Earthquake Engineering Technology and Its Application

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1. Introduction

Recent earthquakes, such as the Osaka–Kobe earthquake (1995) and the Wenchuan earthquake (2008), have challenged earthquake engineering and its application. This Special Issue focuses on current developments in earthquake engineering, including ground motion characteristics, soil and foundation dynamics, wave propagation, behavior of structures, and methods for earthquake resilience and the retrofit of structures that are germane to practicing engineers. In this Special Issue, we have 19 works that improve the understanding of earthquake engineering from theory to application. This combination of both modeling and validation will strengthen our understanding of the impact that earthquakes have on foundations and structures and will help to improve the safety of inhabitants.

2. Seismogeology and Seismic Activity

Detailed geological and geomorphological evidence has suggested that the Yilan-Yitong fault (YYF), one of the key branches of the Tancheng-Lujiang fault zone in northeastern China, has been an active fault since the Holocene that has extended from Liaoning Province to far-eastern Asia. However, there are no clear fault traces or late Quaternary active features northeast of Tangyuan County. They carried out shallow seismic reflection exploration, field geological investigation, and trench excavation across the YYF north of Tangyuan. The results revealed that the YYF is composed of two main branches: the west YYF branch is a late Pleistocene active fault, and the east one is a middle-to-early Pleistocene fault.

The rapid assessment of post-earthquake building damage for rescue and reconstruction is a crucial strategy to reduce the enormous number of human casualties and economic losses caused by earthquakes. Conventional machine learning (ML) approaches for this problem usually employ one-hot encoding to cope with categorical features, and their overall procedure is neither sufficient nor comprehensive. They proposed a three-stage approach, which can directly handle categorical features and enhance the entire methodology of ML applications.

A comprehensive earthquake hazard database is crucial for comprehending the characteristics of earthquake-related losses and establishing accurate loss prediction models. Tongyan Zheng compiled the earthquake events that have caused losses since 1949, and established and shared a database of earthquake hazard information for the Chinese mainland from 1949 to 2021. On this basis, they preliminarily analyzed the spatiotemporal distribution characteristics of 608 earthquake events and the associated losses. Southwest China is in the Circum-Pacific seismic zone where earthquake hazards are highly frequent. The results can provide fundamental data for developing earthquake-related loss prediction models.

Cunpeng Du analyzed the effects of the 2011 Mw 9.0 Tohoku-Oki Earthquake on the locking characteristics and seismic risk of the Yishu fault zone in China. Combined with the b value and strain field characteristics, the properties of deformation of the Yishu fault...
zone before and after the earthquake are comprehensively analyzed. The results show that before the 2011 Tohoku-Oki Mw 9.0 earthquake, the locking degree and depth of the northern segment of the Yishu fault zone were higher, while the locking depth of the southern segment of the fault was shallower. The 2011 Tohoku-Oki earthquake produced different coseismic effects on the southern and northern sections of the Yishu fault zone. The extension on the southern section and compression on the northern section caused the strain release in the southern sections of the Yishu fault zone following the earthquake. After it, the regional locking degree of the southern section of the Yishu fault zone was relieved. However, the locking degree of the northern segment of the fault zone was still high and the depth was deep, at about 26 km.

3. Experimental Investigation of the Seismic Response of Infrastructures

The shaking table tests of a Seismic–Soil–Pile–Superstructure Interaction (SSPSI) in medium-soft and hard base soil were carried out. Silted clay with a unit weight of 1.70 g/cm$^3$ and a shear wave velocity of 175 m/s was adopted to simulate the medium-soft soil, while the composite soil obtained by adding 20% quicklime to silted clay with a unit weight of 1.75 g/cm$^3$ and a shear wave velocity of 300 m/s was adopted to simulate the hard soil in the tests. By inputting the artificial seismic motion time history with different amplitudes synthesized by the RG1.60 response spectrum commonly used in nuclear power engineering to the models, the dynamic interaction characteristics and seismic response laws of the soil–pile–nuclear island structure in the medium-soft and hard base soil were compared, the internal force and deformation distribution characteristics of the pile foundation under different ground conditions were analyzed, and the site conditions and mechanisms of seismic failure of the pile group foundation were described. The research results can provide a reference for site selection and seismic design of a nuclear power plant.

