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Editorial

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Numerical simulation of large-scale structural systems

Overview

Large-scale structural systems or so-called infrastructures are an important part of modern societies. Experimental tests for such systems are rarely applicable as they require enormous expense, and there are many complexities in scaling down of the prototype. On the contrary, with new developments in computer science, numerical simulation of structural systems becomes increasingly feasible.

Numerical simulation and analysis of infrastructures have also become complex, as extra details are involved in the modeling procedure and connecting the different (and sometimes diverse) domains. Thus, this Special Collection is dedicated to the numerical simulation of large structural systems covering both the theoretical and application papers.

This is a challenging task for all scientists, software developers, and engineers. Many infrastructures were built in previous decades with limited information, and their performance should be re-evaluated according to the new findings and standards. The outcome of this Special Collection can be useful for many agencies and scientists working on safety and risk analysis of large-scale structures.

Overall, 25 submissions were received by the editorial team, and 15 manuscripts have been accepted for publication. Figure 1 shows a "word cloud" data-mined from all accepted papers, indicating repetition of relevant keywords. The accepted papers cover a wide range of structural engineering–related issues. In a very broad classification, one may identify five major categories: (1) modal analysis and vibration characteristics, (2) seismic response of large special infrastructures, (3) fundamental theories in discretized numerical methods, (4) thermal analysis and heat transfer, and (5) dynamic effects of trains and tunnels. Figure 2 provides a big picture and presents an overall summary of all the theoretical, numerical, and case studies used in one of the 15 accepted papers.

Summary

Modal analysis and vibration characteristics of the structural systems provide very important information about the dynamic response and transient performance of them. Depending on the complexity of the systems, different analytical, numerical, or direct experimental techniques can be used for this purpose. The first group of our articles discuss this important topic.

Base-isolation system is an effective technique to reduce the vibration response of the structures subjected to seismic excitation. In the article by Du et al.,[1] "Modal property of base-isolated high-rise structure considering soil–structure interaction effect," the authors proposed a simplified methodology to analyze the modal properties of base-isolated high-rise structures with dynamic soil-structure interaction (SSI) effects. The work is founded on a two degree-of-freedom (DOF) model, and is supported by swaying and rocking springs (and dashpots). The closed-form solution for the natural periods, modes, and damping ratios are provided. They found out that tall and slender structures with stiff isolation systems are more affected by SSI effects compared to the flexible super-structures.

Modal analysis is important not only for a continuum structure but also for any specific structural component. Aerostatic spindles are the core component of ultra-precision machine tools and have a significant impact on the quality of machining workpieces. In the article by Chen et al.,[2] "Modal analysis of an aerostatic spindle system for ultra-precision machine tools at different spin speeds," the authors constructed a detailed model of a large-scale gas film. Next, the integral calculation model of spindle and thrust was established which compiles the expressions based on dynamic meshing technique to acquire the flow field and trajectory of aerostatic spindle system. The results indicated that the fourth-order natural frequencies is increased by increasing the rotational speed. This effect declines for higher natural frequencies.

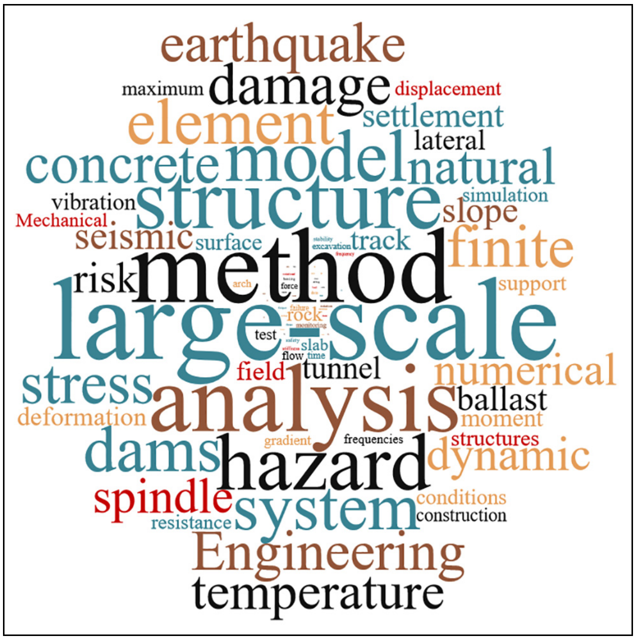

Figure 1. Word cloud from all the accepted papers in this Special Collection.

