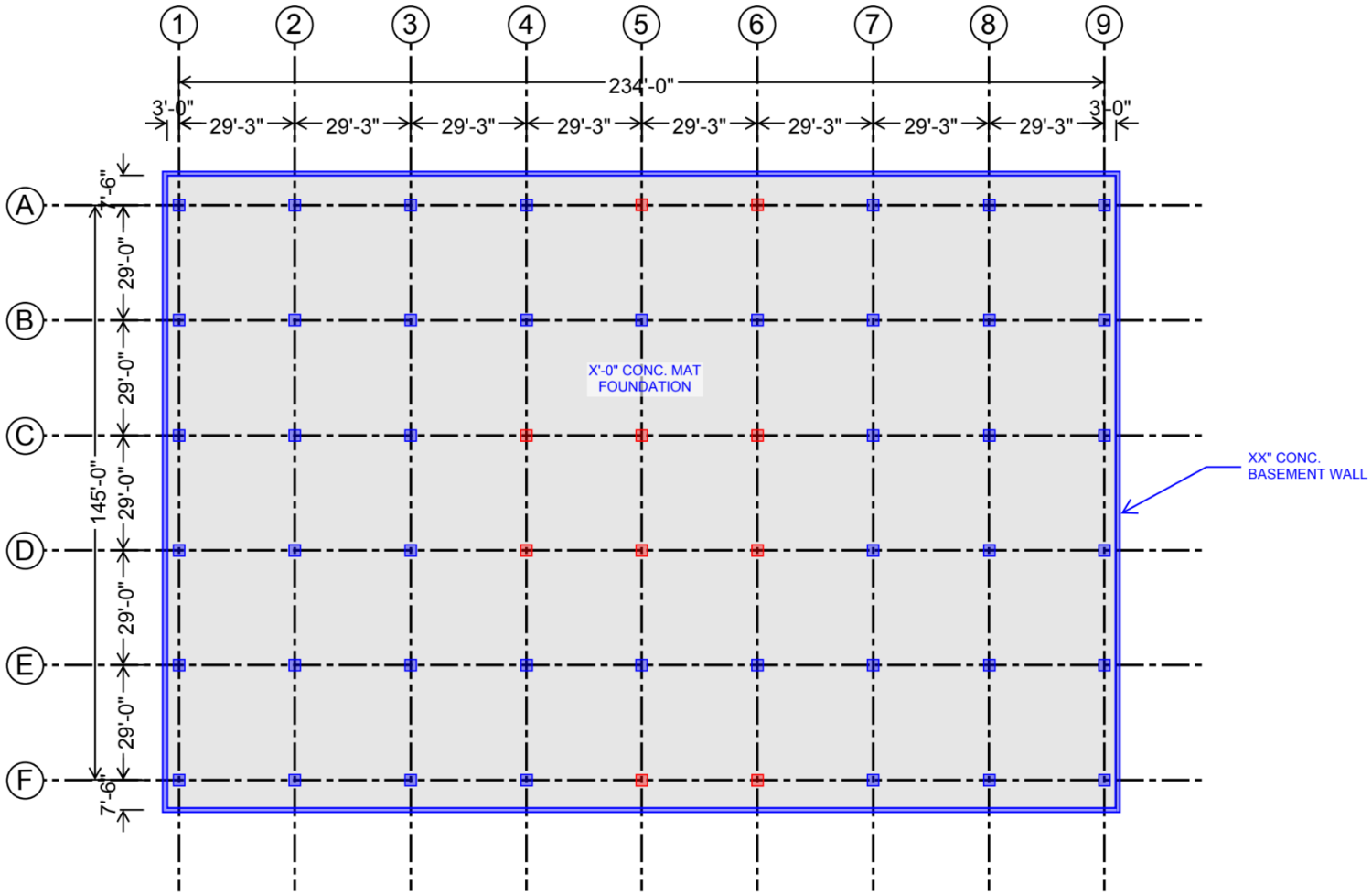

Figure B-2.7: Large office, concrete: Foundation and basement plan

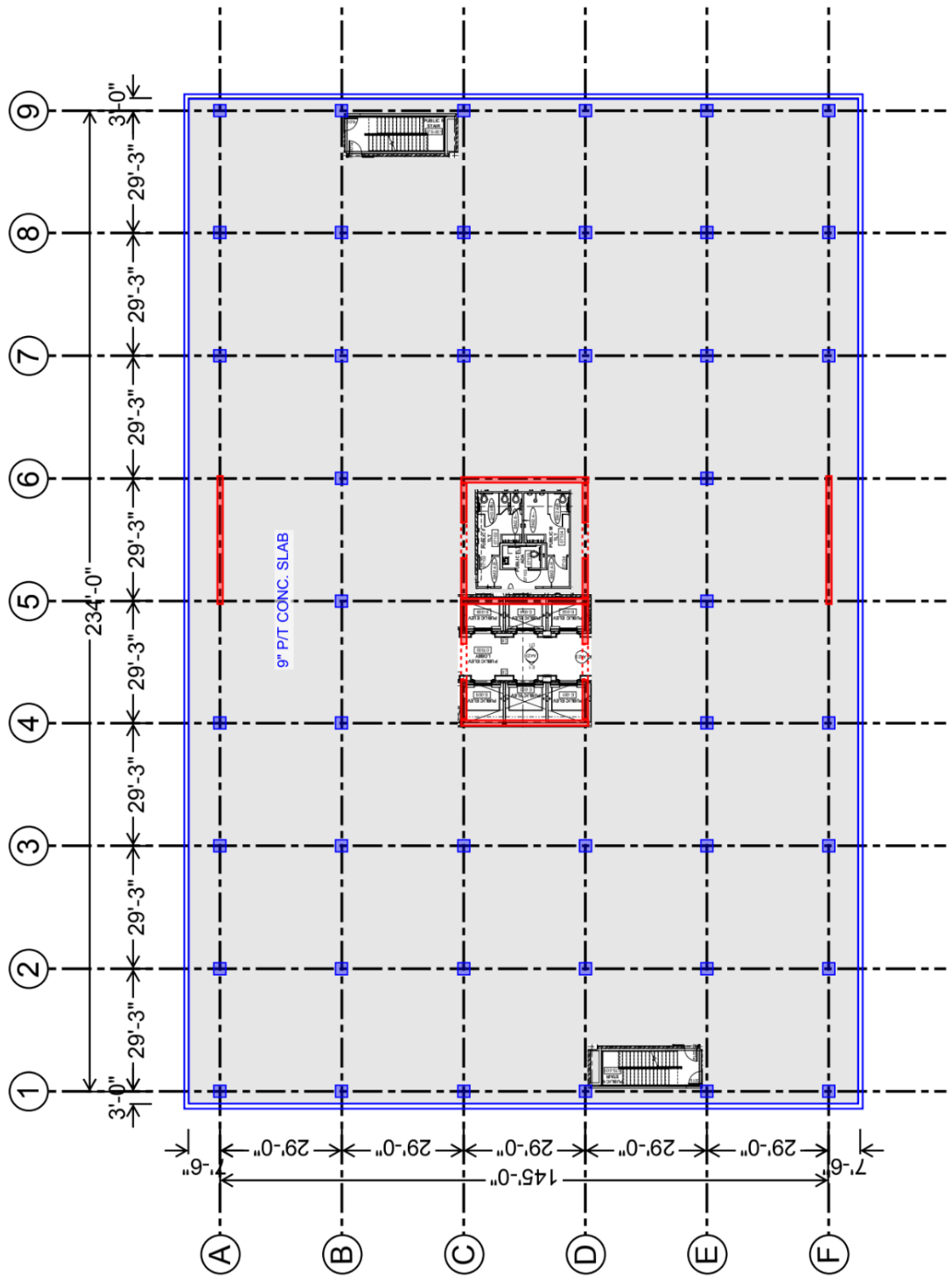

Figure B-2.8: Large office, concrete: Level 1 plan

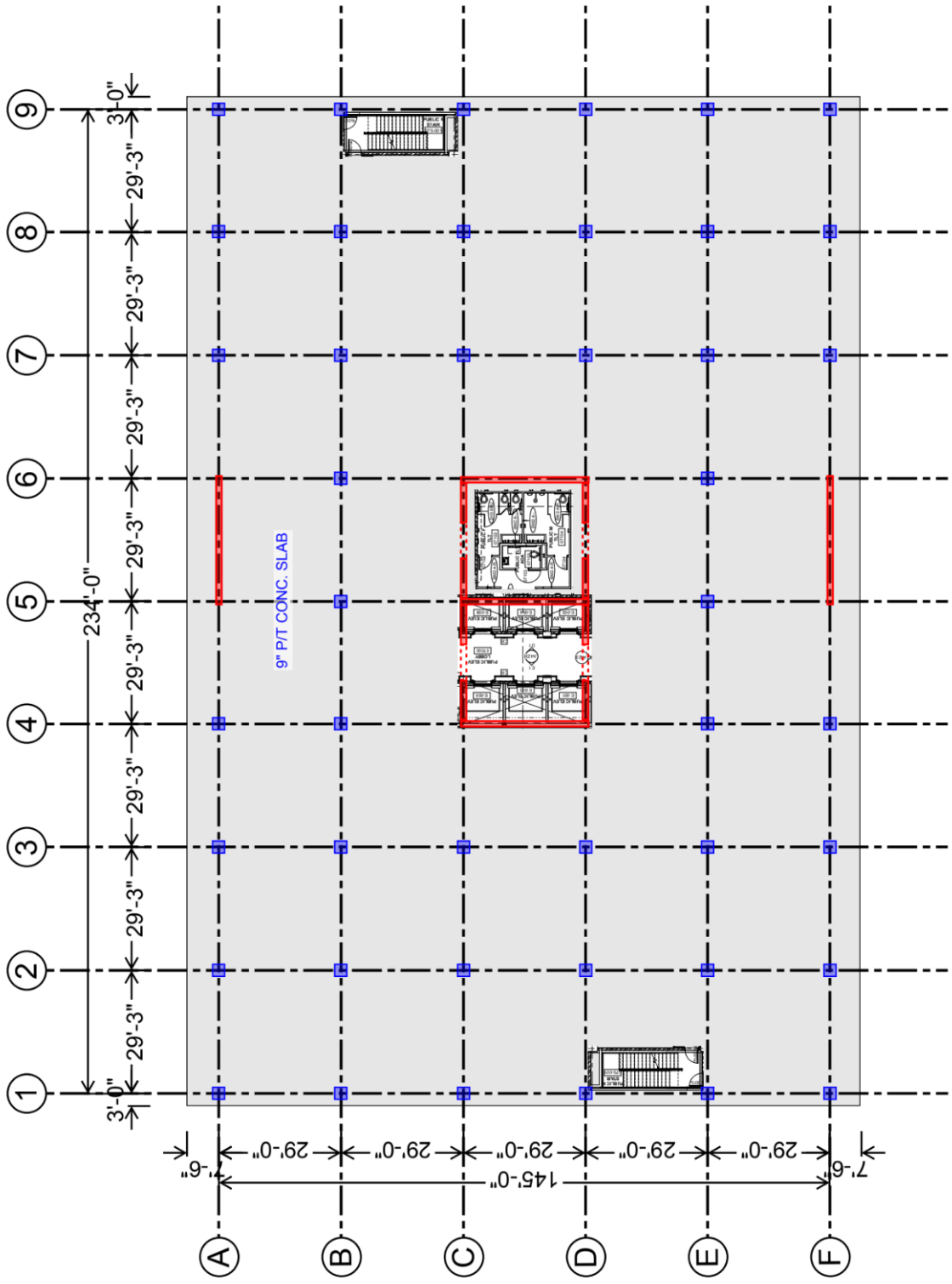

Figure B-2.9: Large office, concrete: Level 2-12 plan

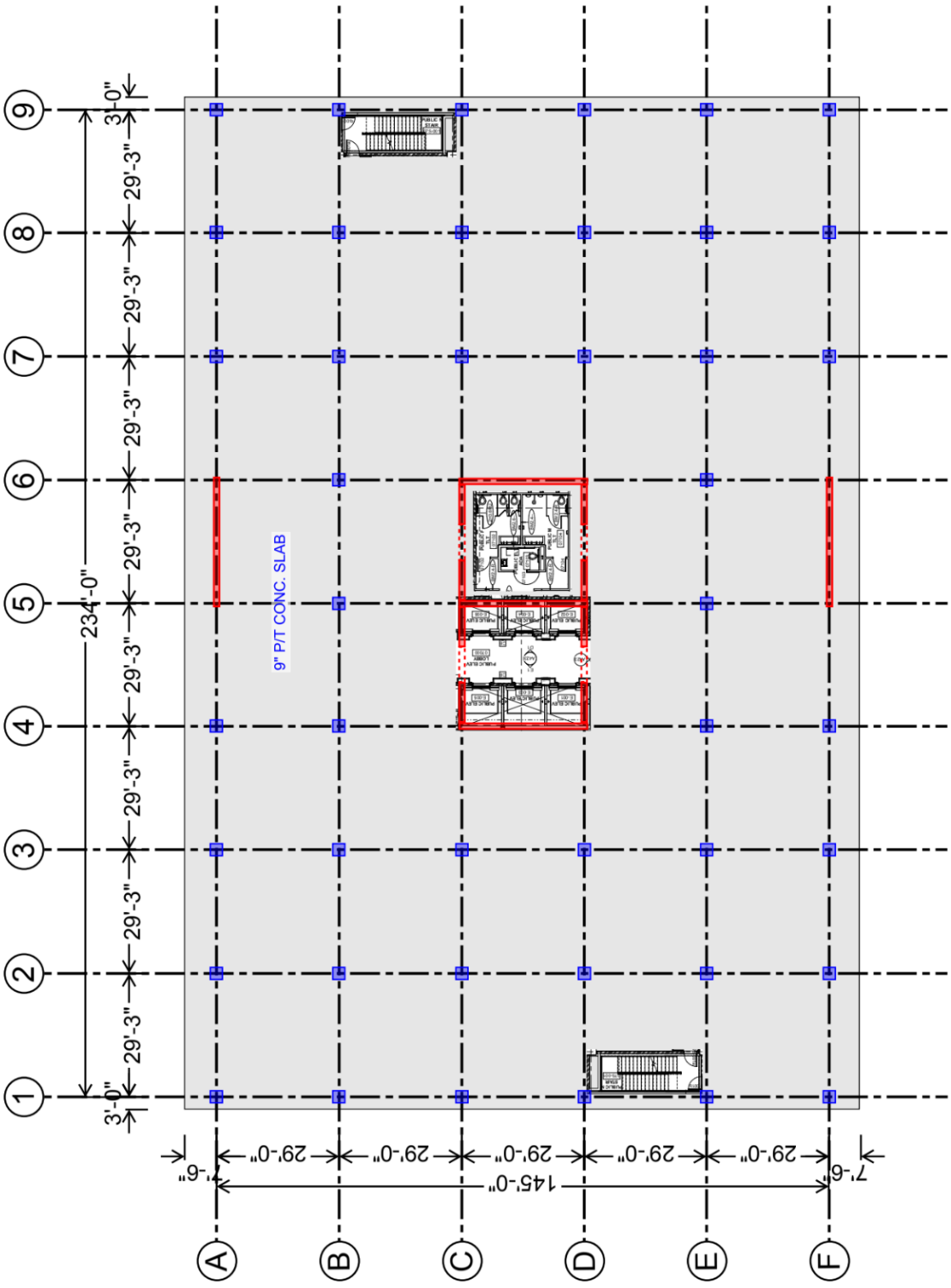

Figure B-2.10: Large office, concrete: Roof plan

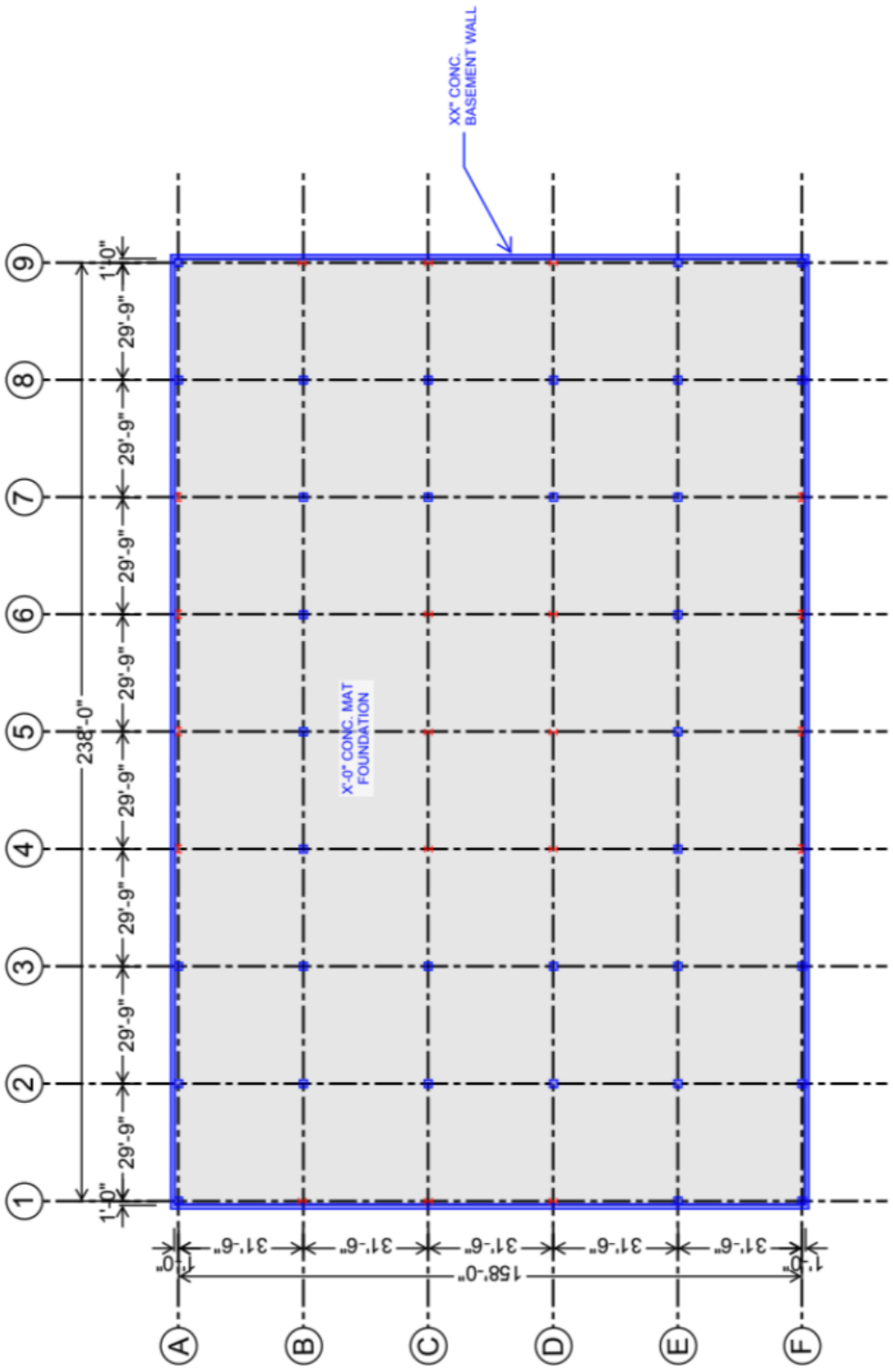

Figure B-2.11: Large office, steel: Foundation and basement plan

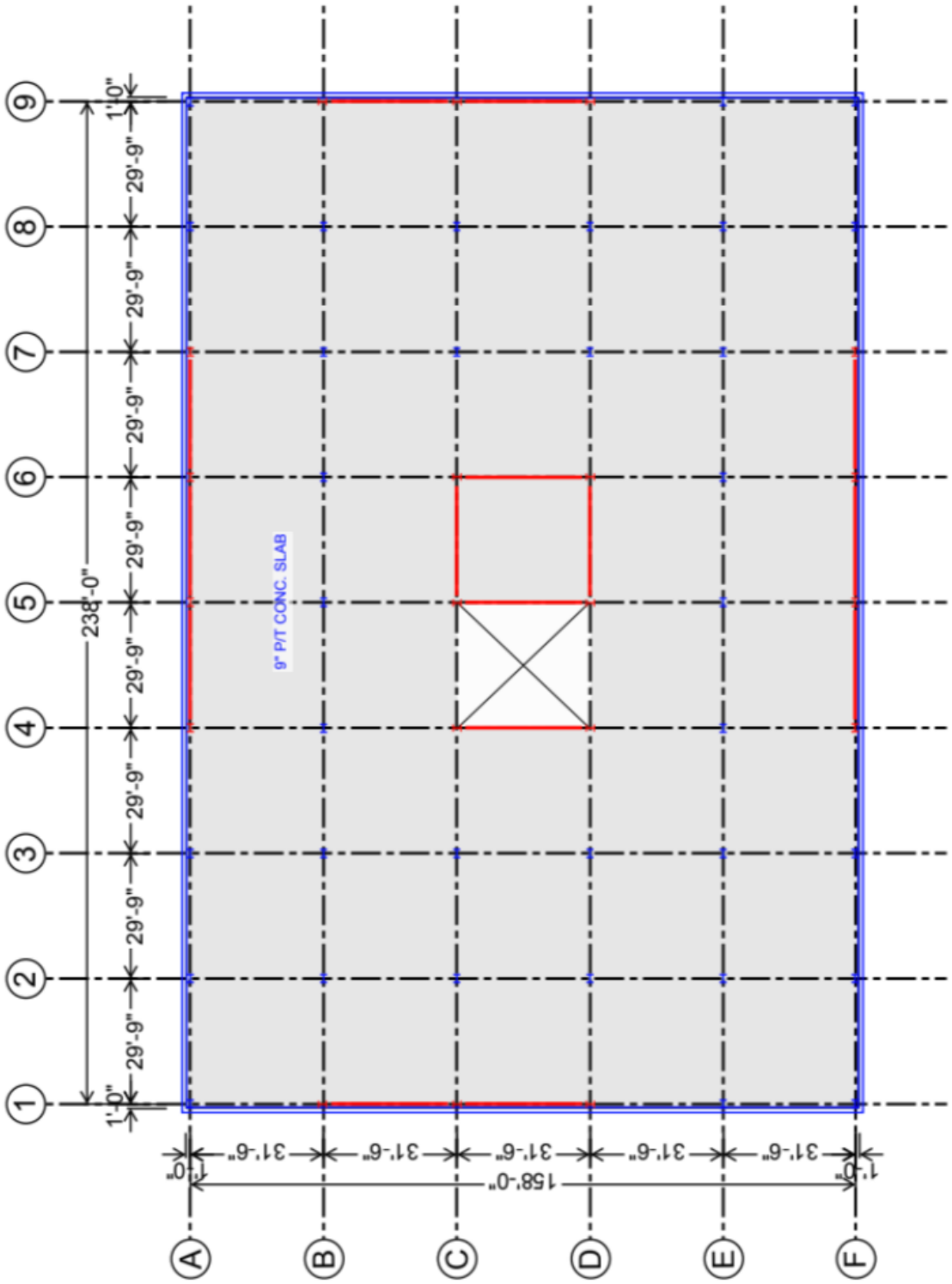

Figure B-2.12: Large office, steel: Level 1 plan

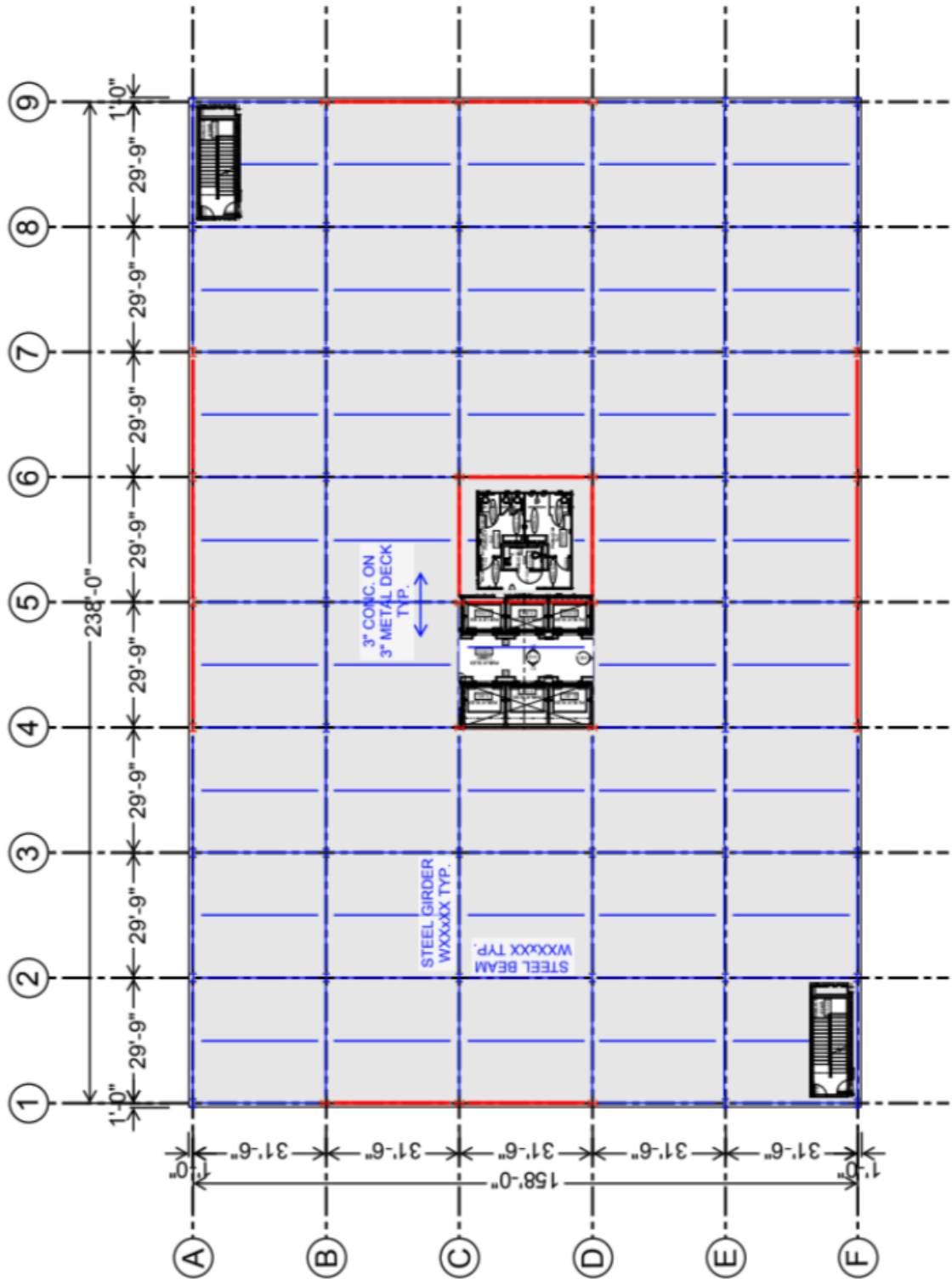

Figure B-2.13: Large office, steel: Level 2-12 plan

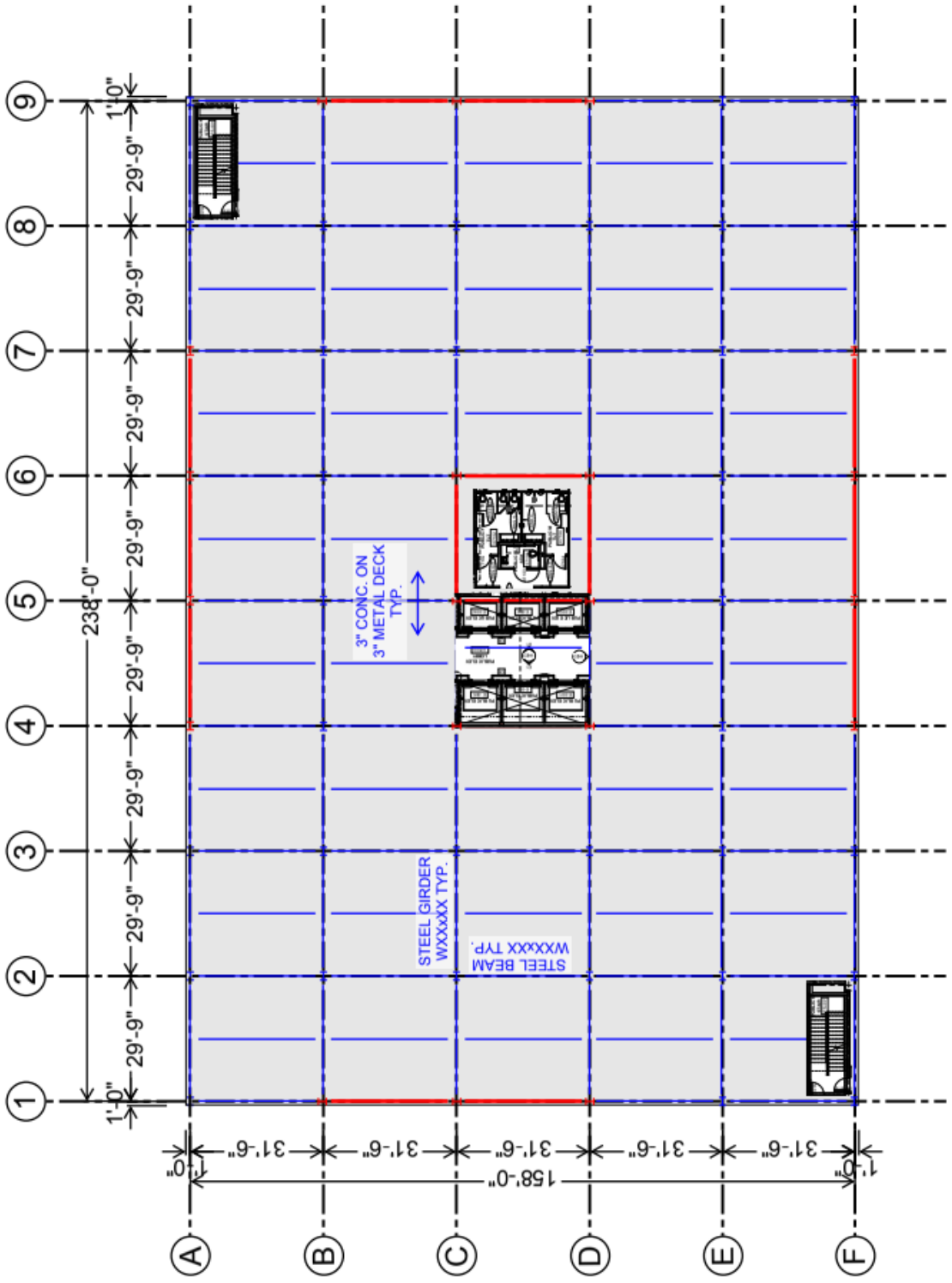

Figure B-2.14: Large office, steel: Roof plan

Appendix B-3 ETABS Output Reports for steel and concrete designs

All output reports from ETABS v22.1.0, extracted October 21, 2024

Appendix B-3.1: Medium, concrete, baseline

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
5000Psi	Concrete	Isotropic	f'c 5000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 3)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2	As3 ft2
C-16x16-5	5000Psi	Concrete Rectangular	Blue	1.7778	0.445267	0.263374	0.263374	0	1.4815	1.4815

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 3)

Name	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft
C-16x16-5	0.395062	0.395062	0.395062	0.395062	0.592593	0.592593	0.3849	0.3849	0	0	0	0

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 3)

Name	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
C-16x16-5			1	1	1	1	0.01	0.01	1	1

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static

3.3 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	

Name	Type	Is Auto	Load Name	SF	Notes
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	
DCmpS3			LLred	1.6	
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	
DConS2			SDL	1.2	
DConS2			LLred	1.6	
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	

Name	Type	Is Auto	Load Name	SF	Notes
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	
UDWalS6			Snow	0.5	
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	
UDWalS17			LLred	1	
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
5000Psi	Concrete	Isotropic	f'c 5000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Shell Sections

Table 2.2 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-5	Wall	Shell-Thin	5000Psi	1		

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=115 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1]

$Kz=2.01(<z>/<zg>)^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ $<z_g>$

$Kz=2.01(<15>/<zg>)^{<<2>/<\alpha>>}$ for z < 15ft $z_{g=1200}$

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] $<qz>=0.00256<Kz><Kzt><Kd><V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] $p=qG<Cp,wind>+<qh><(G<C_{p,lee>)>}$

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	
DCmpS3			LLred	1.6	
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	
DConS2			SDL	1.2	
DConS2			LLred	1.6	

Name	Type	Is Auto	Load Name	SF	Notes
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
DConS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DConS6			Live	1	
DConS6			Snow	0.5	
DConS6			SDL	1.2	
DConS6			LLred	1	
DConS6			Wind	1	
DConS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DConS7			Live	1	
DConS7			Snow	0.5	
DConS7			SDL	1.2	
DConS7			LLred	1	
DConS7			Wind	-1	
DConS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DConS8			Live	1	
DConS8			LLroof	0.5	
DConS8			SDL	1.2	
DConS8			LLred	1	
DConS8			Wind	1	
DConS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DConS9			Live	1	
DConS9			LLroof	0.5	
DConS9			SDL	1.2	
DConS9			LLred	1	
DConS9			Wind	-1	
DConS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DConS10			Snow	1.6	
DConS10			SDL	1.2	
DConS10			Wind	0.5	
DConS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DConS11			Snow	1.6	
DConS11			SDL	1.2	
DConS11			Wind	-0.5	
DConS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DConS12			LLroof	1.6	
DConS12			SDL	1.2	
DConS12			Wind	0.5	
DConS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]
DConS13			LLroof	1.6	
DConS13			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
DConS13			Wind	-0.5	
DConS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DConS14			SDL	0.9	
DConS14			Wind	1	
DConS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DConS15			SDL	0.9	
DConS15			Wind	-1	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS6			Snow	0.5	
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS6			Wind	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS7			Wind	-1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS8			Wind	1	
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS9			Wind	-1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS10			Wind	0.5	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS11			Wind	-0.5	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS12			Wind	0.5	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS13			Wind	-0.5	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS14			Wind	1	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS15			Wind	-1	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	
UDWalS17			LLred	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
5000Psi	Concrete	Isotropic	f'c 5000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Shell Sections

Table 2.2 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-5	Wall	Shell-Thin	5000Psi	1		

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=141 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1]

$Kz=2.01(<z>/<zg>)^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ $<z_g>$

$Kz=2.01(<15>/<zg>)^{<<2>/<\alpha>>}$ for z < 15ft $z_{g=1200}$

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] $<qz>=0.00256<Kz><Kzt><Kd><V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] $p=qG<Cp,wind>+<qh><(G<C_{p,lee>)>}$

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	
DCmpS3			LLred	1.6	
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	
DConS2			SDL	1.2	
DConS2			LLred	1.6	

Name	Type	Is Auto	Load Name	SF	Notes
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
DConS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DConS6			Live	1	
DConS6			Snow	0.5	
DConS6			SDL	1.2	
DConS6			LLred	1	
DConS6			Wind	1	
DConS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DConS7			Live	1	
DConS7			Snow	0.5	
DConS7			SDL	1.2	
DConS7			LLred	1	
DConS7			Wind	-1	
DConS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DConS8			Live	1	
DConS8			LLroof	0.5	
DConS8			SDL	1.2	
DConS8			LLred	1	
DConS8			Wind	1	
DConS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DConS9			Live	1	
DConS9			LLroof	0.5	
DConS9			SDL	1.2	
DConS9			LLred	1	
DConS9			Wind	-1	
DConS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DConS10			Snow	1.6	
DConS10			SDL	1.2	
DConS10			Wind	0.5	
DConS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DConS11			Snow	1.6	
DConS11			SDL	1.2	
DConS11			Wind	-0.5	
DConS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DConS12			LLroof	1.6	
DConS12			SDL	1.2	
DConS12			Wind	0.5	
DConS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]
DConS13			LLroof	1.6	
DConS13			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
DConS13			Wind	-0.5	
DConS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DConS14			SDL	0.9	
DConS14			Wind	1	
DConS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DConS15			SDL	0.9	
DConS15			Wind	-1	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS6			Snow	0.5	
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS6			Wind	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS7			Wind	-1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS8			Wind	1	
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS9			Wind	-1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS10			Wind	0.5	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS11			Wind	-0.5	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS12			Wind	0.5	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS13			Wind	-0.5	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS14			Wind	1	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS15			Wind	-1	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	
UDWalS17			LLred	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
5000Psi	Concrete	Isotropic	f'c 5000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Shell Sections

Table 2.2 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-5	Wall	Shell-Thin	5000Psi	1		

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQx(1/3)	Yes	Seismic	0	ASCE 7-16
EQx(2/3)	Yes	Seismic	0	ASCE 7-16
EQx(3/3)	Yes	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
EQy(1/3)	Yes	Seismic	0	ASCE 7-16
EQy(2/3)	Yes	Seismic	0	ASCE 7-16
EQy(3/3)	Yes	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=1 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1]

Kz=2.01(<z>/<zg>)$^{<<2>/<α>>}$ for 15ft ≤ z ≤ <z_g>

Kz=2.01(<15>/<zg>)$^{<<2>/<α>>}$ for z < 15ft $z_{g=1200}$

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] <qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n $C_{t=0.02ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1] R=5

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2] $S_{s=0.37g}$

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1] SMS=<Fa><$S_{S>}$ $S_{MS=0.55648g}$

MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.2618g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.370987g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.174533g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n — $C_{t=0.02ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1] — R=5

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2] — $S_{s=0.37g}$

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.55648g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.2618g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.370987g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.174533g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
DCmpS3			LLred	1.6	
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	
DConS2			SDL	1.2	
DConS2			LLred	1.6	
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
DConS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DConS6			Live	1	
DConS6			Snow	0.5	
DConS6			SDL	1.2	
DConS6			LLred	1	
DConS6			Wind	1	
DConS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DConS7			Live	1	
DConS7			Snow	0.5	
DConS7			SDL	1.2	
DConS7			LLred	1	
DConS7			Wind	-1	
DConS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DConS8			Live	1	
DConS8			LLroof	0.5	
DConS8			SDL	1.2	
DConS8			LLred	1	
DConS8			Wind	1	
DConS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DConS9			Live	1	
DConS9			LLroof	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
DConS9			SDL	1.2	
DConS9			LLred	1	
DConS9			Wind	-1	
DConS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DConS10			Snow	1.6	
DConS10			SDL	1.2	
DConS10			Wind	0.5	
DConS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DConS11			Snow	1.6	
DConS11			SDL	1.2	
DConS11			Wind	-0.5	
DConS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DConS12			LLroof	1.6	
DConS12			SDL	1.2	
DConS12			Wind	0.5	
DConS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]
DConS13			LLroof	1.6	
DConS13			SDL	1.2	
DConS13			Wind	-0.5	
DConS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DConS14			SDL	0.9	
DConS14			Wind	1	
DConS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DConS15			SDL	0.9	
DConS15			Wind	-1	
DConS16	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS16			Live	1	
DConS16			Snow	0.2	
DConS16			SDL	1.3	
DConS16			LLred	1	
DConS16			EQx	1	
DConS17	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS17			Live	1	
DConS17			Snow	0.2	
DConS17			SDL	1.3	
DConS17			LLred	1	
DConS17			EQx	-1	
DConS18	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS18			Live	1	
DConS18			Snow	0.2	
DConS18			SDL	1.3	
DConS18			LLred	1	
DConS18			EQy	1	
DConS19	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS19			Live	1	
DConS19			Snow	0.2	
DConS19			SDL	1.3	
DConS19			LLred	1	
DConS19			EQy	-1	
DConS20	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS20			SDL	0.8	
DConS20			EQx	1	
DConS21	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS21			SDL	0.8	

Name	Type	Is Auto	Load Name	SF	Notes
DConS21			EQx	-1	
DConS22	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS22			SDL	0.8	
DConS22			EQy	1	
DConS23	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS23			SDL	0.8	
DConS23			EQy	-1	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS6			Snow	0.5	
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS6			Wind	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS7			Wind	-1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS8			Wind	1	
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS9			Wind	-1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS10			Wind	0.5	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS11			Wind	-0.5	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS12			Wind	0.5	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS13			Wind	-0.5	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS14			Wind	1	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS15			Wind	-1	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS16			EQx	1	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS17			LLred	1	
UDWalS17			EQx	-1	
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS18			EQy	1	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS19			EQy	-1	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	
UDWalS20			EQx	1	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS21			EQx	-1	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS22			EQy	1	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	
UDWalS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
5000Psi	Concrete	Isotropic	f'c 5000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Shell Sections

Table 2.2 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-5	Wall	Shell-Thin	5000Psi	1		

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQx(1/3)	Yes	Seismic	0	ASCE 7-16
EQx(2/3)	Yes	Seismic	0	ASCE 7-16
EQx(3/3)	Yes	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
EQy(1/3)	Yes	Seismic	0	ASCE 7-16
EQy(2/3)	Yes	Seismic	0	ASCE 7-16
EQy(3/3)	Yes	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=103 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1]

$Kz=2.01(<z>/<zg>)^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ $<z_g>$

$Kz=2.01(<15>/<zg>)^{<<2>/<\alpha>>}$ for z < 15ft $z_{g=1200}$

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] $<qz>=0.00256<Kz><Kzt><Kd><V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] $p=qG<Cp,wind>+<qh><(G<C_{p,lee>)>}$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.02ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]	R=6
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]	
Importance Factor, I [ASCE Table 1.5-2]	

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]	
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]	$S_{s=1.491g}$
Site Class [ASCE Table 20.3-1] = D - Stiff Soil	
Site Coefficient, F_a [ASCE Table 11.4-1]	
Site Coefficient, F_v [ASCE Table 11.4-2]	

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$

MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n — $C_{t=0.02ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1] — R=6

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2] — $S_{s=1.491g}$

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	
DCmpS3			LLred	1.6	

Name	Type	Is Auto	Load Name	SF	Notes
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	
DConS2			SDL	1.2	
DConS2			LLred	1.6	
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
DConS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DConS6			Live	1	
DConS6			Snow	0.5	
DConS6			SDL	1.2	
DConS6			LLred	1	
DConS6			Wind	1	
DConS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DConS7			Live	1	
DConS7			Snow	0.5	
DConS7			SDL	1.2	
DConS7			LLred	1	
DConS7			Wind	-1	
DConS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DConS8			Live	1	
DConS8			LLroof	0.5	
DConS8			SDL	1.2	
DConS8			LLred	1	
DConS8			Wind	1	
DConS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DConS9			Live	1	
DConS9			LLroof	0.5	
DConS9			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
DConS9			LLred	1	
DConS9			Wind	-1	
DConS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DConS10			Snow	1.6	
DConS10			SDL	1.2	
DConS10			Wind	0.5	
DConS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DConS11			Snow	1.6	
DConS11			SDL	1.2	
DConS11			Wind	-0.5	
DConS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DConS12			LLroof	1.6	
DConS12			SDL	1.2	
DConS12			Wind	0.5	
DConS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]
DConS13			LLroof	1.6	
DConS13			SDL	1.2	
DConS13			Wind	-0.5	
DConS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DConS14			SDL	0.9	
DConS14			Wind	1	
DConS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DConS15			SDL	0.9	
DConS15			Wind	-1	
DConS16	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS16			Live	1	
DConS16			Snow	0.2	
DConS16			SDL	1.3	
DConS16			LLred	1	
DConS16			EQx	2.55	
DConS17	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS17			Live	1	
DConS17			Snow	0.2	
DConS17			SDL	1.3	
DConS17			LLred	1	
DConS17			EQx	-2.55	
DConS18	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS18			Live	1	
DConS18			Snow	0.2	
DConS18			SDL	1.3	
DConS18			LLred	1	
DConS18			EQy	2.55	
DConS19	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS19			Live	1	
DConS19			Snow	0.2	
DConS19			SDL	1.3	
DConS19			LLred	1	
DConS19			EQy	-2.55	
DConS20	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS20			SDL	0.8	
DConS20			EQx	2.55	
DConS21	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS21			SDL	0.8	
DConS21			EQx	-2.55	

Name	Type	Is Auto	Load Name	SF	Notes
DConS22	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS22			SDL	0.8	
DConS22			EQy	2.55	
DConS23	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS23			SDL	0.8	
DConS23			EQy	-2.55	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	
UDWalS6			Snow	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS6			Wind	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS7			Wind	-1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS8			Wind	1	
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS9			Wind	-1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS10			Wind	0.5	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS11			Wind	-0.5	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS12			Wind	0.5	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS13			Wind	-0.5	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS14			Wind	1	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS15			Wind	-1	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS16			EQx	2.55	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	
UDWalS17			LLred	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS17			EQx	-2.55	
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS18			EQy	2.55	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS19			EQy	-2.55	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	
UDWalS20			EQx	2.55	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS21			EQx	-2.55	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS22			EQy	2.55	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	
UDWalS23			EQy	-2.55	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 3)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2	As3 ft2	S33Pos ft3
W16X26	A992Fy50	Steel I/Wide Flange	Green	0.0533	1.3E-05	0.014516	0.000462	0	0.0273	0.022	0.02219
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0492	1.7E-05	0.003988	0.000883	0	0.0135	0.0301	0.01207
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	0.0715	3.7E-05	0.006125	0.002054	0	0.0175	0.0459	0.018102
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	0.0979	9.5E-05	0.008873	0.002937	0	0.0236	0.0643	0.025054

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 3)

Name	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft
W16X26	0.02219	0.002018	0.002018	0.025579	0.003171	0.5217	0.09312	0.000189	0.0335	0	0	0
W8X24	0.01207	0.003259	0.003259	0.013368	0.004959	0.28481	0.13398	8.7E-05	0.03283	0	0	0
W8X35	0.018102	0.006148	0.006148	0.020081	0.009317	0.29262	0.16947	0.000207	0.03283	0	0	0
W8X48	0.025054	0.008691	0.008691	0.028356	0.013252	0.30104	0.17319	0.000311	0.03292	0	0	0

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 3)

Name	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W16X26	0			1	1	1	1	1	1	1	1
W8X24	0			1	1	1	1	1	1	1	1
W8X35	0			1	1	1	1	1	1	1	1
W8X48	0			1	1	1	1	1	1	1	1

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031

Name	Diameter ft	Area ft2
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=115 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1]

Kz=2.01(<z>/<zg>)$^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ $<z_g>$

Kz=2.01(<15>/<zg>)$^{<<2>/<\alpha>>}$ for z < 15ft $z_{g=1200}$

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] <qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]		
Coefficient, x [ASCE Table 12.8-2]		
Structure Height Above Base, h_n		$C_{t=0.028ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]		

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]		
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]		R=6
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]		
Importance Factor, I [ASCE Table 1.5-2]		

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		$S_{s=1.03g}$
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.12064g}$

MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.6664g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.747093g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.444267g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n — $C_{t=0.028ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1] — R=6

