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Editorial

Infrastructure Safety from the Perspective of Resilience Theory

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With the rapid development of urbanization, the scales of urban population and land use are tremendously expanding. On one hand, urban infrastructure is becoming stronger, which makes our lives better, but on the other hand, the internal complexity of the urban infrastructure is also growing. Especially since the 21st century, natural or human-made disasters have occurred frequently around the world, and various new types of disasters have continued to emerge and shock the world, including climate change, accident disasters, financial crises, epidemic diseases and terrorist attacks, etc. To be specific, the outbreak of urban security incidents (e.g., the Katrina hurricane, the Wenchuan earthquake, the Fukushima nuclear leak, the Indonesian tsunami, the Qingdao oil pipeline explosion, and the Zhengzhou flood, etc.) has resulted in heavy economic losses and severe life casualties to human society, and all these uncertain factors may lead to various risk and damage in infrastructures. Confronted with these factors, urban infrastructure often shows potential vulnerability and exposed fragility.

Due to its vital role in modern communities and cities, civil infrastructure should be able to resist and recover from natural or human-made disasters. In the face of the urban security situation in the new era, how can we ensure urban security and take precautions in the urban planning stage? It can be seen that the issue of urban security and urban resilience has become an important point in the process of urban planning and construction. Scientists, politicians and urban managers have carried out corresponding research and taken emergency measures, in which how to realize the resilient civil infrastructure is the most important aspect. At this stage, developing resilient civil infrastructure has garnered significant research attention over the world.

1. Significance of Infrastructure Resilience in Civil Engineering

The definition of resilience evolves from the Latin word resilio, which means to bounce back. In 1973, Holling et al. [1] introduced the concept of resilience into ecology to describe the ability of an ecosystem to continue to maintain equilibrium after external disturbances or to return to a state of equilibrium after the equilibrium was disrupted. Subsequently, the concept of resilience has been introduced into engineering, social sciences and other fields successively. Resilience is an inherent ability and characteristic of a system and is a common phenomenon in nature. It has different names in different systems, such as elasticity, recovery, reduction, and compliance.

In the field of civil engineering, the idea of resilience has been around for a long time. At the material level, if the external force is regarded as a disturbance, the material will deform after being subjected to the external force. As long as the deformation is within the elastic range, the material can return to the initial state after the external force is removed. Therefore, the elasticity of the material level can be regarded as a kind of resilience. At the urban infrastructure level, urban resilience refers to the ability of an urban system to maintain or quickly restore its functions when affected by disasters, that is, when a city is affected by disasters, as long as its control parameters do not exceed a certain threshold, the functions of the system characteristics and their operating modes are maintained or can be rapidly restored to their pre-hazard state. Urban resilience consists of multiple levels, including components, structures, and communities, in which the resilience of urban infrastructure is the key to ensuring the basic functions of the urban system and is the core link of urban resilience in its further evolution.

Although there are differences in the understanding of the resilience concept in multiple aspects, the following consensus has been formed, i.e., the resilience of infrastructures emphasizes the ability to absorb external shocks and disturbances, and the ability to restore the original state or achieve a new equilibrium state through learning and reorganization. From the perspective of disaster prevention and damage mitigation, the resilience of infrastructures basically covers three elements: (1) the ability to reduce the impact of disasters or emergencies; (2) the adaptation to disasters or emergencies; (3) the ability to efficiently recover from disasters or emergencies. Chang and Shinozuka [2] adopted the quantitative measures to demonstrate the concept of infrastructure resilience and came to the conclusion that more dimensions including technical, organizational, social, and economic facets are needed to collaboratively address the complexity of resilience. Cimellaro et al. [3] introduced the concepts of disaster resilience and its quantitative evaluation, and a unified terminology for a common reference framework was well proposed for further work. Paton and Johnston [4] explained the significance of infrastructure resilience, and an integrated approach in the perspective of disaster mitigation was given for general resilience improvement. Cutter et al. [5] indicated that infrastructure resilience is a national imperative, which is posing significant risks and challenges to human society, thus, more preparedness efforts to an adequate degree are urgently required for in-depth progress.

2. Transition to the Resilient Infrastructures in Civil Engineering

Compared with the traditional urban communities and disaster prevention strategies, this editorial also points out three significant aspects for the future transitions to resilient infrastructures in civil engineering, including the perspective transition, the technical transition, and the scale transition.

2.1. Perspective Transition

The traditional disaster prevention and resilience planning follow the traditional 'engineering design', which focuses on engineering defense. The planning and construction of various disaster prevention projects are based on normative requirements, and the fortification standards are proposed correspondingly. However, most of the current disaster prevention disciplines are formulated based on the former fortification standards or historical disaster statistics. With rapid urbanization and extreme disasters becoming more frequent in recent years, as well as technological changes and innovations, the timeliness of risk prediction under this engineering thinking is getting shorter and shorter. Especially in recent decades, the design standards and technical specifications of the original fortification levels, supporting facilities and other defense projects have been continuously updated and revised [6,7].