In the macro-scale, the dynamic characteristics of the structural system can be computed using the experimental techniques. In an article by Mirtaheri and Salehi,[3] "Ambient vibration testing of existing buildings: experimental, numerical and code provisions," the authors performed a set of comprehensive ambient vibration tests on over 40 steel and concrete buildings to compute the natural frequencies. Results were then contrasted with numerical simulations and the simplified standards/regulations. They reported significant differences between the experimental program and code-based simplified equations.

Earthquake engineering and seismic performance assessment of the structures and infrastructures is another important field in risk analysis. A wide range of techniques have been proposed for dynamic analysis, which includes both the linear elastic and nonlinear damage analyses. While simplified beam/column elements are mainly used for framed structures, more advanced continuum models are usually adopted for infrastructures such as dams, nuclear power plants, and bridges. The second group of our articles discuss this timely topic.

The frequent use of single- and double-layer lattice space structures specially in the seismic prone area

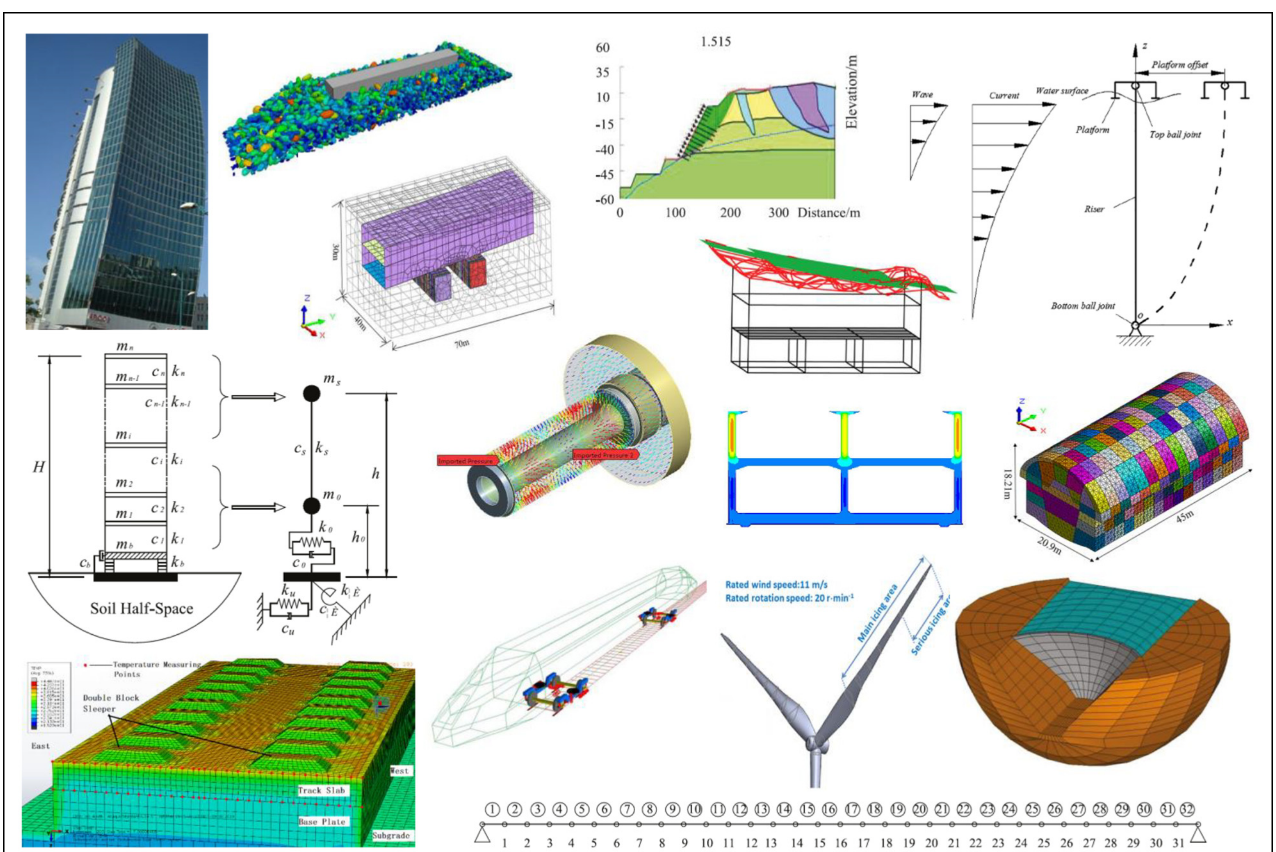

Figure 2. Examples of the models, theories, and case studies in the accepted papers.

reveals the importance of the dynamic studies on these shell-type structures. In an article by Nie et al.,[4] "Seismic behavior study on a space double-layer lattice structure with a lower supporting structure," the authors carried out a series of shaking table experiments on lattice structures. Subsequently, a nonlinear finite element model is also developed using parameters calibrated based on material testing of the steel members. The numerical model is validated with the test results, and the advantages of using curved beams (instead of the straight ones) were highlighted.

Varying environmental conditions as well as man-made changes increases the risk of slope failure. In an article by Tao et al.,[5] "Slope stability evaluation and monitoring of Tonglushan ancient copper mine relics," the authors analyzed the slope stability in relation to earthquakes and rainfall with limit equilibrium methods. Stability of the slopes were confirmed under reinforcement condition and sustained rainfall; however, not under earthquake excitation. In addition, the impact of mining blasting activities on slope stability was analyzed. They also investigated the potential use of remote monitoring and warning systems to continuously monitor the stability of the slope.