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2] — $S_{s=1.03g}$

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.12064g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.6664g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.747093g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.444267g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	
UDStlS6			LLred	1	
UDStlS6			Wind	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS7			Wind	-1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS8			LLred	1	
UDStlS8			Wind	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS9			Wind	-1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS10			Wind	0.5	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	
UDStlS11			Wind	-0.5	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS12			Wind	0.5	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS13			Wind	-0.5	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS14			Wind	1	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS15			Wind	-1	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS16			EQx	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS17			EQx	-1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS18			EQy	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS19			EQy	-1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	
UDStlS20			EQx	1	
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS21			EQx	-1	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS22			EQy	1	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	
UDStlS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 4)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
ASColPn$_{T4\text{-}1}$		Auto Select							
W10X100	A992Fy50	Steel I/Wide Flange	Green	0.2035	0.000526	0.030044	0.009983	0	0.0524
W10X112	A992Fy50	Steel I/Wide Flange	Cyan	0.2285	0.000728	0.034529	0.011381	0	0.0598
W10X12	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0246	3E-06	0.002595	0.000105	0	0.013
W10X15	A992Fy50	Steel I/Wide Flange	Blue	0.0306	5E-06	0.003323	0.000139	0	0.016
W10X17	A992Fy50	Steel I/Wide Flange	Green	0.0347	8E-06	0.00395	0.000172	0	0.0168
W10X19	A992Fy50	Steel I/Wide Flange	Cyan	0.039	1.1E-05	0.004644	0.000207	0	0.0177
W10X22	A992Fy50	Steel I/Wide Flange	Red	0.0451	1.2E-05	0.005691	0.00055	0	0.017
W10X26	A992Fy50	Steel I/Wide Flange	Magenta	0.0528	1.9E-05	0.006944	0.00068	0	0.0186
W10X30	A992Fy50	Steel I/Wide Flange	Yellow	0.0614	3E-05	0.008198	0.000805	0	0.0219
W10X33	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0674	2.8E-05	0.008247	0.001765	0	0.0196
W10X39	A992Fy50	Steel I/Wide Flange	Blue	0.0799	4.7E-05	0.010079	0.00217	0	0.0217
W10X45	A992Fy50	Steel I/Wide Flange	Green	0.0924	7.3E-05	0.01196	0.002575	0	0.0245
W10X49	A992Fy50	Steel I/Wide Flange	Cyan	0.1	6.7E-05	0.013117	0.004504	0	0.0236
W10X54	A992Fy50	Steel I/Wide Flange	Red	0.1097	8.8E-05	0.014612	0.004967	0	0.026
W10X60	A992Fy50	Steel I/Wide Flange	Magenta	0.1229	0.00012	0.016445	0.005594	0	0.0298
W10X68	A992Fy50	Steel I/Wide Flange	Yellow	0.1382	0.000172	0.019001	0.006462	0	0.0339
W10X77	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1576	0.000246	0.021943	0.007427	0	0.039
W10X88	A992Fy50	Steel I/Wide Flange	Blue	0.1806	0.000363	0.025752	0.008632	0	0.0454
W12X106	A992Fy50	Steel I/Wide Flange	Yellow	0.2167	0.00044	0.044994	0.014516	0	0.0546
W12X120	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.2444	0.000622	0.051601	0.016638	0	0.0646
W12X136	A992Fy50	Steel I/Wide Flange	Blue	0.2771	0.000892	0.059799	0.019194	0	0.0735
W12X14	A992Fy50	Steel I/Wide Flange	Cyan	0.0289	3E-06	0.004273	0.000114	0	0.0165
W12X152	A992Fy50	Steel I/Wide Flange	Blue	0.3104	0.001244	0.068962	0.021894	0	0.0828
W12X16	A992Fy50	Steel I/Wide Flange	Red	0.0327	5E-06	0.004967	0.000136	0	0.0183
W12X170	A992Fy50	Steel I/Wide Flange	Green	0.3472	0.001717	0.079572	0.024932	0	0.0933
W12X19	A992Fy50	Steel I/Wide Flange	Magenta	0.0387	9E-06	0.006269	0.000181	0	0.0199
W12X190	A992Fy50	Steel I/Wide Flange	Cyan	0.3889	0.002353	0.091146	0.028405	0	0.106
W12X210	A992Fy50	Steel I/Wide Flange	Red	0.4292	0.00312	0.103202	0.032022	0	0.1205
W12X22	A992Fy50	Steel I/Wide Flange	Yellow	0.045	1.4E-05	0.007523	0.000225	0	0.0222
W12X230	A992Fy50	Steel I/Wide Flange	Magenta	0.4701	0.004041	0.116705	0.035783	0	0.1353
W12X252	A992Fy50	Steel I/Wide Flange	Yellow	0.5146	0.005208	0.131173	0.039931	0	0.1497
W12X26	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0531	1.4E-05	0.009838	0.000834	0	0.0195
W12X279	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.5688	0.006896	0.149981	0.045187	0	0.1689
W12X30	A992Fy50	Steel I/Wide Flange	Blue	0.061	2.2E-05	0.011478	0.000979	0	0.0222

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W12X305	A992Fy50	Steel I/Wide Flange	Blue	0.6215	0.008922	0.1712	0.050637	0	0.1845
W12X336	A992Fy50	Steel I/Wide Flange	Green	0.6868	0.011719	0.195795	0.057388	0	0.2077
W12X35	A992Fy50	Steel I/Wide Flange	Green	0.0715	3.6E-05	0.013744	0.001182	0	0.026
W12X40	A992Fy50	Steel I/Wide Flange	Cyan	0.0813	4.4E-05	0.014805	0.002127	0	0.0244
W12X45	A992Fy50	Steel I/Wide Flange	Red	0.091	6.1E-05	0.016782	0.002411	0	0.0281
W12X50	A992Fy50	Steel I/Wide Flange	Magenta	0.1014	8.2E-05	0.018856	0.002715	0	0.0313
W12X53	A992Fy50	Steel I/Wide Flange	Yellow	0.1083	7.6E-05	0.020496	0.00462	0	0.029
W12X58	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1181	0.000101	0.022907	0.00516	0	0.0305
W12X65	A992Fy50	Steel I/Wide Flange	Blue	0.1326	0.000105	0.025704	0.008391	0	0.0328
W12X72	A992Fy50	Steel I/Wide Flange	Green	0.1465	0.000141	0.028791	0.009404	0	0.0367
W12X79	A992Fy50	Steel I/Wide Flange	Cyan	0.1611	0.000185	0.031925	0.010417	0	0.0405
W12X87	A992Fy50	Steel I/Wide Flange	Red	0.1778	0.000246	0.035687	0.011622	0	0.0447
W12X96	A992Fy50	Steel I/Wide Flange	Magenta	0.1958	0.00033	0.040172	0.013021	0	0.0485
W14X109	A992Fy50	Steel I/Wide Flange	Green	0.2222	0.000343	0.059799	0.021557	0	0.0521
W14X120	A992Fy50	Steel I/Wide Flange	Cyan	0.2451	0.000452	0.066551	0.023872	0	0.0594
W14X132	A992Fy50	Steel I/Wide Flange	Red	0.2694	0.000593	0.073785	0.026427	0	0.0658
W14X145	A992Fy50	Steel I/Wide Flange	Magenta	0.2965	0.000733	0.082465	0.032649	0	0.0699
W14X159	A992Fy50	Steel I/Wide Flange	Yellow	0.3243	0.00095	0.091628	0.036073	0	0.0776
W14X176	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.3597	0.001278	0.103202	0.040413	0	0.0876
W14X193	A992Fy50	Steel I/Wide Flange	Blue	0.3944	0.001678	0.115741	0.044898	0	0.0958
W14X211	A992Fy50	Steel I/Wide Flange	Green	0.4306	0.002151	0.128279	0.049672	0	0.1068
W14X22	A992Fy50	Steel I/Wide Flange	Cyan	0.0451	1E-05	0.009597	0.000338	0	0.0219
W14X233	A992Fy50	Steel I/Wide Flange	Cyan	0.4757	0.002869	0.145158	0.055459	0	0.1189
W14X257	A992Fy50	Steel I/Wide Flange	Red	0.525	0.003815	0.163966	0.062211	0	0.1344
W14X26	A992Fy50	Steel I/Wide Flange	Red	0.0534	1.7E-05	0.011815	0.00043	0	0.0246
W14X283	A992Fy50	Steel I/Wide Flange	Magenta	0.5785	0.005015	0.185185	0.069444	0	0.1496
W14X30	A992Fy50	Steel I/Wide Flange	Magenta	0.0615	1.8E-05	0.014034	0.000945	0	0.0259
W14X311	A992Fy50	Steel I/Wide Flange	Yellow	0.6347	0.006559	0.208816	0.077643	0	0.1674
W14X34	A992Fy50	Steel I/Wide Flange	Yellow	0.0694	2.7E-05	0.016397	0.001124	0	0.0277
W14X342	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.7014	0.008584	0.236304	0.087288	0	0.1872
W14X370	A992Fy50	Steel I/Wide Flange	Blue	0.7569	0.010706	0.262346	0.095968	0	0.2063
W14X38	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0778	3.8E-05	0.018567	0.001288	0	0.0304
W14X398	A992Fy50	Steel I/Wide Flange	Green	0.8125	0.013166	0.289352	0.104649	0	0.2249
W14X426	A992Fy50	Steel I/Wide Flange	Cyan	0.8681	0.015963	0.318287	0.113812	0	0.2441
W14X43	A992Fy50	Steel I/Wide Flange	Blue	0.0875	5.1E-05	0.02064	0.00218	0	0.029
W14X455	A992Fy50	Steel I/Wide Flange	Red	0.9306	0.019049	0.34674	0.123457	0	0.2665
W14X48	A992Fy50	Steel I/Wide Flange	Green	0.0979	7E-05	0.023341	0.002479	0	0.0326
W14X500	A992Fy50	Steel I/Wide Flange	Red	1.0208	0.024788	0.39593	0.138889	0	0.2981
W14X53	A992Fy50	Steel I/Wide Flange	Cyan	0.1083	9.4E-05	0.02609	0.002783	0	0.0357
W14X550	A992Fy50	Steel I/Wide Flange	Magenta	1.125	0.032263	0.454765	0.156732	0	0.3339
W14X605	A992Fy50	Steel I/Wide Flange	Yellow	1.2361	0.041908	0.520833	0.177469	0	0.3774
W14X61	A992Fy50	Steel I/Wide Flange	Red	0.1243	0.000106	0.030864	0.00516	0	0.0362
W14X665	A992Fy50	Steel I/Wide Flange	Gray8Dark	1.3611	0.054012	0.597994	0.2011	0	0.4245
W14X68	A992Fy50	Steel I/Wide Flange	Magenta	0.1389	0.000145	0.034819	0.005835	0	0.0403
W14X730	A992Fy50	Steel I/Wide Flange	Blue	1.4931	0.069927	0.689622	0.227623	0	0.4776
W14X74	A992Fy50	Steel I/Wide Flange	Yellow	0.1514	0.000187	0.038339	0.006462	0	0.0444
W14X82	A992Fy50	Steel I/Wide Flange	Yellow	0.1667	0.000245	0.042486	0.007137	0	0.0506
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.184	0.000196	0.048177	0.017458	0	0.0428
W14X99	A992Fy50	Steel I/Wide Flange	Blue	0.2021	0.000259	0.05353	0.019387	0	0.0478
W8X10	A992Fy50	Steel I/Wide Flange	Green	0.0206	2E-06	0.001485	0.000101	0	0.0093
W8X13	A992Fy50	Steel I/Wide Flange	Cyan	0.0267	4E-06	0.00191	0.000132	0	0.0128
W8X15	A992Fy50	Steel I/Wide Flange	Red	0.0308	7E-06	0.002315	0.000164	0	0.0138
W8X18	A992Fy50	Steel I/Wide Flange	Magenta	0.0365	8E-06	0.002985	0.000384	0	0.013
W8X21	A992Fy50	Steel I/Wide Flange	Yellow	0.0428	1.4E-05	0.003631	0.000471	0	0.0144

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0492	1.7E-05	0.003988	0.000883	0	0.0135
W8X28	A992Fy50	Steel I/Wide Flange	Blue	0.0573	2.6E-05	0.004726	0.001046	0	0.016
W8X31	A992Fy50	Steel I/Wide Flange	Green	0.0634	2.6E-05	0.005305	0.001789	0	0.0158
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	0.0715	3.7E-05	0.006125	0.002054	0	0.0175
W8X40	A992Fy50	Steel I/Wide Flange	Red	0.0813	5.4E-05	0.007041	0.002368	0	0.0206
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	0.0979	9.5E-05	0.008873	0.002937	0	0.0236
W8X58	A992Fy50	Steel I/Wide Flange	Magenta	0.1188	0.000161	0.010995	0.003622	0	0.031
W8X67	A992Fy50	Steel I/Wide Flange	Yellow	0.1368	0.000244	0.013117	0.004273	0	0.0356

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 4)

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
ASColPn$_{T4\text{-}1}$											
W10X100	0.1335	0.064961	0.064961	0.023261	0.023261	0.075231	0.035301	0.38426	0.2215	0.001701	0.04167
W10X112	0.1505	0.072693	0.072693	0.026264	0.026264	0.085069	0.040046	0.38876	0.22319	0.002021	0.04167
W10X12	0.0096	0.006309	0.006309	0.000637	0.000637	0.007292	0.001007	0.32487	0.0654	1.7E-05	0.025
W10X15	0.0125	0.007983	0.007983	0.000836	0.000836	0.009259	0.001331	0.32939	0.06746	2.3E-05	0.025
W10X17	0.0153	0.009385	0.009385	0.001028	0.001028	0.010822	0.00162	0.33761	0.07039	2.8E-05	0.025
W10X19	0.0184	0.010927	0.010927	0.001235	0.001235	0.0125	0.001939	0.34496	0.07281	3.4E-05	0.025
W10X22	0.024	0.01339	0.01339	0.002295	0.002295	0.015046	0.00353	0.35533	0.11045	9.2E-05	0.025
W10X26	0.0294	0.016181	0.016181	0.002828	0.002828	0.018113	0.00434	0.3625	0.11343	0.000115	0.025
W10X30	0.0343	0.018739	0.018739	0.003327	0.003327	0.021181	0.005116	0.36544	0.11454	0.000139	0.025
W10X33	0.0401	0.020341	0.020341	0.005322	0.005322	0.022454	0.008102	0.34971	0.16179	0.000265	0.04167
W10X39	0.049	0.024385	0.024385	0.006519	0.006519	0.027083	0.009954	0.35526	0.16485	0.000333	0.04167
W10X45	0.0576	0.02842	0.02842	0.007706	0.007706	0.031771	0.011748	0.35985	0.16698	0.000401	0.04167
W10X49	0.0648	0.031481	0.031481	0.01081	0.01081	0.034954	0.016377	0.36218	0.21223	0.000696	0.04167
W10X54	0.0712	0.034722	0.034722	0.011921	0.011921	0.038542	0.018113	0.36493	0.21277	0.000772	0.04208
W10X60	0.0795	0.038694	0.038694	0.013293	0.013293	0.043171	0.020255	0.36577	0.21333	0.000886	0.04167
W10X68	0.09	0.043848	0.043848	0.015356	0.015356	0.049363	0.023206	0.3708	0.21624	0.001027	0.04167
W10X77	0.1027	0.049681	0.049681	0.017475	0.017475	0.056481	0.026563	0.37309	0.21705	0.00122	0.04167
W10X88	0.118	0.057227	0.057227	0.020114	0.020114	0.065394	0.030729	0.37766	0.21865	0.001453	0.04167
W12X106	0.1398	0.08371	0.08371	0.028556	0.028556	0.094907	0.043461	0.4557	0.25884	0.003558	0.05
W12X120	0.158	0.094536	0.094536	0.032464	0.032464	0.107639	0.049421	0.45945	0.26089	0.004144	0.04917
W12X136	0.1794	0.107103	0.107103	0.037149	0.037149	0.123843	0.056713	0.46456	0.26319	0.004909	0.05
W12X14	0.0103	0.008617	0.008617	0.000688	0.000688	0.010069	0.0011	0.38458	0.06277	2.7E-05	0.025
W12X152	0.2025	0.12081	0.12081	0.042037	0.042037	0.140625	0.064236	0.47134	0.26558	0.005773	0.05
W12X16	0.0122	0.009934	0.009934	0.000818	0.000818	0.011632	0.001308	0.3897	0.06448	3.2E-05	0.025
W12X170	0.2275	0.136409	0.136409	0.04749	0.04749	0.159144	0.072917	0.47871	0.26797	0.006739	0.05
W12X19	0.0162	0.012333	0.012333	0.001085	0.001085	0.014294	0.001725	0.40259	0.06847	4.4E-05	0.025
W12X190	0.2558	0.15191	0.15191	0.053678	0.053678	0.179977	0.082755	0.48412	0.27026	0.007971	0.04917
W12X210	0.2815	0.168493	0.168493	0.060041	0.060041	0.201389	0.092014	0.49038	0.27315	0.00911	0.05
W12X22	0.0198	0.014679	0.014679	0.001338	0.001338	0.016956	0.002118	0.40888	0.07067	5.5E-05	0.025
W12X230	0.3091	0.185492	0.185492	0.066573	0.066573	0.22338	0.102431	0.49823	0.27588	0.010528	0.05
W12X252	0.3385	0.204425	0.204425	0.073718	0.073718	0.247685	0.113426	0.50489	0.27856	0.011928	0.05
W12X26	0.0285	0.019353	0.019353	0.003085	0.003085	0.021528	0.004728	0.43033	0.12532	0.000203	0.025
W12X279	0.3745	0.226386	0.226386	0.082786	0.082786	0.278356	0.127315	0.51352	0.28187	0.013975	0.05
W12X30	0.0332	0.022395	0.022395	0.003604	0.003604	0.024942	0.005532	0.43362	0.12664	0.000239	0.025
W12X305	0.414	0.252073	0.252073	0.092066	0.092066	0.310764	0.141204	0.52483	0.28543	0.016063	0.04917
W12X336	0.4591	0.279707	0.279707	0.102785	0.102785	0.348958	0.158565	0.53393	0.28906	0.019036	0.04917
W12X35	0.0395	0.026389	0.026389	0.004323	0.004323	0.02963	0.006655	0.43835	0.12852	0.000294	0.025
W12X40	0.0477	0.029859	0.029859	0.006372	0.006372	0.032986	0.009722	0.42687	0.16179	0.000479	0.04208

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W12X45	0.0536	0.033287	0.033287	0.007189	0.007189	0.037153	0.010995	0.42951	0.16281	0.000556	0.04208
W12X50	0.0599	0.037094	0.037094	0.008065	0.008065	0.041609	0.012326	0.43125	0.16364	0.00063	0.04167
W12X53	0.0666	0.040653	0.040653	0.011088	0.011088	0.045081	0.01684	0.43496	0.20651	0.001066	0.05042
W12X58	0.0741	0.045063	0.045063	0.012384	0.012384	0.05	0.018808	0.4405	0.20907	0.001193	0.05
W12X65	0.084	0.050983	0.050983	0.016782	0.016782	0.056019	0.025521	0.44022	0.25152	0.001928	0.04958
W12X72	0.0931	0.056177	0.056177	0.018808	0.018808	0.0625	0.028472	0.44327	0.25333	0.002185	0.05
W12X79	0.1029	0.061791	0.061791	0.020661	0.020661	0.068866	0.031424	0.44515	0.25427	0.002472	0.04958
W12X87	0.1134	0.068519	0.068519	0.023052	0.023052	0.076389	0.034954	0.44804	0.25569	0.002736	0.05
W12X96	0.1271	0.075915	0.075915	0.025615	0.025615	0.085069	0.039063	0.45292	0.25786	0.003175	0.05
W14X109	0.1453	0.100363	0.100363	0.035436	0.035436	0.111111	0.053646	0.51875	0.31146	0.006746	0.05
W14X120	0.1599	0.110153	0.110153	0.038974	0.038974	0.122685	0.059028	0.52104	0.31206	0.007661	0.05
W14X132	0.1752	0.120465	0.120465	0.043147	0.043147	0.135417	0.065394	0.5233	0.31318	0.008532	0.05
W14X145	0.1955	0.133727	0.133727	0.050553	0.050553	0.150463	0.076968	0.52735	0.33182	0.010646	0.05
W14X159	0.2149	0.146605	0.146605	0.055496	0.055496	0.166088	0.084491	0.53154	0.33351	0.012023	0.05
W14X176	0.238	0.162951	0.162951	0.061778	0.061778	0.185185	0.094329	0.53562	0.33518	0.013648	0.05
W14X193	0.2617	0.179211	0.179211	0.068634	0.068634	0.20544	0.104167	0.54169	0.33738	0.015372	0.05
W14X211	0.2853	0.196096	0.196096	0.075451	0.075451	0.225694	0.114583	0.54584	0.33966	0.017167	0.05
W14X22	0.0194	0.016812	0.016812	0.00162	0.00162	0.019213	0.002541	0.46145	0.08655	0.000104	0.03333
W14X233	0.3165	0.217737	0.217737	0.083712	0.083712	0.252315	0.127894	0.5524	0.34145	0.019673	0.05
W14X257	0.35	0.23995	0.23995	0.093316	0.093316	0.281829	0.142361	0.55885	0.34423	0.022744	0.05
W14X26	0.0245	0.0204	0.0204	0.00205	0.00205	0.023264	0.003206	0.47037	0.0897	0.000136	0.03333
W14X283	0.3857	0.266134	0.266134	0.10352	0.10352	0.313657	0.158565	0.5658	0.34648	0.025801	0.05
W14X30	0.03	0.024406	0.024406	0.003371	0.003371	0.027373	0.005203	0.47785	0.12402	0.000295	0.03333
W14X311	0.4238	0.293074	0.293074	0.115026	0.115026	0.348958	0.175926	0.57357	0.34975	0.029527	0.05
W14X34	0.0355	0.028108	0.028108	0.003995	0.003995	0.031597	0.006134	0.48591	0.1272	0.000358	0.03333
W14X342	0.4688	0.324074	0.324074	0.127738	0.127738	0.388889	0.195602	0.58044	0.35277	0.034344	0.05
W14X370	0.508	0.351748	0.351748	0.13959	0.13959	0.425926	0.21412	0.58871	0.35607	0.038726	0.05
W14X38	0.0404	0.031603	0.031603	0.004565	0.004565	0.03559	0.007002	0.48859	0.12867	0.000412	0.03333
W14X398	0.5476	0.379478	0.379478	0.1513	0.1513	0.463542	0.232639	0.59676	0.35889	0.043424	0.04917
W14X426	0.5876	0.408497	0.408497	0.163562	0.163562	0.502894	0.251157	0.60553	0.36209	0.048452	0.04917
W14X43	0.0491	0.036158	0.036158	0.006539	0.006539	0.040278	0.010012	0.48569	0.15783	0.000657	0.04917
W14X455	0.6242	0.437987	0.437987	0.176367	0.176367	0.541667	0.270833	0.61042	0.36424	0.052954	0.05
W14X48	0.0553	0.040593	0.040593	0.007409	0.007409	0.04537	0.011343	0.48824	0.15911	0.00075	0.04958
W14X500	0.6887	0.484812	0.484812	0.196078	0.196078	0.607639	0.302083	0.62278	0.36886	0.062197	0.05
W14X53	0.0616	0.045047	0.045047	0.008286	0.008286	0.050405	0.012731	0.49074	0.16027	0.000845	0.04917
W14X550	0.7605	0.540314	0.540314	0.218696	0.218696	0.68287	0.337384	0.6358	0.37325	0.072774	0.05
W14X605	0.8378	0.598086	0.598086	0.244785	0.244785	0.763889	0.377315	0.64911	0.37891	0.085695	0.05
W14X61	0.0747	0.053291	0.053291	0.012384	0.012384	0.059028	0.018981	0.49829	0.20374	0.001581	0.04958
W14X665	0.926	0.664438	0.664438	0.272677	0.272677	0.856481	0.422454	0.66283	0.38438	0.102032	0.05
W14X68	0.0833	0.059689	0.059689	0.014005	0.014005	0.066551	0.021354	0.50069	0.20497	0.001772	0.04917
W14X730	1.0172	0.738881	0.738881	0.305193	0.305193	0.960648	0.472222	0.67962	0.39045	0.120205	0.05
W14X74	0.0918	0.064798	0.064798	0.015356	0.015356	0.072917	0.023438	0.50324	0.20661	0.002031	0.04958
W14X82	0.0999	0.071306	0.071306	0.01696	0.01696	0.08044	0.025926	0.5049	0.20694	0.002222	0.04958
W14X90	0.1192	0.082589	0.082589	0.028895	0.028895	0.090856	0.04375	0.51166	0.308	0.005335	0.05
W14X99	0.1318	0.090473	0.090473	0.031868	0.031868	0.100116	0.04838	0.51468	0.30973	0.0061	0.05
W8X10	0.0093	0.004518	0.004518	0.000614	0.000614	0.005133	0.000961	0.26881	0.07002	1E-05	0.025
W8X13	0.0118	0.005736	0.005736	0.00079	0.00079	0.006597	0.001244	0.26761	0.07026	1.4E-05	0.025
W8X15	0.0146	0.00685	0.00685	0.000983	0.000983	0.00787	0.001545	0.274	0.07303	1.7E-05	0.025
W8X18	0.0201	0.008801	0.008801	0.001757	0.001757	0.009838	0.002697	0.28587	0.10258	4.1E-05	0.025
W8X21	0.0244	0.010526	0.010526	0.002146	0.002146	0.011806	0.003293	0.29136	0.10495	5.1E-05	0.025
W8X24	0.0301	0.01207	0.01207	0.003259	0.003259	0.013368	0.004959	0.28481	0.13398	8.7E-05	0.03283
W8X28	0.0352	0.014073	0.014073	0.00384	0.00384	0.015741	0.005845	0.28721	0.13515	0.000105	0.03283
W8X31	0.0403	0.015914	0.015914	0.005367	0.005367	0.017593	0.00816	0.28925	0.16798	0.000178	0.03283

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W8X35	0.0459	0.018102	0.018102	0.006148	0.006148	0.020081	0.009317	0.29262	0.16947	0.000207	0.03283
W8X40	0.0523	0.020483	0.020483	0.007042	0.007042	0.023032	0.010706	0.29438	0.17071	0.000243	0.03283
W8X48	0.0643	0.025054	0.025054	0.008691	0.008691	0.028356	0.013252	0.30104	0.17319	0.000311	0.03292
W8X58	0.0771	0.030159	0.030159	0.010574	0.010574	0.034606	0.016146	0.30429	0.17464	0.000396	0.0325
W8X67	0.0896	0.034979	0.034979	0.012385	0.012385	0.040567	0.018924	0.30965	0.17673	0.000482	0.03292

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 4)

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
ASColPn$_{T4-1}$										
W10X100	0	0	0	0			1	1	1	1
W10X112	0	0	0	0			1	1	1	1
W10X12	0	0	0	0			1	1	1	1
W10X15	0	0	0	0			1	1	1	1
W10X17	0	0	0	0			1	1	1	1
W10X19	0	0	0	0			1	1	1	1
W10X22	0	0	0	0			1	1	1	1
W10X26	0	0	0	0			1	1	1	1
W10X30	0	0	0	0			1	1	1	1
W10X33	0	0	0	0			1	1	1	1
W10X39	0	0	0	0			1	1	1	1
W10X45	0	0	0	0			1	1	1	1
W10X49	0	0	0	0			1	1	1	1
W10X54	0	0	0	0			1	1	1	1
W10X60	0	0	0	0			1	1	1	1
W10X68	0	0	0	0			1	1	1	1
W10X77	0	0	0	0			1	1	1	1
W10X88	0	0	0	0			1	1	1	1
W12X106	0	0	0	0			1	1	1	1
W12X120	0	0	0	0			1	1	1	1
W12X136	0	0	0	0			1	1	1	1
W12X14	0	0	0	0			1	1	1	1
W12X152	0	0	0	0			1	1	1	1
W12X16	0	0	0	0			1	1	1	1
W12X170	0	0	0	0			1	1	1	1
W12X19	0	0	0	0			1	1	1	1
W12X190	0	0	0	0			1	1	1	1
W12X210	0	0	0	0			1	1	1	1
W12X22	0	0	0	0			1	1	1	1
W12X230	0	0	0	0			1	1	1	1
W12X252	0	0	0	0			1	1	1	1
W12X26	0	0	0	0			1	1	1	1
W12X279	0	0	0	0			1	1	1	1
W12X30	0	0	0	0			1	1	1	1
W12X305	0	0	0	0			1	1	1	1
W12X336	0	0	0	0			1	1	1	1
W12X35	0	0	0	0			1	1	1	1
W12X40	0	0	0	0			1	1	1	1
W12X45	0	0	0	0			1	1	1	1
W12X50	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W12X53	0	0	0	0			1	1	1	1
W12X58	0	0	0	0			1	1	1	1
W12X65	0	0	0	0			1	1	1	1
W12X72	0	0	0	0			1	1	1	1
W12X79	0	0	0	0			1	1	1	1
W12X87	0	0	0	0			1	1	1	1
W12X96	0	0	0	0			1	1	1	1
W14X109	0	0	0	0			1	1	1	1
W14X120	0	0	0	0			1	1	1	1
W14X132	0	0	0	0			1	1	1	1
W14X145	0	0	0	0			1	1	1	1
W14X159	0	0	0	0			1	1	1	1
W14X176	0	0	0	0			1	1	1	1
W14X193	0	0	0	0			1	1	1	1
W14X211	0	0	0	0			1	1	1	1
W14X22	0	0	0	0			1	1	1	1
W14X233	0	0	0	0			1	1	1	1
W14X257	0	0	0	0			1	1	1	1
W14X26	0	0	0	0			1	1	1	1
W14X283	0	0	0	0			1	1	1	1
W14X30	0	0	0	0			1	1	1	1
W14X311	0	0	0	0			1	1	1	1
W14X34	0	0	0	0			1	1	1	1
W14X342	0	0	0	0			1	1	1	1
W14X370	0	0	0	0			1	1	1	1
W14X38	0	0	0	0			1	1	1	1
W14X398	0	0	0	0			1	1	1	1
W14X426	0	0	0	0			1	1	1	1
W14X43	0	0	0	0			1	1	1	1
W14X455	0	0	0	0			1	1	1	1
W14X48	0	0	0	0			1	1	1	1
W14X500	0	0	0	0			1	1	1	1
W14X53	0	0	0	0			1	1	1	1
W14X550	0	0	0	0			1	1	1	1
W14X605	0	0	0	0			1	1	1	1
W14X61	0	0	0	0			1	1	1	1
W14X665	0	0	0	0			1	1	1	1
W14X68	0	0	0	0			1	1	1	1
W14X730	0	0	0	0			1	1	1	1
W14X74	0	0	0	0			1	1	1	1
W14X82	0	0	0	0			1	1	1	1
W14X90	0	0	0	0			1	1	1	1
W14X99	0	0	0	0			1	1	1	1
W8X10	0	0	0	0			1	1	1	1
W8X13	0	0	0	0			1	1	1	1
W8X15	0	0	0	0			1	1	1	1
W8X18	0	0	0	0			1	1	1	1
W8X21	0	0	0	0			1	1	1	1
W8X24	0	0	0	0			1	1	1	1
W8X28	0	0	0	0			1	1	1	1
W8X31	0	0	0	0			1	1	1	1
W8X35	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W8X40	0	0	0	0			1	1	1	1
W8X48	0	0	0	0			1	1	1	1
W8X58	0	0	0	0			1	1	1	1
W8X67	0	0	0	0			1	1	1	1

Table 2.2 - Frame Section Property Definitions - Summary (Part 4 of 4)

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
ASColPn$_{T4-1}$				
W10X100	1	1	1	1
W10X112	1	1	1	1
W10X12	1	1	1	1
W10X15	1	1	1	1
W10X17	1	1	1	1
W10X19	1	1	1	1
W10X22	1	1	1	1
W10X26	1	1	1	1
W10X30	1	1	1	1
W10X33	1	1	1	1
W10X39	1	1	1	1
W10X45	1	1	1	1
W10X49	1	1	1	1
W10X54	1	1	1	1
W10X60	1	1	1	1
W10X68	1	1	1	1
W10X77	1	1	1	1
W10X88	1	1	1	1
W12X106	1	1	1	1
W12X120	1	1	1	1
W12X136	1	1	1	1
W12X14	1	1	1	1
W12X152	1	1	1	1
W12X16	1	1	1	1
W12X170	1	1	1	1
W12X19	1	1	1	1
W12X190	1	1	1	1
W12X210	1	1	1	1
W12X22	1	1	1	1
W12X230	1	1	1	1
W12X252	1	1	1	1
W12X26	1	1	1	1
W12X279	1	1	1	1
W12X30	1	1	1	1
W12X305	1	1	1	1
W12X336	1	1	1	1
W12X35	1	1	1	1
W12X40	1	1	1	1
W12X45	1	1	1	1
W12X50	1	1	1	1
W12X53	1	1	1	1
W12X58	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X65	1	1	1	1
W12X72	1	1	1	1
W12X79	1	1	1	1
W12X87	1	1	1	1
W12X96	1	1	1	1
W14X109	1	1	1	1
W14X120	1	1	1	1
W14X132	1	1	1	1
W14X145	1	1	1	1
W14X159	1	1	1	1
W14X176	1	1	1	1
W14X193	1	1	1	1
W14X211	1	1	1	1
W14X22	1	1	1	1
W14X233	1	1	1	1
W14X257	1	1	1	1
W14X26	1	1	1	1
W14X283	1	1	1	1
W14X30	1	1	1	1
W14X311	1	1	1	1
W14X34	1	1	1	1
W14X342	1	1	1	1
W14X370	1	1	1	1
W14X38	1	1	1	1
W14X398	1	1	1	1
W14X426	1	1	1	1
W14X43	1	1	1	1
W14X455	1	1	1	1
W14X48	1	1	1	1
W14X500	1	1	1	1
W14X53	1	1	1	1
W14X550	1	1	1	1
W14X605	1	1	1	1
W14X61	1	1	1	1
W14X665	1	1	1	1
W14X68	1	1	1	1
W14X730	1	1	1	1
W14X74	1	1	1	1
W14X82	1	1	1	1
W14X90	1	1	1	1
W14X99	1	1	1	1
W8X10	1	1	1	1
W8X13	1	1	1	1
W8X15	1	1	1	1
W8X18	1	1	1	1
W8X21	1	1	1	1
W8X24	1	1	1	1
W8X28	1	1	1	1
W8X31	1	1	1	1
W8X35	1	1	1	1
W8X40	1	1	1	1
W8X48	1	1	1	1
W8X58	1	1	1	1
W8X67	1	1	1	1

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=115 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1]

Kz=2.01(<z>/<zg>)$^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ <z_g>

Kz=2.01(<15>/<zg>)$^{<<2>/<\alpha>>}$ for z < 15ft $z_{g=1200}$

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] <qz>=0.00256<Kz><Kzt><Kd><V^{2}>

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] p=qG<Cp,wind>+<qh><(G<$C_{p,lee}$>)>

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS6			LLred	1	
UDStlS6			Wind	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS7			Wind	-1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS8			Wind	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS9			Wind	-1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS10			Wind	0.5	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	
UDStlS11			Wind	-0.5	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS12			Wind	0.5	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS13			Wind	-0.5	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS14			Wind	1	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS15			Wind	-1	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 4)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
ASColPn$_{T4\text{-}1}$		Auto Select							
W10X100	A992Fy50	Steel I/Wide Flange	Green	0.2035	0.000526	0.030044	0.009983	0	0.0524
W10X112	A992Fy50	Steel I/Wide Flange	Cyan	0.2285	0.000728	0.034529	0.011381	0	0.0598
W10X12	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0246	3E-06	0.002595	0.000105	0	0.013
W10X15	A992Fy50	Steel I/Wide Flange	Blue	0.0306	5E-06	0.003323	0.000139	0	0.016
W10X17	A992Fy50	Steel I/Wide Flange	Green	0.0347	8E-06	0.00395	0.000172	0	0.0168
W10X19	A992Fy50	Steel I/Wide Flange	Cyan	0.039	1.1E-05	0.004644	0.000207	0	0.0177
W10X22	A992Fy50	Steel I/Wide Flange	Red	0.0451	1.2E-05	0.005691	0.00055	0	0.017
W10X26	A992Fy50	Steel I/Wide Flange	Magenta	0.0528	1.9E-05	0.006944	0.00068	0	0.0186
W10X30	A992Fy50	Steel I/Wide Flange	Yellow	0.0614	3E-05	0.008198	0.000805	0	0.0219
W10X33	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0674	2.8E-05	0.008247	0.001765	0	0.0196
W10X39	A992Fy50	Steel I/Wide Flange	Blue	0.0799	4.7E-05	0.010079	0.00217	0	0.0217
W10X45	A992Fy50	Steel I/Wide Flange	Green	0.0924	7.3E-05	0.01196	0.002575	0	0.0245
W10X49	A992Fy50	Steel I/Wide Flange	Cyan	0.1	6.7E-05	0.013117	0.004504	0	0.0236
W10X54	A992Fy50	Steel I/Wide Flange	Red	0.1097	8.8E-05	0.014612	0.004967	0	0.026
W10X60	A992Fy50	Steel I/Wide Flange	Magenta	0.1229	0.00012	0.016445	0.005594	0	0.0298
W10X68	A992Fy50	Steel I/Wide Flange	Yellow	0.1382	0.000172	0.019001	0.006462	0	0.0339
W10X77	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1576	0.000246	0.021943	0.007427	0	0.039
W10X88	A992Fy50	Steel I/Wide Flange	Blue	0.1806	0.000363	0.025752	0.008632	0	0.0454
W12X106	A992Fy50	Steel I/Wide Flange	Yellow	0.2167	0.00044	0.044994	0.014516	0	0.0546
W12X120	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.2444	0.000622	0.051601	0.016638	0	0.0646
W12X136	A992Fy50	Steel I/Wide Flange	Blue	0.2771	0.000892	0.059799	0.019194	0	0.0735
W12X14	A992Fy50	Steel I/Wide Flange	Cyan	0.0289	3E-06	0.004273	0.000114	0	0.0165
W12X152	A992Fy50	Steel I/Wide Flange	Blue	0.3104	0.001244	0.068962	0.021894	0	0.0828
W12X16	A992Fy50	Steel I/Wide Flange	Red	0.0327	5E-06	0.004967	0.000136	0	0.0183
W12X170	A992Fy50	Steel I/Wide Flange	Green	0.3472	0.001717	0.079572	0.024932	0	0.0933
W12X19	A992Fy50	Steel I/Wide Flange	Magenta	0.0387	9E-06	0.006269	0.000181	0	0.0199
W12X190	A992Fy50	Steel I/Wide Flange	Cyan	0.3889	0.002353	0.091146	0.028405	0	0.106
W12X210	A992Fy50	Steel I/Wide Flange	Red	0.4292	0.00312	0.103202	0.032022	0	0.1205
W12X22	A992Fy50	Steel I/Wide Flange	Yellow	0.045	1.4E-05	0.007523	0.000225	0	0.0222
W12X230	A992Fy50	Steel I/Wide Flange	Magenta	0.4701	0.004041	0.116705	0.035783	0	0.1353
W12X252	A992Fy50	Steel I/Wide Flange	Yellow	0.5146	0.005208	0.131173	0.039931	0	0.1497
W12X26	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0531	1.4E-05	0.009838	0.000834	0	0.0195
W12X279	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.5688	0.006896	0.149981	0.045187	0	0.1689

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W12X30	A992Fy50	Steel I/Wide Flange	Blue	0.061	2.2E-05	0.011478	0.000979	0	0.0222
W12X305	A992Fy50	Steel I/Wide Flange	Blue	0.6215	0.008922	0.1712	0.050637	0	0.1845
W12X336	A992Fy50	Steel I/Wide Flange	Green	0.6868	0.011719	0.195795	0.057388	0	0.2077
W12X35	A992Fy50	Steel I/Wide Flange	Green	0.0715	3.6E-05	0.013744	0.001182	0	0.026
W12X40	A992Fy50	Steel I/Wide Flange	Cyan	0.0813	4.4E-05	0.014805	0.002127	0	0.0244
W12X45	A992Fy50	Steel I/Wide Flange	Red	0.091	6.1E-05	0.016782	0.002411	0	0.0281
W12X50	A992Fy50	Steel I/Wide Flange	Magenta	0.1014	8.2E-05	0.018856	0.002715	0	0.0313
W12X53	A992Fy50	Steel I/Wide Flange	Yellow	0.1083	7.6E-05	0.020496	0.00462	0	0.029
W12X58	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1181	0.000101	0.022907	0.00516	0	0.0305
W12X65	A992Fy50	Steel I/Wide Flange	Blue	0.1326	0.000105	0.025704	0.008391	0	0.0328
W12X72	A992Fy50	Steel I/Wide Flange	Green	0.1465	0.000141	0.028791	0.009404	0	0.0367
W12X79	A992Fy50	Steel I/Wide Flange	Cyan	0.1611	0.000185	0.031925	0.010417	0	0.0405
W12X87	A992Fy50	Steel I/Wide Flange	Red	0.1778	0.000246	0.035687	0.011622	0	0.0447
W12X96	A992Fy50	Steel I/Wide Flange	Magenta	0.1958	0.00033	0.040172	0.013021	0	0.0485
W14X109	A992Fy50	Steel I/Wide Flange	Green	0.2222	0.000343	0.059799	0.021557	0	0.0521
W14X120	A992Fy50	Steel I/Wide Flange	Cyan	0.2451	0.000452	0.066551	0.023872	0	0.0594
W14X132	A992Fy50	Steel I/Wide Flange	Red	0.2694	0.000593	0.073785	0.026427	0	0.0658
W14X145	A992Fy50	Steel I/Wide Flange	Magenta	0.2965	0.000733	0.082465	0.032649	0	0.0699
W14X159	A992Fy50	Steel I/Wide Flange	Yellow	0.3243	0.00095	0.091628	0.036073	0	0.0776
W14X176	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.3597	0.001278	0.103202	0.040413	0	0.0876
W14X193	A992Fy50	Steel I/Wide Flange	Blue	0.3944	0.001678	0.115741	0.044898	0	0.0958
W14X211	A992Fy50	Steel I/Wide Flange	Green	0.4306	0.002151	0.128279	0.049672	0	0.1068
W14X22	A992Fy50	Steel I/Wide Flange	Cyan	0.0451	1E-05	0.009597	0.000338	0	0.0219
W14X233	A992Fy50	Steel I/Wide Flange	Cyan	0.4757	0.002869	0.145158	0.055459	0	0.1189
W14X257	A992Fy50	Steel I/Wide Flange	Red	0.525	0.003815	0.163966	0.062211	0	0.1344
W14X26	A992Fy50	Steel I/Wide Flange	Red	0.0534	1.7E-05	0.011815	0.00043	0	0.0246
W14X283	A992Fy50	Steel I/Wide Flange	Magenta	0.5785	0.005015	0.185185	0.069444	0	0.1496
W14X30	A992Fy50	Steel I/Wide Flange	Magenta	0.0615	1.8E-05	0.014034	0.000945	0	0.0259
W14X311	A992Fy50	Steel I/Wide Flange	Yellow	0.6347	0.006559	0.208816	0.077643	0	0.1674
W14X34	A992Fy50	Steel I/Wide Flange	Yellow	0.0694	2.7E-05	0.016397	0.001124	0	0.0277
W14X342	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.7014	0.008584	0.236304	0.087288	0	0.1872
W14X370	A992Fy50	Steel I/Wide Flange	Blue	0.7569	0.010706	0.262346	0.095968	0	0.2063
W14X38	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0778	3.8E-05	0.018567	0.001288	0	0.0304
W14X398	A992Fy50	Steel I/Wide Flange	Green	0.8125	0.013166	0.289352	0.104649	0	0.2249
W14X426	A992Fy50	Steel I/Wide Flange	Cyan	0.8681	0.015963	0.318287	0.113812	0	0.2441
W14X43	A992Fy50	Steel I/Wide Flange	Blue	0.0875	5.1E-05	0.02064	0.00218	0	0.029
W14X455	A992Fy50	Steel I/Wide Flange	Red	0.9306	0.019049	0.34674	0.123457	0	0.2665
W14X48	A992Fy50	Steel I/Wide Flange	Green	0.0979	7E-05	0.023341	0.002479	0	0.0326
W14X500	A992Fy50	Steel I/Wide Flange	Red	1.0208	0.024788	0.39593	0.138889	0	0.2981
W14X53	A992Fy50	Steel I/Wide Flange	Cyan	0.1083	9.4E-05	0.02609	0.002783	0	0.0357
W14X550	A992Fy50	Steel I/Wide Flange	Magenta	1.125	0.032263	0.454765	0.156732	0	0.3339
W14X605	A992Fy50	Steel I/Wide Flange	Yellow	1.2361	0.041908	0.520833	0.177469	0	0.3774
W14X61	A992Fy50	Steel I/Wide Flange	Red	0.1243	0.000106	0.030864	0.00516	0	0.0362
W14X665	A992Fy50	Steel I/Wide Flange	Gray8Dark	1.3611	0.054012	0.597994	0.2011	0	0.4245
W14X68	A992Fy50	Steel I/Wide Flange	Magenta	0.1389	0.000145	0.034819	0.005835	0	0.0403
W14X730	A992Fy50	Steel I/Wide Flange	Blue	1.4931	0.069927	0.689622	0.227623	0	0.4776
W14X74	A992Fy50	Steel I/Wide Flange	Yellow	0.1514	0.000187	0.038339	0.006462	0	0.0444
W14X82	A992Fy50	Steel I/Wide Flange	Yellow	0.1667	0.000245	0.042486	0.007137	0	0.0506
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.184	0.000196	0.048177	0.017458	0	0.0428
W14X99	A992Fy50	Steel I/Wide Flange	Blue	0.2021	0.000259	0.05353	0.019387	0	0.0478
W8X10	A992Fy50	Steel I/Wide Flange	Green	0.0206	2E-06	0.001485	0.000101	0	0.0093
W8X13	A992Fy50	Steel I/Wide Flange	Cyan	0.0267	4E-06	0.00191	0.000132	0	0.0128
W8X15	A992Fy50	Steel I/Wide Flange	Red	0.0308	7E-06	0.002315	0.000164	0	0.0138
W8X18	A992Fy50	Steel I/Wide Flange	Magenta	0.0365	8E-06	0.002985	0.000384	0	0.013

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W8X21	A992Fy50	Steel I/Wide Flange	Yellow	0.0428	1.4E-05	0.003631	0.000471	0	0.0144
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0492	1.7E-05	0.003988	0.000883	0	0.0135
W8X28	A992Fy50	Steel I/Wide Flange	Blue	0.0573	2.6E-05	0.004726	0.001046	0	0.016
W8X31	A992Fy50	Steel I/Wide Flange	Green	0.0634	2.6E-05	0.005305	0.001789	0	0.0158
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	0.0715	3.7E-05	0.006125	0.002054	0	0.0175
W8X40	A992Fy50	Steel I/Wide Flange	Red	0.0813	5.4E-05	0.007041	0.002368	0	0.0206
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	0.0979	9.5E-05	0.008873	0.002937	0	0.0236
W8X58	A992Fy50	Steel I/Wide Flange	Magenta	0.1188	0.000161	0.010995	0.003622	0	0.031
W8X67	A992Fy50	Steel I/Wide Flange	Yellow	0.1368	0.000244	0.013117	0.004273	0	0.0356

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 4)