In order to compare and analyze the seismic response characteristics of a safety-related nuclear structure on a non-rock site in the condition of raft and pile group foundations under unidirectional and multidirectional seismic motion input, a large-scale shaking table test of the soil–nuclear structure system was carried out in this paper. In the test, the soil was uniform silted clay, and the shear wave velocity was 213 m/s. The results of the test show that the acceleration response of the safety-related nuclear plant is affected by the directions of the input seismic motion and the forms of the foundation. When the seismic motion is input simultaneously in three directions, the acceleration responses of the horizontal motion and vertical rocking of the safety-related plant are larger than those of the single-direction input. The acceleration response of the horizontal motion and vertical rocking of the safety-related structure with the pile group foundation is smaller than that with the raft foundation. The values of most frequency bands in the horizontal acceleration Fourier amplitude spectrum at the top of the pile–foundation structure are smaller than those at the top of the raft–foundation structure, while the displacement is basically the same as those of the raft–foundation structure.

In the catastrophe insurance industry, it is impractical for a catastrophe model to simulate millions of sites’ environments in a short time. Hence, the attenuation relation is often adopted to simulate the ground motion on account of calculation speed, and both ground motion expectations and uncertainties must be calculated. Due to the vulnerability curves of our model being based on simulations with a large number of deterministic ground motions, it is necessary but not efficient for loss assessment to analyze all possible ground motion amplitudes and their corresponding loss rates. They developed a simplified method to rapidly simulate loss expectations and uncertainties. In this research, Chinese masonry buildings are the focus. The result shows that the modified method gives accurate loss results quickly.

4. Engineering Site and Geological Hazard

$V_{s30}$ (the equivalent shear-wave velocity of soil layers within a depth of 30 m underground) is widely used in the field of seismic engineering; however, due to the limitation of
funds, time, measuring devices, and other factors, the depth for testing shear-wave velocity in an engineering site rarely reaches 30 m underground. Therefore, it is necessary to predict Vs30 effectively. They analyzed the existing models using 343 boreholes with depths greater than 30 m in Tangshan, China. This analysis shows that the topographic slope method is not suitable for predicting Vs30 in Tangshan. The Boore (2011) model overestimates, while Boore (2004) underestimates Vs30 in Tangshan, while Junju Xie’s (2016) model has ideal prediction results. We propose three new models in this paper, including the bottom constant velocity (BCV) model, linear model, and conditional independent model. We find that the BCV model has limited prediction ability, and the linear model is more suitable when \( z \leq 18 \) m, while the conditional independent model shows good performance under conditions where \( z > 18 \) m. We propose that the model can be accurately and effectively applied in Tangshan and other regions with low shear-wave velocity.

At 17:00 (UTC+8) on 1 June 2022, an Ms 6.1 reverse earthquake struck Lushan County, Ya’an City, Sichuan Province. This earthquake event had a focal depth of 10 km and the epicenter was located at 30.37° N and 102.94° E. Shao X documented a comprehensive coseismic landslide inventory for this event and analyzed the distribution pattern and factors controlling the landslides. The landslide area density (LAD) increased with an increase in the above factors and is explained by an exponential relationship, indicating that the occurrence of coseismic landslides in this area was more easily affected by topographic factors than seismic factors. Most small-scale landslides were clustered in the ridge area, which shows the seismic amplification effects of mountain slopes. Due to the impact of the direction of seismic wave propagation, hillslopes facing northeast-east (NE-E) were more prone to collapse than southwest-facing ones. Based on the distribution pattern of the landslides, we suggest that the seismogenic fault of this event was NW dipping. These findings indicate that it is effective to identify the dipping of seismogenic faults using the spatial distribution pattern of coseismic landslides.

Velocity changes (\( \frac{dv}{v} \)) during and after earthquakes are important indicators for understanding the earthquake-induced mechanical damage evolution of rock slopes. However, studying slope responses associated with various seismic loading still remains challenging due to limited in situ observations. Huang H. conducted a 20 min temporal resolution monitoring of \( \frac{dv}{v} \) at the frequency band between 2 and 20 Hz by applying ambient noise interferometry on the Pubugou rock slope in Southwest China. They observe an instantaneous \(~0.41\%\) \( \frac{dv}{v} \) drop in the slope caused by the 2021 M 7.4 Maduo earthquake at a distance of 780 kM, following a characterized logarithmic recovery process of \(~31.39\) h towards its pre-earthquake state. Moreover, the \( \frac{dv}{v} \) in five narrow frequency bands show a similar drop and subsequently increased recovery times associated with the deceased frequencies due to the long-distance earthquake shaking. We discuss two possible mechanisms related to the heterogeneous rock slope excited by the long-distance earthquake at a low frequency. This study motivates the damage assessment of the rock slope using in situ \( \frac{dv}{v} \) and furthers the understanding of subsurface geological risks under diverse seismic loadings.