There are many dams around the world which are already 50 years or older. Having limited funding, the seismic risk analysis is a powerful tool in order to prioritize the need for rehabilitation of those dams. In an article by Hariri-Ardebili and Nuss,[6] "Seismic risk prioritization of a large portfolio of dams: revisited," the authors provided a state-of-the-art review on the potential failure mode and risk analysis of concrete dams. Different qualitative, semi-quantitative, and quantitative approaches were discussed, and as a potential application, the seismic risk of the 18 dams was evaluated. The semi-quantitative approach was also compared with the finite element model for one of the selected dams, and the impact of modeling uncertainty was discussed.

Any type of large-scale simulation requires a solid theoretical background which eventually solves multiple governing equations. In addition to the finite element technique which is a widely used numerical method, other approaches based on boundary elements, discrete elements, or even mesh-free technique are used for particular problems. The third group of our articles discuss the fundamental aspects of the numerical simulations and analytical techniques.

Finite element model updating is a technique to improve the prediction of the numerical simulations with the data from experimental test. In an article by Yang et al.,[7] "An improved spectral decomposition flexibility perturbation method for finite element model updating," the authors presented an improved technique in two aspects: (1) adopting a uniform correction model and (2) using the twice singular-value-truncation method. A beam structure is used as a vehicle for model updating in a noisy environment, and it is reported that only the results obtained by the second singular value truncation is stable.

The drilling riser is an important piece of equipment used to link the subsea wellhead with the drilling platform. In an article by Tang et al.,[8] "Investigation of the mechanical response of a deep-water drilling riser to ocean currents and waves," the authors studied the effects of tension ratio and platform deflection on the displacement, moment, and the stress of the drilling riser under shear flow. They concluded that there is a direct relation between increasing the tension ratio and the decrease in displacements and moments. They further proposed to use these findings to improve the design of drilling riser.