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
$ASColPn_{T4\text{-}1}$											
W10X100	0.1335	0.064961	0.064961	0.023261	0.023261	0.075231	0.035301	0.38426	0.2215	0.001701	0.04167
W10X112	0.1505	0.072693	0.072693	0.026264	0.026264	0.085069	0.040046	0.38876	0.22319	0.002021	0.04167
W10X12	0.0096	0.006309	0.006309	0.000637	0.000637	0.007292	0.001007	0.32487	0.0654	1.7E-05	0.025
W10X15	0.0125	0.007983	0.007983	0.000836	0.000836	0.009259	0.001331	0.32939	0.06746	2.3E-05	0.025
W10X17	0.0153	0.009385	0.009385	0.001028	0.001028	0.010822	0.00162	0.33761	0.07039	2.8E-05	0.025
W10X19	0.0184	0.010927	0.010927	0.001235	0.001235	0.0125	0.001939	0.34496	0.07281	3.4E-05	0.025
W10X22	0.024	0.01339	0.01339	0.002295	0.002295	0.015046	0.00353	0.35533	0.11045	9.2E-05	0.025
W10X26	0.0294	0.016181	0.016181	0.002828	0.002828	0.018113	0.00434	0.3625	0.11343	0.000115	0.025
W10X30	0.0343	0.018739	0.018739	0.003327	0.003327	0.021181	0.005116	0.36544	0.11454	0.000139	0.025
W10X33	0.0401	0.020341	0.020341	0.005322	0.005322	0.022454	0.008102	0.34971	0.16179	0.000265	0.04167
W10X39	0.049	0.024385	0.024385	0.006519	0.006519	0.027083	0.009954	0.35526	0.16485	0.000333	0.04167
W10X45	0.0576	0.02842	0.02842	0.007706	0.007706	0.031771	0.011748	0.35985	0.16698	0.000401	0.04167
W10X49	0.0648	0.031481	0.031481	0.01081	0.01081	0.034954	0.016377	0.36218	0.21223	0.000696	0.04167
W10X54	0.0712	0.034722	0.034722	0.011921	0.011921	0.038542	0.018113	0.36493	0.21277	0.000772	0.04208
W10X60	0.0795	0.038694	0.038694	0.013293	0.013293	0.043171	0.020255	0.36577	0.21333	0.000886	0.04167
W10X68	0.09	0.043848	0.043848	0.015356	0.015356	0.049363	0.023206	0.3708	0.21624	0.001027	0.04167
W10X77	0.1027	0.049681	0.049681	0.017475	0.017475	0.056481	0.026563	0.37309	0.21705	0.00122	0.04167
W10X88	0.118	0.057227	0.057227	0.020114	0.020114	0.065394	0.030729	0.37766	0.21865	0.001453	0.04167
W12X106	0.1398	0.08371	0.08371	0.028556	0.028556	0.094907	0.043461	0.4557	0.25884	0.003558	0.05
W12X120	0.158	0.094536	0.094536	0.032464	0.032464	0.107639	0.049421	0.45945	0.26089	0.004144	0.04917
W12X136	0.1794	0.107103	0.107103	0.037149	0.037149	0.123843	0.056713	0.46456	0.26319	0.004909	0.05
W12X14	0.0103	0.008617	0.008617	0.000688	0.000688	0.010069	0.0011	0.38458	0.06277	2.7E-05	0.025
W12X152	0.2025	0.12081	0.12081	0.042037	0.042037	0.140625	0.064236	0.47134	0.26558	0.005773	0.05
W12X16	0.0122	0.009934	0.009934	0.000818	0.000818	0.011632	0.001308	0.3897	0.06448	3.2E-05	0.025
W12X170	0.2275	0.136409	0.136409	0.04749	0.04749	0.159144	0.072917	0.47871	0.26797	0.006739	0.05
W12X19	0.0162	0.012333	0.012333	0.001085	0.001085	0.014294	0.001725	0.40259	0.06847	4.4E-05	0.025
W12X190	0.2558	0.15191	0.15191	0.053678	0.053678	0.179977	0.082755	0.48412	0.27026	0.007971	0.04917
W12X210	0.2815	0.168493	0.168493	0.060041	0.060041	0.201389	0.092014	0.49038	0.27315	0.00911	0.05
W12X22	0.0198	0.014679	0.014679	0.001338	0.001338	0.016956	0.002118	0.40888	0.07067	5.5E-05	0.025
W12X230	0.3091	0.185492	0.185492	0.066573	0.066573	0.22338	0.102431	0.49823	0.27588	0.010528	0.05
W12X252	0.3385	0.204425	0.204425	0.073718	0.073718	0.247685	0.113426	0.50489	0.27856	0.011928	0.05
W12X26	0.0285	0.019353	0.019353	0.003085	0.003085	0.021528	0.004728	0.43033	0.12532	0.000203	0.025
W12X279	0.3745	0.226386	0.226386	0.082786	0.082786	0.278356	0.127315	0.51352	0.28187	0.013975	0.05
W12X30	0.0332	0.022395	0.022395	0.003604	0.003604	0.024942	0.005532	0.43362	0.12664	0.000239	0.025
W12X305	0.414	0.252073	0.252073	0.092066	0.092066	0.310764	0.141204	0.52483	0.28543	0.016063	0.04917
W12X336	0.4591	0.279707	0.279707	0.102785	0.102785	0.348958	0.158565	0.53393	0.28906	0.019036	0.04917
W12X35	0.0395	0.026389	0.026389	0.004323	0.004323	0.02963	0.006655	0.43835	0.12852	0.000294	0.025

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W12X40	0.0477	0.029859	0.029859	0.006372	0.006372	0.032986	0.009722	0.42687	0.16179	0.000479	0.04208
W12X45	0.0536	0.033287	0.033287	0.007189	0.007189	0.037153	0.010995	0.42951	0.16281	0.000556	0.04208
W12X50	0.0599	0.037094	0.037094	0.008065	0.008065	0.041609	0.012326	0.43125	0.16364	0.00063	0.04167
W12X53	0.0666	0.040653	0.040653	0.011088	0.011088	0.045081	0.01684	0.43496	0.20651	0.001066	0.05042
W12X58	0.0741	0.045063	0.045063	0.012384	0.012384	0.05	0.018808	0.4405	0.20907	0.001193	0.05
W12X65	0.084	0.050983	0.050983	0.016782	0.016782	0.056019	0.025521	0.44022	0.25152	0.001928	0.04958
W12X72	0.0931	0.056177	0.056177	0.018808	0.018808	0.0625	0.028472	0.44327	0.25333	0.002185	0.05
W12X79	0.1029	0.061791	0.061791	0.020661	0.020661	0.068866	0.031424	0.44515	0.25427	0.002472	0.04958
W12X87	0.1134	0.068519	0.068519	0.023052	0.023052	0.076389	0.034954	0.44804	0.25569	0.002736	0.05
W12X96	0.1271	0.075915	0.075915	0.025615	0.025615	0.085069	0.039063	0.45292	0.25786	0.003175	0.05
W14X109	0.1453	0.100363	0.100363	0.035436	0.035436	0.111111	0.053646	0.51875	0.31146	0.006746	0.05
W14X120	0.1599	0.110153	0.110153	0.038974	0.038974	0.122685	0.059028	0.52104	0.31206	0.007661	0.05
W14X132	0.1752	0.120465	0.120465	0.043147	0.043147	0.135417	0.065394	0.5233	0.31318	0.008532	0.05
W14X145	0.1955	0.133727	0.133727	0.050553	0.050553	0.150463	0.076968	0.52735	0.33182	0.010646	0.05
W14X159	0.2149	0.146605	0.146605	0.055496	0.055496	0.166088	0.084491	0.53154	0.33351	0.012023	0.05
W14X176	0.238	0.162951	0.162951	0.061778	0.061778	0.185185	0.094329	0.53562	0.33518	0.013648	0.05
W14X193	0.2617	0.179211	0.179211	0.068634	0.068634	0.20544	0.104167	0.54169	0.33738	0.015372	0.05
W14X211	0.2853	0.196096	0.196096	0.075451	0.075451	0.225694	0.114583	0.54584	0.33966	0.017167	0.05
W14X22	0.0194	0.016812	0.016812	0.00162	0.00162	0.019213	0.002541	0.46145	0.08655	0.000104	0.03333
W14X233	0.3165	0.217737	0.217737	0.083712	0.083712	0.252315	0.127894	0.5524	0.34145	0.019673	0.05
W14X257	0.35	0.23995	0.23995	0.093316	0.093316	0.281829	0.142361	0.55885	0.34423	0.022744	0.05
W14X26	0.0245	0.0204	0.0204	0.00205	0.00205	0.023264	0.003206	0.47037	0.0897	0.000136	0.03333
W14X283	0.3857	0.266134	0.266134	0.10352	0.10352	0.313657	0.158565	0.5658	0.34648	0.025801	0.05
W14X30	0.03	0.024406	0.024406	0.003371	0.003371	0.027373	0.005203	0.47785	0.12402	0.000295	0.03333
W14X311	0.4238	0.293074	0.293074	0.115026	0.115026	0.348958	0.175926	0.57357	0.34975	0.029527	0.05
W14X34	0.0355	0.028108	0.028108	0.003995	0.003995	0.031597	0.006134	0.48591	0.1272	0.000358	0.03333
W14X342	0.4688	0.324074	0.324074	0.127738	0.127738	0.388889	0.195602	0.58044	0.35277	0.034344	0.05
W14X370	0.508	0.351748	0.351748	0.13959	0.13959	0.425926	0.21412	0.58871	0.35607	0.038726	0.05
W14X38	0.0404	0.031603	0.031603	0.004565	0.004565	0.03559	0.007002	0.48859	0.12867	0.000412	0.03333
W14X398	0.5476	0.379478	0.379478	0.1513	0.1513	0.463542	0.232639	0.59676	0.35889	0.043424	0.04917
W14X426	0.5876	0.408497	0.408497	0.163562	0.163562	0.502894	0.251157	0.60553	0.36209	0.048452	0.04917
W14X43	0.0491	0.036158	0.036158	0.006539	0.006539	0.040278	0.010012	0.48569	0.15783	0.000657	0.04917
W14X455	0.6242	0.437987	0.437987	0.176367	0.176367	0.541667	0.270833	0.61042	0.36424	0.052954	0.05
W14X48	0.0553	0.040593	0.040593	0.007409	0.007409	0.04537	0.011343	0.48824	0.15911	0.00075	0.04958
W14X500	0.6887	0.484812	0.484812	0.196078	0.196078	0.607639	0.302083	0.62278	0.36886	0.062197	0.05
W14X53	0.0616	0.045047	0.045047	0.008286	0.008286	0.050405	0.012731	0.49074	0.16027	0.000845	0.04917
W14X550	0.7605	0.540314	0.540314	0.218696	0.218696	0.68287	0.337384	0.6358	0.37325	0.072774	0.05
W14X605	0.8378	0.598086	0.598086	0.244785	0.244785	0.763889	0.377315	0.64911	0.37891	0.085695	0.05
W14X61	0.0747	0.053291	0.053291	0.012384	0.012384	0.059028	0.018981	0.49829	0.20374	0.001581	0.04958
W14X665	0.926	0.664438	0.664438	0.272677	0.272677	0.856481	0.422454	0.66283	0.38438	0.102032	0.05
W14X68	0.0833	0.059689	0.059689	0.014005	0.014005	0.066551	0.021354	0.50069	0.20497	0.001772	0.04917
W14X730	1.0172	0.738881	0.738881	0.305193	0.305193	0.960648	0.472222	0.67962	0.39045	0.120205	0.05
W14X74	0.0918	0.064798	0.064798	0.015356	0.015356	0.072917	0.023438	0.50324	0.20661	0.002031	0.04958
W14X82	0.0999	0.071306	0.071306	0.01696	0.01696	0.08044	0.025926	0.5049	0.20694	0.002222	0.04958
W14X90	0.1192	0.082589	0.082589	0.028895	0.028895	0.090856	0.04375	0.51166	0.308	0.005335	0.05
W14X99	0.1318	0.090473	0.090473	0.031868	0.031868	0.100116	0.04838	0.51468	0.30973	0.0061	0.05
W8X10	0.0093	0.004518	0.004518	0.000614	0.000614	0.005133	0.000961	0.26881	0.07002	1E-05	0.025
W8X13	0.0118	0.005736	0.005736	0.00079	0.00079	0.006597	0.001244	0.26761	0.07026	1.4E-05	0.025
W8X15	0.0146	0.00685	0.00685	0.000983	0.000983	0.00787	0.001545	0.274	0.07303	1.7E-05	0.025
W8X18	0.0201	0.008801	0.008801	0.001757	0.001757	0.009838	0.002697	0.28587	0.10258	4.1E-05	0.025
W8X21	0.0244	0.010526	0.010526	0.002146	0.002146	0.011806	0.003293	0.29136	0.10495	5.1E-05	0.025
W8X24	0.0301	0.01207	0.01207	0.003259	0.003259	0.013368	0.004959	0.28481	0.13398	8.7E-05	0.03283
W8X28	0.0352	0.014073	0.014073	0.00384	0.00384	0.015741	0.005845	0.28721	0.13515	0.000105	0.03283

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W8X31	0.0403	0.015914	0.015914	0.005367	0.005367	0.017593	0.00816	0.28925	0.16798	0.000178	0.03283
W8X35	0.0459	0.018102	0.018102	0.006148	0.006148	0.020081	0.009317	0.29262	0.16947	0.000207	0.03283
W8X40	0.0523	0.020483	0.020483	0.007042	0.007042	0.023032	0.010706	0.29438	0.17071	0.000243	0.03283
W8X48	0.0643	0.025054	0.025054	0.008691	0.008691	0.028356	0.013252	0.30104	0.17319	0.000311	0.03292
W8X58	0.0771	0.030159	0.030159	0.010574	0.010574	0.034606	0.016146	0.30429	0.17464	0.000396	0.0325
W8X67	0.0896	0.034979	0.034979	0.012385	0.012385	0.040567	0.018924	0.30965	0.17673	0.000482	0.03292

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 4)

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
ASColPn$_{T4-1}$										
W10X100	0	0	0	0			1	1	1	1
W10X112	0	0	0	0			1	1	1	1
W10X12	0	0	0	0			1	1	1	1
W10X15	0	0	0	0			1	1	1	1
W10X17	0	0	0	0			1	1	1	1
W10X19	0	0	0	0			1	1	1	1
W10X22	0	0	0	0			1	1	1	1
W10X26	0	0	0	0			1	1	1	1
W10X30	0	0	0	0			1	1	1	1
W10X33	0	0	0	0			1	1	1	1
W10X39	0	0	0	0			1	1	1	1
W10X45	0	0	0	0			1	1	1	1
W10X49	0	0	0	0			1	1	1	1
W10X54	0	0	0	0			1	1	1	1
W10X60	0	0	0	0			1	1	1	1
W10X68	0	0	0	0			1	1	1	1
W10X77	0	0	0	0			1	1	1	1
W10X88	0	0	0	0			1	1	1	1
W12X106	0	0	0	0			1	1	1	1
W12X120	0	0	0	0			1	1	1	1
W12X136	0	0	0	0			1	1	1	1
W12X14	0	0	0	0			1	1	1	1
W12X152	0	0	0	0			1	1	1	1
W12X16	0	0	0	0			1	1	1	1
W12X170	0	0	0	0			1	1	1	1
W12X19	0	0	0	0			1	1	1	1
W12X190	0	0	0	0			1	1	1	1
W12X210	0	0	0	0			1	1	1	1
W12X22	0	0	0	0			1	1	1	1
W12X230	0	0	0	0			1	1	1	1
W12X252	0	0	0	0			1	1	1	1
W12X26	0	0	0	0			1	1	1	1
W12X279	0	0	0	0			1	1	1	1
W12X30	0	0	0	0			1	1	1	1
W12X305	0	0	0	0			1	1	1	1
W12X336	0	0	0	0			1	1	1	1
W12X35	0	0	0	0			1	1	1	1
W12X40	0	0	0	0			1	1	1	1
W12X45	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W12X50	0	0	0	0			1	1	1	1
W12X53	0	0	0	0			1	1	1	1
W12X58	0	0	0	0			1	1	1	1
W12X65	0	0	0	0			1	1	1	1
W12X72	0	0	0	0			1	1	1	1
W12X79	0	0	0	0			1	1	1	1
W12X87	0	0	0	0			1	1	1	1
W12X96	0	0	0	0			1	1	1	1
W14X109	0	0	0	0			1	1	1	1
W14X120	0	0	0	0			1	1	1	1
W14X132	0	0	0	0			1	1	1	1
W14X145	0	0	0	0			1	1	1	1
W14X159	0	0	0	0			1	1	1	1
W14X176	0	0	0	0			1	1	1	1
W14X193	0	0	0	0			1	1	1	1
W14X211	0	0	0	0			1	1	1	1
W14X22	0	0	0	0			1	1	1	1
W14X233	0	0	0	0			1	1	1	1
W14X257	0	0	0	0			1	1	1	1
W14X26	0	0	0	0			1	1	1	1
W14X283	0	0	0	0			1	1	1	1
W14X30	0	0	0	0			1	1	1	1
W14X311	0	0	0	0			1	1	1	1
W14X34	0	0	0	0			1	1	1	1
W14X342	0	0	0	0			1	1	1	1
W14X370	0	0	0	0			1	1	1	1
W14X38	0	0	0	0			1	1	1	1
W14X398	0	0	0	0			1	1	1	1
W14X426	0	0	0	0			1	1	1	1
W14X43	0	0	0	0			1	1	1	1
W14X455	0	0	0	0			1	1	1	1
W14X48	0	0	0	0			1	1	1	1
W14X500	0	0	0	0			1	1	1	1
W14X53	0	0	0	0			1	1	1	1
W14X550	0	0	0	0			1	1	1	1
W14X605	0	0	0	0			1	1	1	1
W14X61	0	0	0	0			1	1	1	1
W14X665	0	0	0	0			1	1	1	1
W14X68	0	0	0	0			1	1	1	1
W14X730	0	0	0	0			1	1	1	1
W14X74	0	0	0	0			1	1	1	1
W14X82	0	0	0	0			1	1	1	1
W14X90	0	0	0	0			1	1	1	1
W14X99	0	0	0	0			1	1	1	1
W8X10	0	0	0	0			1	1	1	1
W8X13	0	0	0	0			1	1	1	1
W8X15	0	0	0	0			1	1	1	1
W8X18	0	0	0	0			1	1	1	1
W8X21	0	0	0	0			1	1	1	1
W8X24	0	0	0	0			1	1	1	1
W8X28	0	0	0	0			1	1	1	1
W8X31	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W8X35	0	0	0	0			1	1	1	1
W8X40	0	0	0	0			1	1	1	1
W8X48	0	0	0	0			1	1	1	1
W8X58	0	0	0	0			1	1	1	1
W8X67	0	0	0	0			1	1	1	1

Table 2.2 - Frame Section Property Definitions - Summary (Part 4 of 4)

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
$ASColPn_{T4\text{-}1}$				
W10X100	1	1	1	1
W10X112	1	1	1	1
W10X12	1	1	1	1
W10X15	1	1	1	1
W10X17	1	1	1	1
W10X19	1	1	1	1
W10X22	1	1	1	1
W10X26	1	1	1	1
W10X30	1	1	1	1
W10X33	1	1	1	1
W10X39	1	1	1	1
W10X45	1	1	1	1
W10X49	1	1	1	1
W10X54	1	1	1	1
W10X60	1	1	1	1
W10X68	1	1	1	1
W10X77	1	1	1	1
W10X88	1	1	1	1
W12X106	1	1	1	1
W12X120	1	1	1	1
W12X136	1	1	1	1
W12X14	1	1	1	1
W12X152	1	1	1	1
W12X16	1	1	1	1
W12X170	1	1	1	1
W12X19	1	1	1	1
W12X190	1	1	1	1
W12X210	1	1	1	1
W12X22	1	1	1	1
W12X230	1	1	1	1
W12X252	1	1	1	1
W12X26	1	1	1	1
W12X279	1	1	1	1
W12X30	1	1	1	1
W12X305	1	1	1	1
W12X336	1	1	1	1
W12X35	1	1	1	1
W12X40	1	1	1	1
W12X45	1	1	1	1
W12X50	1	1	1	1
W12X53	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X58	1	1	1	1
W12X65	1	1	1	1
W12X72	1	1	1	1
W12X79	1	1	1	1
W12X87	1	1	1	1
W12X96	1	1	1	1
W14X109	1	1	1	1
W14X120	1	1	1	1
W14X132	1	1	1	1
W14X145	1	1	1	1
W14X159	1	1	1	1
W14X176	1	1	1	1
W14X193	1	1	1	1
W14X211	1	1	1	1
W14X22	1	1	1	1
W14X233	1	1	1	1
W14X257	1	1	1	1
W14X26	1	1	1	1
W14X283	1	1	1	1
W14X30	1	1	1	1
W14X311	1	1	1	1
W14X34	1	1	1	1
W14X342	1	1	1	1
W14X370	1	1	1	1
W14X38	1	1	1	1
W14X398	1	1	1	1
W14X426	1	1	1	1
W14X43	1	1	1	1
W14X455	1	1	1	1
W14X48	1	1	1	1
W14X500	1	1	1	1
W14X53	1	1	1	1
W14X550	1	1	1	1
W14X605	1	1	1	1
W14X61	1	1	1	1
W14X665	1	1	1	1
W14X68	1	1	1	1
W14X730	1	1	1	1
W14X74	1	1	1	1
W14X82	1	1	1	1
W14X90	1	1	1	1
W14X99	1	1	1	1
W8X10	1	1	1	1
W8X13	1	1	1	1
W8X15	1	1	1	1
W8X18	1	1	1	1
W8X21	1	1	1	1
W8X24	1	1	1	1
W8X28	1	1	1	1
W8X31	1	1	1	1
W8X35	1	1	1	1
W8X40	1	1	1	1
W8X48	1	1	1	1
W8X58	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W8X67	1	1	1	1

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=141 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1]

Kz=2.01(<z>/<zg>)$^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ <z_g>

Kz=2.01(<15>/<zg>)$^{<<2>/<\alpha>>}$ for z < 15ft $z_{g=1200}$

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] <qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] p=qG<Cp,wind>+<qh><(G<$C_{p,lee>}$)>

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS6			LLred	1	
UDStlS6			Wind	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS7			Wind	-1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS8			Wind	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS9			Wind	-1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS10			Wind	0.5	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	
UDStlS11			Wind	-0.5	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS12			Wind	0.5	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS13			Wind	-0.5	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS14			Wind	1	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS15			Wind	-1	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 4)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
ASColPn$_{T4\text{-}1}$		Auto Select							
W10X100	A992Fy50	Steel I/Wide Flange	Green	0.2035	0.000526	0.030044	0.009983	0	0.0524
W10X112	A992Fy50	Steel I/Wide Flange	Cyan	0.2285	0.000728	0.034529	0.011381	0	0.0598
W10X12	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0246	3E-06	0.002595	0.000105	0	0.013
W10X15	A992Fy50	Steel I/Wide Flange	Blue	0.0306	5E-06	0.003323	0.000139	0	0.016
W10X17	A992Fy50	Steel I/Wide Flange	Green	0.0347	8E-06	0.00395	0.000172	0	0.0168
W10X19	A992Fy50	Steel I/Wide Flange	Cyan	0.039	1.1E-05	0.004644	0.000207	0	0.0177
W10X22	A992Fy50	Steel I/Wide Flange	Red	0.0451	1.2E-05	0.005691	0.00055	0	0.017
W10X26	A992Fy50	Steel I/Wide Flange	Magenta	0.0528	1.9E-05	0.006944	0.00068	0	0.0186
W10X30	A992Fy50	Steel I/Wide Flange	Yellow	0.0614	3E-05	0.008198	0.000805	0	0.0219
W10X33	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0674	2.8E-05	0.008247	0.001765	0	0.0196
W10X39	A992Fy50	Steel I/Wide Flange	Blue	0.0799	4.7E-05	0.010079	0.00217	0	0.0217
W10X45	A992Fy50	Steel I/Wide Flange	Green	0.0924	7.3E-05	0.01196	0.002575	0	0.0245
W10X49	A992Fy50	Steel I/Wide Flange	Cyan	0.1	6.7E-05	0.013117	0.004504	0	0.0236
W10X54	A992Fy50	Steel I/Wide Flange	Red	0.1097	8.8E-05	0.014612	0.004967	0	0.026
W10X60	A992Fy50	Steel I/Wide Flange	Magenta	0.1229	0.00012	0.016445	0.005594	0	0.0298
W10X68	A992Fy50	Steel I/Wide Flange	Yellow	0.1382	0.000172	0.019001	0.006462	0	0.0339
W10X77	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1576	0.000246	0.021943	0.007427	0	0.039
W10X88	A992Fy50	Steel I/Wide Flange	Blue	0.1806	0.000363	0.025752	0.008632	0	0.0454
W12X106	A992Fy50	Steel I/Wide Flange	Yellow	0.2167	0.00044	0.044994	0.014516	0	0.0546
W12X120	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.2444	0.000622	0.051601	0.016638	0	0.0646
W12X136	A992Fy50	Steel I/Wide Flange	Blue	0.2771	0.000892	0.059799	0.019194	0	0.0735
W12X14	A992Fy50	Steel I/Wide Flange	Cyan	0.0289	3E-06	0.004273	0.000114	0	0.0165
W12X152	A992Fy50	Steel I/Wide Flange	Blue	0.3104	0.001244	0.068962	0.021894	0	0.0828
W12X16	A992Fy50	Steel I/Wide Flange	Red	0.0327	5E-06	0.004967	0.000136	0	0.0183
W12X170	A992Fy50	Steel I/Wide Flange	Green	0.3472	0.001717	0.079572	0.024932	0	0.0933
W12X19	A992Fy50	Steel I/Wide Flange	Magenta	0.0387	9E-06	0.006269	0.000181	0	0.0199
W12X190	A992Fy50	Steel I/Wide Flange	Cyan	0.3889	0.002353	0.091146	0.028405	0	0.106
W12X210	A992Fy50	Steel I/Wide Flange	Red	0.4292	0.00312	0.103202	0.032022	0	0.1205
W12X22	A992Fy50	Steel I/Wide Flange	Yellow	0.045	1.4E-05	0.007523	0.000225	0	0.0222
W12X230	A992Fy50	Steel I/Wide Flange	Magenta	0.4701	0.004041	0.116705	0.035783	0	0.1353
W12X252	A992Fy50	Steel I/Wide Flange	Yellow	0.5146	0.005208	0.131173	0.039931	0	0.1497
W12X26	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0531	1.4E-05	0.009838	0.000834	0	0.0195
W12X279	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.5688	0.006896	0.149981	0.045187	0	0.1689

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W12X30	A992Fy50	Steel I/Wide Flange	Blue	0.061	2.2E-05	0.011478	0.000979	0	0.0222
W12X305	A992Fy50	Steel I/Wide Flange	Blue	0.6215	0.008922	0.1712	0.050637	0	0.1845
W12X336	A992Fy50	Steel I/Wide Flange	Green	0.6868	0.011719	0.195795	0.057388	0	0.2077
W12X35	A992Fy50	Steel I/Wide Flange	Green	0.0715	3.6E-05	0.013744	0.001182	0	0.026
W12X40	A992Fy50	Steel I/Wide Flange	Cyan	0.0813	4.4E-05	0.014805	0.002127	0	0.0244
W12X45	A992Fy50	Steel I/Wide Flange	Red	0.091	6.1E-05	0.016782	0.002411	0	0.0281
W12X50	A992Fy50	Steel I/Wide Flange	Magenta	0.1014	8.2E-05	0.018856	0.002715	0	0.0313
W12X53	A992Fy50	Steel I/Wide Flange	Yellow	0.1083	7.6E-05	0.020496	0.00462	0	0.029
W12X58	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1181	0.000101	0.022907	0.00516	0	0.0305
W12X65	A992Fy50	Steel I/Wide Flange	Blue	0.1326	0.000105	0.025704	0.008391	0	0.0328
W12X72	A992Fy50	Steel I/Wide Flange	Green	0.1465	0.000141	0.028791	0.009404	0	0.0367
W12X79	A992Fy50	Steel I/Wide Flange	Cyan	0.1611	0.000185	0.031925	0.010417	0	0.0405
W12X87	A992Fy50	Steel I/Wide Flange	Red	0.1778	0.000246	0.035687	0.011622	0	0.0447
W12X96	A992Fy50	Steel I/Wide Flange	Magenta	0.1958	0.00033	0.040172	0.013021	0	0.0485
W14X109	A992Fy50	Steel I/Wide Flange	Green	0.2222	0.000343	0.059799	0.021557	0	0.0521
W14X120	A992Fy50	Steel I/Wide Flange	Cyan	0.2451	0.000452	0.066551	0.023872	0	0.0594
W14X132	A992Fy50	Steel I/Wide Flange	Red	0.2694	0.000593	0.073785	0.026427	0	0.0658
W14X145	A992Fy50	Steel I/Wide Flange	Magenta	0.2965	0.000733	0.082465	0.032649	0	0.0699
W14X159	A992Fy50	Steel I/Wide Flange	Yellow	0.3243	0.00095	0.091628	0.036073	0	0.0776
W14X176	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.3597	0.001278	0.103202	0.040413	0	0.0876
W14X193	A992Fy50	Steel I/Wide Flange	Blue	0.3944	0.001678	0.115741	0.044898	0	0.0958
W14X211	A992Fy50	Steel I/Wide Flange	Green	0.4306	0.002151	0.128279	0.049672	0	0.1068
W14X22	A992Fy50	Steel I/Wide Flange	Cyan	0.0451	1E-05	0.009597	0.000338	0	0.0219
W14X233	A992Fy50	Steel I/Wide Flange	Cyan	0.4757	0.002869	0.145158	0.055459	0	0.1189
W14X257	A992Fy50	Steel I/Wide Flange	Red	0.525	0.003815	0.163966	0.062211	0	0.1344
W14X26	A992Fy50	Steel I/Wide Flange	Red	0.0534	1.7E-05	0.011815	0.00043	0	0.0246
W14X283	A992Fy50	Steel I/Wide Flange	Magenta	0.5785	0.005015	0.185185	0.069444	0	0.1496
W14X30	A992Fy50	Steel I/Wide Flange	Magenta	0.0615	1.8E-05	0.014034	0.000945	0	0.0259
W14X311	A992Fy50	Steel I/Wide Flange	Yellow	0.6347	0.006559	0.208816	0.077643	0	0.1674
W14X34	A992Fy50	Steel I/Wide Flange	Yellow	0.0694	2.7E-05	0.016397	0.001124	0	0.0277
W14X342	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.7014	0.008584	0.236304	0.087288	0	0.1872
W14X370	A992Fy50	Steel I/Wide Flange	Blue	0.7569	0.010706	0.262346	0.095968	0	0.2063
W14X38	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0778	3.8E-05	0.018567	0.001288	0	0.0304
W14X398	A992Fy50	Steel I/Wide Flange	Green	0.8125	0.013166	0.289352	0.104649	0	0.2249
W14X426	A992Fy50	Steel I/Wide Flange	Cyan	0.8681	0.015963	0.318287	0.113812	0	0.2441
W14X43	A992Fy50	Steel I/Wide Flange	Blue	0.0875	5.1E-05	0.02064	0.00218	0	0.029
W14X455	A992Fy50	Steel I/Wide Flange	Red	0.9306	0.019049	0.34674	0.123457	0	0.2665
W14X48	A992Fy50	Steel I/Wide Flange	Green	0.0979	7E-05	0.023341	0.002479	0	0.0326
W14X500	A992Fy50	Steel I/Wide Flange	Red	1.0208	0.024788	0.39593	0.138889	0	0.2981
W14X53	A992Fy50	Steel I/Wide Flange	Cyan	0.1083	9.4E-05	0.02609	0.002783	0	0.0357
W14X550	A992Fy50	Steel I/Wide Flange	Magenta	1.125	0.032263	0.454765	0.156732	0	0.3339
W14X605	A992Fy50	Steel I/Wide Flange	Yellow	1.2361	0.041908	0.520833	0.177469	0	0.3774
W14X61	A992Fy50	Steel I/Wide Flange	Red	0.1243	0.000106	0.030864	0.00516	0	0.0362
W14X665	A992Fy50	Steel I/Wide Flange	Gray8Dark	1.3611	0.054012	0.597994	0.2011	0	0.4245
W14X68	A992Fy50	Steel I/Wide Flange	Magenta	0.1389	0.000145	0.034819	0.005835	0	0.0403
W14X730	A992Fy50	Steel I/Wide Flange	Blue	1.4931	0.069927	0.689622	0.227623	0	0.4776
W14X74	A992Fy50	Steel I/Wide Flange	Yellow	0.1514	0.000187	0.038339	0.006462	0	0.0444
W14X82	A992Fy50	Steel I/Wide Flange	Yellow	0.1667	0.000245	0.042486	0.007137	0	0.0506
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.184	0.000196	0.048177	0.017458	0	0.0428
W14X99	A992Fy50	Steel I/Wide Flange	Blue	0.2021	0.000259	0.05353	0.019387	0	0.0478
W8X10	A992Fy50	Steel I/Wide Flange	Green	0.0206	2E-06	0.001485	0.000101	0	0.0093
W8X13	A992Fy50	Steel I/Wide Flange	Cyan	0.0267	4E-06	0.00191	0.000132	0	0.0128
W8X15	A992Fy50	Steel I/Wide Flange	Red	0.0308	7E-06	0.002315	0.000164	0	0.0138
W8X18	A992Fy50	Steel I/Wide Flange	Magenta	0.0365	8E-06	0.002985	0.000384	0	0.013

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W8X21	A992Fy50	Steel I/Wide Flange	Yellow	0.0428	1.4E-05	0.003631	0.000471	0	0.0144
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0492	1.7E-05	0.003988	0.000883	0	0.0135
W8X28	A992Fy50	Steel I/Wide Flange	Blue	0.0573	2.6E-05	0.004726	0.001046	0	0.016
W8X31	A992Fy50	Steel I/Wide Flange	Green	0.0634	2.6E-05	0.005305	0.001789	0	0.0158
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	0.0715	3.7E-05	0.006125	0.002054	0	0.0175
W8X40	A992Fy50	Steel I/Wide Flange	Red	0.0813	5.4E-05	0.007041	0.002368	0	0.0206
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	0.0979	9.5E-05	0.008873	0.002937	0	0.0236
W8X58	A992Fy50	Steel I/Wide Flange	Magenta	0.1188	0.000161	0.010995	0.003622	0	0.031
W8X67	A992Fy50	Steel I/Wide Flange	Yellow	0.1368	0.000244	0.013117	0.004273	0	0.0356

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 4)

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
$ASColPn_{T4\text{-}1}$											
W10X100	0.1335	0.064961	0.064961	0.023261	0.023261	0.075231	0.035301	0.38426	0.2215	0.001701	0.04167
W10X112	0.1505	0.072693	0.072693	0.026264	0.026264	0.085069	0.040046	0.38876	0.22319	0.002021	0.04167
W10X12	0.0096	0.006309	0.006309	0.000637	0.000637	0.007292	0.001007	0.32487	0.0654	1.7E-05	0.025
W10X15	0.0125	0.007983	0.007983	0.000836	0.000836	0.009259	0.001331	0.32939	0.06746	2.3E-05	0.025
W10X17	0.0153	0.009385	0.009385	0.001028	0.001028	0.010822	0.00162	0.33761	0.07039	2.8E-05	0.025
W10X19	0.0184	0.010927	0.010927	0.001235	0.001235	0.0125	0.001939	0.34496	0.07281	3.4E-05	0.025
W10X22	0.024	0.01339	0.01339	0.002295	0.002295	0.015046	0.00353	0.35533	0.11045	9.2E-05	0.025
W10X26	0.0294	0.016181	0.016181	0.002828	0.002828	0.018113	0.00434	0.3625	0.11343	0.000115	0.025
W10X30	0.0343	0.018739	0.018739	0.003327	0.003327	0.021181	0.005116	0.36544	0.11454	0.000139	0.025
W10X33	0.0401	0.020341	0.020341	0.005322	0.005322	0.022454	0.008102	0.34971	0.16179	0.000265	0.04167
W10X39	0.049	0.024385	0.024385	0.006519	0.006519	0.027083	0.009954	0.35526	0.16485	0.000333	0.04167
W10X45	0.0576	0.02842	0.02842	0.007706	0.007706	0.031771	0.011748	0.35985	0.16698	0.000401	0.04167
W10X49	0.0648	0.031481	0.031481	0.01081	0.01081	0.034954	0.016377	0.36218	0.21223	0.000696	0.04167
W10X54	0.0712	0.034722	0.034722	0.011921	0.011921	0.038542	0.018113	0.36493	0.21277	0.000772	0.04208
W10X60	0.0795	0.038694	0.038694	0.013293	0.013293	0.043171	0.020255	0.36577	0.21333	0.000886	0.04167
W10X68	0.09	0.043848	0.043848	0.015356	0.015356	0.049363	0.023206	0.3708	0.21624	0.001027	0.04167
W10X77	0.1027	0.049681	0.049681	0.017475	0.017475	0.056481	0.026563	0.37309	0.21705	0.00122	0.04167
W10X88	0.118	0.057227	0.057227	0.020114	0.020114	0.065394	0.030729	0.37766	0.21865	0.001453	0.04167
W12X106	0.1398	0.08371	0.08371	0.028556	0.028556	0.094907	0.043461	0.4557	0.25884	0.003558	0.05
W12X120	0.158	0.094536	0.094536	0.032464	0.032464	0.107639	0.049421	0.45945	0.26089	0.004144	0.04917
W12X136	0.1794	0.107103	0.107103	0.037149	0.037149	0.123843	0.056713	0.46456	0.26319	0.004909	0.05
W12X14	0.0103	0.008617	0.008617	0.000688	0.000688	0.010069	0.0011	0.38458	0.06277	2.7E-05	0.025
W12X152	0.2025	0.12081	0.12081	0.042037	0.042037	0.140625	0.064236	0.47134	0.26558	0.005773	0.05
W12X16	0.0122	0.009934	0.009934	0.000818	0.000818	0.011632	0.001308	0.3897	0.06448	3.2E-05	0.025
W12X170	0.2275	0.136409	0.136409	0.04749	0.04749	0.159144	0.072917	0.47871	0.26797	0.006739	0.05
W12X19	0.0162	0.012333	0.012333	0.001085	0.001085	0.014294	0.001725	0.40259	0.06847	4.4E-05	0.025
W12X190	0.2558	0.15191	0.15191	0.053678	0.053678	0.179977	0.082755	0.48412	0.27026	0.007971	0.04917
W12X210	0.2815	0.168493	0.168493	0.060041	0.060041	0.201389	0.092014	0.49038	0.27315	0.00911	0.05
W12X22	0.0198	0.014679	0.014679	0.001338	0.001338	0.016956	0.002118	0.40888	0.07067	5.5E-05	0.025
W12X230	0.3091	0.185492	0.185492	0.066573	0.066573	0.22338	0.102431	0.49823	0.27588	0.010528	0.05
W12X252	0.3385	0.204425	0.204425	0.073718	0.073718	0.247685	0.113426	0.50489	0.27856	0.011928	0.05
W12X26	0.0285	0.019353	0.019353	0.003085	0.003085	0.021528	0.004728	0.43033	0.12532	0.000203	0.025
W12X279	0.3745	0.226386	0.226386	0.082786	0.082786	0.278356	0.127315	0.51352	0.28187	0.013975	0.05
W12X30	0.0332	0.022395	0.022395	0.003604	0.003604	0.024942	0.005532	0.43362	0.12664	0.000239	0.025
W12X305	0.414	0.252073	0.252073	0.092066	0.092066	0.310764	0.141204	0.52483	0.28543	0.016063	0.04917
W12X336	0.4591	0.279707	0.279707	0.102785	0.102785	0.348958	0.158565	0.53393	0.28906	0.019036	0.04917
W12X35	0.0395	0.026389	0.026389	0.004323	0.004323	0.02963	0.006655	0.43835	0.12852	0.000294	0.025

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W12X40	0.0477	0.029859	0.029859	0.006372	0.006372	0.032986	0.009722	0.42687	0.16179	0.000479	0.04208
W12X45	0.0536	0.033287	0.033287	0.007189	0.007189	0.037153	0.010995	0.42951	0.16281	0.000556	0.04208
W12X50	0.0599	0.037094	0.037094	0.008065	0.008065	0.041609	0.012326	0.43125	0.16364	0.00063	0.04167
W12X53	0.0666	0.040653	0.040653	0.011088	0.011088	0.045081	0.01684	0.43496	0.20651	0.001066	0.05042
W12X58	0.0741	0.045063	0.045063	0.012384	0.012384	0.05	0.018808	0.4405	0.20907	0.001193	0.05
W12X65	0.084	0.050983	0.050983	0.016782	0.016782	0.056019	0.025521	0.44022	0.25152	0.001928	0.04958
W12X72	0.0931	0.056177	0.056177	0.018808	0.018808	0.0625	0.028472	0.44327	0.25333	0.002185	0.05
W12X79	0.1029	0.061791	0.061791	0.020661	0.020661	0.068866	0.031424	0.44515	0.25427	0.002472	0.04958
W12X87	0.1134	0.068519	0.068519	0.023052	0.023052	0.076389	0.034954	0.44804	0.25569	0.002736	0.05
W12X96	0.1271	0.075915	0.075915	0.025615	0.025615	0.085069	0.039063	0.45292	0.25786	0.003175	0.05
W14X109	0.1453	0.100363	0.100363	0.035436	0.035436	0.111111	0.053646	0.51875	0.31146	0.006746	0.05
W14X120	0.1599	0.110153	0.110153	0.038974	0.038974	0.122685	0.059028	0.52104	0.31206	0.007661	0.05
W14X132	0.1752	0.120465	0.120465	0.043147	0.043147	0.135417	0.065394	0.5233	0.31318	0.008532	0.05
W14X145	0.1955	0.133727	0.133727	0.050553	0.050553	0.150463	0.076968	0.52735	0.33182	0.010646	0.05
W14X159	0.2149	0.146605	0.146605	0.055496	0.055496	0.166088	0.084491	0.53154	0.33351	0.012023	0.05
W14X176	0.238	0.162951	0.162951	0.061778	0.061778	0.185185	0.094329	0.53562	0.33518	0.013648	0.05
W14X193	0.2617	0.179211	0.179211	0.068634	0.068634	0.20544	0.104167	0.54169	0.33738	0.015372	0.05
W14X211	0.2853	0.196096	0.196096	0.075451	0.075451	0.225694	0.114583	0.54584	0.33966	0.017167	0.05
W14X22	0.0194	0.016812	0.016812	0.00162	0.00162	0.019213	0.002541	0.46145	0.08655	0.000104	0.03333
W14X233	0.3165	0.217737	0.217737	0.083712	0.083712	0.252315	0.127894	0.5524	0.34145	0.019673	0.05
W14X257	0.35	0.23995	0.23995	0.093316	0.093316	0.281829	0.142361	0.55885	0.34423	0.022744	0.05
W14X26	0.0245	0.0204	0.0204	0.00205	0.00205	0.023264	0.003206	0.47037	0.0897	0.000136	0.03333
W14X283	0.3857	0.266134	0.266134	0.10352	0.10352	0.313657	0.158565	0.5658	0.34648	0.025801	0.05
W14X30	0.03	0.024406	0.024406	0.003371	0.003371	0.027373	0.005203	0.47785	0.12402	0.000295	0.03333
W14X311	0.4238	0.293074	0.293074	0.115026	0.115026	0.348958	0.175926	0.57357	0.34975	0.029527	0.05
W14X34	0.0355	0.028108	0.028108	0.003995	0.003995	0.031597	0.006134	0.48591	0.1272	0.000358	0.03333
W14X342	0.4688	0.324074	0.324074	0.127738	0.127738	0.388889	0.195602	0.58044	0.35277	0.034344	0.05
W14X370	0.508	0.351748	0.351748	0.13959	0.13959	0.425926	0.21412	0.58871	0.35607	0.038726	0.05
W14X38	0.0404	0.031603	0.031603	0.004565	0.004565	0.03559	0.007002	0.48859	0.12867	0.000412	0.03333
W14X398	0.5476	0.379478	0.379478	0.1513	0.1513	0.463542	0.232639	0.59676	0.35889	0.043424	0.04917
W14X426	0.5876	0.408497	0.408497	0.163562	0.163562	0.502894	0.251157	0.60553	0.36209	0.048452	0.04917
W14X43	0.0491	0.036158	0.036158	0.006539	0.006539	0.040278	0.010012	0.48569	0.15783	0.000657	0.04917
W14X455	0.6242	0.437987	0.437987	0.176367	0.176367	0.541667	0.270833	0.61042	0.36424	0.052954	0.05
W14X48	0.0553	0.040593	0.040593	0.007409	0.007409	0.04537	0.011343	0.48824	0.15911	0.00075	0.04958
W14X500	0.6887	0.484812	0.484812	0.196078	0.196078	0.607639	0.302083	0.62278	0.36886	0.062197	0.05
W14X53	0.0616	0.045047	0.045047	0.008286	0.008286	0.050405	0.012731	0.49074	0.16027	0.000845	0.04917
W14X550	0.7605	0.540314	0.540314	0.218696	0.218696	0.68287	0.337384	0.6358	0.37325	0.072774	0.05
W14X605	0.8378	0.598086	0.598086	0.244785	0.244785	0.763889	0.377315	0.64911	0.37891	0.085695	0.05
W14X61	0.0747	0.053291	0.053291	0.012384	0.012384	0.059028	0.018981	0.49829	0.20374	0.001581	0.04958
W14X665	0.926	0.664438	0.664438	0.272677	0.272677	0.856481	0.422454	0.66283	0.38438	0.102032	0.05
W14X68	0.0833	0.059689	0.059689	0.014005	0.014005	0.066551	0.021354	0.50069	0.20497	0.001772	0.04917
W14X730	1.0172	0.738881	0.738881	0.305193	0.305193	0.960648	0.472222	0.67962	0.39045	0.120205	0.05
W14X74	0.0918	0.064798	0.064798	0.015356	0.015356	0.072917	0.023438	0.50324	0.20661	0.002031	0.04958
W14X82	0.0999	0.071306	0.071306	0.01696	0.01696	0.08044	0.025926	0.5049	0.20694	0.002222	0.04958
W14X90	0.1192	0.082589	0.082589	0.028895	0.028895	0.090856	0.04375	0.51166	0.308	0.005335	0.05
W14X99	0.1318	0.090473	0.090473	0.031868	0.031868	0.100116	0.04838	0.51468	0.30973	0.0061	0.05
W8X10	0.0093	0.004518	0.004518	0.000614	0.000614	0.005133	0.000961	0.26881	0.07002	1E-05	0.025
W8X13	0.0118	0.005736	0.005736	0.00079	0.00079	0.006597	0.001244	0.26761	0.07026	1.4E-05	0.025
W8X15	0.0146	0.00685	0.00685	0.000983	0.000983	0.00787	0.001545	0.274	0.07303	1.7E-05	0.025
W8X18	0.0201	0.008801	0.008801	0.001757	0.001757	0.009838	0.002697	0.28587	0.10258	4.1E-05	0.025
W8X21	0.0244	0.010526	0.010526	0.002146	0.002146	0.011806	0.003293	0.29136	0.10495	5.1E-05	0.025
W8X24	0.0301	0.01207	0.01207	0.003259	0.003259	0.013368	0.004959	0.28481	0.13398	8.7E-05	0.03283
W8X28	0.0352	0.014073	0.014073	0.00384	0.00384	0.015741	0.005845	0.28721	0.13515	0.000105	0.03283

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W8X31	0.0403	0.015914	0.015914	0.005367	0.005367	0.017593	0.00816	0.28925	0.16798	0.000178	0.03283
W8X35	0.0459	0.018102	0.018102	0.006148	0.006148	0.020081	0.009317	0.29262	0.16947	0.000207	0.03283
W8X40	0.0523	0.020483	0.020483	0.007042	0.007042	0.023032	0.010706	0.29438	0.17071	0.000243	0.03283
W8X48	0.0643	0.025054	0.025054	0.008691	0.008691	0.028356	0.013252	0.30104	0.17319	0.000311	0.03292
W8X58	0.0771	0.030159	0.030159	0.010574	0.010574	0.034606	0.016146	0.30429	0.17464	0.000396	0.0325
W8X67	0.0896	0.034979	0.034979	0.012385	0.012385	0.040567	0.018924	0.30965	0.17673	0.000482	0.03292

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 4)