Post-earthquake road traversability is a critical factor that affects traffic conditions. Therefore, a post-earthquake traffic simulation method considering road traversability was proposed. First, the impact ranges of the earthquake-induced building collapse and the post-earthquake fire spread of buildings were analyzed, and road traversability was determined accordingly. Subsequently, the post-earthquake traffic flow was predicted based on building characteristics, and micro-level vehicle behaviors were simulated considering post-earthquake road traversability to determine the traffic conditions. In addition, the simulation model was validated using actual data. Finally, a segment of the Tongzhou road network in Beijing was selected as a case study to analyze post-earthquake road traversability and simulate traffic conditions on critical road sections. The proposed method can provide post-earthquake traffic conditions, which benefits decision-making during post-earthquake evacuation and rescue.
5. Dynamic Constitutive Behavior of Materials (Soil, Concrete, etc.)

In the seismic response analysis of liquefiable sites, it is challenging to simulate saturated sand’s post-liquefaction deformation with the existing soil dynamic constitutive model, and the current pore-water pressure buildup model cannot reflect the decrease in the actual pore-water pressure under unloading stress. They aim at these problems to propose a feasible and straightforward time-domain post-liquefaction deformation constitutive model through experimental analysis and theoretical research, consisting of reversible pore-water pressure. According to the dynamic triaxial test data, the regularities of large deformation stress and strain behavior of the saturated sand after liquefaction are obtained, and the corresponding loading and unloading criteria are summarized. Combined with the effective stress constitutive model proposed by the author, a soil dynamic constitutive that can describe saturated sand’s post-liquefaction deformation path is obtained. According to the test results, the model can simulate the deformation of saturated sand during the whole liquefaction process. The self-developed program Soilresp1D realized the dynamic response analysis of the liquefiable site, and the results were compared with the experimental results. It shows that the model based on the effective stress-modified logarithmic dynamic skeleton and post-liquefaction deformation constitutive can be directly applied to the dynamic response analysis of the liquefiable site.

Twelve site models were established based on the analysis of the influence of site conditions on earthquake damage and the influence of the soft soil layer on-site seismic response. The equivalent linearization site seismic response analysis is carried out at different input ground motion levels to discuss the influence of soft soil layer thickness and buried depth. The results show that the characteristic period of the response spectrum exhibits a gradual increase as the buried depth or thickness of the soft soil layer increases. Furthermore, the characteristic period of the response spectrum also increases with the rise in the input ground motion peak. Moreover, according to the influence that the characteristics of soft soil thickness, buried depth, and input ground motion intensity have on the characteristic period of the site acceleration response spectrum, a method for adjusting the characteristic period of the site acceleration response spectrum with a soft soil layer is put forward.

As an indispensable part of the lifeline for the offshore gas and oil industry, submarine pipelines under long-term marine environmental loadings have historically been susceptible to earthquakes. This study investigates the impact of trench backfilling on the residual liquefaction around a pipeline and the induced uplift of a pipeline under the combined action of an earthquake, ocean wave, and current loading. A fully coupled nonlinear effective stress analysis method, which can consider the nonlinear hysteresis and the large deformation after liquefaction of the seabed soil, is adopted to describe the interaction between the seabed soil and the submarine pipeline. Taking a typical borehole in the Bohai strait as the site condition, the nonlinear seismic response analysis of the submarine pipeline under the combined action of seismic loading and ocean wave and current is carried out. The numerical results show that trench backfilling has a significant impact on the seismic response of the pipeline. The existence of trench backfilling reduces the accumulation of the residual excess pore water pressure, so that the seabed liquefaction around the pipeline is mitigated and the uplift of the pipeline is also decreased.