Ballasted tracks are traditional granular railway structures with complex mechanical properties which are used due to their low cost, low vibration and low noise, and easy maintenance. In an article by Zeng et al.,[9] "Ballast bed resistance characteristics based on discrete-element modeling," the authors performed an in situ experiment to study the changing characteristics of the lateral and longitudinal resistance of a ballast bed. In addition, a three-dimensional (3D) discrete-element model was developed, in which the ballast particles of various sizes were randomly distributed over the bed. Interior ballast particles are not connected by broken bonds, and there is no force between the neighboring particles.

Structural response of the engineering structures may also be highly affected by thermal loads. Spatial and temporal temperature variations due to heat transfer (e.g. conduction, convection, and radiation) should be considered in any realistic simulation. The heat transfer analysis can be performed in the context of linear, nonlinear, steady-state, and transient solutions. Coupling the thermal solution with mechanical analysis and chemical reaction is another challenging topic in multi-scale multi-physics analysis of structures. The fourth group of our articles discuss these multidisciplinary topics.

There is a close relation between the heat flux density of solar radiation, received at the surface of a ballastless track bed slab, and its alignment and geographical latitude. In an article by Zeng et al.,[10] "Influence of track line environment on the temperature field of a double-block ballastless track slab," the authors established the theories of solar radiation and boundary heat transfer by a double-block ballastless track structure. The model is verified based on experimental data. The horizontal and vertical temperature gradients of the plate were found to be in the most adverse conditions, when the angle between the south and the normal directions of the side surface was equal to 90°.

Developing a reference research on anti-icing and de-icing technologies for the large-scale horizontal-axis wind turbines is a very important task. In an article by Li et al.,[11] "Temperature effect on icing distribution near blade tip of large-scale horizontal-axis wind turbine by numerical simulation," the authors performed a series of quasi-3D numerical simulations to investigate the temperature effect on characteristics of icing distribution near the tip of the blade. They showed that the icing shape changes from horn icing to streamline icing with the decrease in temperature.

Controlling the potential crack growth during the construction of concrete structures is an essential task in large-scale projects. In an article by Wang et al.,[12] "concrete thermal stress analysis during tunnel construction," the authors studied the thermal stresses during the construction of a double-hole, double-deck concrete tunnel structure. The numerical model is validated by field observations and the high-risk regions are detected. The optimized construction plan is recommended by a series of parametric analyses on initial concrete temperature, formwork stripping time, and the construction season ambient temperature.

Dynamic loads induced by trains on the structural components as well as construction difficulties of the railways and tunnels in urban area are another challenge for civil engineers. The fifth, and final, group of our articles explore this issue from both scientific and engineering points of view.

The high-speed EMU trains adopt a lightweight design and power distributed technology. In an article by Lu et al.,[13] "Analysis methods of the dynamic structural stress in a full-scale welded carbody for high-speed trains," the authors proposed a new shell finite element transformation method between random loads and dynamic stresses. The multi-axial random dynamic load spectra of full-scale carbody are obtained by the vehicle system dynamics method. Systematic analysis of dynamic structural stresses provides a reference model for the fatigue durability evaluation of the large-scale welded structures.

Construction process of large-scale tunnels is a challenging task and needs a detailed numerical simulation supported by field tests in terms of the settlement gradient and the final settlement value. In an article by Wang et al.,[14] "Study on adaptability of primary support arch cover method for large-span embedded tunnels in the upper-soft lower-hard stratum," the authors studied the detailed excavation process of the tunnel by the double-side drift method. The numerical simulation results showed that the primary support arch cover method is effective in settlement control, plastic zone distribution, and supporting structure safety.

In a separate research by Hou et al.,[15] "Study on the settlement of large-span metro station's baseplate caused by the tunnels newly built beneath it," the authors studied the influence of tunnel excavation on the adjacent buildings. They investigated the settlement laws of the existing station's baseplate using four techniques: full-face excavation method, benching tunneling method, side heading method, and the central diaphragm (CD) method. Following the numerical simulations, the CD method is found to be the most efficient and accurate method to ensure the safety and normal operation of existing stations.

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