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
ASColPn$_{T4-1}$										
W10X100	0	0	0	0			1	1	1	1
W10X112	0	0	0	0			1	1	1	1
W10X12	0	0	0	0			1	1	1	1
W10X15	0	0	0	0			1	1	1	1
W10X17	0	0	0	0			1	1	1	1
W10X19	0	0	0	0			1	1	1	1
W10X22	0	0	0	0			1	1	1	1
W10X26	0	0	0	0			1	1	1	1
W10X30	0	0	0	0			1	1	1	1
W10X33	0	0	0	0			1	1	1	1
W10X39	0	0	0	0			1	1	1	1
W10X45	0	0	0	0			1	1	1	1
W10X49	0	0	0	0			1	1	1	1
W10X54	0	0	0	0			1	1	1	1
W10X60	0	0	0	0			1	1	1	1
W10X68	0	0	0	0			1	1	1	1
W10X77	0	0	0	0			1	1	1	1
W10X88	0	0	0	0			1	1	1	1
W12X106	0	0	0	0			1	1	1	1
W12X120	0	0	0	0			1	1	1	1
W12X136	0	0	0	0			1	1	1	1
W12X14	0	0	0	0			1	1	1	1
W12X152	0	0	0	0			1	1	1	1
W12X16	0	0	0	0			1	1	1	1
W12X170	0	0	0	0			1	1	1	1
W12X19	0	0	0	0			1	1	1	1
W12X190	0	0	0	0			1	1	1	1
W12X210	0	0	0	0			1	1	1	1
W12X22	0	0	0	0			1	1	1	1
W12X230	0	0	0	0			1	1	1	1
W12X252	0	0	0	0			1	1	1	1
W12X26	0	0	0	0			1	1	1	1
W12X279	0	0	0	0			1	1	1	1
W12X30	0	0	0	0			1	1	1	1
W12X305	0	0	0	0			1	1	1	1
W12X336	0	0	0	0			1	1	1	1
W12X35	0	0	0	0			1	1	1	1
W12X40	0	0	0	0			1	1	1	1
W12X45	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W12X50	0	0	0	0			1	1	1	1
W12X53	0	0	0	0			1	1	1	1
W12X58	0	0	0	0			1	1	1	1
W12X65	0	0	0	0			1	1	1	1
W12X72	0	0	0	0			1	1	1	1
W12X79	0	0	0	0			1	1	1	1
W12X87	0	0	0	0			1	1	1	1
W12X96	0	0	0	0			1	1	1	1
W14X109	0	0	0	0			1	1	1	1
W14X120	0	0	0	0			1	1	1	1
W14X132	0	0	0	0			1	1	1	1
W14X145	0	0	0	0			1	1	1	1
W14X159	0	0	0	0			1	1	1	1
W14X176	0	0	0	0			1	1	1	1
W14X193	0	0	0	0			1	1	1	1
W14X211	0	0	0	0			1	1	1	1
W14X22	0	0	0	0			1	1	1	1
W14X233	0	0	0	0			1	1	1	1
W14X257	0	0	0	0			1	1	1	1
W14X26	0	0	0	0			1	1	1	1
W14X283	0	0	0	0			1	1	1	1
W14X30	0	0	0	0			1	1	1	1
W14X311	0	0	0	0			1	1	1	1
W14X34	0	0	0	0			1	1	1	1
W14X342	0	0	0	0			1	1	1	1
W14X370	0	0	0	0			1	1	1	1
W14X38	0	0	0	0			1	1	1	1
W14X398	0	0	0	0			1	1	1	1
W14X426	0	0	0	0			1	1	1	1
W14X43	0	0	0	0			1	1	1	1
W14X455	0	0	0	0			1	1	1	1
W14X48	0	0	0	0			1	1	1	1
W14X500	0	0	0	0			1	1	1	1
W14X53	0	0	0	0			1	1	1	1
W14X550	0	0	0	0			1	1	1	1
W14X605	0	0	0	0			1	1	1	1
W14X61	0	0	0	0			1	1	1	1
W14X665	0	0	0	0			1	1	1	1
W14X68	0	0	0	0			1	1	1	1
W14X730	0	0	0	0			1	1	1	1
W14X74	0	0	0	0			1	1	1	1
W14X82	0	0	0	0			1	1	1	1
W14X90	0	0	0	0			1	1	1	1
W14X99	0	0	0	0			1	1	1	1
W8X10	0	0	0	0			1	1	1	1
W8X13	0	0	0	0			1	1	1	1
W8X15	0	0	0	0			1	1	1	1
W8X18	0	0	0	0			1	1	1	1
W8X21	0	0	0	0			1	1	1	1
W8X24	0	0	0	0			1	1	1	1
W8X28	0	0	0	0			1	1	1	1
W8X31	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W8X35	0	0	0	0			1	1	1	1
W8X40	0	0	0	0			1	1	1	1
W8X48	0	0	0	0			1	1	1	1
W8X58	0	0	0	0			1	1	1	1
W8X67	0	0	0	0			1	1	1	1

Table 2.2 - Frame Section Property Definitions - Summary (Part 4 of 4)

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
$ASColPn_{T4\text{-}1}$				
W10X100	1	1	1	1
W10X112	1	1	1	1
W10X12	1	1	1	1
W10X15	1	1	1	1
W10X17	1	1	1	1
W10X19	1	1	1	1
W10X22	1	1	1	1
W10X26	1	1	1	1
W10X30	1	1	1	1
W10X33	1	1	1	1
W10X39	1	1	1	1
W10X45	1	1	1	1
W10X49	1	1	1	1
W10X54	1	1	1	1
W10X60	1	1	1	1
W10X68	1	1	1	1
W10X77	1	1	1	1
W10X88	1	1	1	1
W12X106	1	1	1	1
W12X120	1	1	1	1
W12X136	1	1	1	1
W12X14	1	1	1	1
W12X152	1	1	1	1
W12X16	1	1	1	1
W12X170	1	1	1	1
W12X19	1	1	1	1
W12X190	1	1	1	1
W12X210	1	1	1	1
W12X22	1	1	1	1
W12X230	1	1	1	1
W12X252	1	1	1	1
W12X26	1	1	1	1
W12X279	1	1	1	1
W12X30	1	1	1	1
W12X305	1	1	1	1
W12X336	1	1	1	1
W12X35	1	1	1	1
W12X40	1	1	1	1
W12X45	1	1	1	1
W12X50	1	1	1	1
W12X53	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X58	1	1	1	1
W12X65	1	1	1	1
W12X72	1	1	1	1
W12X79	1	1	1	1
W12X87	1	1	1	1
W12X96	1	1	1	1
W14X109	1	1	1	1
W14X120	1	1	1	1
W14X132	1	1	1	1
W14X145	1	1	1	1
W14X159	1	1	1	1
W14X176	1	1	1	1
W14X193	1	1	1	1
W14X211	1	1	1	1
W14X22	1	1	1	1
W14X233	1	1	1	1
W14X257	1	1	1	1
W14X26	1	1	1	1
W14X283	1	1	1	1
W14X30	1	1	1	1
W14X311	1	1	1	1
W14X34	1	1	1	1
W14X342	1	1	1	1
W14X370	1	1	1	1
W14X38	1	1	1	1
W14X398	1	1	1	1
W14X426	1	1	1	1
W14X43	1	1	1	1
W14X455	1	1	1	1
W14X48	1	1	1	1
W14X500	1	1	1	1
W14X53	1	1	1	1
W14X550	1	1	1	1
W14X605	1	1	1	1
W14X61	1	1	1	1
W14X665	1	1	1	1
W14X68	1	1	1	1
W14X730	1	1	1	1
W14X74	1	1	1	1
W14X82	1	1	1	1
W14X90	1	1	1	1
W14X99	1	1	1	1
W8X10	1	1	1	1
W8X13	1	1	1	1
W8X15	1	1	1	1
W8X18	1	1	1	1
W8X21	1	1	1	1
W8X24	1	1	1	1
W8X28	1	1	1	1
W8X31	1	1	1	1
W8X35	1	1	1	1
W8X40	1	1	1	1
W8X48	1	1	1	1
W8X58	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W8X67	1	1	1	1

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQx(1/3)	Yes	Seismic	0	ASCE 7-16
EQx(2/3)	Yes	Seismic	0	ASCE 7-16
EQx(3/3)	Yes	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
EQy(1/3)	Yes	Seismic	0	ASCE 7-16
EQy(2/3)	Yes	Seismic	0	ASCE 7-16
EQy(3/3)	Yes	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	

3.2 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n $C_{t=0.02ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1] R=3.25

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

$S_{s=0.37g}$

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.55648g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.2618g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.370987g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.174533g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n

$C_{t=0.02ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]	R=3.25
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]	
Importance Factor, I [ASCE Table 1.5-2]	
Ss and S1 Source = 0.75	
Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]	
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]	
Site Class [ASCE Table 20.3-1] = D - Stiff Soil	$S_{s=0.37g}$
Site Coefficient, F_a [ASCE Table 11.4-1]	
Site Coefficient, F_v [ASCE Table 11.4-2]	

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.55648g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.2618g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.370987g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.174533g}$

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
EQx	Linear Static
EQy	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	
UDStlS6			LLred	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS16			EQx	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS17			EQx	-1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS18			EQy	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS19			EQy	-1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	
UDStlS20			EQx	1	
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS21			EQx	-1	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS22			EQy	1	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	
UDStlS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 4)

Name	Material	Shape	Color	Area in2	J in4	I33 in4	I22 in4	I23 in4	As2 in2
ASColPn$_{T4\text{-}1}$		Auto Select							
W10X100	A992Fy50	Steel I/Wide Flange	Green	29.3	10.9	623	207	0	7.55
W10X112	A992Fy50	Steel I/Wide Flange	Cyan	32.9	15.1	716	236	0	8.61
W10X12	A992Fy50	Steel I/Wide Flange	Gray8Dark	3.54	0.05	53.8	2.18	0	1.88
W10X15	A992Fy50	Steel I/Wide Flange	Blue	4.41	0.1	68.9	2.89	0	2.3
W10X17	A992Fy50	Steel I/Wide Flange	Green	4.99	0.16	81.9	3.56	0	2.42
W10X19	A992Fy50	Steel I/Wide Flange	Cyan	5.62	0.23	96.3	4.29	0	2.55
W10X22	A992Fy50	Steel I/Wide Flange	Red	6.49	0.24	118	11.4	0	2.45
W10X26	A992Fy50	Steel I/Wide Flange	Magenta	7.61	0.4	144	14.1	0	2.68
W10X30	A992Fy50	Steel I/Wide Flange	Yellow	8.84	0.62	170	16.7	0	3.15
W10X33	A992Fy50	Steel I/Wide Flange	Gray8Dark	9.71	0.58	171	36.6	0	2.82
W10X39	A992Fy50	Steel I/Wide Flange	Blue	11.5	0.98	209	45	0	3.12
W10X45	A992Fy50	Steel I/Wide Flange	Green	13.3	1.51	248	53.4	0	3.54
W10X49	A992Fy50	Steel I/Wide Flange	Cyan	14.4	1.39	272	93.4	0	3.4
W10X54	A992Fy50	Steel I/Wide Flange	Red	15.8	1.82	303	103	0	3.74
W10X60	A992Fy50	Steel I/Wide Flange	Magenta	17.7	2.48	341	116	0	4.28
W10X68	A992Fy50	Steel I/Wide Flange	Yellow	19.9	3.56	394	134	0	4.89
W10X77	A992Fy50	Steel I/Wide Flange	Gray8Dark	22.7	5.11	455	154	0	5.62
W10X88	A992Fy50	Steel I/Wide Flange	Blue	26	7.53	534	179	0	6.53
W12X106	A992Fy50	Steel I/Wide Flange	Yellow	31.2	9.13	933	301	0	7.87
W12X120	A992Fy50	Steel I/Wide Flange	Gray8Dark	35.2	12.9	1070	345	0	9.3
W12X136	A992Fy50	Steel I/Wide Flange	Blue	39.9	18.5	1240	398	0	10.59
W12X14	A992Fy50	Steel I/Wide Flange	Cyan	4.16	0.07	88.6	2.36	0	2.38
W12X152	A992Fy50	Steel I/Wide Flange	Blue	44.7	25.8	1430	454	0	11.92
W12X16	A992Fy50	Steel I/Wide Flange	Red	4.71	0.1	103	2.82	0	2.64
W12X170	A992Fy50	Steel I/Wide Flange	Green	50	35.6	1650	517	0	13.44
W12X19	A992Fy50	Steel I/Wide Flange	Magenta	5.57	0.18	130	3.76	0	2.87
W12X190	A992Fy50	Steel I/Wide Flange	Cyan	56	48.8	1890	589	0	15.26
W12X210	A992Fy50	Steel I/Wide Flange	Red	61.8	64.7	2140	664	0	17.35
W12X22	A992Fy50	Steel I/Wide Flange	Yellow	6.48	0.29	156	4.66	0	3.2
W12X230	A992Fy50	Steel I/Wide Flange	Magenta	67.7	83.8	2420	742	0	19.48
W12X252	A992Fy50	Steel I/Wide Flange	Yellow	74.1	108	2720	828	0	21.56
W12X26	A992Fy50	Steel I/Wide Flange	Gray8Dark	7.65	0.3	204	17.3	0	2.81
W12X279	A992Fy50	Steel I/Wide Flange	Gray8Dark	81.9	143	3110	937	0	24.33
W12X30	A992Fy50	Steel I/Wide Flange	Blue	8.79	0.46	238	20.3	0	3.2

Name	Material	Shape	Color	Area in2	J in4	I33 in4	I22 in4	I23 in4	As2 in2
W12X305	A992Fy50	Steel I/Wide Flange	Blue	89.5	185	3550	1050	0	26.57
W12X336	A992Fy50	Steel I/Wide Flange	Green	98.9	243	4060	1190	0	29.9
W12X35	A992Fy50	Steel I/Wide Flange	Green	10.3	0.74	285	24.5	0	3.75
W12X40	A992Fy50	Steel I/Wide Flange	Cyan	11.7	0.91	307	44.1	0	3.51
W12X45	A992Fy50	Steel I/Wide Flange	Red	13.1	1.26	348	50	0	4.05
W12X50	A992Fy50	Steel I/Wide Flange	Magenta	14.6	1.71	391	56.3	0	4.51
W12X53	A992Fy50	Steel I/Wide Flange	Yellow	15.6	1.58	425	95.8	0	4.17
W12X58	A992Fy50	Steel I/Wide Flange	Gray8Dark	17	2.1	475	107	0	4.39
W12X65	A992Fy50	Steel I/Wide Flange	Blue	19.1	2.18	533	174	0	4.72
W12X72	A992Fy50	Steel I/Wide Flange	Green	21.1	2.93	597	195	0	5.29
W12X79	A992Fy50	Steel I/Wide Flange	Cyan	23.2	3.84	662	216	0	5.83
W12X87	A992Fy50	Steel I/Wide Flange	Red	25.6	5.1	740	241	0	6.44
W12X96	A992Fy50	Steel I/Wide Flange	Magenta	28.2	6.85	833	270	0	6.99
W14X109	A992Fy50	Steel I/Wide Flange	Green	32	7.12	1240	447	0	7.51
W14X120	A992Fy50	Steel I/Wide Flange	Cyan	35.3	9.37	1380	495	0	8.56
W14X132	A992Fy50	Steel I/Wide Flange	Red	38.8	12.3	1530	548	0	9.48
W14X145	A992Fy50	Steel I/Wide Flange	Magenta	42.7	15.2	1710	677	0	10.06
W14X159	A992Fy50	Steel I/Wide Flange	Yellow	46.7	19.7	1900	748	0	11.18
W14X176	A992Fy50	Steel I/Wide Flange	Gray8Dark	51.8	26.5	2140	838	0	12.62
W14X193	A992Fy50	Steel I/Wide Flange	Blue	56.8	34.8	2400	931	0	13.8
W14X211	A992Fy50	Steel I/Wide Flange	Green	62	44.6	2660	1030	0	15.39
W14X22	A992Fy50	Steel I/Wide Flange	Cyan	6.49	0.21	199	7	0	3.15
W14X233	A992Fy50	Steel I/Wide Flange	Cyan	68.5	59.5	3010	1150	0	17.12
W14X257	A992Fy50	Steel I/Wide Flange	Red	75.6	79.1	3400	1290	0	19.35
W14X26	A992Fy50	Steel I/Wide Flange	Red	7.69	0.36	245	8.91	0	3.54
W14X283	A992Fy50	Steel I/Wide Flange	Magenta	83.3	104	3840	1440	0	21.54
W14X30	A992Fy50	Steel I/Wide Flange	Magenta	8.85	0.38	291	19.6	0	3.73
W14X311	A992Fy50	Steel I/Wide Flange	Yellow	91.4	136	4330	1610	0	24.11
W14X34	A992Fy50	Steel I/Wide Flange	Yellow	10	0.57	340	23.3	0	3.99
W14X342	A992Fy50	Steel I/Wide Flange	Gray8Dark	101	178	4900	1810	0	26.95
W14X370	A992Fy50	Steel I/Wide Flange	Blue	109	222	5440	1990	0	29.71
W14X38	A992Fy50	Steel I/Wide Flange	Gray8Dark	11.2	0.8	385	26.7	0	4.37
W14X398	A992Fy50	Steel I/Wide Flange	Green	117	273	6000	2170	0	32.39
W14X426	A992Fy50	Steel I/Wide Flange	Cyan	125	331	6600	2360	0	35.16
W14X43	A992Fy50	Steel I/Wide Flange	Blue	12.6	1.05	428	45.2	0	4.18
W14X455	A992Fy50	Steel I/Wide Flange	Red	134	395	7190	2560	0	38.38
W14X48	A992Fy50	Steel I/Wide Flange	Green	14.1	1.45	484	51.4	0	4.69
W14X500	A992Fy50	Steel I/Wide Flange	Red	147	514	8210	2880	0	42.92
W14X53	A992Fy50	Steel I/Wide Flange	Cyan	15.6	1.94	541	57.7	0	5.14
W14X550	A992Fy50	Steel I/Wide Flange	Magenta	162	669	9430	3250	0	48.08
W14X605	A992Fy50	Steel I/Wide Flange	Yellow	178	869	10800	3680	0	54.34
W14X61	A992Fy50	Steel I/Wide Flange	Red	17.9	2.19	640	107	0	5.21
W14X665	A992Fy50	Steel I/Wide Flange	Gray8Dark	196	1120	12400	4170	0	61.13
W14X68	A992Fy50	Steel I/Wide Flange	Magenta	20	3.01	722	121	0	5.81
W14X730	A992Fy50	Steel I/Wide Flange	Blue	215	1450	14300	4720	0	68.77
W14X74	A992Fy50	Steel I/Wide Flange	Yellow	21.8	3.87	795	134	0	6.39
W14X82	A992Fy50	Steel I/Wide Flange	Yellow	24	5.07	881	148	0	7.29
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	26.5	4.06	999	362	0	6.16
W14X99	A992Fy50	Steel I/Wide Flange	Blue	29.1	5.37	1110	402	0	6.89
W27X194	A992Fy50	Steel I/Wide Flange	Green	57.1	27.1	7860	619	0	21.08
W8X10	A992Fy50	Steel I/Wide Flange	Green	2.96	0.04	30.8	2.09	0	1.34
W8X13	A992Fy50	Steel I/Wide Flange	Cyan	3.84	0.09	39.6	2.73	0	1.84
W8X15	A992Fy50	Steel I/Wide Flange	Red	4.44	0.14	48	3.41	0	1.99
W8X18	A992Fy50	Steel I/Wide Flange	Magenta	5.26	0.17	61.9	7.97	0	1.87

Name	Material	Shape	Color	Area in2	J in4	I33 in4	I22 in4	I23 in4	As2 in2
W8X21	A992Fy50	Steel I/Wide Flange	Yellow	6.16	0.28	75.3	9.77	0	2.07
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	7.08	0.35	82.7	18.3	0	1.94
W8X28	A992Fy50	Steel I/Wide Flange	Blue	8.25	0.54	98	21.7	0	2.3
W8X31	A992Fy50	Steel I/Wide Flange	Green	9.13	0.54	110	37.1	0	2.28
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	10.3	0.77	127	42.6	0	2.52
W8X40	A992Fy50	Steel I/Wide Flange	Red	11.7	1.12	146	49.1	0	2.97
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	14.1	1.96	184	60.9	0	3.4
W8X58	A992Fy50	Steel I/Wide Flange	Magenta	17.1	3.33	228	75.1	0	4.46
W8X67	A992Fy50	Steel I/Wide Flange	Yellow	19.7	5.05	272	88.6	0	5.13

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 4)

Name	As3 in2	S33Pos in3	S33Neg in3	S22Pos in3	S22Neg in3	Z33 in3	Z22 in3	R33 in	R22 in	Cw in6	Fillet Radius in
$ASColPn_{T4\text{-}1}$											
W10X100	19.23	112.25	112.25	40.19	40.19	130	61	4.6112	2.658	5079.02	0.5
W10X112	21.67	125.61	125.61	45.38	45.38	147	69.2	4.6651	2.6783	6035.74	0.5
W10X12	1.39	10.9	10.9	1.1	1.1	12.6	1.74	3.8984	0.7847	50.7	0.3
W10X15	1.8	13.79	13.79	1.45	1.45	16	2.3	3.9527	0.8095	68.02	0.3
W10X17	2.21	16.22	16.22	1.78	1.78	18.7	2.8	4.0513	0.8446	84.63	0.3
W10X19	2.65	18.88	18.88	2.13	2.13	21.6	3.35	4.1395	0.8737	102.79	0.3
W10X22	3.45	23.14	23.14	3.97	3.97	26	6.1	4.264	1.3253	276.11	0.3
W10X26	4.23	27.96	27.96	4.89	4.89	31.3	7.5	4.35	1.3612	342.39	0.3
W10X30	4.94	32.38	32.38	5.75	5.75	36.6	8.84	4.3853	1.3745	415.93	0.3
W10X33	5.77	35.15	35.15	9.2	9.2	38.8	14	4.1965	1.9415	789.8	0.5
W10X39	7.06	42.14	42.14	11.26	11.26	46.8	17.2	4.2631	1.9781	993.2	0.5
W10X45	8.29	49.11	49.11	13.32	13.32	54.9	20.3	4.3182	2.0038	1197.62	0.5
W10X49	9.33	54.4	54.4	18.68	18.68	60.4	28.3	4.3461	2.5468	2079.32	0.5
W10X54	10.25	60	60	20.6	20.6	66.6	31.3	4.3792	2.5532	2305.36	0.505
W10X60	11.45	66.86	66.86	22.97	22.97	74.6	35	4.3893	2.56	2645.67	0.5
W10X68	12.96	75.77	75.77	26.53	26.53	85.3	40.1	4.4496	2.5949	3065.46	0.5
W10X77	14.79	85.85	85.85	30.2	30.2	97.6	45.9	4.4771	2.6046	3641.95	0.5
W10X88	17	98.89	98.89	34.76	34.76	113	53.1	4.5319	2.6239	4337.84	0.5
W12X106	20.13	144.65	144.65	49.34	49.34	164	75.1	5.4684	3.106	10624.95	0.6
W12X120	22.76	163.36	163.36	56.1	56.1	186	85.4	5.5134	3.1307	12372.73	0.59
W12X136	25.83	185.07	185.07	64.19	64.19	214	98	5.5747	3.1583	14659.41	0.6
W12X14	1.49	14.89	14.89	1.19	1.19	17.4	1.9	4.615	0.7532	79.96	0.3
W12X152	29.17	208.76	208.76	72.64	72.64	243	111	5.6561	3.1869	17236.82	0.6
W12X16	1.76	17.17	17.17	1.41	1.41	20.1	2.26	4.6764	0.7738	96.59	0.3
W12X170	32.76	235.71	235.71	82.06	82.06	275	126	5.7446	3.2156	20121.75	0.6
W12X19	2.34	21.31	21.31	1.88	1.88	24.7	2.98	4.8311	0.8216	132.05	0.3
W12X190	36.83	262.5	262.5	92.76	92.76	311	143	5.8095	3.2431	23802.17	0.59
W12X210	40.53	291.16	291.16	103.75	103.75	348	159	5.8845	3.2779	27201.46	0.6
W12X22	2.85	25.37	25.37	2.31	2.31	29.3	3.66	4.9065	0.848	163.44	0.3
W12X230	44.51	320.53	320.53	115.04	115.04	386	177	5.9788	3.3106	31435.26	0.6
W12X252	48.75	353.25	353.25	127.38	127.38	428	196	6.0586	3.3428	35616.63	0.6
W12X26	4.11	33.44	33.44	5.33	5.33	37.2	8.17	5.164	1.5038	604.7	0.3
W12X279	53.93	391.2	391.2	143.05	143.05	481	220	6.1622	3.3824	41730.31	0.6
W12X30	4.78	38.7	38.7	6.23	6.23	43.1	9.56	5.2035	1.5197	714.75	0.3
W12X305	59.62	435.58	435.58	159.09	159.09	537	244	6.298	3.4252	47964.37	0.59
W12X336	66.11	483.33	483.33	177.61	177.61	603	274	6.4072	3.4688	56841.7	0.59
W12X35	5.69	45.6	45.6	7.47	7.47	51.2	11.5	5.2602	1.5423	877.84	0.3

Name	As3 in2	S33Pos in3	S33Neg in3	S22Pos in3	S22Neg in3	Z33 in3	Z22 in3	R33 in	R22 in	Cw in6	Fillet Radius in
W12X40	6.88	51.6	51.6	11.01	11.01	57	16.8	5.1224	1.9415	1429.42	0.505
W12X45	7.71	57.52	57.52	12.42	12.42	64.2	19	5.1541	1.9537	1660.07	0.505
W12X50	8.62	64.1	64.1	13.94	13.94	71.9	21.3	5.175	1.9637	1879.83	0.5
W12X53	9.58	70.25	70.25	19.16	19.16	77.9	29.1	5.2195	2.4781	3182.28	0.605
W12X58	10.67	77.87	77.87	21.4	21.4	86.4	32.5	5.2859	2.5088	3563.56	0.6
W12X65	12.1	88.1	88.1	29	29	96.8	44.1	5.2826	3.0183	5755.8	0.595
W12X72	13.4	97.07	97.07	32.5	32.5	108	49.2	5.3192	3.04	6524.79	0.6
W12X79	14.82	106.77	106.77	35.7	35.7	119	54.3	5.3418	3.0513	7382.47	0.595
W12X87	16.34	118.4	118.4	39.83	39.83	132	60.4	5.3765	3.0682	8170.69	0.6
W12X96	18.3	131.18	131.18	44.26	44.26	147	67.5	5.435	3.0943	9481.45	0.6
W14X109	20.93	173.43	173.43	61.23	61.23	192	92.7	6.225	3.7375	20143.94	0.6
W14X120	23.03	190.34	190.34	67.35	67.35	212	102	6.2525	3.7447	22876.42	0.6
W14X132	25.24	208.16	208.16	74.56	74.56	234	113	6.2796	3.7582	25475.05	0.6
W14X145	28.16	231.08	231.08	87.35	87.35	260	133	6.3283	3.9818	31789.61	0.6
W14X159	30.94	253.33	253.33	95.9	95.9	287	146	6.3785	4.0021	35900.2	0.6
W14X176	34.28	281.58	281.58	106.75	106.75	320	163	6.4275	4.0221	40753.37	0.6
W14X193	37.68	309.68	309.68	118.6	118.6	355	180	6.5003	4.0486	45900.86	0.6
W14X211	41.08	338.85	338.85	130.38	130.38	390	198	6.5501	4.0759	51260.57	0.6
W14X22	2.79	29.05	29.05	2.8	2.8	33.2	4.39	5.5374	1.0385	311.66	0.4
W14X233	45.58	376.25	376.25	144.65	144.65	436	221	6.6288	4.0974	58744.2	0.6
W14X257	50.4	414.63	414.63	161.25	161.25	487	246	6.7062	4.1308	67911.81	0.6
W14X26	3.52	35.25	35.25	3.54	3.54	40.2	5.54	5.6444	1.0764	404.69	0.4
W14X283	55.55	459.88	459.88	178.88	178.88	542	274	6.7896	4.1578	77041.62	0.6
W14X30	4.32	42.17	42.17	5.82	5.82	47.3	8.99	5.7342	1.4882	879.99	0.4
W14X311	61.02	506.43	506.43	198.77	198.77	603	304	6.8829	4.197	88167.81	0.6
W14X34	5.12	48.57	48.57	6.9	6.9	54.6	10.6	5.831	1.5264	1069.72	0.4
W14X342	67.51	560	560	220.73	220.73	672	338	6.9653	4.2333	102549.89	0.6
W14X370	73.15	607.82	607.82	241.21	241.21	736	370	7.0646	4.2728	115635.76	0.6
W14X38	5.81	54.61	54.61	7.89	7.89	61.5	12.1	5.863	1.544	1228.8	0.4
W14X398	78.85	655.74	655.74	261.45	261.45	801	402	7.1611	4.3066	129662.64	0.59
W14X426	84.61	705.88	705.88	282.63	282.63	869	434	7.2664	4.3451	144675.59	0.59
W14X43	7.07	62.48	62.48	11.3	11.3	69.6	17.3	5.8282	1.894	1961.13	0.59
W14X455	89.88	756.84	756.84	304.76	304.76	936	468	7.3251	4.3709	158119.67	0.6
W14X48	7.96	70.14	70.14	12.8	12.8	78.4	19.6	5.8589	1.9093	2238.36	0.595
W14X500	99.17	837.76	837.76	338.82	338.82	1050	522	7.4733	4.4263	185718.56	0.6
W14X53	8.87	77.84	77.84	14.32	14.32	87.1	22	5.8889	1.9232	2524.14	0.59
W14X550	109.51	933.66	933.66	377.91	377.91	1180	583	7.6295	4.479	217302.77	0.6
W14X605	120.64	1033.49	1033.49	422.99	422.99	1320	652	7.7894	4.5469	255882.59	0.6
W14X61	10.75	92.09	92.09	21.4	21.4	102	32.8	5.9795	2.4449	4721.8	0.595
W14X665	133.34	1148.15	1148.15	471.19	471.19	1480	730	7.9539	4.6125	304665.11	0.6
W14X68	12	103.14	103.14	24.2	24.2	115	36.9	6.0083	2.4597	5290.75	0.59
W14X730	146.48	1276.79	1276.79	527.37	527.37	1660	816	8.1555	4.6855	358929.34	0.6
W14X74	13.21	111.97	111.97	26.53	26.53	126	40.5	6.0389	2.4793	6064.62	0.595
W14X82	14.39	123.22	123.22	29.31	29.31	139	44.8	6.0587	2.4833	6635	0.595
W14X90	17.16	142.71	142.71	49.93	49.93	157	75.6	6.1399	3.696	15929.46	0.6
W14X99	18.98	156.34	156.34	55.07	55.07	173	83.6	6.1761	3.7168	18215.75	0.6
W27X194	31.27	559.43	559.43	88.43	88.43	631	136	11.7326	3.2925	109710.93	0.79
W8X10	1.35	7.81	7.81	1.06	1.06	8.87	1.66	3.2257	0.8403	30.85	0.3
W8X13	1.7	9.91	9.91	1.37	1.37	11.4	2.15	3.2113	0.8432	40.68	0.3
W8X15	2.11	11.84	11.84	1.7	1.7	13.6	2.67	3.288	0.8764	51.62	0.3
W8X18	2.89	15.21	15.21	3.04	3.04	17	4.66	3.4305	1.2309	121.36	0.3
W8X21	3.51	18.19	18.19	3.71	3.71	20.4	5.69	3.4963	1.2594	151.47	0.3
W8X24	4.33	20.86	20.86	5.63	5.63	23.1	8.57	3.4177	1.6077	259.52	0.394

Name	As3 in2	S33Pos in3	S33Neg in3	S22Pos in3	S22Neg in3	Z33 in3	Z22 in3	R33 in	R22 in	Cw in6	Fillet Radius in
W8X28	5.07	24.32	24.32	6.64	6.64	27.2	10.1	3.4466	1.6218	312.63	0.394
W8X31	5.8	27.5	27.5	9.28	9.28	30.4	14.1	3.4711	2.0158	531.09	0.394
W8X35	6.62	31.28	31.28	10.62	10.62	34.7	16.1	3.5114	2.0337	618.58	0.394
W8X40	7.53	35.39	35.39	12.17	12.17	39.8	18.5	3.5325	2.0486	725.19	0.394
W8X48	9.26	43.29	43.29	15.02	15.02	49	22.9	3.6124	2.0783	929.82	0.395
W8X58	11.1	52.11	52.11	18.27	18.27	59.8	27.9	3.6515	2.0957	1181.76	0.39
W8X67	12.9	60.44	60.44	21.4	21.4	70.1	32.7	3.7158	2.1207	1438.47	0.395

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 4)

Name	CG Offset 3 in	CG Offset 2 in	PNA Offset 3 in	PNA Offset 2 in	SC Offset 3 in	SC Offset 2 in	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
$ASColPn_{T4-1}$										
W10X100	0	0	0	0			1	1	1	1
W10X112	0	0	0	0			1	1	1	1
W10X12	0	0	0	0			1	1	1	1
W10X15	0	0	0	0			1	1	1	1
W10X17	0	0	0	0			1	1	1	1
W10X19	0	0	0	0			1	1	1	1
W10X22	0	0	0	0			1	1	1	1
W10X26	0	0	0	0			1	1	1	1
W10X30	0	0	0	0			1	1	1	1
W10X33	0	0	0	0			1	1	1	1
W10X39	0	0	0	0			1	1	1	1
W10X45	0	0	0	0			1	1	1	1
W10X49	0	0	0	0			1	1	1	1
W10X54	0	0	0	0			1	1	1	1
W10X60	0	0	0	0			1	1	1	1
W10X68	0	0	0	0			1	1	1	1
W10X77	0	0	0	0			1	1	1	1
W10X88	0	0	0	0			1	1	1	1
W12X106	0	0	0	0			1	1	1	1
W12X120	0	0	0	0			1	1	1	1
W12X136	0	0	0	0			1	1	1	1
W12X14	0	0	0	0			1	1	1	1
W12X152	0	0	0	0			1	1	1	1
W12X16	0	0	0	0			1	1	1	1
W12X170	0	0	0	0			1	1	1	1
W12X19	0	0	0	0			1	1	1	1
W12X190	0	0	0	0			1	1	1	1
W12X210	0	0	0	0			1	1	1	1
W12X22	0	0	0	0			1	1	1	1
W12X230	0	0	0	0			1	1	1	1
W12X252	0	0	0	0			1	1	1	1
W12X26	0	0	0	0			1	1	1	1
W12X279	0	0	0	0			1	1	1	1
W12X30	0	0	0	0			1	1	1	1
W12X305	0	0	0	0			1	1	1	1
W12X336	0	0	0	0			1	1	1	1
W12X35	0	0	0	0			1	1	1	1
W12X40	0	0	0	0			1	1	1	1

Name	CG Offset 3 in	CG Offset 2 in	PNA Offset 3 in	PNA Offset 2 in	SC Offset 3 in	SC Offset 2 in	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W12X45	0	0	0	0			1	1	1	1
W12X50	0	0	0	0			1	1	1	1
W12X53	0	0	0	0			1	1	1	1
W12X58	0	0	0	0			1	1	1	1
W12X65	0	0	0	0			1	1	1	1
W12X72	0	0	0	0			1	1	1	1
W12X79	0	0	0	0			1	1	1	1
W12X87	0	0	0	0			1	1	1	1
W12X96	0	0	0	0			1	1	1	1
W14X109	0	0	0	0			1	1	1	1
W14X120	0	0	0	0			1	1	1	1
W14X132	0	0	0	0			1	1	1	1
W14X145	0	0	0	0			1	1	1	1
W14X159	0	0	0	0			1	1	1	1
W14X176	0	0	0	0			1	1	1	1
W14X193	0	0	0	0			1	1	1	1
W14X211	0	0	0	0			1	1	1	1
W14X22	0	0	0	0			1	1	1	1
W14X233	0	0	0	0			1	1	1	1
W14X257	0	0	0	0			1	1	1	1
W14X26	0	0	0	0			1	1	1	1
W14X283	0	0	0	0			1	1	1	1
W14X30	0	0	0	0			1	1	1	1
W14X311	0	0	0	0			1	1	1	1
W14X34	0	0	0	0			1	1	1	1
W14X342	0	0	0	0			1	1	1	1
W14X370	0	0	0	0			1	1	1	1
W14X38	0	0	0	0			1	1	1	1
W14X398	0	0	0	0			1	1	1	1
W14X426	0	0	0	0			1	1	1	1
W14X43	0	0	0	0			1	1	1	1
W14X455	0	0	0	0			1	1	1	1
W14X48	0	0	0	0			1	1	1	1
W14X500	0	0	0	0			1	1	1	1
W14X53	0	0	0	0			1	1	1	1
W14X550	0	0	0	0			1	1	1	1
W14X605	0	0	0	0			1	1	1	1
W14X61	0	0	0	0			1	1	1	1
W14X665	0	0	0	0			1	1	1	1
W14X68	0	0	0	0			1	1	1	1
W14X730	0	0	0	0			1	1	1	1
W14X74	0	0	0	0			1	1	1	1
W14X82	0	0	0	0			1	1	1	1
W14X90	0	0	0	0			1	1	1	1
W14X99	0	0	0	0			1	1	1	1
W27X194	0	0	0	0			1	1	1	1
W8X10	0	0	0	0			1	1	1	1
W8X13	0	0	0	0			1	1	1	1
W8X15	0	0	0	0			1	1	1	1
W8X18	0	0	0	0			1	1	1	1
W8X21	0	0	0	0			1	1	1	1
W8X24	0	0	0	0			1	1	1	1

Name	CG Offset 3 in	CG Offset 2 in	PNA Offset 3 in	PNA Offset 2 in	SC Offset 3 in	SC Offset 2 in	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W8X28	0	0	0	0			1	1	1	1
W8X31	0	0	0	0			1	1	1	1
W8X35	0	0	0	0			1	1	1	1
W8X40	0	0	0	0			1	1	1	1
W8X48	0	0	0	0			1	1	1	1
W8X58	0	0	0	0			1	1	1	1
W8X67	0	0	0	0			1	1	1	1

Table 2.2 - Frame Section Property Definitions - Summary (Part 4 of 4)

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
ASColPn$_{T4-1}$				
W10X100	1	1	1	1
W10X112	1	1	1	1
W10X12	1	1	1	1
W10X15	1	1	1	1
W10X17	1	1	1	1
W10X19	1	1	1	1
W10X22	1	1	1	1
W10X26	1	1	1	1
W10X30	1	1	1	1
W10X33	1	1	1	1
W10X39	1	1	1	1
W10X45	1	1	1	1
W10X49	1	1	1	1
W10X54	1	1	1	1
W10X60	1	1	1	1
W10X68	1	1	1	1
W10X77	1	1	1	1
W10X88	1	1	1	1
W12X106	1	1	1	1
W12X120	1	1	1	1
W12X136	1	1	1	1
W12X14	1	1	1	1
W12X152	1	1	1	1
W12X16	1	1	1	1
W12X170	1	1	1	1
W12X19	1	1	1	1
W12X190	1	1	1	1
W12X210	1	1	1	1
W12X22	1	1	1	1
W12X230	1	1	1	1
W12X252	1	1	1	1
W12X26	1	1	1	1
W12X279	1	1	1	1
W12X30	1	1	1	1
W12X305	1	1	1	1
W12X336	1	1	1	1
W12X35	1	1	1	1
W12X40	1	1	1	1
W12X45	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X50	1	1	1	1
W12X53	1	1	1	1
W12X58	1	1	1	1
W12X65	1	1	1	1
W12X72	1	1	1	1
W12X79	1	1	1	1
W12X87	1	1	1	1
W12X96	1	1	1	1
W14X109	1	1	1	1
W14X120	1	1	1	1
W14X132	1	1	1	1
W14X145	1	1	1	1
W14X159	1	1	1	1
W14X176	1	1	1	1
W14X193	1	1	1	1
W14X211	1	1	1	1
W14X22	1	1	1	1
W14X233	1	1	1	1
W14X257	1	1	1	1
W14X26	1	1	1	1
W14X283	1	1	1	1
W14X30	1	1	1	1
W14X311	1	1	1	1
W14X34	1	1	1	1
W14X342	1	1	1	1
W14X370	1	1	1	1
W14X38	1	1	1	1
W14X398	1	1	1	1
W14X426	1	1	1	1
W14X43	1	1	1	1
W14X455	1	1	1	1
W14X48	1	1	1	1
W14X500	1	1	1	1
W14X53	1	1	1	1
W14X550	1	1	1	1
W14X605	1	1	1	1
W14X61	1	1	1	1
W14X665	1	1	1	1
W14X68	1	1	1	1
W14X730	1	1	1	1
W14X74	1	1	1	1
W14X82	1	1	1	1
W14X90	1	1	1	1
W14X99	1	1	1	1
W27X194	1	1	1	1
W8X10	1	1	1	1
W8X13	1	1	1	1
W8X15	1	1	1	1
W8X18	1	1	1	1
W8X21	1	1	1	1
W8X24	1	1	1	1
W8X28	1	1	1	1
W8X31	1	1	1	1
W8X35	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W8X40	1	1	1	1
W8X48	1	1	1	1
W8X58	1	1	1	1
W8X67	1	1	1	1

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter in	Area in2
#4	0.5	0.2
#6	0.75	0.44
#9	1.128	1

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	

3.2 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n $C_{t=0.02ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1] R=6

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		$S_{s=1.491g}$
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.02ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	R=6

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

$S_{s=1.491g}$

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
EQx	Linear Static
EQy	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	
UDStlS6			LLred	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS16			EQx	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS17			EQx	-1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS18			EQy	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS19			EQy	-1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	
UDStlS20			EQx	1	
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS21			EQx	-1	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS22			EQy	1	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	
UDStlS23			EQy	-1	

Appendix B-3.11: Large, concrete, baseline

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
6000Psi	Concrete	Isotropic	f'c 6000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 3)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2	As3 ft2
C-24x24-6	6000Psi	Concrete Rectangular	Yellow	4	2.253333	1.333333	1.333333	0	3.3333	3.3333
C-30x30-6	6000Psi	Concrete Rectangular	Blue	6.25	5.501302	3.255208	3.255208	0	5.2083	5.2083

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 3)

Name	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft
C-24x24-6	1.333333	1.333333	1.333333	1.333333	2	2	0.57735	0.57735	0	0	0	0
C-30x30-6	2.604167	2.604167	2.604167	2.604167	3.90625	3.90625	0.72169	0.72169	0	0	0	0

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 3)

Name	Area Modifier	As2 Modifier	As3 Modifier	J Modifier	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
C-24x24-6	1	1	1	1	1	1	1	1
C-30x30-6	1	1	1	1	1	1	1	1

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQx(1/3)	Yes	Seismic	0	ASCE 7-16
EQx(2/3)	Yes	Seismic	0	ASCE 7-16
EQx(3/3)	Yes	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
EQy(1/3)	Yes	Seismic	0	ASCE 7-16
EQy(2/3)	Yes	Seismic	0	ASCE 7-16
EQy(3/3)	Yes	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1] V=103 mph

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1]

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, $K_{z;}$ [ASCE Table 27.3-1]

Kz=2.01(<z>/<zg>)$^{<<2>/<α>>}$ for 15ft ≤ z ≤ $<z_{g>}$

Kz=2.01(<15>/<zg>)$^{<<2>/<α>>}$ for z < $z_{g=1200}$ 15ft

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] <qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>}$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2] $C_{t=0.028ft}$

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

R=6

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

$S_{s=1.491g}$

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n — $C_{t=0.028ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1] — R=6

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2] — $S_{s=1.491g}$

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	
DCmpS3			LLred	1.6	
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
DConS2			SDL	1.2	
DConS2			LLred	1.6	
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
DConS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DConS6			Live	1	
DConS6			Snow	0.5	
DConS6			SDL	1.2	
DConS6			LLred	1	
DConS6			Wind	1	
DConS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DConS7			Live	1	
DConS7			Snow	0.5	
DConS7			SDL	1.2	
DConS7			LLred	1	
DConS7			Wind	-1	
DConS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DConS8			Live	1	
DConS8			LLroof	0.5	
DConS8			SDL	1.2	
DConS8			LLred	1	
DConS8			Wind	1	
DConS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DConS9			Live	1	
DConS9			LLroof	0.5	
DConS9			SDL	1.2	
DConS9			LLred	1	
DConS9			Wind	-1	
DConS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DConS10			Snow	1.6	
DConS10			SDL	1.2	
DConS10			Wind	0.5	
DConS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DConS11			Snow	1.6	
DConS11			SDL	1.2	
DConS11			Wind	-0.5	
DConS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DConS12			LLroof	1.6	
DConS12			SDL	1.2	
DConS12			Wind	0.5	
DConS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]

Name	Type	Is Auto	Load Name	SF	Notes
DConS13			LLroof	1.6	
DConS13			SDL	1.2	
DConS13			Wind	-0.5	
DConS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DConS14			SDL	0.9	
DConS14			Wind	1	
DConS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DConS15			SDL	0.9	
DConS15			Wind	-1	
DConS16	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS16			Live	1	
DConS16			Snow	0.2	
DConS16			SDL	1.3	
DConS16			LLred	1	
DConS16			EQx	1	
DConS17	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS17			Live	1	
DConS17			Snow	0.2	
DConS17			SDL	1.3	
DConS17			LLred	1	
DConS17			EQx	-1	
DConS18	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS18			Live	1	
DConS18			Snow	0.2	
DConS18			SDL	1.3	
DConS18			LLred	1	
DConS18			EQy	1	
DConS19	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS19			Live	1	
DConS19			Snow	0.2	
DConS19			SDL	1.3	
DConS19			LLred	1	
DConS19			EQy	-1	
DConS20	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS20			SDL	0.8	
DConS20			EQx	1	
DConS21	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS21			SDL	0.8	
DConS21			EQx	-1	
DConS22	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS22			SDL	0.8	
DConS22			EQy	1	
DConS23	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS23			SDL	0.8	
DConS23			EQy	-1	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	

Name	Type	Is Auto	Load Name	SF	Notes
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	
UDWalS6			Snow	0.5	
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS6			Wind	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS7			Wind	-1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS8			Wind	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS9			Wind	-1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS10			Wind	0.5	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS11			Wind	-0.5	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS12			Wind	0.5	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS13			Wind	-0.5	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS14			Wind	1	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS15			Wind	-1	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS16			EQx	1	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	
UDWalS17			LLred	1	
UDWalS17			EQx	-1	
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS18			EQy	1	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS19			EQy	-1	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS20			EQx	1	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS21			EQx	-1	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS22			EQy	1	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	
UDWalS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
5000Psi	Concrete	Isotropic	f'c 5000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Shell Sections

Table 2.2 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-4	Wall	Shell-Thin	4000Psi	1		
12in-5	Wall	Shell-Thin	5000Psi	1		

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQx(1/3)	Yes	Seismic	0	ASCE 7-16
EQx(2/3)	Yes	Seismic	0	ASCE 7-16
EQx(3/3)	Yes	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
EQy(1/3)	Yes	Seismic	0	ASCE 7-16
EQy(2/3)	Yes	Seismic	0	ASCE 7-16
EQy(3/3)	Yes	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1] V=127 mph

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1]

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, $K_{z;}$ [ASCE Table 27.3-1]

Kz=2.01(<z>/<zg>)$^{<<2>/<α>>}$ for 15ft ≤ z ≤ <$z_{g>}$

Kz=2.01(<15>/<zg>)$^{<<2>/<α>>}$ for z < $z_{g=1200}$ 15ft

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] <qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>}$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2] $C_{t=0.028ft}$