Overloaded trucks and earthquakes have become two main factors responsible for bridge damage; consequently, the combination of heavy trucks and seismic loads as a typical occurrence of extreme events is likely to lead to bridge collapse or destructive damage, in which the crucial issues of coupling load model, dynamic equations, and bridge responses have not been adequately addressed. A simplified vehicle–bridge model consisting of many containers is established to simulate vehicle passage, and the dynamic equations are derived for a 5-axle truck on a simply supported beam as an illustration. Then, five ground motions selected from PEER with appropriate peak ground accelerations and durations and the three truck models specified in American Association of State Highway and Transportation Officials, Caltrans and Chinese codes are applied to the finite element
model of a typical reinforced concrete continuous girder bridge, in which the vehicle speed, number of trucks, ground motion and vehicle type are assumed to be random variables and their influences on dynamic responses of the bridge are analyzed. The results show that the seismic load is the governing factor in dynamic responses, but truck load may change displacement shapes.

6. Performance-Based Seismic Design of Structures and Earthquake-Resilient Cities

Globally, tanks play a major part in the provision of access to clean drinking water to the human population. Beyond aiding in the supply of fresh water, tanks are also essential for ensuring good sanitary conditions for people and for livestock. Many countries have realized that a robust water supply and a robust sanitation infrastructure are necessary for sustainable growth. Therefore, there is large demand for the construction of storage tanks. Furthermore, liquid storage tanks are crucial structures which must continue to be operational even after a catastrophic natural event, such as an earthquake, to support rehabilitation efforts. From an engineering point of view, the various forces acting on the tanks and the behavior of the tanks under various loads are important issues which need to be addressed for a safe design. Analyses of these tanks are challenging due to the interaction between the fluid and tank wall. Thus, researchers have conducted several investigations to understand the performance of storage tanks subjected to earthquakes by considering this interaction. They discuss the historical development of various modeling techniques of storage tanks. The interaction with the soil also influences the behavior of the tanks, and hence, in this paper, various modeling approaches for soil structure interaction are also reviewed. Further, a brief history of various systems of base isolation and modeling approaches of base-isolated structures are also discussed.

Incremental dynamic analysis (IDA) is applied to calculate the exceeding probability of rail displacement under different earthquake excitations. A finite element model (FEM) of a high-speed railway track-bridge system is established, which consists of a CRTS II ballastless track of finite length laid on a five-span simply supported girder bridge. Records from five stations in the PEER NGA–West2 strong ground motion dataset are selected as seismic excitation. Based on the simulation, the characteristics of the vertical displacement of the rail under different seismic excitations are investigated, and the probability of the vertical displacement of the rail exceeding the allowable standard is calculated using IDA. The exceeding probability of the rail above the mid-span is larger than that above other parts of the bridge. Within the mid-span, the exceeding probability of the rail is the largest above the center of the bridge.

Borehole shrinkage and collapse are likely to occur when downhole testing is conducted in soft or loose sandy soils, resulting in testing interruption. To prevent this situation from occurring, installing casing in the borehole is a common approach. However, in actual testing, the quality of the signal obtained from measuring points within the depth of the casing is often not ideal, and there is still no clear and unified justification for the causes of interference generated by the casing. Therefore, the team attempts to investigate and elucidate the impact of casing through on-site experiments and numerical simulations. By numerically simulating different casing materials, the contact state between the casing and the hole wall, and the presence of low wave velocity filling soil around the casing, the variation patterns of the affected measurement point signals in the time and frequency domains are investigated. Furthermore, combined with the measured data, the impact characteristics of the casing on the results of the wave velocity testing using the downhole method are systematically explored. This research can provide some insights for the application and data interpretation of signals in the downhole methods of cased wells.

7. Conclusions and Prospects

We are delighted to see that the articles featured in this Special Issue have contributed new knowledge to the field of earthquake engineering technology and its application, provided innovative ideas for future development, and opened new opportunities for
further collaboration and innovation. We extend our gratitude to the staff of Sustainability for their tremendous support to our Guest Editor Team in organizing this Special Issue, as well as their assistance with the review, revision, and verification process. We also thank all authors for their insightful contributions to this Special Issue and all reviewers for their valuable comments and suggestions on the submitted manuscripts.

**Funding:** This work was supported by the Major Program of National Natural Science Foundation of China (52192675).

**Conflicts of Interest:** The authors declare no conflicts of interest.

**List of Contributions**


8. Shao, X.; Xu, C.; Ma, S. Preliminary Analysis of Coseismic Landslides Induced by the 1 June 2022 Ms 6.1 Lushan Earthquake, China. *Sustainability 2022*, 14, 16554.


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