Coefficient, x [ASCE Table 12.8-2]		
Structure Height Above Base, h_n		
Long-Period Transition Period, T_L [ASCE 11.4.5]		

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]		
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]		R=5
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]		
Importance Factor, I [ASCE Table 1.5-2]		

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		$S_{s=0.041g}$
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.0656g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.0264g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.043733g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.0176g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n — $C_{t=0.028ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1] — R=5

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2] — $S_{s=0.041g}$

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.0656g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.0264g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.043733g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.0176g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	
DCmpS3			LLred	1.6	
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
DConS2			SDL	1.2	
DConS2			LLred	1.6	
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
DConS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DConS6			Live	1	
DConS6			Snow	0.5	
DConS6			SDL	1.2	
DConS6			LLred	1	
DConS6			Wind	1	
DConS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DConS7			Live	1	
DConS7			Snow	0.5	
DConS7			SDL	1.2	
DConS7			LLred	1	
DConS7			Wind	-1	
DConS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DConS8			Live	1	
DConS8			LLroof	0.5	
DConS8			SDL	1.2	
DConS8			LLred	1	
DConS8			Wind	1	
DConS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DConS9			Live	1	
DConS9			LLroof	0.5	
DConS9			SDL	1.2	
DConS9			LLred	1	
DConS9			Wind	-1	
DConS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DConS10			Snow	1.6	
DConS10			SDL	1.2	
DConS10			Wind	0.5	
DConS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DConS11			Snow	1.6	
DConS11			SDL	1.2	
DConS11			Wind	-0.5	
DConS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DConS12			LLroof	1.6	
DConS12			SDL	1.2	
DConS12			Wind	0.5	
DConS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]

Name	Type	Is Auto	Load Name	SF	Notes
DConS13			LLroof	1.6	
DConS13			SDL	1.2	
DConS13			Wind	-0.5	
DConS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DConS14			SDL	0.9	
DConS14			Wind	1	
DConS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DConS15			SDL	0.9	
DConS15			Wind	-1	
DConS16	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS16			Live	1	
DConS16			Snow	0.2	
DConS16			SDL	1.3	
DConS16			LLred	1	
DConS16			EQx	1	
DConS17	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS17			Live	1	
DConS17			Snow	0.2	
DConS17			SDL	1.3	
DConS17			LLred	1	
DConS17			EQx	-1	
DConS18	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS18			Live	1	
DConS18			Snow	0.2	
DConS18			SDL	1.3	
DConS18			LLred	1	
DConS18			EQy	1	
DConS19	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS19			Live	1	
DConS19			Snow	0.2	
DConS19			SDL	1.3	
DConS19			LLred	1	
DConS19			EQy	-1	
DConS20	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS20			SDL	0.8	
DConS20			EQx	1	
DConS21	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS21			SDL	0.8	
DConS21			EQx	-1	
DConS22	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS22			SDL	0.8	
DConS22			EQy	1	
DConS23	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS23			SDL	0.8	
DConS23			EQy	-1	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	

Name	Type	Is Auto	Load Name	SF	Notes
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	
UDWalS6			Snow	0.5	
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS6			Wind	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS7			Wind	-1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS8			Wind	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS9			Wind	-1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS10			Wind	0.5	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS11			Wind	-0.5	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS12			Wind	0.5	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS13			Wind	-0.5	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS14			Wind	1	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS15			Wind	-1	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS16			EQx	1	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	
UDWalS17			LLred	1	
UDWalS17			EQx	-1	
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS18			EQy	1	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS19			EQy	-1	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS20			EQx	1	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS21			EQx	-1	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS22			EQy	1	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	
UDWalS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
5000Psi	Concrete	Isotropic	f'c 5000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Shell Sections

Table 2.2 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-4	Wall	Shell-Thin	4000Psi	1		
12in-5	Wall	Shell-Thin	5000Psi	1		

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQx(1/3)	Yes	Seismic	0	ASCE 7-16
EQx(2/3)	Yes	Seismic	0	ASCE 7-16
EQx(3/3)	Yes	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
EQy(1/3)	Yes	Seismic	0	ASCE 7-16
EQy(2/3)	Yes	Seismic	0	ASCE 7-16
EQy(3/3)	Yes	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16
Wind(1/12)	Yes	Wind	0	ASCE 7-16
Wind(10/12)	Yes	Wind	0	ASCE 7-16
Wind(11/12)	Yes	Wind	0	ASCE 7-16
Wind(12/12)	Yes	Wind	0	ASCE 7-16
Wind(2/12)	Yes	Wind	0	ASCE 7-16
Wind(3/12)	Yes	Wind	0	ASCE 7-16
Wind(4/12)	Yes	Wind	0	ASCE 7-16
Wind(5/12)	Yes	Wind	0	ASCE 7-16
Wind(6/12)	Yes	Wind	0	ASCE 7-16
Wind(7/12)	Yes	Wind	0	ASCE 7-16
Wind(8/12)	Yes	Wind	0	ASCE 7-16
Wind(9/12)	Yes	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1] V=150 mph

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1]

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, $K_{z;}$ [ASCE Table 27.3-1]

Kz=2.01(<z>/<zg>)$^{<<2>/<α>>}$ for 15ft ≤ z ≤ $<z_{g>}$

Kz=2.01(<15>/<zg>)$^{<<2>/<α>>}$ for z < $z_{g=1200}$ 15ft

Topographical Factor, K_{zt} [ASCE 26.8.2]

Directionality Factor, K_d [ASCE 26.6]

Gust Effect Factor, G [ASCE 26.9]

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1] <qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$

Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2] p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>}$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2] $C_{t=0.028ft}$

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]	R=5
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]	
Importance Factor, I [ASCE Table 1.5-2]	

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]	
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]	$S_{s=0.068g}$
Site Class [ASCE Table 20.3-1] = D - Stiff Soil	
Site Coefficient, F_a [ASCE Table 11.4-1]	
Site Coefficient, F_v [ASCE Table 11.4-2]	

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.1088g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.072g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.072533g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.048g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n — $C_{t=0.028ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1] — R=5

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2] — $S_{s=0.068g}$

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.1088g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.072g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.072533g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.048g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	
DCmpS3			LLred	1.6	
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
DConS2			SDL	1.2	
DConS2			LLred	1.6	
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
DConS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DConS6			Live	1	
DConS6			Snow	0.5	
DConS6			SDL	1.2	
DConS6			LLred	1	
DConS6			Wind	1	
DConS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DConS7			Live	1	
DConS7			Snow	0.5	
DConS7			SDL	1.2	
DConS7			LLred	1	
DConS7			Wind	-1	
DConS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DConS8			Live	1	
DConS8			LLroof	0.5	
DConS8			SDL	1.2	
DConS8			LLred	1	
DConS8			Wind	1	
DConS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DConS9			Live	1	
DConS9			LLroof	0.5	
DConS9			SDL	1.2	
DConS9			LLred	1	
DConS9			Wind	-1	
DConS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DConS10			Snow	1.6	
DConS10			SDL	1.2	
DConS10			Wind	0.5	
DConS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DConS11			Snow	1.6	
DConS11			SDL	1.2	
DConS11			Wind	-0.5	
DConS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DConS12			LLroof	1.6	
DConS12			SDL	1.2	
DConS12			Wind	0.5	
DConS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]

Name	Type	Is Auto	Load Name	SF	Notes
DConS13			LLroof	1.6	
DConS13			SDL	1.2	
DConS13			Wind	-0.5	
DConS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DConS14			SDL	0.9	
DConS14			Wind	1	
DConS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DConS15			SDL	0.9	
DConS15			Wind	-1	
DConS16	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS16			Live	1	
DConS16			Snow	0.2	
DConS16			SDL	1.3	
DConS16			LLred	1	
DConS16			EQx	1	
DConS17	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS17			Live	1	
DConS17			Snow	0.2	
DConS17			SDL	1.3	
DConS17			LLred	1	
DConS17			EQx	-1	
DConS18	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS18			Live	1	
DConS18			Snow	0.2	
DConS18			SDL	1.3	
DConS18			LLred	1	
DConS18			EQy	1	
DConS19	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS19			Live	1	
DConS19			Snow	0.2	
DConS19			SDL	1.3	
DConS19			LLred	1	
DConS19			EQy	-1	
DConS20	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS20			SDL	0.8	
DConS20			EQx	1	
DConS21	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS21			SDL	0.8	
DConS21			EQx	-1	
DConS22	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS22			SDL	0.8	
DConS22			EQy	1	
DConS23	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS23			SDL	0.8	
DConS23			EQy	-1	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	

Name	Type	Is Auto	Load Name	SF	Notes
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	
UDWalS6			Snow	0.5	
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS6			Wind	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS7			Wind	-1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS8			Wind	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS9			Wind	-1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS10			Wind	0.5	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS11			Wind	-0.5	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS12			Wind	0.5	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS13			Wind	-0.5	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS14			Wind	1	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS15			Wind	-1	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS16			EQx	1	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	
UDWalS17			LLred	1	
UDWalS17			EQx	-1	
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS18			EQy	1	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS19			EQy	-1	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS20			EQx	1	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS21			EQx	-1	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS22			EQy	1	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	
UDWalS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
6000Psi	Concrete	Isotropic	f'c 6000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Shell Sections

Table 2.2 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-4	Wall	Shell-Thin	4000Psi	1		
12in-6	Wall	Shell-Thin	6000Psi	1		

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=103 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1] $z_{g=1200}$

Velocity Pressure Exposure Coefficient, $K_{z;}$ [ASCE Table 27.3-1]	Kz=2.01(<z>/<zg>)$^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ $<z_{g>}$ Kz=2.01(<15>/<zg>)$^{<<2>/<\alpha>>}$ for z < 15ft
Topographical Factor, K_{zt} [ASCE 26.8.2]	
Directionality Factor, K_d [ASCE 26.6]	
Gust Effect Factor, G [ASCE 26.9]	

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1]	<qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$
Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2]	p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.02ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]	R=5
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]	
Importance Factor, I [ASCE Table 1.5-2]	

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		$S_{s=0.37g}$
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.55648g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.2618g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.370987g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.174533g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.02ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	R=5

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

$S_{s=0.37g}$

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.55648g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.2618g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.370987g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.174533g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DCmpC1	Linear Add	Yes	Dead	1.4	Dead [Construction]
DCmpC2	Linear Add	Yes	Dead	1.2	Dead + Construction Live [Construction]
DCmpD1	Linear Add	Yes	Dead	1	Dead [Deflections]
DCmpD1			SDL	1	
DCmpD2	Linear Add	Yes	Dead	1	Dead + Live [Deflections]
DCmpD2			Live	1	
DCmpD2			SDL	1	
DCmpD2			LLred	1	
DCmpS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DCmpS1			SDL	1.4	
DCmpS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DCmpS2			Live	1.6	
DCmpS2			Snow	0.5	
DCmpS2			SDL	1.2	
DCmpS2			LLred	1.6	
DCmpS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS3			Live	1.6	
DCmpS3			LLroof	0.5	
DCmpS3			SDL	1.2	
DCmpS3			LLred	1.6	
DCmpS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DCmpS4			Live	1	
DCmpS4			Snow	1.6	
DCmpS4			SDL	1.2	
DCmpS4			LLred	1	
DCmpS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DCmpS5			Live	1	
DCmpS5			LLroof	1.6	
DCmpS5			SDL	1.2	
DCmpS5			LLred	1	
DConS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DConS1			SDL	1.4	
DConS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DConS2			Live	1.6	
DConS2			Snow	0.5	
DConS2			SDL	1.2	
DConS2			LLred	1.6	
DConS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS3			Live	1.6	
DConS3			LLroof	0.5	
DConS3			SDL	1.2	
DConS3			LLred	1.6	
DConS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DConS4			Live	1	
DConS4			Snow	1.6	
DConS4			SDL	1.2	
DConS4			LLred	1	
DConS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DConS5			Live	1	
DConS5			LLroof	1.6	
DConS5			SDL	1.2	
DConS5			LLred	1	
DConS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DConS6			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
DConS6			Snow	0.5	
DConS6			SDL	1.2	
DConS6			LLred	1	
DConS6			Wind	1	
DConS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DConS7			Live	1	
DConS7			Snow	0.5	
DConS7			SDL	1.2	
DConS7			LLred	1	
DConS7			Wind	-1	
DConS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DConS8			Live	1	
DConS8			LLroof	0.5	
DConS8			SDL	1.2	
DConS8			LLred	1	
DConS8			Wind	1	
DConS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DConS9			Live	1	
DConS9			LLroof	0.5	
DConS9			SDL	1.2	
DConS9			LLred	1	
DConS9			Wind	-1	
DConS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DConS10			Snow	1.6	
DConS10			SDL	1.2	
DConS10			Wind	0.5	
DConS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DConS11			Snow	1.6	
DConS11			SDL	1.2	
DConS11			Wind	-0.5	
DConS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DConS12			LLroof	1.6	
DConS12			SDL	1.2	
DConS12			Wind	0.5	
DConS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]
DConS13			LLroof	1.6	
DConS13			SDL	1.2	
DConS13			Wind	-0.5	
DConS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DConS14			SDL	0.9	
DConS14			Wind	1	
DConS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DConS15			SDL	0.9	
DConS15			Wind	-1	
DConS16	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS16			Live	1	
DConS16			Snow	0.2	
DConS16			SDL	1.3	
DConS16			LLred	1	
DConS16			EQx	1	
DConS17	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS17			Live	1	
DConS17			Snow	0.2	
DConS17			SDL	1.3	

Name	Type	Is Auto	Load Name	SF	Notes
DConS17			LLred	1	
DConS17			EQx	-1	
DConS18	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DConS18			Live	1	
DConS18			Snow	0.2	
DConS18			SDL	1.3	
DConS18			LLred	1	
DConS18			EQy	1	
DConS19	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DConS19			Live	1	
DConS19			Snow	0.2	
DConS19			SDL	1.3	
DConS19			LLred	1	
DConS19			EQy	-1	
DConS20	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS20			SDL	0.8	
DConS20			EQx	1	
DConS21	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS21			SDL	0.8	
DConS21			EQx	-1	
DConS22	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DConS22			SDL	0.8	
DConS22			EQy	1	
DConS23	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DConS23			SDL	0.8	
DConS23			EQy	-1	
ENV-SERV	Envelope	No	UDWalS1	1	
ENV-SERV			UDWalS2	1	
ENV-SERV			UDWalS3	1	
ENV-SERV			UDWalS4	1	
ENV-SERV			UDWalS5	1	
ENV-SERV			UDWalS6	1	
ENV-SERV			UDWalS7	1	
ENV-SERV			UDWalS8	1	
ENV-SERV			UDWalS9	1	
ENV-SERV			UDWalS10	1	
ENV-SERV			UDWalS11	1	
ENV-SERV			UDWalS12	1	
ENV-SERV			UDWalS13	1	
ENV-SERV			UDWalS14	1	
ENV-SERV			UDWalS15	1	
ENV-SERV			UDWalS16	1	
ENV-SERV			UDWalS17	1	
ENV-SERV			UDWalS18	1	
ENV-SERV			UDWalS19	1	
ENV-SERV			UDWalS20	1	
ENV-SERV			UDWalS21	1	
ENV-SERV			UDWalS22	1	
ENV-SERV			UDWalS23	1	
UDWalS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDWalS1			SDL	1.4	
UDWalS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDWalS2			Live	1.6	
UDWalS2			Snow	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS2			SDL	1.2	
UDWalS2			LLred	1.6	
UDWalS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS3			Live	1.6	
UDWalS3			LLroof	0.5	
UDWalS3			SDL	1.2	
UDWalS3			LLred	1.6	
UDWalS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDWalS4			Live	1	
UDWalS4			Snow	1.6	
UDWalS4			SDL	1.2	
UDWalS4			LLred	1	
UDWalS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDWalS5			Live	1	
UDWalS5			LLroof	1.6	
UDWalS5			SDL	1.2	
UDWalS5			LLred	1	
UDWalS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDWalS6			Live	1	
UDWalS6			Snow	0.5	
UDWalS6			SDL	1.2	
UDWalS6			LLred	1	
UDWalS6			Wind	1	
UDWalS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDWalS7			Live	1	
UDWalS7			Snow	0.5	
UDWalS7			SDL	1.2	
UDWalS7			LLred	1	
UDWalS7			Wind	-1	
UDWalS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDWalS8			Live	1	
UDWalS8			LLroof	0.5	
UDWalS8			SDL	1.2	
UDWalS8			LLred	1	
UDWalS8			Wind	1	
UDWalS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDWalS9			Live	1	
UDWalS9			LLroof	0.5	
UDWalS9			SDL	1.2	
UDWalS9			LLred	1	
UDWalS9			Wind	-1	
UDWalS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDWalS10			Snow	1.6	
UDWalS10			SDL	1.2	
UDWalS10			Wind	0.5	
UDWalS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDWalS11			Snow	1.6	
UDWalS11			SDL	1.2	
UDWalS11			Wind	-0.5	
UDWalS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDWalS12			LLroof	1.6	
UDWalS12			SDL	1.2	
UDWalS12			Wind	0.5	
UDWalS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]

Name	Type	Is Auto	Load Name	SF	Notes
UDWalS13			LLroof	1.6	
UDWalS13			SDL	1.2	
UDWalS13			Wind	-0.5	
UDWalS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDWalS14			SDL	0.9	
UDWalS14			Wind	1	
UDWalS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDWalS15			SDL	0.9	
UDWalS15			Wind	-1	
UDWalS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS16			Live	1	
UDWalS16			Snow	0.2	
UDWalS16			SDL	1.3	
UDWalS16			LLred	1	
UDWalS16			EQx	1	
UDWalS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS17			Live	1	
UDWalS17			Snow	0.2	
UDWalS17			SDL	1.3	
UDWalS17			LLred	1	
UDWalS17			EQx	-1	
UDWalS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDWalS18			Live	1	
UDWalS18			Snow	0.2	
UDWalS18			SDL	1.3	
UDWalS18			LLred	1	
UDWalS18			EQy	1	
UDWalS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDWalS19			Live	1	
UDWalS19			Snow	0.2	
UDWalS19			SDL	1.3	
UDWalS19			LLred	1	
UDWalS19			EQy	-1	
UDWalS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS20			SDL	0.8	
UDWalS20			EQx	1	
UDWalS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS21			SDL	0.8	
UDWalS21			EQx	-1	
UDWalS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDWalS22			SDL	0.8	
UDWalS22			EQy	1	
UDWalS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDWalS23			SDL	0.8	
UDWalS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
8000Psi	Concrete	Isotropic	f'c 8000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	

2.2 Shell Sections

Table 2.2 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness in	Deck Material	Deck Depth in
12in-4	Wall	Shell-Thin	4000Psi	12		
42in-8	Wall	Shell-Thin	8000Psi	42		
44in-8	Wall	Shell-Thin	8000Psi	44		
46in-8	Wall	Shell-Thin	8000Psi	46		
48in-8	Wall	Shell-Thin	8000Psi	48		
50in-8	Wall	Shell-Thin	8000Psi	50		
52in-8	Wall	Shell-Thin	8000Psi	52		
54in-8	Wall	Shell-Thin	8000Psi	54		

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter in	Area in2
#4	0.5	0.2
#6	0.75	0.44
#9	1.128	1

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=103 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Ground

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

$z_{g=1200}$

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, $K_{z;}$ [ASCE Table 27.3-1]	Kz=2.01(<z>/<zg>)$^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ <$z_{g>}$ Kz=2.01(<15>/<zg>)$^{<<2>/<\alpha>>}$ for z < 15ft
Topographical Factor, K_{zt} [ASCE 26.8.2]	
Directionality Factor, K_d [ASCE 26.6]	
Gust Effect Factor, G [ASCE 26.9]	

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1]	<qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$
Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2]	p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.02ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]	R=6
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]	
Importance Factor, I [ASCE Table 1.5-2]	

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		$S_{s=1.491g}$
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.02ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	R=6

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

$S_{s=1.491g}$

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
DWalS1	Linear Add	Yes	Dead	1.4	Dead [Strength]
DWalS1			SDL	1.4	
DWalS2	Linear Add	Yes	Dead	1.2	Dead + Live [Strength]
DWalS2			Live	1.6	
DWalS2			Snow	0.5	
DWalS2			SDL	1.2	
DWalS2			LLred	1.6	
DWalS3	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DWalS3			Live	1.6	
DWalS3			LLroof	0.5	
DWalS3			SDL	1.2	
DWalS3			LLred	1.6	
DWalS4	Linear Add	Yes	Dead	1.2	Dead + Live + Snow [Strength]
DWalS4			Live	1	
DWalS4			Snow	1.6	
DWalS4			SDL	1.2	
DWalS4			LLred	1	
DWalS5	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live [Strength]
DWalS5			Live	1	
DWalS5			LLroof	1.6	
DWalS5			SDL	1.2	
DWalS5			LLred	1	
DWalS6	Linear Add	Yes	Dead	1.2	Dead + Live + Wind + Snow [Strength]
DWalS6			Live	1	
DWalS6			Snow	0.5	
DWalS6			SDL	1.2	
DWalS6			LLred	1	
DWalS6			Wind	1	
DWalS7	Linear Add	Yes	Dead	1.2	Dead + Live - Wind + Snow [Strength]
DWalS7			Live	1	
DWalS7			Snow	0.5	
DWalS7			SDL	1.2	
DWalS7			LLred	1	
DWalS7			Wind	-1	
DWalS8	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
DWalS8			Live	1	
DWalS8			LLroof	0.5	
DWalS8			SDL	1.2	
DWalS8			LLred	1	
DWalS8			Wind	1	
DWalS9	Linear Add	Yes	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
DWalS9			Live	1	
DWalS9			LLroof	0.5	
DWalS9			SDL	1.2	
DWalS9			LLred	1	
DWalS9			Wind	-1	
DWalS10	Linear Add	Yes	Dead	1.2	Dead + Snow + Wind [Strength]
DWalS10			Snow	1.6	
DWalS10			SDL	1.2	
DWalS10			Wind	0.5	
DWalS11	Linear Add	Yes	Dead	1.2	Dead + Snow - Wind [Strength]
DWalS11			Snow	1.6	
DWalS11			SDL	1.2	
DWalS11			Wind	-0.5	

Name	Type	Is Auto	Load Name	SF	Notes
DWalS12	Linear Add	Yes	Dead	1.2	Dead + Roof Live + Wind [Strength]
DWalS12			LLroof	1.6	
DWalS12			SDL	1.2	
DWalS12			Wind	0.5	
DWalS13	Linear Add	Yes	Dead	1.2	Dead + Roof Live - Wind [Strength]
DWalS13			LLroof	1.6	
DWalS13			SDL	1.2	
DWalS13			Wind	-0.5	
DWalS14	Linear Add	Yes	Dead	0.9	Dead (min) + Wind [Strength]
DWalS14			SDL	0.9	
DWalS14			Wind	1	
DWalS15	Linear Add	Yes	Dead	0.9	Dead (min) - Wind [Strength]
DWalS15			SDL	0.9	
DWalS15			Wind	-1	
DWalS16	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DWalS16			Live	1	
DWalS16			Snow	0.2	
DWalS16			SDL	1.3	
DWalS16			LLred	1	
DWalS16			EQx	1	
DWalS17	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DWalS17			Live	1	
DWalS17			Snow	0.2	
DWalS17			SDL	1.3	
DWalS17			LLred	1	
DWalS17			EQx	-1	
DWalS18	Linear Add	Yes	Dead	1.3	Dead + Live + Static Earthquake [Strength]
DWalS18			Live	1	
DWalS18			Snow	0.2	
DWalS18			SDL	1.3	
DWalS18			LLred	1	
DWalS18			EQy	1	
DWalS19	Linear Add	Yes	Dead	1.3	Dead + Live - Static Earthquake [Strength]
DWalS19			Live	1	
DWalS19			Snow	0.2	
DWalS19			SDL	1.3	
DWalS19			LLred	1	
DWalS19			EQy	-1	
DWalS20	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DWalS20			SDL	0.8	
DWalS20			EQx	1	
DWalS21	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DWalS21			SDL	0.8	
DWalS21			EQx	-1	
DWalS22	Linear Add	Yes	Dead	0.8	Dead (min) + Static Earthquake [Strength]
DWalS22			SDL	0.8	
DWalS22			EQy	1	
DWalS23	Linear Add	Yes	Dead	0.8	Dead (min) - Static Earthquake [Strength]
DWalS23			SDL	0.8	
DWalS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 3)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2	As3 ft2	S33Pos ft3
W12X65	A992Fy50	Steel I/Wide Flange	Blue	0.1326	0.000105	0.025704	0.008391	0	0.0328	0.084	0.050983
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.184	0.000196	0.048177	0.017458	0	0.0428	0.1192	0.082589
W16X26	A992Fy50	Steel I/Wide Flange	Green	0.0533	1.3E-05	0.014516	0.000462	0	0.0273	0.022	0.02219
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	0.0979	9.5E-05	0.008873	0.002937	0	0.0236	0.0643	0.025054

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 3)

Name	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft
W12X65	0.050983	0.016782	0.016782	0.056019	0.025521	0.44022	0.25152	0.001928	0.04958	0	0	0
W14X90	0.082589	0.028895	0.028895	0.090856	0.04375	0.51166	0.308	0.005335	0.05	0	0	0
W16X26	0.02219	0.002018	0.002018	0.025579	0.003171	0.5217	0.09312	0.000189	0.0335	0	0	0
W8X48	0.025054	0.008691	0.008691	0.028356	0.013252	0.30104	0.17319	0.000311	0.03292	0	0	0

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 3)

Name	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X65	0			1	1	1	1	1	1	1	1
W14X90	0			1	1	1	1	1	1	1	1
W16X26	0			1	1	1	1	1	1	1	1
W8X48	0			1	1	1	1	1	1	1	1

2.3 Reinforcement Sizes

Table 2.3 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031

Name	Diameter ft	Area ft2
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=115 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Basement

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

$z_{g=1200}$

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, $K_{z;}$ [ASCE Table 27.3-1]	Kz=2.01(<z>/<zg>)$^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ <$z_{g>}$ Kz=2.01(<15>/<zg>)$^{<<2>/<\alpha>>}$ for z < 15ft
Topographical Factor, K_{zt} [ASCE 26.8.2]	
Directionality Factor, K_d [ASCE 26.6]	
Gust Effect Factor, G [ASCE 26.9]	

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1]	<qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$
Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2]	p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.028ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]	R=6
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]	
Importance Factor, I [ASCE Table 1.5-2]	

Ss and S1 Source = 0.8

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		$S_{s=1.03g}$
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.12064g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.6664g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.747093g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.444267g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.028ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	R=6

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]		
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]		
Importance Factor, I [ASCE Table 1.5-2]		
Ss and S1 Source = 0.8		
Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		$S_{s=1.03g}$
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.12064g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.6664g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.747093g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.444267g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	
UDStlS6			LLred	1	
UDStlS6			Wind	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS7			Wind	-1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS8			Wind	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS9			Wind	-1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS10			Wind	0.5	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS11			Wind	-0.5	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS12			Wind	0.5	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS13			Wind	-0.5	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS14			Wind	1	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS15			Wind	-1	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS16			EQx	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS17			EQx	-1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS18			EQy	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS19			EQy	-1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	
UDStlS20			EQx	1	
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS21			EQx	-1	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS22			EQy	1	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	
UDStlS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 4)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
ASColPn$_{T4-1}$		Auto Select							
W10X100	A992Fy50	Steel I/Wide Flange	Green	0.2035	0.000526	0.030044	0.009983	0	0.0524
W10X112	A992Fy50	Steel I/Wide Flange	Cyan	0.2285	0.000728	0.034529	0.011381	0	0.0598
W10X12	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0246	3E-06	0.002595	0.000105	0	0.013
W10X15	A992Fy50	Steel I/Wide Flange	Blue	0.0306	5E-06	0.003323	0.000139	0	0.016
W10X17	A992Fy50	Steel I/Wide Flange	Green	0.0347	8E-06	0.00395	0.000172	0	0.0168
W10X19	A992Fy50	Steel I/Wide Flange	Cyan	0.039	1.1E-05	0.004644	0.000207	0	0.0177
W10X22	A992Fy50	Steel I/Wide Flange	Red	0.0451	1.2E-05	0.005691	0.00055	0	0.017
W10X26	A992Fy50	Steel I/Wide Flange	Magenta	0.0528	1.9E-05	0.006944	0.00068	0	0.0186
W10X30	A992Fy50	Steel I/Wide Flange	Yellow	0.0614	3E-05	0.008198	0.000805	0	0.0219
W10X33	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0674	2.8E-05	0.008247	0.001765	0	0.0196
W10X39	A992Fy50	Steel I/Wide Flange	Blue	0.0799	4.7E-05	0.010079	0.00217	0	0.0217
W10X45	A992Fy50	Steel I/Wide Flange	Green	0.0924	7.3E-05	0.01196	0.002575	0	0.0245
W10X49	A992Fy50	Steel I/Wide Flange	Cyan	0.1	6.7E-05	0.013117	0.004504	0	0.0236
W10X54	A992Fy50	Steel I/Wide Flange	Red	0.1097	8.8E-05	0.014612	0.004967	0	0.026
W10X60	A992Fy50	Steel I/Wide Flange	Magenta	0.1229	0.00012	0.016445	0.005594	0	0.0298
W10X68	A992Fy50	Steel I/Wide Flange	Yellow	0.1382	0.000172	0.019001	0.006462	0	0.0339
W10X77	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1576	0.000246	0.021943	0.007427	0	0.039
W10X88	A992Fy50	Steel I/Wide Flange	Blue	0.1806	0.000363	0.025752	0.008632	0	0.0454
W12X106	A992Fy50	Steel I/Wide Flange	Yellow	0.2167	0.00044	0.044994	0.014516	0	0.0546
W12X120	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.2444	0.000622	0.051601	0.016638	0	0.0646
W12X136	A992Fy50	Steel I/Wide Flange	Blue	0.2771	0.000892	0.059799	0.019194	0	0.0735
W12X14	A992Fy50	Steel I/Wide Flange	Cyan	0.0289	3E-06	0.004273	0.000114	0	0.0165
W12X152	A992Fy50	Steel I/Wide Flange	Blue	0.3104	0.001244	0.068962	0.021894	0	0.0828
W12X16	A992Fy50	Steel I/Wide Flange	Red	0.0327	5E-06	0.004967	0.000136	0	0.0183
W12X170	A992Fy50	Steel I/Wide Flange	Green	0.3472	0.001717	0.079572	0.024932	0	0.0933
W12X19	A992Fy50	Steel I/Wide Flange	Magenta	0.0387	9E-06	0.006269	0.000181	0	0.0199
W12X190	A992Fy50	Steel I/Wide Flange	Cyan	0.3889	0.002353	0.091146	0.028405	0	0.106
W12X210	A992Fy50	Steel I/Wide Flange	Red	0.4292	0.00312	0.103202	0.032022	0	0.1205
W12X22	A992Fy50	Steel I/Wide Flange	Yellow	0.045	1.4E-05	0.007523	0.000225	0	0.0222
W12X230	A992Fy50	Steel I/Wide Flange	Magenta	0.4701	0.004041	0.116705	0.035783	0	0.1353
W12X252	A992Fy50	Steel I/Wide Flange	Yellow	0.5146	0.005208	0.131173	0.039931	0	0.1497
W12X26	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0531	1.4E-05	0.009838	0.000834	0	0.0195
W12X279	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.5688	0.006896	0.149981	0.045187	0	0.1689

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W12X30	A992Fy50	Steel I/Wide Flange	Blue	0.061	2.2E-05	0.011478	0.000979	0	0.0222
W12X305	A992Fy50	Steel I/Wide Flange	Blue	0.6215	0.008922	0.1712	0.050637	0	0.1845
W12X336	A992Fy50	Steel I/Wide Flange	Green	0.6868	0.011719	0.195795	0.057388	0	0.2077
W12X35	A992Fy50	Steel I/Wide Flange	Green	0.0715	3.6E-05	0.013744	0.001182	0	0.026
W12X40	A992Fy50	Steel I/Wide Flange	Cyan	0.0813	4.4E-05	0.014805	0.002127	0	0.0244
W12X45	A992Fy50	Steel I/Wide Flange	Red	0.091	6.1E-05	0.016782	0.002411	0	0.0281
W12X50	A992Fy50	Steel I/Wide Flange	Magenta	0.1014	8.2E-05	0.018856	0.002715	0	0.0313
W12X53	A992Fy50	Steel I/Wide Flange	Yellow	0.1083	7.6E-05	0.020496	0.00462	0	0.029
W12X58	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1181	0.000101	0.022907	0.00516	0	0.0305
W12X65	A992Fy50	Steel I/Wide Flange	Blue	0.1326	0.000105	0.025704	0.008391	0	0.0328
W12X72	A992Fy50	Steel I/Wide Flange	Green	0.1465	0.000141	0.028791	0.009404	0	0.0367
W12X79	A992Fy50	Steel I/Wide Flange	Cyan	0.1611	0.000185	0.031925	0.010417	0	0.0405
W12X87	A992Fy50	Steel I/Wide Flange	Red	0.1778	0.000246	0.035687	0.011622	0	0.0447
W12X96	A992Fy50	Steel I/Wide Flange	Magenta	0.1958	0.00033	0.040172	0.013021	0	0.0485
W14X109	A992Fy50	Steel I/Wide Flange	Green	0.2222	0.000343	0.059799	0.021557	0	0.0521
W14X120	A992Fy50	Steel I/Wide Flange	Cyan	0.2451	0.000452	0.066551	0.023872	0	0.0594
W14X132	A992Fy50	Steel I/Wide Flange	Red	0.2694	0.000593	0.073785	0.026427	0	0.0658
W14X145	A992Fy50	Steel I/Wide Flange	Magenta	0.2965	0.000733	0.082465	0.032649	0	0.0699
W14X159	A992Fy50	Steel I/Wide Flange	Yellow	0.3243	0.00095	0.091628	0.036073	0	0.0776
W14X176	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.3597	0.001278	0.103202	0.040413	0	0.0876
W14X193	A992Fy50	Steel I/Wide Flange	Blue	0.3944	0.001678	0.115741	0.044898	0	0.0958
W14X211	A992Fy50	Steel I/Wide Flange	Green	0.4306	0.002151	0.128279	0.049672	0	0.1068
W14X22	A992Fy50	Steel I/Wide Flange	Cyan	0.0451	1E-05	0.009597	0.000338	0	0.0219
W14X233	A992Fy50	Steel I/Wide Flange	Cyan	0.4757	0.002869	0.145158	0.055459	0	0.1189
W14X257	A992Fy50	Steel I/Wide Flange	Red	0.525	0.003815	0.163966	0.062211	0	0.1344
W14X26	A992Fy50	Steel I/Wide Flange	Red	0.0534	1.7E-05	0.011815	0.00043	0	0.0246
W14X283	A992Fy50	Steel I/Wide Flange	Magenta	0.5785	0.005015	0.185185	0.069444	0	0.1496
W14X30	A992Fy50	Steel I/Wide Flange	Magenta	0.0615	1.8E-05	0.014034	0.000945	0	0.0259
W14X311	A992Fy50	Steel I/Wide Flange	Yellow	0.6347	0.006559	0.208816	0.077643	0	0.1674
W14X34	A992Fy50	Steel I/Wide Flange	Yellow	0.0694	2.7E-05	0.016397	0.001124	0	0.0277
W14X342	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.7014	0.008584	0.236304	0.087288	0	0.1872
W14X370	A992Fy50	Steel I/Wide Flange	Blue	0.7569	0.010706	0.262346	0.095968	0	0.2063
W14X38	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0778	3.8E-05	0.018567	0.001288	0	0.0304
W14X398	A992Fy50	Steel I/Wide Flange	Green	0.8125	0.013166	0.289352	0.104649	0	0.2249
W14X426	A992Fy50	Steel I/Wide Flange	Cyan	0.8681	0.015963	0.318287	0.113812	0	0.2441
W14X43	A992Fy50	Steel I/Wide Flange	Blue	0.0875	5.1E-05	0.02064	0.00218	0	0.029
W14X455	A992Fy50	Steel I/Wide Flange	Red	0.9306	0.019049	0.34674	0.123457	0	0.2665
W14X48	A992Fy50	Steel I/Wide Flange	Green	0.0979	7E-05	0.023341	0.002479	0	0.0326
W14X500	A992Fy50	Steel I/Wide Flange	Red	1.0208	0.024788	0.39593	0.138889	0	0.2981
W14X53	A992Fy50	Steel I/Wide Flange	Cyan	0.1083	9.4E-05	0.02609	0.002783	0	0.0357
W14X550	A992Fy50	Steel I/Wide Flange	Magenta	1.125	0.032263	0.454765	0.156732	0	0.3339
W14X605	A992Fy50	Steel I/Wide Flange	Yellow	1.2361	0.041908	0.520833	0.177469	0	0.3774
W14X61	A992Fy50	Steel I/Wide Flange	Red	0.1243	0.000106	0.030864	0.00516	0	0.0362
W14X665	A992Fy50	Steel I/Wide Flange	Gray8Dark	1.3611	0.054012	0.597994	0.2011	0	0.4245
W14X68	A992Fy50	Steel I/Wide Flange	Magenta	0.1389	0.000145	0.034819	0.005835	0	0.0403
W14X730	A992Fy50	Steel I/Wide Flange	Blue	1.4931	0.069927	0.689622	0.227623	0	0.4776
W14X74	A992Fy50	Steel I/Wide Flange	Yellow	0.1514	0.000187	0.038339	0.006462	0	0.0444
W14X82	A992Fy50	Steel I/Wide Flange	Yellow	0.1667	0.000245	0.042486	0.007137	0	0.0506
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.184	0.000196	0.048177	0.017458	0	0.0428
W14X99	A992Fy50	Steel I/Wide Flange	Blue	0.2021	0.000259	0.05353	0.019387	0	0.0478
W24X94	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1924	0.000254	0.130208	0.005257	0	0.0869
W8X10	A992Fy50	Steel I/Wide Flange	Green	0.0206	2E-06	0.001485	0.000101	0	0.0093
W8X13	A992Fy50	Steel I/Wide Flange	Cyan	0.0267	4E-06	0.00191	0.000132	0	0.0128
W8X15	A992Fy50	Steel I/Wide Flange	Red	0.0308	7E-06	0.002315	0.000164	0	0.0138

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W8X18	A992Fy50	Steel I/Wide Flange	Magenta	0.0365	8E-06	0.002985	0.000384	0	0.013
W8X21	A992Fy50	Steel I/Wide Flange	Yellow	0.0428	1.4E-05	0.003631	0.000471	0	0.0144
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0492	1.7E-05	0.003988	0.000883	0	0.0135
W8X28	A992Fy50	Steel I/Wide Flange	Blue	0.0573	2.6E-05	0.004726	0.001046	0	0.016
W8X31	A992Fy50	Steel I/Wide Flange	Green	0.0634	2.6E-05	0.005305	0.001789	0	0.0158
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	0.0715	3.7E-05	0.006125	0.002054	0	0.0175
W8X40	A992Fy50	Steel I/Wide Flange	Red	0.0813	5.4E-05	0.007041	0.002368	0	0.0206
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	0.0979	9.5E-05	0.008873	0.002937	0	0.0236
W8X58	A992Fy50	Steel I/Wide Flange	Magenta	0.1188	0.000161	0.010995	0.003622	0	0.031
W8X67	A992Fy50	Steel I/Wide Flange	Yellow	0.1368	0.000244	0.013117	0.004273	0	0.0356

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 4)

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
ASColPn$_{T4\text{-}1}$											
W10X100	0.1335	0.064961	0.064961	0.023261	0.023261	0.075231	0.035301	0.38426	0.2215	0.001701	0.04167
W10X112	0.1505	0.072693	0.072693	0.026264	0.026264	0.085069	0.040046	0.38876	0.22319	0.002021	0.04167
W10X12	0.0096	0.006309	0.006309	0.000637	0.000637	0.007292	0.001007	0.32487	0.0654	1.7E-05	0.025
W10X15	0.0125	0.007983	0.007983	0.000836	0.000836	0.009259	0.001331	0.32939	0.06746	2.3E-05	0.025
W10X17	0.0153	0.009385	0.009385	0.001028	0.001028	0.010822	0.00162	0.33761	0.07039	2.8E-05	0.025
W10X19	0.0184	0.010927	0.010927	0.001235	0.001235	0.0125	0.001939	0.34496	0.07281	3.4E-05	0.025
W10X22	0.024	0.01339	0.01339	0.002295	0.002295	0.015046	0.00353	0.35533	0.11045	9.2E-05	0.025
W10X26	0.0294	0.016181	0.016181	0.002828	0.002828	0.018113	0.00434	0.3625	0.11343	0.000115	0.025
W10X30	0.0343	0.018739	0.018739	0.003327	0.003327	0.021181	0.005116	0.36544	0.11454	0.000139	0.025
W10X33	0.0401	0.020341	0.020341	0.005322	0.005322	0.022454	0.008102	0.34971	0.16179	0.000265	0.04167
W10X39	0.049	0.024385	0.024385	0.006519	0.006519	0.027083	0.009954	0.35526	0.16485	0.000333	0.04167
W10X45	0.0576	0.02842	0.02842	0.007706	0.007706	0.031771	0.011748	0.35985	0.16698	0.000401	0.04167
W10X49	0.0648	0.031481	0.031481	0.01081	0.01081	0.034954	0.016377	0.36218	0.21223	0.000696	0.04167
W10X54	0.0712	0.034722	0.034722	0.011921	0.011921	0.038542	0.018113	0.36493	0.21277	0.000772	0.04208
W10X60	0.0795	0.038694	0.038694	0.013293	0.013293	0.043171	0.020255	0.36577	0.21333	0.000886	0.04167
W10X68	0.09	0.043848	0.043848	0.015356	0.015356	0.049363	0.023206	0.3708	0.21624	0.001027	0.04167
W10X77	0.1027	0.049681	0.049681	0.017475	0.017475	0.056481	0.026563	0.37309	0.21705	0.00122	0.04167
W10X88	0.118	0.057227	0.057227	0.020114	0.020114	0.065394	0.030729	0.37766	0.21865	0.001453	0.04167
W12X106	0.1398	0.08371	0.08371	0.028556	0.028556	0.094907	0.043461	0.4557	0.25884	0.003558	0.05
W12X120	0.158	0.094536	0.094536	0.032464	0.032464	0.107639	0.049421	0.45945	0.26089	0.004144	0.04917
W12X136	0.1794	0.107103	0.107103	0.037149	0.037149	0.123843	0.056713	0.46456	0.26319	0.004909	0.05
W12X14	0.0103	0.008617	0.008617	0.000688	0.000688	0.010069	0.0011	0.38458	0.06277	2.7E-05	0.025
W12X152	0.2025	0.12081	0.12081	0.042037	0.042037	0.140625	0.064236	0.47134	0.26558	0.005773	0.05
W12X16	0.0122	0.009934	0.009934	0.000818	0.000818	0.011632	0.001308	0.3897	0.06448	3.2E-05	0.025
W12X170	0.2275	0.136409	0.136409	0.04749	0.04749	0.159144	0.072917	0.47871	0.26797	0.006739	0.05
W12X19	0.0162	0.012333	0.012333	0.001085	0.001085	0.014294	0.001725	0.40259	0.06847	4.4E-05	0.025
W12X190	0.2558	0.15191	0.15191	0.053678	0.053678	0.179977	0.082755	0.48412	0.27026	0.007971	0.04917
W12X210	0.2815	0.168493	0.168493	0.060041	0.060041	0.201389	0.092014	0.49038	0.27315	0.00911	0.05
W12X22	0.0198	0.014679	0.014679	0.001338	0.001338	0.016956	0.002118	0.40888	0.07067	5.5E-05	0.025
W12X230	0.3091	0.185492	0.185492	0.066573	0.066573	0.22338	0.102431	0.49823	0.27588	0.010528	0.05
W12X252	0.3385	0.204425	0.204425	0.073718	0.073718	0.247685	0.113426	0.50489	0.27856	0.011928	0.05
W12X26	0.0285	0.019353	0.019353	0.003085	0.003085	0.021528	0.004728	0.43033	0.12532	0.000203	0.025
W12X279	0.3745	0.226386	0.226386	0.082786	0.082786	0.278356	0.127315	0.51352	0.28187	0.013975	0.05
W12X30	0.0332	0.022395	0.022395	0.003604	0.003604	0.024942	0.005532	0.43362	0.12664	0.000239	0.025
W12X305	0.414	0.252073	0.252073	0.092066	0.092066	0.310764	0.141204	0.52483	0.28543	0.016063	0.04917
W12X336	0.4591	0.279707	0.279707	0.102785	0.102785	0.348958	0.158565	0.53393	0.28906	0.019036	0.04917

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W12X35	0.0395	0.026389	0.026389	0.004323	0.004323	0.02963	0.006655	0.43835	0.12852	0.000294	0.025
W12X40	0.0477	0.029859	0.029859	0.006372	0.006372	0.032986	0.009722	0.42687	0.16179	0.000479	0.04208
W12X45	0.0536	0.033287	0.033287	0.007189	0.007189	0.037153	0.010995	0.42951	0.16281	0.000556	0.04208
W12X50	0.0599	0.037094	0.037094	0.008065	0.008065	0.041609	0.012326	0.43125	0.16364	0.00063	0.04167
W12X53	0.0666	0.040653	0.040653	0.011088	0.011088	0.045081	0.01684	0.43496	0.20651	0.001066	0.05042
W12X58	0.0741	0.045063	0.045063	0.012384	0.012384	0.05	0.018808	0.4405	0.20907	0.001193	0.05
W12X65	0.084	0.050983	0.050983	0.016782	0.016782	0.056019	0.025521	0.44022	0.25152	0.001928	0.04958
W12X72	0.0931	0.056177	0.056177	0.018808	0.018808	0.0625	0.028472	0.44327	0.25333	0.002185	0.05
W12X79	0.1029	0.061791	0.061791	0.020661	0.020661	0.068866	0.031424	0.44515	0.25427	0.002472	0.04958
W12X87	0.1134	0.068519	0.068519	0.023052	0.023052	0.076389	0.034954	0.44804	0.25569	0.002736	0.05
W12X96	0.1271	0.075915	0.075915	0.025615	0.025615	0.085069	0.039063	0.45292	0.25786	0.003175	0.05
W14X109	0.1453	0.100363	0.100363	0.035436	0.035436	0.111111	0.053646	0.51875	0.31146	0.006746	0.05
W14X120	0.1599	0.110153	0.110153	0.038974	0.038974	0.122685	0.059028	0.52104	0.31206	0.007661	0.05
W14X132	0.1752	0.120465	0.120465	0.043147	0.043147	0.135417	0.065394	0.5233	0.31318	0.008532	0.05
W14X145	0.1955	0.133727	0.133727	0.050553	0.050553	0.150463	0.076968	0.52735	0.33182	0.010646	0.05
W14X159	0.2149	0.146605	0.146605	0.055496	0.055496	0.166088	0.084491	0.53154	0.33351	0.012023	0.05
W14X176	0.238	0.162951	0.162951	0.061778	0.061778	0.185185	0.094329	0.53562	0.33518	0.013648	0.05
W14X193	0.2617	0.179211	0.179211	0.068634	0.068634	0.20544	0.104167	0.54169	0.33738	0.015372	0.05
W14X211	0.2853	0.196096	0.196096	0.075451	0.075451	0.225694	0.114583	0.54584	0.33966	0.017167	0.05
W14X22	0.0194	0.016812	0.016812	0.00162	0.00162	0.019213	0.002541	0.46145	0.08655	0.000104	0.03333
W14X233	0.3165	0.217737	0.217737	0.083712	0.083712	0.252315	0.127894	0.5524	0.34145	0.019673	0.05
W14X257	0.35	0.23995	0.23995	0.093316	0.093316	0.281829	0.142361	0.55885	0.34423	0.022744	0.05
W14X26	0.0245	0.0204	0.0204	0.00205	0.00205	0.023264	0.003206	0.47037	0.0897	0.000136	0.03333
W14X283	0.3857	0.266134	0.266134	0.10352	0.10352	0.313657	0.158565	0.5658	0.34648	0.025801	0.05
W14X30	0.03	0.024406	0.024406	0.003371	0.003371	0.027373	0.005203	0.47785	0.12402	0.000295	0.03333
W14X311	0.4238	0.293074	0.293074	0.115026	0.115026	0.348958	0.175926	0.57357	0.34975	0.029527	0.05
W14X34	0.0355	0.028108	0.028108	0.003995	0.003995	0.031597	0.006134	0.48591	0.1272	0.000358	0.03333
W14X342	0.4688	0.324074	0.324074	0.127738	0.127738	0.388889	0.195602	0.58044	0.35277	0.034344	0.05
W14X370	0.508	0.351748	0.351748	0.13959	0.13959	0.425926	0.21412	0.58871	0.35607	0.038726	0.05
W14X38	0.0404	0.031603	0.031603	0.004565	0.004565	0.03559	0.007002	0.48859	0.12867	0.000412	0.03333
W14X398	0.5476	0.379478	0.379478	0.1513	0.1513	0.463542	0.232639	0.59676	0.35889	0.043424	0.04917
W14X426	0.5876	0.408497	0.408497	0.163562	0.163562	0.502894	0.251157	0.60553	0.36209	0.048452	0.04917
W14X43	0.0491	0.036158	0.036158	0.006539	0.006539	0.040278	0.010012	0.48569	0.15783	0.000657	0.04917
W14X455	0.6242	0.437987	0.437987	0.176367	0.176367	0.541667	0.270833	0.61042	0.36424	0.052954	0.05
W14X48	0.0553	0.040593	0.040593	0.007409	0.007409	0.04537	0.011343	0.48824	0.15911	0.00075	0.04958
W14X500	0.6887	0.484812	0.484812	0.196078	0.196078	0.607639	0.302083	0.62278	0.36886	0.062197	0.05
W14X53	0.0616	0.045047	0.045047	0.008286	0.008286	0.050405	0.012731	0.49074	0.16027	0.000845	0.04917
W14X550	0.7605	0.540314	0.540314	0.218696	0.218696	0.68287	0.337384	0.6358	0.37325	0.072774	0.05
W14X605	0.8378	0.598086	0.598086	0.244785	0.244785	0.763889	0.377315	0.64911	0.37891	0.085695	0.05
W14X61	0.0747	0.053291	0.053291	0.012384	0.012384	0.059028	0.018981	0.49829	0.20374	0.001581	0.04958
W14X665	0.926	0.664438	0.664438	0.272677	0.272677	0.856481	0.422454	0.66283	0.38438	0.102032	0.05
W14X68	0.0833	0.059689	0.059689	0.014005	0.014005	0.066551	0.021354	0.50069	0.20497	0.001772	0.04917
W14X730	1.0172	0.738881	0.738881	0.305193	0.305193	0.960648	0.472222	0.67962	0.39045	0.120205	0.05
W14X74	0.0918	0.064798	0.064798	0.015356	0.015356	0.072917	0.023438	0.50324	0.20661	0.002031	0.04958
W14X82	0.0999	0.071306	0.071306	0.01696	0.01696	0.08044	0.025926	0.5049	0.20694	0.002222	0.04958
W14X90	0.1192	0.082589	0.082589	0.028895	0.028895	0.090856	0.04375	0.51166	0.308	0.005335	0.05
W14X99	0.1318	0.090473	0.090473	0.031868	0.031868	0.100116	0.04838	0.51468	0.30973	0.0061	0.05
W24X94	0.0919	0.128601	0.128601	0.013909	0.013909	0.146991	0.021701	0.82274	0.16531	0.004999	0.04208
W8X10	0.0093	0.004518	0.004518	0.000614	0.000614	0.005133	0.000961	0.26881	0.07002	1E-05	0.025
W8X13	0.0118	0.005736	0.005736	0.00079	0.00079	0.006597	0.001244	0.26761	0.07026	1.4E-05	0.025
W8X15	0.0146	0.00685	0.00685	0.000983	0.000983	0.00787	0.001545	0.274	0.07303	1.7E-05	0.025
W8X18	0.0201	0.008801	0.008801	0.001757	0.001757	0.009838	0.002697	0.28587	0.10258	4.1E-05	0.025
W8X21	0.0244	0.010526	0.010526	0.002146	0.002146	0.011806	0.003293	0.29136	0.10495	5.1E-05	0.025

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W8X24	0.0301	0.01207	0.01207	0.003259	0.003259	0.013368	0.004959	0.28481	0.13398	8.7E-05	0.03283
W8X28	0.0352	0.014073	0.014073	0.00384	0.00384	0.015741	0.005845	0.28721	0.13515	0.000105	0.03283
W8X31	0.0403	0.015914	0.015914	0.005367	0.005367	0.017593	0.00816	0.28925	0.16798	0.000178	0.03283
W8X35	0.0459	0.018102	0.018102	0.006148	0.006148	0.020081	0.009317	0.29262	0.16947	0.000207	0.03283
W8X40	0.0523	0.020483	0.020483	0.007042	0.007042	0.023032	0.010706	0.29438	0.17071	0.000243	0.03283
W8X48	0.0643	0.025054	0.025054	0.008691	0.008691	0.028356	0.013252	0.30104	0.17319	0.000311	0.03292
W8X58	0.0771	0.030159	0.030159	0.010574	0.010574	0.034606	0.016146	0.30429	0.17464	0.000396	0.0325
W8X67	0.0896	0.034979	0.034979	0.012385	0.012385	0.040567	0.018924	0.30965	0.17673	0.000482	0.03292

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 4)

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
ASColPn$_{T4-1}$										
W10X100	0	0	0	0			1	1	1	1
W10X112	0	0	0	0			1	1	1	1
W10X12	0	0	0	0			1	1	1	1
W10X15	0	0	0	0			1	1	1	1
W10X17	0	0	0	0			1	1	1	1
W10X19	0	0	0	0			1	1	1	1
W10X22	0	0	0	0			1	1	1	1
W10X26	0	0	0	0			1	1	1	1
W10X30	0	0	0	0			1	1	1	1
W10X33	0	0	0	0			1	1	1	1
W10X39	0	0	0	0			1	1	1	1
W10X45	0	0	0	0			1	1	1	1
W10X49	0	0	0	0			1	1	1	1
W10X54	0	0	0	0			1	1	1	1
W10X60	0	0	0	0			1	1	1	1
W10X68	0	0	0	0			1	1	1	1
W10X77	0	0	0	0			1	1	1	1
W10X88	0	0	0	0			1	1	1	1
W12X106	0	0	0	0			1	1	1	1
W12X120	0	0	0	0			1	1	1	1
W12X136	0	0	0	0			1	1	1	1
W12X14	0	0	0	0			1	1	1	1
W12X152	0	0	0	0			1	1	1	1
W12X16	0	0	0	0			1	1	1	1
W12X170	0	0	0	0			1	1	1	1
W12X19	0	0	0	0			1	1	1	1
W12X190	0	0	0	0			1	1	1	1
W12X210	0	0	0	0			1	1	1	1
W12X22	0	0	0	0			1	1	1	1
W12X230	0	0	0	0			1	1	1	1
W12X252	0	0	0	0			1	1	1	1
W12X26	0	0	0	0			1	1	1	1
W12X279	0	0	0	0			1	1	1	1
W12X30	0	0	0	0			1	1	1	1
W12X305	0	0	0	0			1	1	1	1
W12X336	0	0	0	0			1	1	1	1
W12X35	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W12X40	0	0	0	0			1	1	1	1
W12X45	0	0	0	0			1	1	1	1
W12X50	0	0	0	0			1	1	1	1
W12X53	0	0	0	0			1	1	1	1
W12X58	0	0	0	0			1	1	1	1
W12X65	0	0	0	0			1	1	1	1
W12X72	0	0	0	0			1	1	1	1
W12X79	0	0	0	0			1	1	1	1
W12X87	0	0	0	0			1	1	1	1
W12X96	0	0	0	0			1	1	1	1
W14X109	0	0	0	0			1	1	1	1
W14X120	0	0	0	0			1	1	1	1
W14X132	0	0	0	0			1	1	1	1
W14X145	0	0	0	0			1	1	1	1
W14X159	0	0	0	0			1	1	1	1
W14X176	0	0	0	0			1	1	1	1
W14X193	0	0	0	0			1	1	1	1
W14X211	0	0	0	0			1	1	1	1
W14X22	0	0	0	0			1	1	1	1
W14X233	0	0	0	0			1	1	1	1
W14X257	0	0	0	0			1	1	1	1
W14X26	0	0	0	0			1	1	1	1
W14X283	0	0	0	0			1	1	1	1
W14X30	0	0	0	0			1	1	1	1
W14X311	0	0	0	0			1	1	1	1
W14X34	0	0	0	0			1	1	1	1
W14X342	0	0	0	0			1	1	1	1
W14X370	0	0	0	0			1	1	1	1
W14X38	0	0	0	0			1	1	1	1
W14X398	0	0	0	0			1	1	1	1
W14X426	0	0	0	0			1	1	1	1
W14X43	0	0	0	0			1	1	1	1
W14X455	0	0	0	0			1	1	1	1
W14X48	0	0	0	0			1	1	1	1
W14X500	0	0	0	0			1	1	1	1
W14X53	0	0	0	0			1	1	1	1
W14X550	0	0	0	0			1	1	1	1
W14X605	0	0	0	0			1	1	1	1
W14X61	0	0	0	0			1	1	1	1
W14X665	0	0	0	0			1	1	1	1
W14X68	0	0	0	0			1	1	1	1
W14X730	0	0	0	0			1	1	1	1
W14X74	0	0	0	0			1	1	1	1
W14X82	0	0	0	0			1	1	1	1
W14X90	0	0	0	0			1	1	1	1
W14X99	0	0	0	0			1	1	1	1
W24X94	0	0	0	0			1	1	1	1
W8X10	0	0	0	0			1	1	1	1
W8X13	0	0	0	0			1	1	1	1
W8X15	0	0	0	0			1	1	1	1
W8X18	0	0	0	0			1	1	1	1
W8X21	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W8X24	0	0	0	0			1	1	1	1
W8X28	0	0	0	0			1	1	1	1
W8X31	0	0	0	0			1	1	1	1
W8X35	0	0	0	0			1	1	1	1
W8X40	0	0	0	0			1	1	1	1
W8X48	0	0	0	0			1	1	1	1
W8X58	0	0	0	0			1	1	1	1
W8X67	0	0	0	0			1	1	1	1

Table 2.2 - Frame Section Property Definitions - Summary (Part 4 of 4)

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
$ASColPn_{T4\text{-}1}$				
W10X100	1	1	1	1
W10X112	1	1	1	1
W10X12	1	1	1	1
W10X15	1	1	1	1
W10X17	1	1	1	1
W10X19	1	1	1	1
W10X22	1	1	1	1
W10X26	1	1	1	1
W10X30	1	1	1	1
W10X33	1	1	1	1
W10X39	1	1	1	1
W10X45	1	1	1	1
W10X49	1	1	1	1
W10X54	1	1	1	1
W10X60	1	1	1	1
W10X68	1	1	1	1
W10X77	1	1	1	1
W10X88	1	1	1	1
W12X106	1	1	1	1
W12X120	1	1	1	1
W12X136	1	1	1	1
W12X14	1	1	1	1
W12X152	1	1	1	1
W12X16	1	1	1	1
W12X170	1	1	1	1
W12X19	1	1	1	1
W12X190	1	1	1	1
W12X210	1	1	1	1
W12X22	1	1	1	1
W12X230	1	1	1	1
W12X252	1	1	1	1
W12X26	1	1	1	1
W12X279	1	1	1	1
W12X30	1	1	1	1
W12X305	1	1	1	1
W12X336	1	1	1	1
W12X35	1	1	1	1
W12X40	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X45	1	1	1	1
W12X50	1	1	1	1
W12X53	1	1	1	1
W12X58	1	1	1	1
W12X65	1	1	1	1
W12X72	1	1	1	1
W12X79	1	1	1	1
W12X87	1	1	1	1
W12X96	1	1	1	1
W14X109	1	1	1	1
W14X120	1	1	1	1
W14X132	1	1	1	1
W14X145	1	1	1	1
W14X159	1	1	1	1
W14X176	1	1	1	1
W14X193	1	1	1	1
W14X211	1	1	1	1
W14X22	1	1	1	1
W14X233	1	1	1	1
W14X257	1	1	1	1
W14X26	1	1	1	1
W14X283	1	1	1	1
W14X30	1	1	1	1
W14X311	1	1	1	1
W14X34	1	1	1	1
W14X342	1	1	1	1
W14X370	1	1	1	1
W14X38	1	1	1	1
W14X398	1	1	1	1
W14X426	1	1	1	1
W14X43	1	1	1	1
W14X455	1	1	1	1
W14X48	1	1	1	1
W14X500	1	1	1	1
W14X53	1	1	1	1
W14X550	1	1	1	1
W14X605	1	1	1	1
W14X61	1	1	1	1
W14X665	1	1	1	1
W14X68	1	1	1	1
W14X730	1	1	1	1
W14X74	1	1	1	1
W14X82	1	1	1	1
W14X90	1	1	1	1
W14X99	1	1	1	1
W24X94	1	1	1	1
W8X10	1	1	1	1
W8X13	1	1	1	1
W8X15	1	1	1	1
W8X18	1	1	1	1
W8X21	1	1	1	1
W8X24	1	1	1	1
W8X28	1	1	1	1
W8X31	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W8X35	1	1	1	1
W8X40	1	1	1	1
W8X48	1	1	1	1
W8X58	1	1	1	1
W8X67	1	1	1	1

2.3 Shell Sections

Table 2.3 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-4	Wall	Shell-Thin	4000Psi	1		

2.4 Reinforcement Sizes

Table 2.4 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
Dead	No	Dead	1	
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=127 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Basement

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

$z_{g=1200}$

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1] Kz=2.01(<z>/<zg>)$^{<<2>/<α>>}$ for 15ft ≤ z ≤ $<z_g>$

	Kz=2.01(<15>/<zg>)$^{<<2>/<\alpha>>}$ for z < 15ft
Topographical Factor, K_{zt} [ASCE 26.8.2]	
Directionality Factor, K_d [ASCE 26.6]	
Gust Effect Factor, G [ASCE 26.9]	

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1]	<qz>=0.00256<Kz><Kzt><Kd><V$^{2>}$
Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2]	p=qG<Cp,wind>+<qh><(G<$C_{p,lee>}$)>

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	
UDStlS6			LLred	1	
UDStlS6			Wind	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS7			Wind	-1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS8			Wind	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS9			Wind	-1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS10			Wind	0.5	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	
UDStlS11			Wind	-0.5	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS12			Wind	0.5	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS13			Wind	-0.5	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS14			Wind	1	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS15			Wind	-1	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	

Appendix B-3.18: Large, steel, high wind

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 4)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
ASColPn$_{T4-1}$		Auto Select							
W10X100	A992Fy50	Steel I/Wide Flange	Green	0.2035	0.000526	0.030044	0.009983	0	0.0524
W10X112	A992Fy50	Steel I/Wide Flange	Cyan	0.2285	0.000728	0.034529	0.011381	0	0.0598
W10X12	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0246	3E-06	0.002595	0.000105	0	0.013
W10X15	A992Fy50	Steel I/Wide Flange	Blue	0.0306	5E-06	0.003323	0.000139	0	0.016
W10X17	A992Fy50	Steel I/Wide Flange	Green	0.0347	8E-06	0.00395	0.000172	0	0.0168
W10X19	A992Fy50	Steel I/Wide Flange	Cyan	0.039	1.1E-05	0.004644	0.000207	0	0.0177
W10X22	A992Fy50	Steel I/Wide Flange	Red	0.0451	1.2E-05	0.005691	0.00055	0	0.017
W10X26	A992Fy50	Steel I/Wide Flange	Magenta	0.0528	1.9E-05	0.006944	0.00068	0	0.0186
W10X30	A992Fy50	Steel I/Wide Flange	Yellow	0.0614	3E-05	0.008198	0.000805	0	0.0219
W10X33	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0674	2.8E-05	0.008247	0.001765	0	0.0196
W10X39	A992Fy50	Steel I/Wide Flange	Blue	0.0799	4.7E-05	0.010079	0.00217	0	0.0217
W10X45	A992Fy50	Steel I/Wide Flange	Green	0.0924	7.3E-05	0.01196	0.002575	0	0.0245
W10X49	A992Fy50	Steel I/Wide Flange	Cyan	0.1	6.7E-05	0.013117	0.004504	0	0.0236
W10X54	A992Fy50	Steel I/Wide Flange	Red	0.1097	8.8E-05	0.014612	0.004967	0	0.026
W10X60	A992Fy50	Steel I/Wide Flange	Magenta	0.1229	0.00012	0.016445	0.005594	0	0.0298
W10X68	A992Fy50	Steel I/Wide Flange	Yellow	0.1382	0.000172	0.019001	0.006462	0	0.0339
W10X77	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1576	0.000246	0.021943	0.007427	0	0.039
W10X88	A992Fy50	Steel I/Wide Flange	Blue	0.1806	0.000363	0.025752	0.008632	0	0.0454
W12X106	A992Fy50	Steel I/Wide Flange	Yellow	0.2167	0.00044	0.044994	0.014516	0	0.0546
W12X120	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.2444	0.000622	0.051601	0.016638	0	0.0646
W12X136	A992Fy50	Steel I/Wide Flange	Blue	0.2771	0.000892	0.059799	0.019194	0	0.0735
W12X14	A992Fy50	Steel I/Wide Flange	Cyan	0.0289	3E-06	0.004273	0.000114	0	0.0165
W12X152	A992Fy50	Steel I/Wide Flange	Blue	0.3104	0.001244	0.068962	0.021894	0	0.0828
W12X16	A992Fy50	Steel I/Wide Flange	Red	0.0327	5E-06	0.004967	0.000136	0	0.0183
W12X170	A992Fy50	Steel I/Wide Flange	Green	0.3472	0.001717	0.079572	0.024932	0	0.0933
W12X19	A992Fy50	Steel I/Wide Flange	Magenta	0.0387	9E-06	0.006269	0.000181	0	0.0199
W12X190	A992Fy50	Steel I/Wide Flange	Cyan	0.3889	0.002353	0.091146	0.028405	0	0.106
W12X210	A992Fy50	Steel I/Wide Flange	Red	0.4292	0.00312	0.103202	0.032022	0	0.1205
W12X22	A992Fy50	Steel I/Wide Flange	Yellow	0.045	1.4E-05	0.007523	0.000225	0	0.0222
W12X230	A992Fy50	Steel I/Wide Flange	Magenta	0.4701	0.004041	0.116705	0.035783	0	0.1353
W12X252	A992Fy50	Steel I/Wide Flange	Yellow	0.5146	0.005208	0.131173	0.039931	0	0.1497
W12X26	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0531	1.4E-05	0.009838	0.000834	0	0.0195
W12X279	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.5688	0.006896	0.149981	0.045187	0	0.1689

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W12X30	A992Fy50	Steel I/Wide Flange	Blue	0.061	2.2E-05	0.011478	0.000979	0	0.0222
W12X305	A992Fy50	Steel I/Wide Flange	Blue	0.6215	0.008922	0.1712	0.050637	0	0.1845
W12X336	A992Fy50	Steel I/Wide Flange	Green	0.6868	0.011719	0.195795	0.057388	0	0.2077
W12X35	A992Fy50	Steel I/Wide Flange	Green	0.0715	3.6E-05	0.013744	0.001182	0	0.026
W12X40	A992Fy50	Steel I/Wide Flange	Cyan	0.0813	4.4E-05	0.014805	0.002127	0	0.0244
W12X45	A992Fy50	Steel I/Wide Flange	Red	0.091	6.1E-05	0.016782	0.002411	0	0.0281
W12X50	A992Fy50	Steel I/Wide Flange	Magenta	0.1014	8.2E-05	0.018856	0.002715	0	0.0313
W12X53	A992Fy50	Steel I/Wide Flange	Yellow	0.1083	7.6E-05	0.020496	0.00462	0	0.029
W12X58	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1181	0.000101	0.022907	0.00516	0	0.0305
W12X65	A992Fy50	Steel I/Wide Flange	Blue	0.1326	0.000105	0.025704	0.008391	0	0.0328
W12X72	A992Fy50	Steel I/Wide Flange	Green	0.1465	0.000141	0.028791	0.009404	0	0.0367
W12X79	A992Fy50	Steel I/Wide Flange	Cyan	0.1611	0.000185	0.031925	0.010417	0	0.0405
W12X87	A992Fy50	Steel I/Wide Flange	Red	0.1778	0.000246	0.035687	0.011622	0	0.0447
W12X96	A992Fy50	Steel I/Wide Flange	Magenta	0.1958	0.00033	0.040172	0.013021	0	0.0485
W14X109	A992Fy50	Steel I/Wide Flange	Green	0.2222	0.000343	0.059799	0.021557	0	0.0521
W14X120	A992Fy50	Steel I/Wide Flange	Cyan	0.2451	0.000452	0.066551	0.023872	0	0.0594
W14X132	A992Fy50	Steel I/Wide Flange	Red	0.2694	0.000593	0.073785	0.026427	0	0.0658
W14X145	A992Fy50	Steel I/Wide Flange	Magenta	0.2965	0.000733	0.082465	0.032649	0	0.0699
W14X159	A992Fy50	Steel I/Wide Flange	Yellow	0.3243	0.00095	0.091628	0.036073	0	0.0776
W14X176	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.3597	0.001278	0.103202	0.040413	0	0.0876
W14X193	A992Fy50	Steel I/Wide Flange	Blue	0.3944	0.001678	0.115741	0.044898	0	0.0958
W14X211	A992Fy50	Steel I/Wide Flange	Green	0.4306	0.002151	0.128279	0.049672	0	0.1068
W14X22	A992Fy50	Steel I/Wide Flange	Cyan	0.0451	1E-05	0.009597	0.000338	0	0.0219
W14X233	A992Fy50	Steel I/Wide Flange	Cyan	0.4757	0.002869	0.145158	0.055459	0	0.1189
W14X257	A992Fy50	Steel I/Wide Flange	Red	0.525	0.003815	0.163966	0.062211	0	0.1344
W14X26	A992Fy50	Steel I/Wide Flange	Red	0.0534	1.7E-05	0.011815	0.00043	0	0.0246
W14X283	A992Fy50	Steel I/Wide Flange	Magenta	0.5785	0.005015	0.185185	0.069444	0	0.1496
W14X30	A992Fy50	Steel I/Wide Flange	Magenta	0.0615	1.8E-05	0.014034	0.000945	0	0.0259
W14X311	A992Fy50	Steel I/Wide Flange	Yellow	0.6347	0.006559	0.208816	0.077643	0	0.1674
W14X34	A992Fy50	Steel I/Wide Flange	Yellow	0.0694	2.7E-05	0.016397	0.001124	0	0.0277
W14X342	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.7014	0.008584	0.236304	0.087288	0	0.1872
W14X370	A992Fy50	Steel I/Wide Flange	Blue	0.7569	0.010706	0.262346	0.095968	0	0.2063
W14X38	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0778	3.8E-05	0.018567	0.001288	0	0.0304
W14X398	A992Fy50	Steel I/Wide Flange	Green	0.8125	0.013166	0.289352	0.104649	0	0.2249
W14X426	A992Fy50	Steel I/Wide Flange	Cyan	0.8681	0.015963	0.318287	0.113812	0	0.2441
W14X43	A992Fy50	Steel I/Wide Flange	Blue	0.0875	5.1E-05	0.02064	0.00218	0	0.029
W14X455	A992Fy50	Steel I/Wide Flange	Red	0.9306	0.019049	0.34674	0.123457	0	0.2665
W14X48	A992Fy50	Steel I/Wide Flange	Green	0.0979	7E-05	0.023341	0.002479	0	0.0326
W14X500	A992Fy50	Steel I/Wide Flange	Red	1.0208	0.024788	0.39593	0.138889	0	0.2981
W14X53	A992Fy50	Steel I/Wide Flange	Cyan	0.1083	9.4E-05	0.02609	0.002783	0	0.0357
W14X550	A992Fy50	Steel I/Wide Flange	Magenta	1.125	0.032263	0.454765	0.156732	0	0.3339
W14X605	A992Fy50	Steel I/Wide Flange	Yellow	1.2361	0.041908	0.520833	0.177469	0	0.3774
W14X61	A992Fy50	Steel I/Wide Flange	Red	0.1243	0.000106	0.030864	0.00516	0	0.0362
W14X665	A992Fy50	Steel I/Wide Flange	Gray8Dark	1.3611	0.054012	0.597994	0.2011	0	0.4245
W14X68	A992Fy50	Steel I/Wide Flange	Magenta	0.1389	0.000145	0.034819	0.005835	0	0.0403
W14X730	A992Fy50	Steel I/Wide Flange	Blue	1.4931	0.069927	0.689622	0.227623	0	0.4776
W14X74	A992Fy50	Steel I/Wide Flange	Yellow	0.1514	0.000187	0.038339	0.006462	0	0.0444
W14X82	A992Fy50	Steel I/Wide Flange	Yellow	0.1667	0.000245	0.042486	0.007137	0	0.0506
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.184	0.000196	0.048177	0.017458	0	0.0428
W14X99	A992Fy50	Steel I/Wide Flange	Blue	0.2021	0.000259	0.05353	0.019387	0	0.0478
W24X94	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1924	0.000254	0.130208	0.005257	0	0.0869
W8X10	A992Fy50	Steel I/Wide Flange	Green	0.0206	2E-06	0.001485	0.000101	0	0.0093
W8X13	A992Fy50	Steel I/Wide Flange	Cyan	0.0267	4E-06	0.00191	0.000132	0	0.0128
W8X15	A992Fy50	Steel I/Wide Flange	Red	0.0308	7E-06	0.002315	0.000164	0	0.0138

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W8X18	A992Fy50	Steel I/Wide Flange	Magenta	0.0365	8E-06	0.002985	0.000384	0	0.013
W8X21	A992Fy50	Steel I/Wide Flange	Yellow	0.0428	1.4E-05	0.003631	0.000471	0	0.0144
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0492	1.7E-05	0.003988	0.000883	0	0.0135
W8X28	A992Fy50	Steel I/Wide Flange	Blue	0.0573	2.6E-05	0.004726	0.001046	0	0.016
W8X31	A992Fy50	Steel I/Wide Flange	Green	0.0634	2.6E-05	0.005305	0.001789	0	0.0158
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	0.0715	3.7E-05	0.006125	0.002054	0	0.0175
W8X40	A992Fy50	Steel I/Wide Flange	Red	0.0813	5.4E-05	0.007041	0.002368	0	0.0206
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	0.0979	9.5E-05	0.008873	0.002937	0	0.0236
W8X58	A992Fy50	Steel I/Wide Flange	Magenta	0.1188	0.000161	0.010995	0.003622	0	0.031
W8X67	A992Fy50	Steel I/Wide Flange	Yellow	0.1368	0.000244	0.013117	0.004273	0	0.0356

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 4)

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
ASColPn$_{T4\text{-}1}$											
W10X100	0.1335	0.064961	0.064961	0.023261	0.023261	0.075231	0.035301	0.38426	0.2215	0.001701	0.04167
W10X112	0.1505	0.072693	0.072693	0.026264	0.026264	0.085069	0.040046	0.38876	0.22319	0.002021	0.04167
W10X12	0.0096	0.006309	0.006309	0.000637	0.000637	0.007292	0.001007	0.32487	0.0654	1.7E-05	0.025
W10X15	0.0125	0.007983	0.007983	0.000836	0.000836	0.009259	0.001331	0.32939	0.06746	2.3E-05	0.025
W10X17	0.0153	0.009385	0.009385	0.001028	0.001028	0.010822	0.00162	0.33761	0.07039	2.8E-05	0.025
W10X19	0.0184	0.010927	0.010927	0.001235	0.001235	0.0125	0.001939	0.34496	0.07281	3.4E-05	0.025
W10X22	0.024	0.01339	0.01339	0.002295	0.002295	0.015046	0.00353	0.35533	0.11045	9.2E-05	0.025
W10X26	0.0294	0.016181	0.016181	0.002828	0.002828	0.018113	0.00434	0.3625	0.11343	0.000115	0.025
W10X30	0.0343	0.018739	0.018739	0.003327	0.003327	0.021181	0.005116	0.36544	0.11454	0.000139	0.025
W10X33	0.0401	0.020341	0.020341	0.005322	0.005322	0.022454	0.008102	0.34971	0.16179	0.000265	0.04167
W10X39	0.049	0.024385	0.024385	0.006519	0.006519	0.027083	0.009954	0.35526	0.16485	0.000333	0.04167
W10X45	0.0576	0.02842	0.02842	0.007706	0.007706	0.031771	0.011748	0.35985	0.16698	0.000401	0.04167
W10X49	0.0648	0.031481	0.031481	0.01081	0.01081	0.034954	0.016377	0.36218	0.21223	0.000696	0.04167
W10X54	0.0712	0.034722	0.034722	0.011921	0.011921	0.038542	0.018113	0.36493	0.21277	0.000772	0.04208
W10X60	0.0795	0.038694	0.038694	0.013293	0.013293	0.043171	0.020255	0.36577	0.21333	0.000886	0.04167
W10X68	0.09	0.043848	0.043848	0.015356	0.015356	0.049363	0.023206	0.3708	0.21624	0.001027	0.04167
W10X77	0.1027	0.049681	0.049681	0.017475	0.017475	0.056481	0.026563	0.37309	0.21705	0.00122	0.04167
W10X88	0.118	0.057227	0.057227	0.020114	0.020114	0.065394	0.030729	0.37766	0.21865	0.001453	0.04167
W12X106	0.1398	0.08371	0.08371	0.028556	0.028556	0.094907	0.043461	0.4557	0.25884	0.003558	0.05
W12X120	0.158	0.094536	0.094536	0.032464	0.032464	0.107639	0.049421	0.45945	0.26089	0.004144	0.04917
W12X136	0.1794	0.107103	0.107103	0.037149	0.037149	0.123843	0.056713	0.46456	0.26319	0.004909	0.05
W12X14	0.0103	0.008617	0.008617	0.000688	0.000688	0.010069	0.0011	0.38458	0.06277	2.7E-05	0.025
W12X152	0.2025	0.12081	0.12081	0.042037	0.042037	0.140625	0.064236	0.47134	0.26558	0.005773	0.05
W12X16	0.0122	0.009934	0.009934	0.000818	0.000818	0.011632	0.001308	0.3897	0.06448	3.2E-05	0.025
W12X170	0.2275	0.136409	0.136409	0.04749	0.04749	0.159144	0.072917	0.47871	0.26797	0.006739	0.05
W12X19	0.0162	0.012333	0.012333	0.001085	0.001085	0.014294	0.001725	0.40259	0.06847	4.4E-05	0.025
W12X190	0.2558	0.15191	0.15191	0.053678	0.053678	0.179977	0.082755	0.48412	0.27026	0.007971	0.04917
W12X210	0.2815	0.168493	0.168493	0.060041	0.060041	0.201389	0.092014	0.49038	0.27315	0.00911	0.05
W12X22	0.0198	0.014679	0.014679	0.001338	0.001338	0.016956	0.002118	0.40888	0.07067	5.5E-05	0.025
W12X230	0.3091	0.185492	0.185492	0.066573	0.066573	0.22338	0.102431	0.49823	0.27588	0.010528	0.05
W12X252	0.3385	0.204425	0.204425	0.073718	0.073718	0.247685	0.113426	0.50489	0.27856	0.011928	0.05
W12X26	0.0285	0.019353	0.019353	0.003085	0.003085	0.021528	0.004728	0.43033	0.12532	0.000203	0.025
W12X279	0.3745	0.226386	0.226386	0.082786	0.082786	0.278356	0.127315	0.51352	0.28187	0.013975	0.05
W12X30	0.0332	0.022395	0.022395	0.003604	0.003604	0.024942	0.005532	0.43362	0.12664	0.000239	0.025
W12X305	0.414	0.252073	0.252073	0.092066	0.092066	0.310764	0.141204	0.52483	0.28543	0.016063	0.04917
W12X336	0.4591	0.279707	0.279707	0.102785	0.102785	0.348958	0.158565	0.53393	0.28906	0.019036	0.04917

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W12X35	0.0395	0.026389	0.026389	0.004323	0.004323	0.02963	0.006655	0.43835	0.12852	0.000294	0.025
W12X40	0.0477	0.029859	0.029859	0.006372	0.006372	0.032986	0.009722	0.42687	0.16179	0.000479	0.04208
W12X45	0.0536	0.033287	0.033287	0.007189	0.007189	0.037153	0.010995	0.42951	0.16281	0.000556	0.04208
W12X50	0.0599	0.037094	0.037094	0.008065	0.008065	0.041609	0.012326	0.43125	0.16364	0.00063	0.04167
W12X53	0.0666	0.040653	0.040653	0.011088	0.011088	0.045081	0.01684	0.43496	0.20651	0.001066	0.05042
W12X58	0.0741	0.045063	0.045063	0.012384	0.012384	0.05	0.018808	0.4405	0.20907	0.001193	0.05
W12X65	0.084	0.050983	0.050983	0.016782	0.016782	0.056019	0.025521	0.44022	0.25152	0.001928	0.04958
W12X72	0.0931	0.056177	0.056177	0.018808	0.018808	0.0625	0.028472	0.44327	0.25333	0.002185	0.05
W12X79	0.1029	0.061791	0.061791	0.020661	0.020661	0.068866	0.031424	0.44515	0.25427	0.002472	0.04958
W12X87	0.1134	0.068519	0.068519	0.023052	0.023052	0.076389	0.034954	0.44804	0.25569	0.002736	0.05
W12X96	0.1271	0.075915	0.075915	0.025615	0.025615	0.085069	0.039063	0.45292	0.25786	0.003175	0.05
W14X109	0.1453	0.100363	0.100363	0.035436	0.035436	0.111111	0.053646	0.51875	0.31146	0.006746	0.05
W14X120	0.1599	0.110153	0.110153	0.038974	0.038974	0.122685	0.059028	0.52104	0.31206	0.007661	0.05
W14X132	0.1752	0.120465	0.120465	0.043147	0.043147	0.135417	0.065394	0.5233	0.31318	0.008532	0.05
W14X145	0.1955	0.133727	0.133727	0.050553	0.050553	0.150463	0.076968	0.52735	0.33182	0.010646	0.05
W14X159	0.2149	0.146605	0.146605	0.055496	0.055496	0.166088	0.084491	0.53154	0.33351	0.012023	0.05
W14X176	0.238	0.162951	0.162951	0.061778	0.061778	0.185185	0.094329	0.53562	0.33518	0.013648	0.05
W14X193	0.2617	0.179211	0.179211	0.068634	0.068634	0.20544	0.104167	0.54169	0.33738	0.015372	0.05
W14X211	0.2853	0.196096	0.196096	0.075451	0.075451	0.225694	0.114583	0.54584	0.33966	0.017167	0.05
W14X22	0.0194	0.016812	0.016812	0.00162	0.00162	0.019213	0.002541	0.46145	0.08655	0.000104	0.03333
W14X233	0.3165	0.217737	0.217737	0.083712	0.083712	0.252315	0.127894	0.5524	0.34145	0.019673	0.05
W14X257	0.35	0.23995	0.23995	0.093316	0.093316	0.281829	0.142361	0.55885	0.34423	0.022744	0.05
W14X26	0.0245	0.0204	0.0204	0.00205	0.00205	0.023264	0.003206	0.47037	0.0897	0.000136	0.03333
W14X283	0.3857	0.266134	0.266134	0.10352	0.10352	0.313657	0.158565	0.5658	0.34648	0.025801	0.05
W14X30	0.03	0.024406	0.024406	0.003371	0.003371	0.027373	0.005203	0.47785	0.12402	0.000295	0.03333
W14X311	0.4238	0.293074	0.293074	0.115026	0.115026	0.348958	0.175926	0.57357	0.34975	0.029527	0.05
W14X34	0.0355	0.028108	0.028108	0.003995	0.003995	0.031597	0.006134	0.48591	0.1272	0.000358	0.03333
W14X342	0.4688	0.324074	0.324074	0.127738	0.127738	0.388889	0.195602	0.58044	0.35277	0.034344	0.05
W14X370	0.508	0.351748	0.351748	0.13959	0.13959	0.425926	0.21412	0.58871	0.35607	0.038726	0.05
W14X38	0.0404	0.031603	0.031603	0.004565	0.004565	0.03559	0.007002	0.48859	0.12867	0.000412	0.03333
W14X398	0.5476	0.379478	0.379478	0.1513	0.1513	0.463542	0.232639	0.59676	0.35889	0.043424	0.04917
W14X426	0.5876	0.408497	0.408497	0.163562	0.163562	0.502894	0.251157	0.60553	0.36209	0.048452	0.04917
W14X43	0.0491	0.036158	0.036158	0.006539	0.006539	0.040278	0.010012	0.48569	0.15783	0.000657	0.04917
W14X455	0.6242	0.437987	0.437987	0.176367	0.176367	0.541667	0.270833	0.61042	0.36424	0.052954	0.05
W14X48	0.0553	0.040593	0.040593	0.007409	0.007409	0.04537	0.011343	0.48824	0.15911	0.00075	0.04958
W14X500	0.6887	0.484812	0.484812	0.196078	0.196078	0.607639	0.302083	0.62278	0.36886	0.062197	0.05
W14X53	0.0616	0.045047	0.045047	0.008286	0.008286	0.050405	0.012731	0.49074	0.16027	0.000845	0.04917
W14X550	0.7605	0.540314	0.540314	0.218696	0.218696	0.68287	0.337384	0.6358	0.37325	0.072774	0.05
W14X605	0.8378	0.598086	0.598086	0.244785	0.244785	0.763889	0.377315	0.64911	0.37891	0.085695	0.05
W14X61	0.0747	0.053291	0.053291	0.012384	0.012384	0.059028	0.018981	0.49829	0.20374	0.001581	0.04958
W14X665	0.926	0.664438	0.664438	0.272677	0.272677	0.856481	0.422454	0.66283	0.38438	0.102032	0.05
W14X68	0.0833	0.059689	0.059689	0.014005	0.014005	0.066551	0.021354	0.50069	0.20497	0.001772	0.04917
W14X730	1.0172	0.738881	0.738881	0.305193	0.305193	0.960648	0.472222	0.67962	0.39045	0.120205	0.05
W14X74	0.0918	0.064798	0.064798	0.015356	0.015356	0.072917	0.023438	0.50324	0.20661	0.002031	0.04958
W14X82	0.0999	0.071306	0.071306	0.01696	0.01696	0.08044	0.025926	0.5049	0.20694	0.002222	0.04958
W14X90	0.1192	0.082589	0.082589	0.028895	0.028895	0.090856	0.04375	0.51166	0.308	0.005335	0.05
W14X99	0.1318	0.090473	0.090473	0.031868	0.031868	0.100116	0.04838	0.51468	0.30973	0.0061	0.05
W24X94	0.0919	0.128601	0.128601	0.013909	0.013909	0.146991	0.021701	0.82274	0.16531	0.004999	0.04208
W8X10	0.0093	0.004518	0.004518	0.000614	0.000614	0.005133	0.000961	0.26881	0.07002	1E-05	0.025
W8X13	0.0118	0.005736	0.005736	0.00079	0.00079	0.006597	0.001244	0.26761	0.07026	1.4E-05	0.025
W8X15	0.0146	0.00685	0.00685	0.000983	0.000983	0.00787	0.001545	0.274	0.07303	1.7E-05	0.025
W8X18	0.0201	0.008801	0.008801	0.001757	0.001757	0.009838	0.002697	0.28587	0.10258	4.1E-05	0.025
W8X21	0.0244	0.010526	0.010526	0.002146	0.002146	0.011806	0.003293	0.29136	0.10495	5.1E-05	0.025

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W8X24	0.0301	0.01207	0.01207	0.003259	0.003259	0.013368	0.004959	0.28481	0.13398	8.7E-05	0.03283
W8X28	0.0352	0.014073	0.014073	0.00384	0.00384	0.015741	0.005845	0.28721	0.13515	0.000105	0.03283
W8X31	0.0403	0.015914	0.015914	0.005367	0.005367	0.017593	0.00816	0.28925	0.16798	0.000178	0.03283
W8X35	0.0459	0.018102	0.018102	0.006148	0.006148	0.020081	0.009317	0.29262	0.16947	0.000207	0.03283
W8X40	0.0523	0.020483	0.020483	0.007042	0.007042	0.023032	0.010706	0.29438	0.17071	0.000243	0.03283
W8X48	0.0643	0.025054	0.025054	0.008691	0.008691	0.028356	0.013252	0.30104	0.17319	0.000311	0.03292
W8X58	0.0771	0.030159	0.030159	0.010574	0.010574	0.034606	0.016146	0.30429	0.17464	0.000396	0.0325
W8X67	0.0896	0.034979	0.034979	0.012385	0.012385	0.040567	0.018924	0.30965	0.17673	0.000482	0.03292

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 4)

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
ASColPn$_{T4-1}$										
W10X100	0	0	0	0			1	1	1	1
W10X112	0	0	0	0			1	1	1	1
W10X12	0	0	0	0			1	1	1	1
W10X15	0	0	0	0			1	1	1	1
W10X17	0	0	0	0			1	1	1	1
W10X19	0	0	0	0			1	1	1	1
W10X22	0	0	0	0			1	1	1	1
W10X26	0	0	0	0			1	1	1	1
W10X30	0	0	0	0			1	1	1	1
W10X33	0	0	0	0			1	1	1	1
W10X39	0	0	0	0			1	1	1	1
W10X45	0	0	0	0			1	1	1	1
W10X49	0	0	0	0			1	1	1	1
W10X54	0	0	0	0			1	1	1	1
W10X60	0	0	0	0			1	1	1	1
W10X68	0	0	0	0			1	1	1	1
W10X77	0	0	0	0			1	1	1	1
W10X88	0	0	0	0			1	1	1	1
W12X106	0	0	0	0			1	1	1	1
W12X120	0	0	0	0			1	1	1	1
W12X136	0	0	0	0			1	1	1	1
W12X14	0	0	0	0			1	1	1	1
W12X152	0	0	0	0			1	1	1	1
W12X16	0	0	0	0			1	1	1	1
W12X170	0	0	0	0			1	1	1	1
W12X19	0	0	0	0			1	1	1	1
W12X190	0	0	0	0			1	1	1	1
W12X210	0	0	0	0			1	1	1	1
W12X22	0	0	0	0			1	1	1	1
W12X230	0	0	0	0			1	1	1	1
W12X252	0	0	0	0			1	1	1	1
W12X26	0	0	0	0			1	1	1	1
W12X279	0	0	0	0			1	1	1	1
W12X30	0	0	0	0			1	1	1	1
W12X305	0	0	0	0			1	1	1	1
W12X336	0	0	0	0			1	1	1	1
W12X35	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W12X40	0	0	0	0			1	1	1	1
W12X45	0	0	0	0			1	1	1	1
W12X50	0	0	0	0			1	1	1	1
W12X53	0	0	0	0			1	1	1	1
W12X58	0	0	0	0			1	1	1	1
W12X65	0	0	0	0			1	1	1	1
W12X72	0	0	0	0			1	1	1	1
W12X79	0	0	0	0			1	1	1	1
W12X87	0	0	0	0			1	1	1	1
W12X96	0	0	0	0			1	1	1	1
W14X109	0	0	0	0			1	1	1	1
W14X120	0	0	0	0			1	1	1	1
W14X132	0	0	0	0			1	1	1	1
W14X145	0	0	0	0			1	1	1	1
W14X159	0	0	0	0			1	1	1	1
W14X176	0	0	0	0			1	1	1	1
W14X193	0	0	0	0			1	1	1	1
W14X211	0	0	0	0			1	1	1	1
W14X22	0	0	0	0			1	1	1	1
W14X233	0	0	0	0			1	1	1	1
W14X257	0	0	0	0			1	1	1	1
W14X26	0	0	0	0			1	1	1	1
W14X283	0	0	0	0			1	1	1	1
W14X30	0	0	0	0			1	1	1	1
W14X311	0	0	0	0			1	1	1	1
W14X34	0	0	0	0			1	1	1	1
W14X342	0	0	0	0			1	1	1	1
W14X370	0	0	0	0			1	1	1	1
W14X38	0	0	0	0			1	1	1	1
W14X398	0	0	0	0			1	1	1	1
W14X426	0	0	0	0			1	1	1	1
W14X43	0	0	0	0			1	1	1	1
W14X455	0	0	0	0			1	1	1	1
W14X48	0	0	0	0			1	1	1	1
W14X500	0	0	0	0			1	1	1	1
W14X53	0	0	0	0			1	1	1	1
W14X550	0	0	0	0			1	1	1	1
W14X605	0	0	0	0			1	1	1	1
W14X61	0	0	0	0			1	1	1	1
W14X665	0	0	0	0			1	1	1	1
W14X68	0	0	0	0			1	1	1	1
W14X730	0	0	0	0			1	1	1	1
W14X74	0	0	0	0			1	1	1	1
W14X82	0	0	0	0			1	1	1	1
W14X90	0	0	0	0			1	1	1	1
W14X99	0	0	0	0			1	1	1	1
W24X94	0	0	0	0			1	1	1	1
W8X10	0	0	0	0			1	1	1	1
W8X13	0	0	0	0			1	1	1	1
W8X15	0	0	0	0			1	1	1	1
W8X18	0	0	0	0			1	1	1	1
W8X21	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W8X24	0	0	0	0			1	1	1	1
W8X28	0	0	0	0			1	1	1	1
W8X31	0	0	0	0			1	1	1	1
W8X35	0	0	0	0			1	1	1	1
W8X40	0	0	0	0			1	1	1	1
W8X48	0	0	0	0			1	1	1	1
W8X58	0	0	0	0			1	1	1	1
W8X67	0	0	0	0			1	1	1	1

Table 2.2 - Frame Section Property Definitions - Summary (Part 4 of 4)

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
$ASColPn_{T4\text{-}1}$				
W10X100	1	1	1	1
W10X112	1	1	1	1
W10X12	1	1	1	1
W10X15	1	1	1	1
W10X17	1	1	1	1
W10X19	1	1	1	1
W10X22	1	1	1	1
W10X26	1	1	1	1
W10X30	1	1	1	1
W10X33	1	1	1	1
W10X39	1	1	1	1
W10X45	1	1	1	1
W10X49	1	1	1	1
W10X54	1	1	1	1
W10X60	1	1	1	1
W10X68	1	1	1	1
W10X77	1	1	1	1
W10X88	1	1	1	1
W12X106	1	1	1	1
W12X120	1	1	1	1
W12X136	1	1	1	1
W12X14	1	1	1	1
W12X152	1	1	1	1
W12X16	1	1	1	1
W12X170	1	1	1	1
W12X19	1	1	1	1
W12X190	1	1	1	1
W12X210	1	1	1	1
W12X22	1	1	1	1
W12X230	1	1	1	1
W12X252	1	1	1	1
W12X26	1	1	1	1
W12X279	1	1	1	1
W12X30	1	1	1	1
W12X305	1	1	1	1
W12X336	1	1	1	1
W12X35	1	1	1	1
W12X40	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X45	1	1	1	1
W12X50	1	1	1	1
W12X53	1	1	1	1
W12X58	1	1	1	1
W12X65	1	1	1	1
W12X72	1	1	1	1
W12X79	1	1	1	1
W12X87	1	1	1	1
W12X96	1	1	1	1
W14X109	1	1	1	1
W14X120	1	1	1	1
W14X132	1	1	1	1
W14X145	1	1	1	1
W14X159	1	1	1	1
W14X176	1	1	1	1
W14X193	1	1	1	1
W14X211	1	1	1	1
W14X22	1	1	1	1
W14X233	1	1	1	1
W14X257	1	1	1	1
W14X26	1	1	1	1
W14X283	1	1	1	1
W14X30	1	1	1	1
W14X311	1	1	1	1
W14X34	1	1	1	1
W14X342	1	1	1	1
W14X370	1	1	1	1
W14X38	1	1	1	1
W14X398	1	1	1	1
W14X426	1	1	1	1
W14X43	1	1	1	1
W14X455	1	1	1	1
W14X48	1	1	1	1
W14X500	1	1	1	1
W14X53	1	1	1	1
W14X550	1	1	1	1
W14X605	1	1	1	1
W14X61	1	1	1	1
W14X665	1	1	1	1
W14X68	1	1	1	1
W14X730	1	1	1	1
W14X74	1	1	1	1
W14X82	1	1	1	1
W14X90	1	1	1	1
W14X99	1	1	1	1
W24X94	1	1	1	1
W8X10	1	1	1	1
W8X13	1	1	1	1
W8X15	1	1	1	1
W8X18	1	1	1	1
W8X21	1	1	1	1
W8X24	1	1	1	1
W8X28	1	1	1	1
W8X31	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W8X35	1	1	1	1
W8X40	1	1	1	1
W8X48	1	1	1	1
W8X58	1	1	1	1
W8X67	1	1	1	1

2.3 Shell Sections

Table 2.3 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-4	Wall	Shell-Thin	4000Psi	1		

2.4 Reinforcement Sizes

Table 2.4 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
Dead	No	Dead	1	
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=150 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Basement

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

Emperical Exponent, α [ASCE Table 26.9-1]

$z_{g=1200}$

Velocity Pressure Exposure Coefficient, K_z; [ASCE Table 27.3-1] Kz=2.01(<z>/<zg>)$^{<<2>/<α>>}$ for 15ft ≤ z ≤ $<z_g>$

	Kz=2.01(<15>/<zg>)$^{<<2>/<α>>}$ for z < 15ft
Topographical Factor, K_{zt} [ASCE 26.8.2]	
Directionality Factor, K_d [ASCE 26.6]	
Gust Effect Factor, G [ASCE 26.9]	

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1]	<qz>=0.00256<Kz><Kzt><Kd><V$^{2>}$
Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2]	p=qG<Cp,wind>+<qh><(G<$C_{p,lee>}$)>

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	
UDStlS6			LLred	1	
UDStlS6			Wind	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS7			Wind	-1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS8			Wind	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS9			Wind	-1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS10			Wind	0.5	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	
UDStlS11			Wind	-0.5	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS12			Wind	0.5	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS13			Wind	-0.5	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS14			Wind	1	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS15			Wind	-1	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 4)

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
ASColPn$_{T4\text{-}1}$		Auto Select							
W10X100	A992Fy50	Steel I/Wide Flange	Green	0.2035	0.000526	0.030044	0.009983	0	0.0524
W10X112	A992Fy50	Steel I/Wide Flange	Cyan	0.2285	0.000728	0.034529	0.011381	0	0.0598
W10X12	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0246	3E-06	0.002595	0.000105	0	0.013
W10X15	A992Fy50	Steel I/Wide Flange	Blue	0.0306	5E-06	0.003323	0.000139	0	0.016
W10X17	A992Fy50	Steel I/Wide Flange	Green	0.0347	8E-06	0.00395	0.000172	0	0.0168
W10X19	A992Fy50	Steel I/Wide Flange	Cyan	0.039	1.1E-05	0.004644	0.000207	0	0.0177
W10X22	A992Fy50	Steel I/Wide Flange	Red	0.0451	1.2E-05	0.005691	0.00055	0	0.017
W10X26	A992Fy50	Steel I/Wide Flange	Magenta	0.0528	1.9E-05	0.006944	0.00068	0	0.0186
W10X30	A992Fy50	Steel I/Wide Flange	Yellow	0.0614	3E-05	0.008198	0.000805	0	0.0219
W10X33	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0674	2.8E-05	0.008247	0.001765	0	0.0196
W10X39	A992Fy50	Steel I/Wide Flange	Blue	0.0799	4.7E-05	0.010079	0.00217	0	0.0217
W10X45	A992Fy50	Steel I/Wide Flange	Green	0.0924	7.3E-05	0.01196	0.002575	0	0.0245
W10X49	A992Fy50	Steel I/Wide Flange	Cyan	0.1	6.7E-05	0.013117	0.004504	0	0.0236
W10X54	A992Fy50	Steel I/Wide Flange	Red	0.1097	8.8E-05	0.014612	0.004967	0	0.026
W10X60	A992Fy50	Steel I/Wide Flange	Magenta	0.1229	0.00012	0.016445	0.005594	0	0.0298
W10X68	A992Fy50	Steel I/Wide Flange	Yellow	0.1382	0.000172	0.019001	0.006462	0	0.0339
W10X77	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1576	0.000246	0.021943	0.007427	0	0.039
W10X88	A992Fy50	Steel I/Wide Flange	Blue	0.1806	0.000363	0.025752	0.008632	0	0.0454
W12X106	A992Fy50	Steel I/Wide Flange	Yellow	0.2167	0.00044	0.044994	0.014516	0	0.0546
W12X120	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.2444	0.000622	0.051601	0.016638	0	0.0646
W12X136	A992Fy50	Steel I/Wide Flange	Blue	0.2771	0.000892	0.059799	0.019194	0	0.0735
W12X14	A992Fy50	Steel I/Wide Flange	Cyan	0.0289	3E-06	0.004273	0.000114	0	0.0165
W12X152	A992Fy50	Steel I/Wide Flange	Blue	0.3104	0.001244	0.068962	0.021894	0	0.0828
W12X16	A992Fy50	Steel I/Wide Flange	Red	0.0327	5E-06	0.004967	0.000136	0	0.0183
W12X170	A992Fy50	Steel I/Wide Flange	Green	0.3472	0.001717	0.079572	0.024932	0	0.0933
W12X19	A992Fy50	Steel I/Wide Flange	Magenta	0.0387	9E-06	0.006269	0.000181	0	0.0199
W12X190	A992Fy50	Steel I/Wide Flange	Cyan	0.3889	0.002353	0.091146	0.028405	0	0.106
W12X210	A992Fy50	Steel I/Wide Flange	Red	0.4292	0.00312	0.103202	0.032022	0	0.1205
W12X22	A992Fy50	Steel I/Wide Flange	Yellow	0.045	1.4E-05	0.007523	0.000225	0	0.0222
W12X230	A992Fy50	Steel I/Wide Flange	Magenta	0.4701	0.004041	0.116705	0.035783	0	0.1353
W12X252	A992Fy50	Steel I/Wide Flange	Yellow	0.5146	0.005208	0.131173	0.039931	0	0.1497
W12X26	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0531	1.4E-05	0.009838	0.000834	0	0.0195
W12X279	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.5688	0.006896	0.149981	0.045187	0	0.1689

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W12X30	A992Fy50	Steel I/Wide Flange	Blue	0.061	2.2E-05	0.011478	0.000979	0	0.0222
W12X305	A992Fy50	Steel I/Wide Flange	Blue	0.6215	0.008922	0.1712	0.050637	0	0.1845
W12X336	A992Fy50	Steel I/Wide Flange	Green	0.6868	0.011719	0.195795	0.057388	0	0.2077
W12X35	A992Fy50	Steel I/Wide Flange	Green	0.0715	3.6E-05	0.013744	0.001182	0	0.026
W12X40	A992Fy50	Steel I/Wide Flange	Cyan	0.0813	4.4E-05	0.014805	0.002127	0	0.0244
W12X45	A992Fy50	Steel I/Wide Flange	Red	0.091	6.1E-05	0.016782	0.002411	0	0.0281
W12X50	A992Fy50	Steel I/Wide Flange	Magenta	0.1014	8.2E-05	0.018856	0.002715	0	0.0313
W12X53	A992Fy50	Steel I/Wide Flange	Yellow	0.1083	7.6E-05	0.020496	0.00462	0	0.029
W12X58	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1181	0.000101	0.022907	0.00516	0	0.0305
W12X65	A992Fy50	Steel I/Wide Flange	Blue	0.1326	0.000105	0.025704	0.008391	0	0.0328
W12X72	A992Fy50	Steel I/Wide Flange	Green	0.1465	0.000141	0.028791	0.009404	0	0.0367
W12X79	A992Fy50	Steel I/Wide Flange	Cyan	0.1611	0.000185	0.031925	0.010417	0	0.0405
W12X87	A992Fy50	Steel I/Wide Flange	Red	0.1778	0.000246	0.035687	0.011622	0	0.0447
W12X96	A992Fy50	Steel I/Wide Flange	Magenta	0.1958	0.00033	0.040172	0.013021	0	0.0485
W14X109	A992Fy50	Steel I/Wide Flange	Green	0.2222	0.000343	0.059799	0.021557	0	0.0521
W14X120	A992Fy50	Steel I/Wide Flange	Cyan	0.2451	0.000452	0.066551	0.023872	0	0.0594
W14X132	A992Fy50	Steel I/Wide Flange	Red	0.2694	0.000593	0.073785	0.026427	0	0.0658
W14X145	A992Fy50	Steel I/Wide Flange	Magenta	0.2965	0.000733	0.082465	0.032649	0	0.0699
W14X159	A992Fy50	Steel I/Wide Flange	Yellow	0.3243	0.00095	0.091628	0.036073	0	0.0776
W14X176	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.3597	0.001278	0.103202	0.040413	0	0.0876
W14X193	A992Fy50	Steel I/Wide Flange	Blue	0.3944	0.001678	0.115741	0.044898	0	0.0958
W14X211	A992Fy50	Steel I/Wide Flange	Green	0.4306	0.002151	0.128279	0.049672	0	0.1068
W14X22	A992Fy50	Steel I/Wide Flange	Cyan	0.0451	1E-05	0.009597	0.000338	0	0.0219
W14X233	A992Fy50	Steel I/Wide Flange	Cyan	0.4757	0.002869	0.145158	0.055459	0	0.1189
W14X257	A992Fy50	Steel I/Wide Flange	Red	0.525	0.003815	0.163966	0.062211	0	0.1344
W14X26	A992Fy50	Steel I/Wide Flange	Red	0.0534	1.7E-05	0.011815	0.00043	0	0.0246
W14X283	A992Fy50	Steel I/Wide Flange	Magenta	0.5785	0.005015	0.185185	0.069444	0	0.1496
W14X30	A992Fy50	Steel I/Wide Flange	Magenta	0.0615	1.8E-05	0.014034	0.000945	0	0.0259
W14X311	A992Fy50	Steel I/Wide Flange	Yellow	0.6347	0.006559	0.208816	0.077643	0	0.1674
W14X34	A992Fy50	Steel I/Wide Flange	Yellow	0.0694	2.7E-05	0.016397	0.001124	0	0.0277
W14X342	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.7014	0.008584	0.236304	0.087288	0	0.1872
W14X370	A992Fy50	Steel I/Wide Flange	Blue	0.7569	0.010706	0.262346	0.095968	0	0.2063
W14X38	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0778	3.8E-05	0.018567	0.001288	0	0.0304
W14X398	A992Fy50	Steel I/Wide Flange	Green	0.8125	0.013166	0.289352	0.104649	0	0.2249
W14X426	A992Fy50	Steel I/Wide Flange	Cyan	0.8681	0.015963	0.318287	0.113812	0	0.2441
W14X43	A992Fy50	Steel I/Wide Flange	Blue	0.0875	5.1E-05	0.02064	0.00218	0	0.029
W14X455	A992Fy50	Steel I/Wide Flange	Red	0.9306	0.019049	0.34674	0.123457	0	0.2665
W14X48	A992Fy50	Steel I/Wide Flange	Green	0.0979	7E-05	0.023341	0.002479	0	0.0326
W14X500	A992Fy50	Steel I/Wide Flange	Red	1.0208	0.024788	0.39593	0.138889	0	0.2981
W14X53	A992Fy50	Steel I/Wide Flange	Cyan	0.1083	9.4E-05	0.02609	0.002783	0	0.0357
W14X550	A992Fy50	Steel I/Wide Flange	Magenta	1.125	0.032263	0.454765	0.156732	0	0.3339
W14X605	A992Fy50	Steel I/Wide Flange	Yellow	1.2361	0.041908	0.520833	0.177469	0	0.3774
W14X61	A992Fy50	Steel I/Wide Flange	Red	0.1243	0.000106	0.030864	0.00516	0	0.0362
W14X665	A992Fy50	Steel I/Wide Flange	Gray8Dark	1.3611	0.054012	0.597994	0.2011	0	0.4245
W14X68	A992Fy50	Steel I/Wide Flange	Magenta	0.1389	0.000145	0.034819	0.005835	0	0.0403
W14X730	A992Fy50	Steel I/Wide Flange	Blue	1.4931	0.069927	0.689622	0.227623	0	0.4776
W14X74	A992Fy50	Steel I/Wide Flange	Yellow	0.1514	0.000187	0.038339	0.006462	0	0.0444
W14X82	A992Fy50	Steel I/Wide Flange	Yellow	0.1667	0.000245	0.042486	0.007137	0	0.0506
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.184	0.000196	0.048177	0.017458	0	0.0428
W14X99	A992Fy50	Steel I/Wide Flange	Blue	0.2021	0.000259	0.05353	0.019387	0	0.0478
W24X94	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.1924	0.000254	0.130208	0.005257	0	0.0869
W8X10	A992Fy50	Steel I/Wide Flange	Green	0.0206	2E-06	0.001485	0.000101	0	0.0093
W8X13	A992Fy50	Steel I/Wide Flange	Cyan	0.0267	4E-06	0.00191	0.000132	0	0.0128
W8X15	A992Fy50	Steel I/Wide Flange	Red	0.0308	7E-06	0.002315	0.000164	0	0.0138

Name	Material	Shape	Color	Area ft2	J ft4	I33 ft4	I22 ft4	I23 ft4	As2 ft2
W8X18	A992Fy50	Steel I/Wide Flange	Magenta	0.0365	8E-06	0.002985	0.000384	0	0.013
W8X21	A992Fy50	Steel I/Wide Flange	Yellow	0.0428	1.4E-05	0.003631	0.000471	0	0.0144
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	0.0492	1.7E-05	0.003988	0.000883	0	0.0135
W8X28	A992Fy50	Steel I/Wide Flange	Blue	0.0573	2.6E-05	0.004726	0.001046	0	0.016
W8X31	A992Fy50	Steel I/Wide Flange	Green	0.0634	2.6E-05	0.005305	0.001789	0	0.0158
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	0.0715	3.7E-05	0.006125	0.002054	0	0.0175
W8X40	A992Fy50	Steel I/Wide Flange	Red	0.0813	5.4E-05	0.007041	0.002368	0	0.0206
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	0.0979	9.5E-05	0.008873	0.002937	0	0.0236
W8X58	A992Fy50	Steel I/Wide Flange	Magenta	0.1188	0.000161	0.010995	0.003622	0	0.031
W8X67	A992Fy50	Steel I/Wide Flange	Yellow	0.1368	0.000244	0.013117	0.004273	0	0.0356

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 4)

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
ASColPn$_{T4\text{-}1}$											
W10X100	0.1335	0.064961	0.064961	0.023261	0.023261	0.075231	0.035301	0.38426	0.2215	0.001701	0.04167
W10X112	0.1505	0.072693	0.072693	0.026264	0.026264	0.085069	0.040046	0.38876	0.22319	0.002021	0.04167
W10X12	0.0096	0.006309	0.006309	0.000637	0.000637	0.007292	0.001007	0.32487	0.0654	1.7E-05	0.025
W10X15	0.0125	0.007983	0.007983	0.000836	0.000836	0.009259	0.001331	0.32939	0.06746	2.3E-05	0.025
W10X17	0.0153	0.009385	0.009385	0.001028	0.001028	0.010822	0.00162	0.33761	0.07039	2.8E-05	0.025
W10X19	0.0184	0.010927	0.010927	0.001235	0.001235	0.0125	0.001939	0.34496	0.07281	3.4E-05	0.025
W10X22	0.024	0.01339	0.01339	0.002295	0.002295	0.015046	0.00353	0.35533	0.11045	9.2E-05	0.025
W10X26	0.0294	0.016181	0.016181	0.002828	0.002828	0.018113	0.00434	0.3625	0.11343	0.000115	0.025
W10X30	0.0343	0.018739	0.018739	0.003327	0.003327	0.021181	0.005116	0.36544	0.11454	0.000139	0.025
W10X33	0.0401	0.020341	0.020341	0.005322	0.005322	0.022454	0.008102	0.34971	0.16179	0.000265	0.04167
W10X39	0.049	0.024385	0.024385	0.006519	0.006519	0.027083	0.009954	0.35526	0.16485	0.000333	0.04167
W10X45	0.0576	0.02842	0.02842	0.007706	0.007706	0.031771	0.011748	0.35985	0.16698	0.000401	0.04167
W10X49	0.0648	0.031481	0.031481	0.01081	0.01081	0.034954	0.016377	0.36218	0.21223	0.000696	0.04167
W10X54	0.0712	0.034722	0.034722	0.011921	0.011921	0.038542	0.018113	0.36493	0.21277	0.000772	0.04208
W10X60	0.0795	0.038694	0.038694	0.013293	0.013293	0.043171	0.020255	0.36577	0.21333	0.000886	0.04167
W10X68	0.09	0.043848	0.043848	0.015356	0.015356	0.049363	0.023206	0.3708	0.21624	0.001027	0.04167
W10X77	0.1027	0.049681	0.049681	0.017475	0.017475	0.056481	0.026563	0.37309	0.21705	0.00122	0.04167
W10X88	0.118	0.057227	0.057227	0.020114	0.020114	0.065394	0.030729	0.37766	0.21865	0.001453	0.04167
W12X106	0.1398	0.08371	0.08371	0.028556	0.028556	0.094907	0.043461	0.4557	0.25884	0.003558	0.05
W12X120	0.158	0.094536	0.094536	0.032464	0.032464	0.107639	0.049421	0.45945	0.26089	0.004144	0.04917
W12X136	0.1794	0.107103	0.107103	0.037149	0.037149	0.123843	0.056713	0.46456	0.26319	0.004909	0.05
W12X14	0.0103	0.008617	0.008617	0.000688	0.000688	0.010069	0.0011	0.38458	0.06277	2.7E-05	0.025
W12X152	0.2025	0.12081	0.12081	0.042037	0.042037	0.140625	0.064236	0.47134	0.26558	0.005773	0.05
W12X16	0.0122	0.009934	0.009934	0.000818	0.000818	0.011632	0.001308	0.3897	0.06448	3.2E-05	0.025
W12X170	0.2275	0.136409	0.136409	0.04749	0.04749	0.159144	0.072917	0.47871	0.26797	0.006739	0.05
W12X19	0.0162	0.012333	0.012333	0.001085	0.001085	0.014294	0.001725	0.40259	0.06847	4.4E-05	0.025
W12X190	0.2558	0.15191	0.15191	0.053678	0.053678	0.179977	0.082755	0.48412	0.27026	0.007971	0.04917
W12X210	0.2815	0.168493	0.168493	0.060041	0.060041	0.201389	0.092014	0.49038	0.27315	0.00911	0.05
W12X22	0.0198	0.014679	0.014679	0.001338	0.001338	0.016956	0.002118	0.40888	0.07067	5.5E-05	0.025
W12X230	0.3091	0.185492	0.185492	0.066573	0.066573	0.22338	0.102431	0.49823	0.27588	0.010528	0.05
W12X252	0.3385	0.204425	0.204425	0.073718	0.073718	0.247685	0.113426	0.50489	0.27856	0.011928	0.05
W12X26	0.0285	0.019353	0.019353	0.003085	0.003085	0.021528	0.004728	0.43033	0.12532	0.000203	0.025
W12X279	0.3745	0.226386	0.226386	0.082786	0.082786	0.278356	0.127315	0.51352	0.28187	0.013975	0.05
W12X30	0.0332	0.022395	0.022395	0.003604	0.003604	0.024942	0.005532	0.43362	0.12664	0.000239	0.025
W12X305	0.414	0.252073	0.252073	0.092066	0.092066	0.310764	0.141204	0.52483	0.28543	0.016063	0.04917
W12X336	0.4591	0.279707	0.279707	0.102785	0.102785	0.348958	0.158565	0.53393	0.28906	0.019036	0.04917

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W12X35	0.0395	0.026389	0.026389	0.004323	0.004323	0.02963	0.006655	0.43835	0.12852	0.000294	0.025
W12X40	0.0477	0.029859	0.029859	0.006372	0.006372	0.032986	0.009722	0.42687	0.16179	0.000479	0.04208
W12X45	0.0536	0.033287	0.033287	0.007189	0.007189	0.037153	0.010995	0.42951	0.16281	0.000556	0.04208
W12X50	0.0599	0.037094	0.037094	0.008065	0.008065	0.041609	0.012326	0.43125	0.16364	0.00063	0.04167
W12X53	0.0666	0.040653	0.040653	0.011088	0.011088	0.045081	0.01684	0.43496	0.20651	0.001066	0.05042
W12X58	0.0741	0.045063	0.045063	0.012384	0.012384	0.05	0.018808	0.4405	0.20907	0.001193	0.05
W12X65	0.084	0.050983	0.050983	0.016782	0.016782	0.056019	0.025521	0.44022	0.25152	0.001928	0.04958
W12X72	0.0931	0.056177	0.056177	0.018808	0.018808	0.0625	0.028472	0.44327	0.25333	0.002185	0.05
W12X79	0.1029	0.061791	0.061791	0.020661	0.020661	0.068866	0.031424	0.44515	0.25427	0.002472	0.04958
W12X87	0.1134	0.068519	0.068519	0.023052	0.023052	0.076389	0.034954	0.44804	0.25569	0.002736	0.05
W12X96	0.1271	0.075915	0.075915	0.025615	0.025615	0.085069	0.039063	0.45292	0.25786	0.003175	0.05
W14X109	0.1453	0.100363	0.100363	0.035436	0.035436	0.111111	0.053646	0.51875	0.31146	0.006746	0.05
W14X120	0.1599	0.110153	0.110153	0.038974	0.038974	0.122685	0.059028	0.52104	0.31206	0.007661	0.05
W14X132	0.1752	0.120465	0.120465	0.043147	0.043147	0.135417	0.065394	0.5233	0.31318	0.008532	0.05
W14X145	0.1955	0.133727	0.133727	0.050553	0.050553	0.150463	0.076968	0.52735	0.33182	0.010646	0.05
W14X159	0.2149	0.146605	0.146605	0.055496	0.055496	0.166088	0.084491	0.53154	0.33351	0.012023	0.05
W14X176	0.238	0.162951	0.162951	0.061778	0.061778	0.185185	0.094329	0.53562	0.33518	0.013648	0.05
W14X193	0.2617	0.179211	0.179211	0.068634	0.068634	0.20544	0.104167	0.54169	0.33738	0.015372	0.05
W14X211	0.2853	0.196096	0.196096	0.075451	0.075451	0.225694	0.114583	0.54584	0.33966	0.017167	0.05
W14X22	0.0194	0.016812	0.016812	0.00162	0.00162	0.019213	0.002541	0.46145	0.08655	0.000104	0.03333
W14X233	0.3165	0.217737	0.217737	0.083712	0.083712	0.252315	0.127894	0.5524	0.34145	0.019673	0.05
W14X257	0.35	0.23995	0.23995	0.093316	0.093316	0.281829	0.142361	0.55885	0.34423	0.022744	0.05
W14X26	0.0245	0.0204	0.0204	0.00205	0.00205	0.023264	0.003206	0.47037	0.0897	0.000136	0.03333
W14X283	0.3857	0.266134	0.266134	0.10352	0.10352	0.313657	0.158565	0.5658	0.34648	0.025801	0.05
W14X30	0.03	0.024406	0.024406	0.003371	0.003371	0.027373	0.005203	0.47785	0.12402	0.000295	0.03333
W14X311	0.4238	0.293074	0.293074	0.115026	0.115026	0.348958	0.175926	0.57357	0.34975	0.029527	0.05
W14X34	0.0355	0.028108	0.028108	0.003995	0.003995	0.031597	0.006134	0.48591	0.1272	0.000358	0.03333
W14X342	0.4688	0.324074	0.324074	0.127738	0.127738	0.388889	0.195602	0.58044	0.35277	0.034344	0.05
W14X370	0.508	0.351748	0.351748	0.13959	0.13959	0.425926	0.21412	0.58871	0.35607	0.038726	0.05
W14X38	0.0404	0.031603	0.031603	0.004565	0.004565	0.03559	0.007002	0.48859	0.12867	0.000412	0.03333
W14X398	0.5476	0.379478	0.379478	0.1513	0.1513	0.463542	0.232639	0.59676	0.35889	0.043424	0.04917
W14X426	0.5876	0.408497	0.408497	0.163562	0.163562	0.502894	0.251157	0.60553	0.36209	0.048452	0.04917
W14X43	0.0491	0.036158	0.036158	0.006539	0.006539	0.040278	0.010012	0.48569	0.15783	0.000657	0.04917
W14X455	0.6242	0.437987	0.437987	0.176367	0.176367	0.541667	0.270833	0.61042	0.36424	0.052954	0.05
W14X48	0.0553	0.040593	0.040593	0.007409	0.007409	0.04537	0.011343	0.48824	0.15911	0.00075	0.04958
W14X500	0.6887	0.484812	0.484812	0.196078	0.196078	0.607639	0.302083	0.62278	0.36886	0.062197	0.05
W14X53	0.0616	0.045047	0.045047	0.008286	0.008286	0.050405	0.012731	0.49074	0.16027	0.000845	0.04917
W14X550	0.7605	0.540314	0.540314	0.218696	0.218696	0.68287	0.337384	0.6358	0.37325	0.072774	0.05
W14X605	0.8378	0.598086	0.598086	0.244785	0.244785	0.763889	0.377315	0.64911	0.37891	0.085695	0.05
W14X61	0.0747	0.053291	0.053291	0.012384	0.012384	0.059028	0.018981	0.49829	0.20374	0.001581	0.04958
W14X665	0.926	0.664438	0.664438	0.272677	0.272677	0.856481	0.422454	0.66283	0.38438	0.102032	0.05
W14X68	0.0833	0.059689	0.059689	0.014005	0.014005	0.066551	0.021354	0.50069	0.20497	0.001772	0.04917
W14X730	1.0172	0.738881	0.738881	0.305193	0.305193	0.960648	0.472222	0.67962	0.39045	0.120205	0.05
W14X74	0.0918	0.064798	0.064798	0.015356	0.015356	0.072917	0.023438	0.50324	0.20661	0.002031	0.04958
W14X82	0.0999	0.071306	0.071306	0.01696	0.01696	0.08044	0.025926	0.5049	0.20694	0.002222	0.04958
W14X90	0.1192	0.082589	0.082589	0.028895	0.028895	0.090856	0.04375	0.51166	0.308	0.005335	0.05
W14X99	0.1318	0.090473	0.090473	0.031868	0.031868	0.100116	0.04838	0.51468	0.30973	0.0061	0.05
W24X94	0.0919	0.128601	0.128601	0.013909	0.013909	0.146991	0.021701	0.82274	0.16531	0.004999	0.04208
W8X10	0.0093	0.004518	0.004518	0.000614	0.000614	0.005133	0.000961	0.26881	0.07002	1E-05	0.025
W8X13	0.0118	0.005736	0.005736	0.00079	0.00079	0.006597	0.001244	0.26761	0.07026	1.4E-05	0.025
W8X15	0.0146	0.00685	0.00685	0.000983	0.000983	0.00787	0.001545	0.274	0.07303	1.7E-05	0.025
W8X18	0.0201	0.008801	0.008801	0.001757	0.001757	0.009838	0.002697	0.28587	0.10258	4.1E-05	0.025
W8X21	0.0244	0.010526	0.010526	0.002146	0.002146	0.011806	0.003293	0.29136	0.10495	5.1E-05	0.025

Name	As3 ft2	S33Pos ft3	S33Neg ft3	S22Pos ft3	S22Neg ft3	Z33 ft3	Z22 ft3	R33 ft	R22 ft	Cw ft6	Fillet Radius ft
W8X24	0.0301	0.01207	0.01207	0.003259	0.003259	0.013368	0.004959	0.28481	0.13398	8.7E-05	0.03283
W8X28	0.0352	0.014073	0.014073	0.00384	0.00384	0.015741	0.005845	0.28721	0.13515	0.000105	0.03283
W8X31	0.0403	0.015914	0.015914	0.005367	0.005367	0.017593	0.00816	0.28925	0.16798	0.000178	0.03283
W8X35	0.0459	0.018102	0.018102	0.006148	0.006148	0.020081	0.009317	0.29262	0.16947	0.000207	0.03283
W8X40	0.0523	0.020483	0.020483	0.007042	0.007042	0.023032	0.010706	0.29438	0.17071	0.000243	0.03283
W8X48	0.0643	0.025054	0.025054	0.008691	0.008691	0.028356	0.013252	0.30104	0.17319	0.000311	0.03292
W8X58	0.0771	0.030159	0.030159	0.010574	0.010574	0.034606	0.016146	0.30429	0.17464	0.000396	0.0325
W8X67	0.0896	0.034979	0.034979	0.012385	0.012385	0.040567	0.018924	0.30965	0.17673	0.000482	0.03292

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 4)

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
ASColPn$_{T4-1}$										
W10X100	0	0	0	0			1	1	1	1
W10X112	0	0	0	0			1	1	1	1
W10X12	0	0	0	0			1	1	1	1
W10X15	0	0	0	0			1	1	1	1
W10X17	0	0	0	0			1	1	1	1
W10X19	0	0	0	0			1	1	1	1
W10X22	0	0	0	0			1	1	1	1
W10X26	0	0	0	0			1	1	1	1
W10X30	0	0	0	0			1	1	1	1
W10X33	0	0	0	0			1	1	1	1
W10X39	0	0	0	0			1	1	1	1
W10X45	0	0	0	0			1	1	1	1
W10X49	0	0	0	0			1	1	1	1
W10X54	0	0	0	0			1	1	1	1
W10X60	0	0	0	0			1	1	1	1
W10X68	0	0	0	0			1	1	1	1
W10X77	0	0	0	0			1	1	1	1
W10X88	0	0	0	0			1	1	1	1
W12X106	0	0	0	0			1	1	1	1
W12X120	0	0	0	0			1	1	1	1
W12X136	0	0	0	0			1	1	1	1
W12X14	0	0	0	0			1	1	1	1
W12X152	0	0	0	0			1	1	1	1
W12X16	0	0	0	0			1	1	1	1
W12X170	0	0	0	0			1	1	1	1
W12X19	0	0	0	0			1	1	1	1
W12X190	0	0	0	0			1	1	1	1
W12X210	0	0	0	0			1	1	1	1
W12X22	0	0	0	0			1	1	1	1
W12X230	0	0	0	0			1	1	1	1
W12X252	0	0	0	0			1	1	1	1
W12X26	0	0	0	0			1	1	1	1
W12X279	0	0	0	0			1	1	1	1
W12X30	0	0	0	0			1	1	1	1
W12X305	0	0	0	0			1	1	1	1
W12X336	0	0	0	0			1	1	1	1
W12X35	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W12X40	0	0	0	0			1	1	1	1
W12X45	0	0	0	0			1	1	1	1
W12X50	0	0	0	0			1	1	1	1
W12X53	0	0	0	0			1	1	1	1
W12X58	0	0	0	0			1	1	1	1
W12X65	0	0	0	0			1	1	1	1
W12X72	0	0	0	0			1	1	1	1
W12X79	0	0	0	0			1	1	1	1
W12X87	0	0	0	0			1	1	1	1
W12X96	0	0	0	0			1	1	1	1
W14X109	0	0	0	0			1	1	1	1
W14X120	0	0	0	0			1	1	1	1
W14X132	0	0	0	0			1	1	1	1
W14X145	0	0	0	0			1	1	1	1
W14X159	0	0	0	0			1	1	1	1
W14X176	0	0	0	0			1	1	1	1
W14X193	0	0	0	0			1	1	1	1
W14X211	0	0	0	0			1	1	1	1
W14X22	0	0	0	0			1	1	1	1
W14X233	0	0	0	0			1	1	1	1
W14X257	0	0	0	0			1	1	1	1
W14X26	0	0	0	0			1	1	1	1
W14X283	0	0	0	0			1	1	1	1
W14X30	0	0	0	0			1	1	1	1
W14X311	0	0	0	0			1	1	1	1
W14X34	0	0	0	0			1	1	1	1
W14X342	0	0	0	0			1	1	1	1
W14X370	0	0	0	0			1	1	1	1
W14X38	0	0	0	0			1	1	1	1
W14X398	0	0	0	0			1	1	1	1
W14X426	0	0	0	0			1	1	1	1
W14X43	0	0	0	0			1	1	1	1
W14X455	0	0	0	0			1	1	1	1
W14X48	0	0	0	0			1	1	1	1
W14X500	0	0	0	0			1	1	1	1
W14X53	0	0	0	0			1	1	1	1
W14X550	0	0	0	0			1	1	1	1
W14X605	0	0	0	0			1	1	1	1
W14X61	0	0	0	0			1	1	1	1
W14X665	0	0	0	0			1	1	1	1
W14X68	0	0	0	0			1	1	1	1
W14X730	0	0	0	0			1	1	1	1
W14X74	0	0	0	0			1	1	1	1
W14X82	0	0	0	0			1	1	1	1
W14X90	0	0	0	0			1	1	1	1
W14X99	0	0	0	0			1	1	1	1
W24X94	0	0	0	0			1	1	1	1
W8X10	0	0	0	0			1	1	1	1
W8X13	0	0	0	0			1	1	1	1
W8X15	0	0	0	0			1	1	1	1
W8X18	0	0	0	0			1	1	1	1
W8X21	0	0	0	0			1	1	1	1

Name	CG Offset 3 ft	CG Offset 2 ft	PNA Offset 3 ft	PNA Offset 2 ft	SC Offset 3 ft	SC Offset 2 ft	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W8X24	0	0	0	0			1	1	1	1
W8X28	0	0	0	0			1	1	1	1
W8X31	0	0	0	0			1	1	1	1
W8X35	0	0	0	0			1	1	1	1
W8X40	0	0	0	0			1	1	1	1
W8X48	0	0	0	0			1	1	1	1
W8X58	0	0	0	0			1	1	1	1
W8X67	0	0	0	0			1	1	1	1

Table 2.2 - Frame Section Property Definitions - Summary (Part 4 of 4)

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
$ASColPn_{T4\text{-}1}$				
W10X100	1	1	1	1
W10X112	1	1	1	1
W10X12	1	1	1	1
W10X15	1	1	1	1
W10X17	1	1	1	1
W10X19	1	1	1	1
W10X22	1	1	1	1
W10X26	1	1	1	1
W10X30	1	1	1	1
W10X33	1	1	1	1
W10X39	1	1	1	1
W10X45	1	1	1	1
W10X49	1	1	1	1
W10X54	1	1	1	1
W10X60	1	1	1	1
W10X68	1	1	1	1
W10X77	1	1	1	1
W10X88	1	1	1	1
W12X106	1	1	1	1
W12X120	1	1	1	1
W12X136	1	1	1	1
W12X14	1	1	1	1
W12X152	1	1	1	1
W12X16	1	1	1	1
W12X170	1	1	1	1
W12X19	1	1	1	1
W12X190	1	1	1	1
W12X210	1	1	1	1
W12X22	1	1	1	1
W12X230	1	1	1	1
W12X252	1	1	1	1
W12X26	1	1	1	1
W12X279	1	1	1	1
W12X30	1	1	1	1
W12X305	1	1	1	1
W12X336	1	1	1	1
W12X35	1	1	1	1
W12X40	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X45	1	1	1	1
W12X50	1	1	1	1
W12X53	1	1	1	1
W12X58	1	1	1	1
W12X65	1	1	1	1
W12X72	1	1	1	1
W12X79	1	1	1	1
W12X87	1	1	1	1
W12X96	1	1	1	1
W14X109	1	1	1	1
W14X120	1	1	1	1
W14X132	1	1	1	1
W14X145	1	1	1	1
W14X159	1	1	1	1
W14X176	1	1	1	1
W14X193	1	1	1	1
W14X211	1	1	1	1
W14X22	1	1	1	1
W14X233	1	1	1	1
W14X257	1	1	1	1
W14X26	1	1	1	1
W14X283	1	1	1	1
W14X30	1	1	1	1
W14X311	1	1	1	1
W14X34	1	1	1	1
W14X342	1	1	1	1
W14X370	1	1	1	1
W14X38	1	1	1	1
W14X398	1	1	1	1
W14X426	1	1	1	1
W14X43	1	1	1	1
W14X455	1	1	1	1
W14X48	1	1	1	1
W14X500	1	1	1	1
W14X53	1	1	1	1
W14X550	1	1	1	1
W14X605	1	1	1	1
W14X61	1	1	1	1
W14X665	1	1	1	1
W14X68	1	1	1	1
W14X730	1	1	1	1
W14X74	1	1	1	1
W14X82	1	1	1	1
W14X90	1	1	1	1
W14X99	1	1	1	1
W24X94	1	1	1	1
W8X10	1	1	1	1
W8X13	1	1	1	1
W8X15	1	1	1	1
W8X18	1	1	1	1
W8X21	1	1	1	1
W8X24	1	1	1	1
W8X28	1	1	1	1
W8X31	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W8X35	1	1	1	1
W8X40	1	1	1	1
W8X48	1	1	1	1
W8X58	1	1	1	1
W8X67	1	1	1	1

2.3 Shell Sections

Table 2.3 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness ft	Deck Material	Deck Depth ft
12in-4	Wall	Shell-Thin	4000Psi	1		

2.4 Reinforcement Sizes

Table 2.4 - Reinforcing Bar Sizes

Name	Diameter ft	Area ft2
#4	0.04167	0.0014
#6	0.0625	0.0031
#9	0.094	0.0069

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	
Wind	No	Wind	0	ASCE 7-16

3.2 Auto Wind Loading

ASCE 7-16 Auto Wind Load Calculation

This calculation presents the automatically generated lateral wind loads for load pattern Wind according to ASCE 7-16, as calculated by ETABS.

Exposure Parameters

Exposure From = Diaphragms

Exposure Category = B

Wind Direction = 0 degrees

Basic Wind Speed, V [ASCE 26.5.1]

Windward Coefficient, $C_{p,wind}$ [ASCE 27.4.1] V=112 mph

Leeward Coefficient, $C_{p,lee}$ [ASCE 27.4.1]

Wind Case = All Cases

Top Story = Roof

Bottom Story = Basement

Include Parapet = No

Factors and Coefficients

Gradient Height, z_g [ASCE Table 26.9-1]

$z_{g=1200}$

Emperical Exponent, α [ASCE Table 26.9-1]

Velocity Pressure Exposure Coefficient, $K_{z;}$ [ASCE Table 27.3-1]	Kz=2.01(<z>/<zg>)$^{<<2>/<\alpha>>}$ for 15ft ≤ z ≤ <$z_{g>}$ Kz=2.01(<15>/<zg>)$^{<<2>/<\alpha>>}$ for z < 15ft
Topographical Factor, K_{zt} [ASCE 26.8.2]	
Directionality Factor, K_d [ASCE 26.6]	
Gust Effect Factor, G [ASCE 26.9]	

Lateral Loading

Velocity Pressure, q_z [ASCE 27.3.2 Eq. 27.3-1]	<qz>=0.00256<Kz><Kzt><Kd><$V^{2>}$
Design Wind Pressure, p [ASCE 27.4.2 Eq. 27.4-2]	p=qG<Cp,wind>+<qh><(G<$C_{p,lee>)>$

3.3 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.02ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]	R=3.25
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]	
Importance Factor, I [ASCE Table 1.5-2]	

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		$S_{s=0.37g}$
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.55648g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.2618g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.370987g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.174533g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]	
Coefficient, x [ASCE Table 12.8-2]	
Structure Height Above Base, h_n	$C_{t=0.02ft}$
Long-Period Transition Period, T_L [ASCE 11.4.5]	

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]	R=3.25

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]		
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]		
Importance Factor, I [ASCE Table 1.5-2]		
Ss and S1 Source = 0.75		
Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		$S_{s=0.37g}$
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=0.55648g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.2618g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.370987g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.174533g}$

3.4 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
Wind	Linear Static
EQx	Linear Static
EQy	Linear Static

3.5 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlD2			LLred	1	
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	
UDStlS6			LLred	1	
UDStlS6			Wind	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS7			Wind	-1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS8			Wind	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS9			Wind	-1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS10			Wind	0.5	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS11			Wind	-0.5	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS12			Wind	0.5	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	
UDStlS13			Wind	-0.5	
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS14			Wind	1	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS15			Wind	-1	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS16			EQx	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS17			EQx	-1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS18			EQy	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS19			EQy	-1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	
UDStlS20			EQx	1	
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS21			EQx	-1	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS22			EQy	1	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	
UDStlS23			EQy	-1	

2 Properties

This chapter provides property information for materials, frame sections, shell sections, and links.

2.1 Materials

Table 2.1 - Material Properties - General

Material	Type	SymType	Grade	Color	Notes
4000Psi	Concrete	Isotropic	f'c 4000 psi	Magenta	
A416Gr270	Tendon	Uniaxial	Grade 270	Gray8Dark	
A615Gr60	Rebar	Uniaxial	Grade 60	Yellow	
A992Fy50	Steel	Isotropic	Grade 50	Red	

2.2 Frame Sections

Table 2.2 - Frame Section Property Definitions - Summary (Part 1 of 4)

Name	Material	Shape	Color	Area in2	J in4	I33 in4	I22 in4	I23 in4	As2 in2
ASColPn$_{T4-1}$		Auto Select							
W10X100	A992Fy50	Steel I/Wide Flange	Green	29.3	10.9	623	207	0	7.55
W10X112	A992Fy50	Steel I/Wide Flange	Cyan	32.9	15.1	716	236	0	8.61
W10X12	A992Fy50	Steel I/Wide Flange	Gray8Dark	3.54	0.05	53.8	2.18	0	1.88
W10X15	A992Fy50	Steel I/Wide Flange	Blue	4.41	0.1	68.9	2.89	0	2.3
W10X17	A992Fy50	Steel I/Wide Flange	Green	4.99	0.16	81.9	3.56	0	2.42
W10X19	A992Fy50	Steel I/Wide Flange	Cyan	5.62	0.23	96.3	4.29	0	2.55
W10X22	A992Fy50	Steel I/Wide Flange	Red	6.49	0.24	118	11.4	0	2.45
W10X26	A992Fy50	Steel I/Wide Flange	Magenta	7.61	0.4	144	14.1	0	2.68
W10X30	A992Fy50	Steel I/Wide Flange	Yellow	8.84	0.62	170	16.7	0	3.15
W10X33	A992Fy50	Steel I/Wide Flange	Gray8Dark	9.71	0.58	171	36.6	0	2.82
W10X39	A992Fy50	Steel I/Wide Flange	Blue	11.5	0.98	209	45	0	3.12
W10X45	A992Fy50	Steel I/Wide Flange	Green	13.3	1.51	248	53.4	0	3.54
W10X49	A992Fy50	Steel I/Wide Flange	Cyan	14.4	1.39	272	93.4	0	3.4
W10X54	A992Fy50	Steel I/Wide Flange	Red	15.8	1.82	303	103	0	3.74
W10X60	A992Fy50	Steel I/Wide Flange	Magenta	17.7	2.48	341	116	0	4.28
W10X68	A992Fy50	Steel I/Wide Flange	Yellow	19.9	3.56	394	134	0	4.89
W10X77	A992Fy50	Steel I/Wide Flange	Gray8Dark	22.7	5.11	455	154	0	5.62
W10X88	A992Fy50	Steel I/Wide Flange	Blue	26	7.53	534	179	0	6.53
W12X106	A992Fy50	Steel I/Wide Flange	Yellow	31.2	9.13	933	301	0	7.87
W12X120	A992Fy50	Steel I/Wide Flange	Gray8Dark	35.2	12.9	1070	345	0	9.3
W12X136	A992Fy50	Steel I/Wide Flange	Blue	39.9	18.5	1240	398	0	10.59
W12X14	A992Fy50	Steel I/Wide Flange	Cyan	4.16	0.07	88.6	2.36	0	2.38
W12X152	A992Fy50	Steel I/Wide Flange	Blue	44.7	25.8	1430	454	0	11.92
W12X16	A992Fy50	Steel I/Wide Flange	Red	4.71	0.1	103	2.82	0	2.64
W12X170	A992Fy50	Steel I/Wide Flange	Green	50	35.6	1650	517	0	13.44
W12X19	A992Fy50	Steel I/Wide Flange	Magenta	5.57	0.18	130	3.76	0	2.87
W12X190	A992Fy50	Steel I/Wide Flange	Cyan	56	48.8	1890	589	0	15.26
W12X210	A992Fy50	Steel I/Wide Flange	Red	61.8	64.7	2140	664	0	17.35
W12X22	A992Fy50	Steel I/Wide Flange	Yellow	6.48	0.29	156	4.66	0	3.2
W12X230	A992Fy50	Steel I/Wide Flange	Magenta	67.7	83.8	2420	742	0	19.48
W12X252	A992Fy50	Steel I/Wide Flange	Yellow	74.1	108	2720	828	0	21.56
W12X26	A992Fy50	Steel I/Wide Flange	Gray8Dark	7.65	0.3	204	17.3	0	2.81

Name	Material	Shape	Color	Area in2	J in4	I33 in4	I22 in4	I23 in4	As2 in2
W12X279	A992Fy50	Steel I/Wide Flange	Gray8Dark	81.9	143	3110	937	0	24.33
W12X30	A992Fy50	Steel I/Wide Flange	Blue	8.79	0.46	238	20.3	0	3.2
W12X305	A992Fy50	Steel I/Wide Flange	Blue	89.5	185	3550	1050	0	26.57
W12X336	A992Fy50	Steel I/Wide Flange	Green	98.9	243	4060	1190	0	29.9
W12X35	A992Fy50	Steel I/Wide Flange	Green	10.3	0.74	285	24.5	0	3.75
W12X40	A992Fy50	Steel I/Wide Flange	Cyan	11.7	0.91	307	44.1	0	3.51
W12X45	A992Fy50	Steel I/Wide Flange	Red	13.1	1.26	348	50	0	4.05
W12X50	A992Fy50	Steel I/Wide Flange	Magenta	14.6	1.71	391	56.3	0	4.51
W12X53	A992Fy50	Steel I/Wide Flange	Yellow	15.6	1.58	425	95.8	0	4.17
W12X58	A992Fy50	Steel I/Wide Flange	Gray8Dark	17	2.1	475	107	0	4.39
W12X65	A992Fy50	Steel I/Wide Flange	Blue	19.1	2.18	533	174	0	4.72
W12X72	A992Fy50	Steel I/Wide Flange	Green	21.1	2.93	597	195	0	5.29
W12X79	A992Fy50	Steel I/Wide Flange	Cyan	23.2	3.84	662	216	0	5.83
W12X87	A992Fy50	Steel I/Wide Flange	Red	25.6	5.1	740	241	0	6.44
W12X96	A992Fy50	Steel I/Wide Flange	Magenta	28.2	6.85	833	270	0	6.99
W14X109	A992Fy50	Steel I/Wide Flange	Green	32	7.12	1240	447	0	7.51
W14X120	A992Fy50	Steel I/Wide Flange	Cyan	35.3	9.37	1380	495	0	8.56
W14X132	A992Fy50	Steel I/Wide Flange	Red	38.8	12.3	1530	548	0	9.48
W14X145	A992Fy50	Steel I/Wide Flange	Magenta	42.7	15.2	1710	677	0	10.06
W14X159	A992Fy50	Steel I/Wide Flange	Yellow	46.7	19.7	1900	748	0	11.18
W14X176	A992Fy50	Steel I/Wide Flange	Gray8Dark	51.8	26.5	2140	838	0	12.62
W14X193	A992Fy50	Steel I/Wide Flange	Blue	56.8	34.8	2400	931	0	13.8
W14X211	A992Fy50	Steel I/Wide Flange	Green	62	44.6	2660	1030	0	15.39
W14X22	A992Fy50	Steel I/Wide Flange	Cyan	6.49	0.21	199	7	0	3.15
W14X233	A992Fy50	Steel I/Wide Flange	Cyan	68.5	59.5	3010	1150	0	17.12
W14X257	A992Fy50	Steel I/Wide Flange	Red	75.6	79.1	3400	1290	0	19.35
W14X26	A992Fy50	Steel I/Wide Flange	Red	7.69	0.36	245	8.91	0	3.54
W14X283	A992Fy50	Steel I/Wide Flange	Magenta	83.3	104	3840	1440	0	21.54
W14X30	A992Fy50	Steel I/Wide Flange	Magenta	8.85	0.38	291	19.6	0	3.73
W14X311	A992Fy50	Steel I/Wide Flange	Yellow	91.4	136	4330	1610	0	24.11
W14X34	A992Fy50	Steel I/Wide Flange	Yellow	10	0.57	340	23.3	0	3.99
W14X342	A992Fy50	Steel I/Wide Flange	Gray8Dark	101	178	4900	1810	0	26.95
W14X370	A992Fy50	Steel I/Wide Flange	Blue	109	222	5440	1990	0	29.71
W14X38	A992Fy50	Steel I/Wide Flange	Gray8Dark	11.2	0.8	385	26.7	0	4.37
W14X398	A992Fy50	Steel I/Wide Flange	Green	117	273	6000	2170	0	32.39
W14X426	A992Fy50	Steel I/Wide Flange	Cyan	125	331	6600	2360	0	35.16
W14X43	A992Fy50	Steel I/Wide Flange	Blue	12.6	1.05	428	45.2	0	4.18
W14X455	A992Fy50	Steel I/Wide Flange	Red	134	395	7190	2560	0	38.38
W14X48	A992Fy50	Steel I/Wide Flange	Green	14.1	1.45	484	51.4	0	4.69
W14X500	A992Fy50	Steel I/Wide Flange	Red	147	514	8210	2880	0	42.92
W14X53	A992Fy50	Steel I/Wide Flange	Cyan	15.6	1.94	541	57.7	0	5.14
W14X550	A992Fy50	Steel I/Wide Flange	Magenta	162	669	9430	3250	0	48.08
W14X605	A992Fy50	Steel I/Wide Flange	Yellow	178	869	10800	3680	0	54.34
W14X61	A992Fy50	Steel I/Wide Flange	Red	17.9	2.19	640	107	0	5.21
W14X665	A992Fy50	Steel I/Wide Flange	Gray8Dark	196	1120	12400	4170	0	61.13
W14X68	A992Fy50	Steel I/Wide Flange	Magenta	20	3.01	722	121	0	5.81
W14X730	A992Fy50	Steel I/Wide Flange	Blue	215	1450	14300	4720	0	68.77
W14X74	A992Fy50	Steel I/Wide Flange	Yellow	21.8	3.87	795	134	0	6.39
W14X82	A992Fy50	Steel I/Wide Flange	Yellow	24	5.07	881	148	0	7.29
W14X90	A992Fy50	Steel I/Wide Flange	Gray8Dark	26.5	4.06	999	362	0	6.16
W14X99	A992Fy50	Steel I/Wide Flange	Blue	29.1	5.37	1110	402	0	6.89
W24X94	A992Fy50	Steel I/Wide Flange	Gray8Dark	27.7	5.26	2700	109	0	12.51
W8X10	A992Fy50	Steel I/Wide Flange	Green	2.96	0.04	30.8	2.09	0	1.34
W8X13	A992Fy50	Steel I/Wide Flange	Cyan	3.84	0.09	39.6	2.73	0	1.84

Name	Material	Shape	Color	Area in2	J in4	I33 in4	I22 in4	I23 in4	As2 in2
W8X15	A992Fy50	Steel I/Wide Flange	Red	4.44	0.14	48	3.41	0	1.99
W8X18	A992Fy50	Steel I/Wide Flange	Magenta	5.26	0.17	61.9	7.97	0	1.87
W8X21	A992Fy50	Steel I/Wide Flange	Yellow	6.16	0.28	75.3	9.77	0	2.07
W8X24	A992Fy50	Steel I/Wide Flange	Gray8Dark	7.08	0.35	82.7	18.3	0	1.94
W8X28	A992Fy50	Steel I/Wide Flange	Blue	8.25	0.54	98	21.7	0	2.3
W8X31	A992Fy50	Steel I/Wide Flange	Green	9.13	0.54	110	37.1	0	2.28
W8X35	A992Fy50	Steel I/Wide Flange	Cyan	10.3	0.77	127	42.6	0	2.52
W8X40	A992Fy50	Steel I/Wide Flange	Red	11.7	1.12	146	49.1	0	2.97
W8X48	A992Fy50	Steel I/Wide Flange	Magenta	14.1	1.96	184	60.9	0	3.4
W8X58	A992Fy50	Steel I/Wide Flange	Magenta	17.1	3.33	228	75.1	0	4.46
W8X67	A992Fy50	Steel I/Wide Flange	Yellow	19.7	5.05	272	88.6	0	5.13

Table 2.2 - Frame Section Property Definitions - Summary (Part 2 of 4)

Name	As3 in2	S33Pos in3	S33Neg in3	S22Pos in3	S22Neg in3	Z33 in3	Z22 in3	R33 in	R22 in	Cw in6	Fillet Radius in
ASColPn$_{T4\text{-}1}$											
W10X100	19.23	112.25	112.25	40.19	40.19	130	61	4.6112	2.658	5079.02	0.5
W10X112	21.67	125.61	125.61	45.38	45.38	147	69.2	4.6651	2.6783	6035.74	0.5
W10X12	1.39	10.9	10.9	1.1	1.1	12.6	1.74	3.8984	0.7847	50.7	0.3
W10X15	1.8	13.79	13.79	1.45	1.45	16	2.3	3.9527	0.8095	68.02	0.3
W10X17	2.21	16.22	16.22	1.78	1.78	18.7	2.8	4.0513	0.8446	84.63	0.3
W10X19	2.65	18.88	18.88	2.13	2.13	21.6	3.35	4.1395	0.8737	102.79	0.3
W10X22	3.45	23.14	23.14	3.97	3.97	26	6.1	4.264	1.3253	276.11	0.3
W10X26	4.23	27.96	27.96	4.89	4.89	31.3	7.5	4.35	1.3612	342.39	0.3
W10X30	4.94	32.38	32.38	5.75	5.75	36.6	8.84	4.3853	1.3745	415.93	0.3
W10X33	5.77	35.15	35.15	9.2	9.2	38.8	14	4.1965	1.9415	789.8	0.5
W10X39	7.06	42.14	42.14	11.26	11.26	46.8	17.2	4.2631	1.9781	993.2	0.5
W10X45	8.29	49.11	49.11	13.32	13.32	54.9	20.3	4.3182	2.0038	1197.62	0.5
W10X49	9.33	54.4	54.4	18.68	18.68	60.4	28.3	4.3461	2.5468	2079.32	0.5
W10X54	10.25	60	60	20.6	20.6	66.6	31.3	4.3792	2.5532	2305.36	0.505
W10X60	11.45	66.86	66.86	22.97	22.97	74.6	35	4.3893	2.56	2645.67	0.5
W10X68	12.96	75.77	75.77	26.53	26.53	85.3	40.1	4.4496	2.5949	3065.46	0.5
W10X77	14.79	85.85	85.85	30.2	30.2	97.6	45.9	4.4771	2.6046	3641.95	0.5
W10X88	17	98.89	98.89	34.76	34.76	113	53.1	4.5319	2.6239	4337.84	0.5
W12X106	20.13	144.65	144.65	49.34	49.34	164	75.1	5.4684	3.106	10624.95	0.6
W12X120	22.76	163.36	163.36	56.1	56.1	186	85.4	5.5134	3.1307	12372.73	0.59
W12X136	25.83	185.07	185.07	64.19	64.19	214	98	5.5747	3.1583	14659.41	0.6
W12X14	1.49	14.89	14.89	1.19	1.19	17.4	1.9	4.615	0.7532	79.96	0.3
W12X152	29.17	208.76	208.76	72.64	72.64	243	111	5.6561	3.1869	17236.82	0.6
W12X16	1.76	17.17	17.17	1.41	1.41	20.1	2.26	4.6764	0.7738	96.59	0.3
W12X170	32.76	235.71	235.71	82.06	82.06	275	126	5.7446	3.2156	20121.75	0.6
W12X19	2.34	21.31	21.31	1.88	1.88	24.7	2.98	4.8311	0.8216	132.05	0.3
W12X190	36.83	262.5	262.5	92.76	92.76	311	143	5.8095	3.2431	23802.17	0.59
W12X210	40.53	291.16	291.16	103.75	103.75	348	159	5.8845	3.2779	27201.46	0.6
W12X22	2.85	25.37	25.37	2.31	2.31	29.3	3.66	4.9065	0.848	163.44	0.3
W12X230	44.51	320.53	320.53	115.04	115.04	386	177	5.9788	3.3106	31435.26	0.6
W12X252	48.75	353.25	353.25	127.38	127.38	428	196	6.0586	3.3428	35616.63	0.6
W12X26	4.11	33.44	33.44	5.33	5.33	37.2	8.17	5.164	1.5038	604.7	0.3
W12X279	53.93	391.2	391.2	143.05	143.05	481	220	6.1622	3.3824	41730.31	0.6
W12X30	4.78	38.7	38.7	6.23	6.23	43.1	9.56	5.2035	1.5197	714.75	0.3
W12X305	59.62	435.58	435.58	159.09	159.09	537	244	6.298	3.4252	47964.37	0.59

Name	As3 in2	S33Pos in3	S33Neg in3	S22Pos in3	S22Neg in3	Z33 in3	Z22 in3	R33 in	R22 in	Cw in6	Fillet Radius in
W12X336	66.11	483.33	483.33	177.61	177.61	603	274	6.4072	3.4688	56841.7	0.59
W12X35	5.69	45.6	45.6	7.47	7.47	51.2	11.5	5.2602	1.5423	877.84	0.3
W12X40	6.88	51.6	51.6	11.01	11.01	57	16.8	5.1224	1.9415	1429.42	0.505
W12X45	7.71	57.52	57.52	12.42	12.42	64.2	19	5.1541	1.9537	1660.07	0.505
W12X50	8.62	64.1	64.1	13.94	13.94	71.9	21.3	5.175	1.9637	1879.83	0.5
W12X53	9.58	70.25	70.25	19.16	19.16	77.9	29.1	5.2195	2.4781	3182.28	0.605
W12X58	10.67	77.87	77.87	21.4	21.4	86.4	32.5	5.2859	2.5088	3563.56	0.6
W12X65	12.1	88.1	88.1	29	29	96.8	44.1	5.2826	3.0183	5755.8	0.595
W12X72	13.4	97.07	97.07	32.5	32.5	108	49.2	5.3192	3.04	6524.79	0.6
W12X79	14.82	106.77	106.77	35.7	35.7	119	54.3	5.3418	3.0513	7382.47	0.595
W12X87	16.34	118.4	118.4	39.83	39.83	132	60.4	5.3765	3.0682	8170.69	0.6
W12X96	18.3	131.18	131.18	44.26	44.26	147	67.5	5.435	3.0943	9481.45	0.6
W14X109	20.93	173.43	173.43	61.23	61.23	192	92.7	6.225	3.7375	20143.94	0.6
W14X120	23.03	190.34	190.34	67.35	67.35	212	102	6.2525	3.7447	22876.42	0.6
W14X132	25.24	208.16	208.16	74.56	74.56	234	113	6.2796	3.7582	25475.05	0.6
W14X145	28.16	231.08	231.08	87.35	87.35	260	133	6.3283	3.9818	31789.61	0.6
W14X159	30.94	253.33	253.33	95.9	95.9	287	146	6.3785	4.0021	35900.2	0.6
W14X176	34.28	281.58	281.58	106.75	106.75	320	163	6.4275	4.0221	40753.37	0.6
W14X193	37.68	309.68	309.68	118.6	118.6	355	180	6.5003	4.0486	45900.86	0.6
W14X211	41.08	338.85	338.85	130.38	130.38	390	198	6.5501	4.0759	51260.57	0.6
W14X22	2.79	29.05	29.05	2.8	2.8	33.2	4.39	5.5374	1.0385	311.66	0.4
W14X233	45.58	376.25	376.25	144.65	144.65	436	221	6.6288	4.0974	58744.2	0.6
W14X257	50.4	414.63	414.63	161.25	161.25	487	246	6.7062	4.1308	67911.81	0.6
W14X26	3.52	35.25	35.25	3.54	3.54	40.2	5.54	5.6444	1.0764	404.69	0.4
W14X283	55.55	459.88	459.88	178.88	178.88	542	274	6.7896	4.1578	77041.62	0.6
W14X30	4.32	42.17	42.17	5.82	5.82	47.3	8.99	5.7342	1.4882	879.99	0.4
W14X311	61.02	506.43	506.43	198.77	198.77	603	304	6.8829	4.197	88167.81	0.6
W14X34	5.12	48.57	48.57	6.9	6.9	54.6	10.6	5.831	1.5264	1069.72	0.4
W14X342	67.51	560	560	220.73	220.73	672	338	6.9653	4.2333	102549.89	0.6
W14X370	73.15	607.82	607.82	241.21	241.21	736	370	7.0646	4.2728	115635.76	0.6
W14X38	5.81	54.61	54.61	7.89	7.89	61.5	12.1	5.863	1.544	1228.8	0.4
W14X398	78.85	655.74	655.74	261.45	261.45	801	402	7.1611	4.3066	129662.64	0.59
W14X426	84.61	705.88	705.88	282.63	282.63	869	434	7.2664	4.3451	144675.59	0.59
W14X43	7.07	62.48	62.48	11.3	11.3	69.6	17.3	5.8282	1.894	1961.13	0.59
W14X455	89.88	756.84	756.84	304.76	304.76	936	468	7.3251	4.3709	158119.67	0.6
W14X48	7.96	70.14	70.14	12.8	12.8	78.4	19.6	5.8589	1.9093	2238.36	0.595
W14X500	99.17	837.76	837.76	338.82	338.82	1050	522	7.4733	4.4263	185718.56	0.6
W14X53	8.87	77.84	77.84	14.32	14.32	87.1	22	5.8889	1.9232	2524.14	0.59
W14X550	109.51	933.66	933.66	377.91	377.91	1180	583	7.6295	4.479	217302.77	0.6
W14X605	120.64	1033.49	1033.49	422.99	422.99	1320	652	7.7894	4.5469	255882.59	0.6
W14X61	10.75	92.09	92.09	21.4	21.4	102	32.8	5.9795	2.4449	4721.8	0.595
W14X665	133.34	1148.15	1148.15	471.19	471.19	1480	730	7.9539	4.6125	304665.11	0.6
W14X68	12	103.14	103.14	24.2	24.2	115	36.9	6.0083	2.4597	5290.75	0.59
W14X730	146.48	1276.79	1276.79	527.37	527.37	1660	816	8.1555	4.6855	358929.34	0.6
W14X74	13.21	111.97	111.97	26.53	26.53	126	40.5	6.0389	2.4793	6064.62	0.595
W14X82	14.39	123.22	123.22	29.31	29.31	139	44.8	6.0587	2.4833	6635	0.595
W14X90	17.16	142.71	142.71	49.93	49.93	157	75.6	6.1399	3.696	15929.46	0.6
W14X99	18.98	156.34	156.34	55.07	55.07	173	83.6	6.1761	3.7168	18215.75	0.6
W24X94	13.23	222.22	222.22	24.04	24.04	254	37.5	9.8728	1.9837	14927.18	0.505
W8X10	1.35	7.81	7.81	1.06	1.06	8.87	1.66	3.2257	0.8403	30.85	0.3
W8X13	1.7	9.91	9.91	1.37	1.37	11.4	2.15	3.2113	0.8432	40.68	0.3
W8X15	2.11	11.84	11.84	1.7	1.7	13.6	2.67	3.288	0.8764	51.62	0.3
W8X18	2.89	15.21	15.21	3.04	3.04	17	4.66	3.4305	1.2309	121.36	0.3

Name	As3 in2	S33Pos in3	S33Neg in3	S22Pos in3	S22Neg in3	Z33 in3	Z22 in3	R33 in	R22 in	Cw in6	Fillet Radius in
W8X21	3.51	18.19	18.19	3.71	3.71	20.4	5.69	3.4963	1.2594	151.47	0.3
W8X24	4.33	20.86	20.86	5.63	5.63	23.1	8.57	3.4177	1.6077	259.52	0.394
W8X28	5.07	24.32	24.32	6.64	6.64	27.2	10.1	3.4466	1.6218	312.63	0.394
W8X31	5.8	27.5	27.5	9.28	9.28	30.4	14.1	3.4711	2.0158	531.09	0.394
W8X35	6.62	31.28	31.28	10.62	10.62	34.7	16.1	3.5114	2.0337	618.58	0.394
W8X40	7.53	35.39	35.39	12.17	12.17	39.8	18.5	3.5325	2.0486	725.19	0.394
W8X48	9.26	43.29	43.29	15.02	15.02	49	22.9	3.6124	2.0783	929.82	0.395
W8X58	11.1	52.11	52.11	18.27	18.27	59.8	27.9	3.6515	2.0957	1181.76	0.39
W8X67	12.9	60.44	60.44	21.4	21.4	70.1	32.7	3.7158	2.1207	1438.47	0.395

Table 2.2 - Frame Section Property Definitions - Summary (Part 3 of 4)

Name	CG Offset 3 in	CG Offset 2 in	PNA Offset 3 in	PNA Offset 2 in	SC Offset 3 in	SC Offset 2 in	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
ASColPn$_{T4\text{-}1}$										
W10X100	0	0	0	0			1	1	1	1
W10X112	0	0	0	0			1	1	1	1
W10X12	0	0	0	0			1	1	1	1
W10X15	0	0	0	0			1	1	1	1
W10X17	0	0	0	0			1	1	1	1
W10X19	0	0	0	0			1	1	1	1
W10X22	0	0	0	0			1	1	1	1
W10X26	0	0	0	0			1	1	1	1
W10X30	0	0	0	0			1	1	1	1
W10X33	0	0	0	0			1	1	1	1
W10X39	0	0	0	0			1	1	1	1
W10X45	0	0	0	0			1	1	1	1
W10X49	0	0	0	0			1	1	1	1
W10X54	0	0	0	0			1	1	1	1
W10X60	0	0	0	0			1	1	1	1
W10X68	0	0	0	0			1	1	1	1
W10X77	0	0	0	0			1	1	1	1
W10X88	0	0	0	0			1	1	1	1
W12X106	0	0	0	0			1	1	1	1
W12X120	0	0	0	0			1	1	1	1
W12X136	0	0	0	0			1	1	1	1
W12X14	0	0	0	0			1	1	1	1
W12X152	0	0	0	0			1	1	1	1
W12X16	0	0	0	0			1	1	1	1
W12X170	0	0	0	0			1	1	1	1
W12X19	0	0	0	0			1	1	1	1
W12X190	0	0	0	0			1	1	1	1
W12X210	0	0	0	0			1	1	1	1
W12X22	0	0	0	0			1	1	1	1
W12X230	0	0	0	0			1	1	1	1
W12X252	0	0	0	0			1	1	1	1
W12X26	0	0	0	0			1	1	1	1
W12X279	0	0	0	0			1	1	1	1
W12X30	0	0	0	0			1	1	1	1
W12X305	0	0	0	0			1	1	1	1
W12X336	0	0	0	0			1	1	1	1

Name	CG Offset 3 in	CG Offset 2 in	PNA Offset 3 in	PNA Offset 2 in	SC Offset 3 in	SC Offset 2 in	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W12X35	0	0	0	0			1	1	1	1
W12X40	0	0	0	0			1	1	1	1
W12X45	0	0	0	0			1	1	1	1
W12X50	0	0	0	0			1	1	1	1
W12X53	0	0	0	0			1	1	1	1
W12X58	0	0	0	0			1	1	1	1
W12X65	0	0	0	0			1	1	1	1
W12X72	0	0	0	0			1	1	1	1
W12X79	0	0	0	0			1	1	1	1
W12X87	0	0	0	0			1	1	1	1
W12X96	0	0	0	0			1	1	1	1
W14X109	0	0	0	0			1	1	1	1
W14X120	0	0	0	0			1	1	1	1
W14X132	0	0	0	0			1	1	1	1
W14X145	0	0	0	0			1	1	1	1
W14X159	0	0	0	0			1	1	1	1
W14X176	0	0	0	0			1	1	1	1
W14X193	0	0	0	0			1	1	1	1
W14X211	0	0	0	0			1	1	1	1
W14X22	0	0	0	0			1	1	1	1
W14X233	0	0	0	0			1	1	1	1
W14X257	0	0	0	0			1	1	1	1
W14X26	0	0	0	0			1	1	1	1
W14X283	0	0	0	0			1	1	1	1
W14X30	0	0	0	0			1	1	1	1
W14X311	0	0	0	0			1	1	1	1
W14X34	0	0	0	0			1	1	1	1
W14X342	0	0	0	0			1	1	1	1
W14X370	0	0	0	0			1	1	1	1
W14X38	0	0	0	0			1	1	1	1
W14X398	0	0	0	0			1	1	1	1
W14X426	0	0	0	0			1	1	1	1
W14X43	0	0	0	0			1	1	1	1
W14X455	0	0	0	0			1	1	1	1
W14X48	0	0	0	0			1	1	1	1
W14X500	0	0	0	0			1	1	1	1
W14X53	0	0	0	0			1	1	1	1
W14X550	0	0	0	0			1	1	1	1
W14X605	0	0	0	0			1	1	1	1
W14X61	0	0	0	0			1	1	1	1
W14X665	0	0	0	0			1	1	1	1
W14X68	0	0	0	0			1	1	1	1
W14X730	0	0	0	0			1	1	1	1
W14X74	0	0	0	0			1	1	1	1
W14X82	0	0	0	0			1	1	1	1
W14X90	0	0	0	0			1	1	1	1
W14X99	0	0	0	0			1	1	1	1
W24X94	0	0	0	0			1	1	1	1
W8X10	0	0	0	0			1	1	1	1
W8X13	0	0	0	0			1	1	1	1
W8X15	0	0	0	0			1	1	1	1
W8X18	0	0	0	0			1	1	1	1

Name	CG Offset 3 in	CG Offset 2 in	PNA Offset 3 in	PNA Offset 2 in	SC Offset 3 in	SC Offset 2 in	Area Modifier	As2 Modifier	As3 Modifier	J Modifier
W8X21	0	0	0	0			1	1	1	1
W8X24	0	0	0	0			1	1	1	1
W8X28	0	0	0	0			1	1	1	1
W8X31	0	0	0	0			1	1	1	1
W8X35	0	0	0	0			1	1	1	1
W8X40	0	0	0	0			1	1	1	1
W8X48	0	0	0	0			1	1	1	1
W8X58	0	0	0	0			1	1	1	1
W8X67	0	0	0	0			1	1	1	1

Table 2.2 - Frame Section Property Definitions - Summary (Part 4 of 4)

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
ASColPn$_{T4-1}$				
W10X100	1	1	1	1
W10X112	1	1	1	1
W10X12	1	1	1	1
W10X15	1	1	1	1
W10X17	1	1	1	1
W10X19	1	1	1	1
W10X22	1	1	1	1
W10X26	1	1	1	1
W10X30	1	1	1	1
W10X33	1	1	1	1
W10X39	1	1	1	1
W10X45	1	1	1	1
W10X49	1	1	1	1
W10X54	1	1	1	1
W10X60	1	1	1	1
W10X68	1	1	1	1
W10X77	1	1	1	1
W10X88	1	1	1	1
W12X106	1	1	1	1
W12X120	1	1	1	1
W12X136	1	1	1	1
W12X14	1	1	1	1
W12X152	1	1	1	1
W12X16	1	1	1	1
W12X170	1	1	1	1
W12X19	1	1	1	1
W12X190	1	1	1	1
W12X210	1	1	1	1
W12X22	1	1	1	1
W12X230	1	1	1	1
W12X252	1	1	1	1
W12X26	1	1	1	1
W12X279	1	1	1	1
W12X30	1	1	1	1
W12X305	1	1	1	1
W12X336	1	1	1	1
W12X35	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W12X40	1	1	1	1
W12X45	1	1	1	1
W12X50	1	1	1	1
W12X53	1	1	1	1
W12X58	1	1	1	1
W12X65	1	1	1	1
W12X72	1	1	1	1
W12X79	1	1	1	1
W12X87	1	1	1	1
W12X96	1	1	1	1
W14X109	1	1	1	1
W14X120	1	1	1	1
W14X132	1	1	1	1
W14X145	1	1	1	1
W14X159	1	1	1	1
W14X176	1	1	1	1
W14X193	1	1	1	1
W14X211	1	1	1	1
W14X22	1	1	1	1
W14X233	1	1	1	1
W14X257	1	1	1	1
W14X26	1	1	1	1
W14X283	1	1	1	1
W14X30	1	1	1	1
W14X311	1	1	1	1
W14X34	1	1	1	1
W14X342	1	1	1	1
W14X370	1	1	1	1
W14X38	1	1	1	1
W14X398	1	1	1	1
W14X426	1	1	1	1
W14X43	1	1	1	1
W14X455	1	1	1	1
W14X48	1	1	1	1
W14X500	1	1	1	1
W14X53	1	1	1	1
W14X550	1	1	1	1
W14X605	1	1	1	1
W14X61	1	1	1	1
W14X665	1	1	1	1
W14X68	1	1	1	1
W14X730	1	1	1	1
W14X74	1	1	1	1
W14X82	1	1	1	1
W14X90	1	1	1	1
W14X99	1	1	1	1
W24X94	1	1	1	1
W8X10	1	1	1	1
W8X13	1	1	1	1
W8X15	1	1	1	1
W8X18	1	1	1	1
W8X21	1	1	1	1
W8X24	1	1	1	1
W8X28	1	1	1	1

Name	I33 Modifier	I22 Modifier	Mass Modifier	Weight Modifier
W8X31	1	1	1	1
W8X35	1	1	1	1
W8X40	1	1	1	1
W8X48	1	1	1	1
W8X58	1	1	1	1
W8X67	1	1	1	1

2.3 Shell Sections

Table 2.3 - Area Section Property Definitions - Summary

Name	Type	Element Type	Material	Total Thickness in	Deck Material	Deck Depth in
12in-4	Wall	Shell-Thin	4000Psi	12		

2.4 Reinforcement Sizes

Table 2.4 - Reinforcing Bar Sizes

Name	Diameter in	Area in2
#4	0.5	0.2
#6	0.75	0.44
#9	1.128	1

3 Loads

This chapter provides loading information as applied to the model.

3.1 Load Patterns

Table 3.1 - Load Pattern Definitions

Name	Is Auto Load	Type	Self Weight Multiplier	Auto Load
~LLRF	Yes	Other	0	
Dead	No	Dead	1	
EQx	No	Seismic	0	ASCE 7-16
EQx(1/3)	Yes	Seismic	0	ASCE 7-16
EQx(2/3)	Yes	Seismic	0	ASCE 7-16
EQx(3/3)	Yes	Seismic	0	ASCE 7-16
EQy	No	Seismic	0	ASCE 7-16
EQy(1/3)	Yes	Seismic	0	ASCE 7-16
EQy(2/3)	Yes	Seismic	0	ASCE 7-16
EQy(3/3)	Yes	Seismic	0	ASCE 7-16
LLnonred	No	Live	0	
LLred	No	Reducible Live	0	
LLroof	No	Roof Live	0	
SDL	No	Super Dead	0	
Snow	No	Snow	0	

3.2 Auto Seismic Loading

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQx according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n $C_{t=0.02ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1] R=6

System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]

Deflection Amplification Factor, C_d [ASCE Table 12.2-1]

Importance Factor, I [ASCE Table 1.5-2]

Ss and S1 Source = 0.75

Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]

Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]

Site Class [ASCE Table 20.3-1] = D - Stiff Soil

$S_{s=1.491g}$

Site Coefficient, F_a [ASCE Table 11.4-1]

Site Coefficient, F_v [ASCE Table 11.4-2]

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

ASCE 7-16 Auto Seismic Load Calculation

This calculation presents the automatically generated lateral seismic loads for load pattern EQy according to ASCE 7-16, as calculated by ETABS.

Direction and Eccentricity

Direction = Multiple

Eccentricity Ratio = 5% for all diaphragms

Structural Period

Period Calculation Method = Program Calculated

Coefficient, C_t [ASCE Table 12.8-2]

Coefficient, x [ASCE Table 12.8-2]

Structure Height Above Base, h_n

$C_{t=0.02ft}$

Long-Period Transition Period, T_L [ASCE 11.4.5]

Factors and Coefficients

Response Modification Factor, R [ASCE Table 12.2-1]		
System Overstrength Factor, Ω_0 [ASCE Table 12.2-1]		R=6
Deflection Amplification Factor, C_d [ASCE Table 12.2-1]		
Importance Factor, I [ASCE Table 1.5-2]		
Ss and S1 Source = 0.75		
Mapped MCE Spectral Response Acceleration, S_s [ASCE 11.4.2]		
Mapped MCE Spectral Response Acceleration, S_1 [ASCE 11.4.2]		$S_{s=1.491g}$
Site Class [ASCE Table 20.3-1] = D - Stiff Soil		
Site Coefficient, F_a [ASCE Table 11.4-1]		
Site Coefficient, F_v [ASCE Table 11.4-2]		

Seismic Response

MCE Spectral Response Acceleration, S_{MS} [ASCE 11.4.4, Eq. 11.4-1]	SMS=<Fa><$S_{S>}$	$S_{MS=1.491g}$
MCE Spectral Response Acceleration, S_{M1} [ASCE 11.4.4, Eq. 11.4-2]	SM1=<Fv><$S_{1>}$	$S_{M1=0.903891g}$
Design Spectral Response Acceleration, S_{DS} [ASCE 11.4.5, Eq. 11.4-3]	SDS=<<2>/<3>><$S_{MS>}$	$S_{DS=0.994g}$
Design Spectral Response Acceleration, S_{D1} [ASCE 11.4.5, Eq. 11.4-4]	SD1=<<2>/<3>><$S_{M1>}$	$S_{D1=0.602594g}$

3.3 Load Cases

Table 3.2 - Load Case Definitions - Summary

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
Snow	Linear Static
LLroof	Linear Static
SDL	Linear Static
LLred	Linear Static
EQx	Linear Static
EQy	Linear Static

3.4 Load Combinations

Table 3.3 - Load Combination Definitions

Name	Type	Is Auto	Load Name	SF	Notes
UDCmpC1	Linear Add	No	Dead	1.4	Dead [Construction]
UDCmpC2	Linear Add	No	Dead	1.2	Dead + Construction Live [Construction]
UDCmpD1	Linear Add	No	Dead	1	Dead [Deflections]
UDCmpD1			SDL	1	
UDCmpD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDCmpD2			Live	1	
UDCmpD2			SDL	1	
UDCmpD2			LLred	1	
UDCmpS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDCmpS1			SDL	1.4	
UDCmpS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDCmpS2			Live	1.6	
UDCmpS2			Snow	0.5	
UDCmpS2			SDL	1.2	
UDCmpS2			LLred	1.6	
UDCmpS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS3			Live	1.6	
UDCmpS3			LLroof	0.5	
UDCmpS3			SDL	1.2	
UDCmpS3			LLred	1.6	
UDCmpS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDCmpS4			Live	1	
UDCmpS4			Snow	1.6	
UDCmpS4			SDL	1.2	
UDCmpS4			LLred	1	
UDCmpS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDCmpS5			Live	1	
UDCmpS5			LLroof	1.6	
UDCmpS5			SDL	1.2	
UDCmpS5			LLred	1	
UDStlD1	Linear Add	No	Dead	1	Dead [Deflections]
UDStlD1			SDL	1	
UDStlD2	Linear Add	No	Dead	1	Dead + Live [Deflections]
UDStlD2			Live	1	
UDStlD2			SDL	1	
UDStlD2			LLred	1	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS1	Linear Add	No	Dead	1.4	Dead [Strength]
UDStlS1			SDL	1.4	
UDStlS2	Linear Add	No	Dead	1.2	Dead + Live [Strength]
UDStlS2			Live	1.6	
UDStlS2			Snow	0.5	
UDStlS2			SDL	1.2	
UDStlS2			LLred	1.6	
UDStlS3	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS3			Live	1.6	
UDStlS3			LLroof	0.5	
UDStlS3			SDL	1.2	
UDStlS3			LLred	1.6	
UDStlS4	Linear Add	No	Dead	1.2	Dead + Live + Snow [Strength]
UDStlS4			Live	1	
UDStlS4			Snow	1.6	
UDStlS4			SDL	1.2	
UDStlS4			LLred	1	
UDStlS5	Linear Add	No	Dead	1.2	Dead + Live + Roof Live [Strength]
UDStlS5			Live	1	
UDStlS5			LLroof	1.6	
UDStlS5			SDL	1.2	
UDStlS5			LLred	1	
UDStlS6	Linear Add	No	Dead	1.2	Dead + Live + Wind + Snow [Strength]
UDStlS6			Live	1	
UDStlS6			Snow	0.5	
UDStlS6			SDL	1.2	
UDStlS6			LLred	1	
UDStlS7	Linear Add	No	Dead	1.2	Dead + Live - Wind + Snow [Strength]
UDStlS7			Live	1	
UDStlS7			Snow	0.5	
UDStlS7			SDL	1.2	
UDStlS7			LLred	1	
UDStlS8	Linear Add	No	Dead	1.2	Dead + Live + Roof Live + Wind [Strength]
UDStlS8			Live	1	
UDStlS8			LLroof	0.5	
UDStlS8			SDL	1.2	
UDStlS8			LLred	1	
UDStlS9	Linear Add	No	Dead	1.2	Dead + Live + Roof Live - Wind [Strength]
UDStlS9			Live	1	
UDStlS9			LLroof	0.5	
UDStlS9			SDL	1.2	
UDStlS9			LLred	1	
UDStlS10	Linear Add	No	Dead	1.2	Dead + Snow + Wind [Strength]
UDStlS10			Snow	1.6	
UDStlS10			SDL	1.2	
UDStlS11	Linear Add	No	Dead	1.2	Dead + Snow - Wind [Strength]
UDStlS11			Snow	1.6	
UDStlS11			SDL	1.2	
UDStlS12	Linear Add	No	Dead	1.2	Dead + Roof Live + Wind [Strength]
UDStlS12			LLroof	1.6	
UDStlS12			SDL	1.2	
UDStlS13	Linear Add	No	Dead	1.2	Dead + Roof Live - Wind [Strength]
UDStlS13			LLroof	1.6	
UDStlS13			SDL	1.2	

Name	Type	Is Auto	Load Name	SF	Notes
UDStlS14	Linear Add	No	Dead	0.9	Dead (min) + Wind [Strength]
UDStlS14			SDL	0.9	
UDStlS15	Linear Add	No	Dead	0.9	Dead (min) - Wind [Strength]
UDStlS15			SDL	0.9	
UDStlS16	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS16			Live	1	
UDStlS16			Snow	0.2	
UDStlS16			SDL	1.3	
UDStlS16			LLred	1	
UDStlS16			EQx	1	
UDStlS17	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS17			Live	1	
UDStlS17			Snow	0.2	
UDStlS17			SDL	1.3	
UDStlS17			LLred	1	
UDStlS17			EQx	-1	
UDStlS18	Linear Add	No	Dead	1.3	Dead + Live + Static Earthquake [Strength]
UDStlS18			Live	1	
UDStlS18			Snow	0.2	
UDStlS18			SDL	1.3	
UDStlS18			LLred	1	
UDStlS18			EQy	1	
UDStlS19	Linear Add	No	Dead	1.3	Dead + Live - Static Earthquake [Strength]
UDStlS19			Live	1	
UDStlS19			Snow	0.2	
UDStlS19			SDL	1.3	
UDStlS19			LLred	1	
UDStlS19			EQy	-1	
UDStlS20	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS20			SDL	0.8	
UDStlS20			EQx	1	
UDStlS21	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS21			SDL	0.8	
UDStlS21			EQx	-1	
UDStlS22	Linear Add	No	Dead	0.8	Dead (min) + Static Earthquake [Strength]
UDStlS22			SDL	0.8	
UDStlS22			EQy	1	
UDStlS23	Linear Add	No	Dead	0.8	Dead (min) - Static Earthquake [Strength]
UDStlS23			SDL	0.8	
UDStlS23			EQy	-1	

Appendix B-4

Table B-4-1: MUI (kg/m^2) by size, primary structural material, loading condition, and climate zone for all commercial office models modeled in Chapter V.

Size	Primary Structural Material	Lateral Loading Condition	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
M	Concrete	Base	1144	938	938	938	938	938	939	939	939	939	939	939	940	940	940	941
M	Concrete	High EQ	1478	1271	1271	1271	1271	1271	1273	1273	1273	1273	1273	1273	1273	1273	1274	1275
M	Concrete	Mod EQ	1349	1142	1142	1142	1142	1142	1144	1144	1144	1144	1144	1144	1144	1144	1145	1146
M	Concrete	High W	1261	1054	1054	1055	1055	1055	1056	1056	1056	1056	1056	1056	1056	1056	1057	1058
M	Concrete	Mod W	1254	1048	1048	1048	1048	1048	1049	1049	1049	1049	1049	1049	1050	1050	1050	1051
M	Steel	Base	684	477	477	477	477	477	479	479	479	479	479	479	479	479	480	481
M	Steel	High EQ	829	623	623	623	623	623	624	624	624	625	625	625	625	625	626	627
M	Steel	Mod EQ	814	608	608	608	608	608	609	609	609	610	610	610	610	610	611	612
M	Steel	High W	722	515	515	516	516	516	517	517	517	517	517	517	517	517	518	519
M	Steel	Mod W	716	509	509	510	510	510	511	511	511	511	511	511	511	511	512	513
M	Wood C	Base	631	425	425	425	425	425	426	426	426	427	427	427	427	427	427	428
M	Wood C	High EQ	828	622	622	622	622	622	623	623	623	623	623	623	624	624	624	625
M	Wood C	Mod EQ	697	491	491	491	491	491	492	492	492	493	493	493	493	493	494	495
M	Wood C	High W	697	491	491	491	491	491	492	492	492	493	493	493	493	493	494	495
M	Wood C	Mod W	670	464	464	464	464	464	465	465	465	466	466	466	466	466	466	467
M	Wood W	Base	631	425	425	425	425	425	426	426	426	427	427	427	427	427	427	428
M	Wood W	High EQ	814	608	608	608	608	608	609	609	609	609	609	609	610	610	610	611
M	Wood W	Mod EQ	676	470	470	470	470	470	471	471	471	471	471	471	472	472	472	473
M	Wood W	High W	676	470	470	470	470	470	471	471	471	471	471	471	472	472	472	473
M	Wood W	Mod W	676	470	470	470	470	470	471	471	471	471	471	471	472	472	472	473
M	Wood S	Base	631	425	425	425	425	425	426	426	426	427	427	427	427	427	427	428
M	Wood S	High EQ	805	598	598	599	599	599	600	600	600	600	600	600	600	600	601	602

M	Wood S	Mod EQ	715	508	508	509	509	509	510	510	510	510	510	510	510	510	511	512
M	Wood S	High W	683	477	477	477	477	477	478	478	478	479	479	479	479	479	480	481
M	Wood S	Mod W	662	456	456	456	456	456	457	457	457	457	457	457	458	458	458	459
L	Concrete	Base	1077	962	962	962	962	962	962	962	962	962	962	962	962	962	963	963
L	Concrete	High EQ	1502	1386	1386	1386	1386	1386	1387	1387	1387	1387	1387	1387	1387	1387	1387	1387
L	Concrete	Mod EQ	1149	1034	1034	1034	1034	1034	1034	1034	1034	1034	1034	1034	1034	1034	1034	1035
L	Concrete	High W	1146	1031	1031	1031	1031	1031	1031	1031	1031	1031	1031	1031	1031	1031	1031	1031
L	Concrete	Mod W	1138	1023	1023	1023	1023	1023	1023	1023	1023	1023	1023	1023	1023	1023	1023	1023
L	Steel	Base	731	615	615	615	615	615	616	616	616	616	616	616	616	616	616	616
L	Steel	High EQ	860	745	745	745	745	745	745	745	745	745	745	745	745	745	746	746
L	Steel	Mod EQ	782	667	667	667	667	667	667	667	667	667	667	667	667	667	667	668
L	Steel	High W	761	646	646	646	646	646	646	646	646	646	646	646	646	646	647	647
L	Steel	Mod W	752	637	637	637	637	637	637	637	637	637	637	637	637	637	637	637
L	Wood C	Base	718	603	603	603	603	603	603	603	603	604	604	604	604	604	604	604
L	Wood C	High EQ	987	872	872	872	872	872	872	872	872	872	872	872	872	872	872	872
L	Wood C	Mod EQ	762	647	647	647	647	647	647	647	647	647	647	647	647	647	647	647
L	Wood C	High W	776	661	661	661	661	661	661	661	661	661	661	661	661	661	661	661
L	Wood C	Mod W	762	647	647	647	647	647	647	647	647	647	647	647	647	647	647	648
L	Wood W	Base	718	603	603	603	603	603	603	603	603	604	604	604	604	604	604	604
L	Wood W	High EQ	786	671	671	671	671	671	671	671	671	671	671	671	671	671	671	672
L	Wood W	Mod EQ	723	608	608	608	608	608	608	608	608	608	608	608	608	608	608	609
L	Wood W	High W	723	608	608	608	608	608	608	608	608	608	608	608	608	608	608	609
L	Wood W	Mod W	723	608	608	608	608	608	608	608	608	608	608	608	608	608	608	609
L	Wood S	Base	718	603	603	603	603	603	603	603	603	604	604	604	604	604	604	604
L	Wood S	High EQ	804	689	689	689	689	689	689	689	689	689	689	689	689	689	689	689
L	Wood S	Mod EQ	722	607	607	607	607	607	607	607	607	607	607	607	608	608	608	608
L	Wood S	High W	733	618	618	618	618	618	618	618	618	618	618	618	618	618	618	618
L	Wood S	Mod W	727	612	612	612	612	612	612	612	612	612	612	612	612	612	612	612

Appendix C. Multifamily residential apartment supplementary information

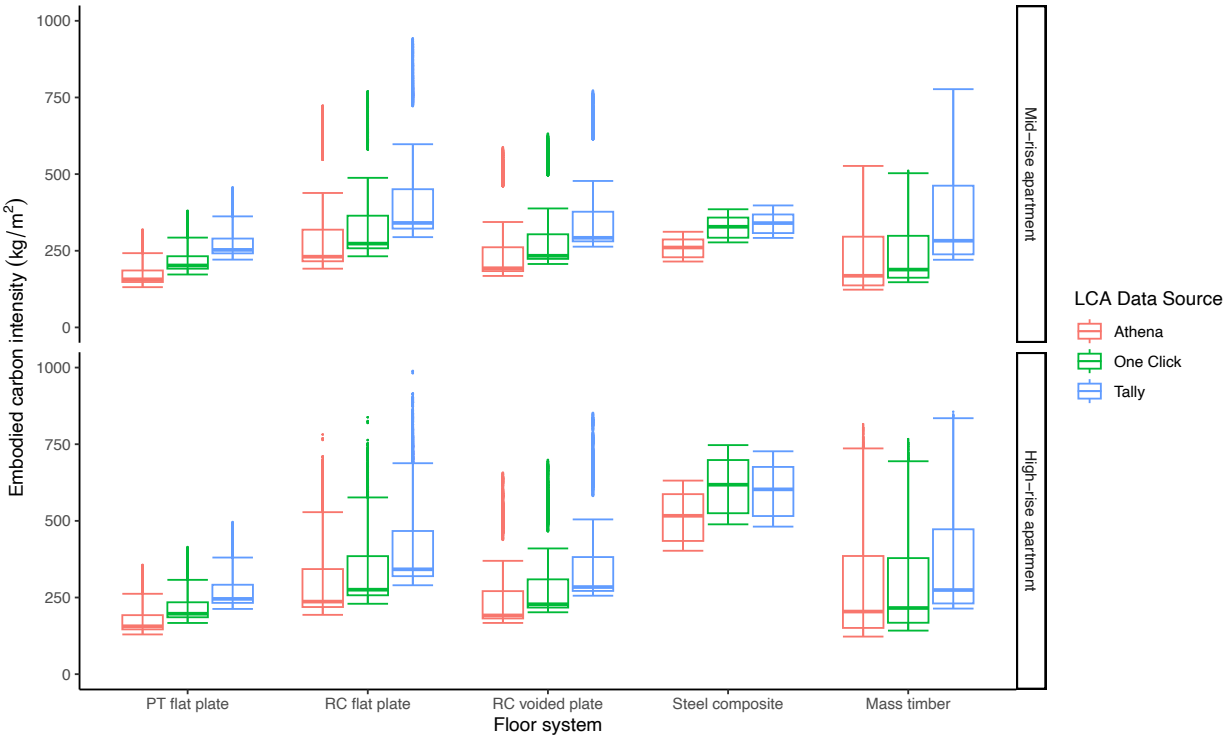

Figure C-1. *ECI using Athena, One Click, and Tally to evaluate LCA modules A-C for* Multifamily residential apartment buildings

Table C-1. *ECI using Athena, One Click, and Tally to evaluate LCA modules A-C for multifamily residential apartment buildings, based on Figure C-1.*

Size	Floor system	LCA tool	Min	Q1	Median	Q3	Max
Mid-rise apartment	PT flat plate	Athena	131	148	156	185	312
		Tally	173	191	201	231	372
		One click	221	241	252	289	447
	RC flat plate	Athena	192	215	230	314	715
		Tally	232	257	272	359	761
		One click	295	322	340	444	933
	RC voided plate	Athena	168	183	192	257	579
		Tally	207	223	233	299	623
		One click	263	280	291	372	761
	Steel composite	Athena	215	228	259	286	307
		Tally	277	292	326	358	380
		One click	292	307	340	368	392
	Wood composite	Athena	123	150	199	356	1666
		Tally	147	171	215	354	1500
		One click	221	257	325	543	2377
High-rise apartment	PT flat plate	Athena	130	145	155	191	345
		Tally	167	185	196	233	402
		One click	213	232	244	290	481
	RC flat plate	Athena	194	218	235	335	767
		Tally	230	256	274	377	823
		One click	290	318	340	464	986
	RC voided plate	Athena	167	181	191	265	642
		Tally	202	217	227	303	683
		One click	256	271	283	375	832
	Steel composite	Athena	403	434	514	587	624
		Tally	489	524	615	698	739
		One click	481	515	600	675	718
	Wood composite	Athena	123	150	201	380	803
		Tally	142	167	213	373	754
		One click	214	252	323	570	1153