Thus, in the preparation of future resilience civil infrastructure, the first thing to change is the planning concept (i.e., perspective transition), from defense planning based on traditional engineering thinking to adaptive planning based on dynamic risk assessment, and from the perspective of disaster mitigation to risk strategy. Urban infrastructure resilience will be more inclined to predict the macro situation of key defense objects and high-risk areas through continuous dynamic tracking and monitoring. At the same time, combined with the perspective transition and technological progress, putting forward the disaster prevention and mitigation measures that adapt to the new normal of urban resilience and systematic safety will be a future trend.

2.2. Technical Transition

Traditional disaster prevention and resilience planning is accustomed to using engineering technical standard formulas or empirical values to calculate the safety requirements and to ensure the safe operation during a period. With the development of resilient civil infrastructure, an important premise and a critical guarantee to realize the city-scale resilience enhancement is the transformation to novel technology [8,9]. Compared with the conventional force-based civil infrastructure in design, the future resilient infrastructure will focus more on the performance theory and post-disaster function in the life-cycle procedure, and this largely depends on the improvement and upgrade of resilient technologies.

In the aspect of resilient engineering structures, its typical representative is a resilient building structure (i.e., recoverable structure), which refers to a structure that can quickly restore its function without repair or minor repair after the hazard. As a new type of structural system, this resilient building structure can not only protect people's life and property during the hazard but also help people to resume normal life as soon as possible after the hazard. The resilient building structure is believed to be promising in both construction and mechanism, and it generally indicates cost-effective maintenance throughout the life cycle. The recoverability of its function is mainly achieved by adopting rocking walls, rocking frames, and self-resetting or replaceable components. Resilient building structures can shorten post-hazard recovery time and reduce hazard losses, thus hugely improving the general resilience on the urban scale. In addition, in the aspect of resilient materials and components, the typical representatives include ultra-high performance concrete, smart memory alloy, high ductility reinforcement, etc., and more references can be found in Li [10], Graybeal [11], Song et al. [12], and Vugrin et al. [13]. To sum up, the technical transition is a significant step in the enhancement of the urban resilient system, and it also lays a critical foundation for risk-based decision-making in the future.

2.3. Scale Transition

Traditional disaster prevention and resilience planning is mainly centered on earthquakes, fires, floods, geological disasters and war threats. Meanwhile, disaster prevention measures are mainly engineering measures, primarily for earthquake resistance engineering, fire protection engineering, flood control engineering and civil air defense engineering, but their corresponding communications and coordination mechanisms are not clear. At the same time, the traditional disaster prevention targets are mainly aimed at the individual structure level, while lacking disaster prevention and resilience improvement strategies at the urban infrastructure or community system level. Non-engineering measures for urban systems such as disaster prevention management systems, information intelligence systems, material security systems, and safety education systems are simple and vague, and their practical operability is not strong. To some extent, urban risk trends are showing more incompatibility, which is posing huge challenges to disaster prevention and resilience planning in the city-scale context of urban security in the new era [14,15].

Thus, the research scope of disaster prevention and resilience planning under the transition of macro scale has been extended to the public safety of the entire urban infrastructure, covering production safety, damage mitigation, nuclear safety, explosion avoidance, social security, anti-terrorism, food qualification, inspection and quarantine, and many other aspects. Resilient civil infrastructures require that cities not only have the ability to reduce the impact of disasters (engineering measures) but also have the ability to adapt quickly and recover quickly when facing disasters and risks, especially at a macro community level or an integrated region level. The construction of resilient infrastructure and public safety system is mainly to improve the urban ability to deal with hazards, alleviate the urban public situation, and enhance the safety of urban survival, through preventing, controlling and dealing with various urban safety issues that endanger the development of the resilient infrastructure. To enable the urban infrastructure to respond as effectively as possible in the face of emergencies and disasters, the scale transition in research and practice is definitely necessary, which gives a more comprehensive blueprint and a more exhaustive direction in the further development of resilient civil infrastructure.

3. Purpose of This Topic "Resilient Civil Infrastructure"

Through the above analysis, it is found that the overall goal of resilient civil infrastructure is to minimize the impact of disaster risks on the city scale and to improve the sense of security from a macro perspective. The construction of civil infrastructure is based on the identification of risks that are suffered by cities in the future, and we need to focus more on the consideration and evaluation of the impact of low-probability and huge-impact disasters, emerging disasters, slow-onset disasters, as well as the combined disasters. Moreover, it is required to take urban systems (economy, society, and institutions) as the guide to effectively improve the general infrastructure resilience and efficiently achieve a comprehensive risk response. In addition, the construction of resilient civil infrastructure, as a comprehensive, all-round and long-term work, still faces severe challenges in the future, especially in terms of implementation paths, technical methods and organizational management, which still needs to be further explored and be made pioneered breakthroughs by industry and academia.

In a sense, the enhancement of resilience for civil structures and infrastructures is a promising and urgent topic for research and application. Although significant advances have been made in this field in recent years, there are still important challenges related to the more effective resilience quantification and resilience enhancement of civil infrastructures to multiple disasters. These challenges require further, more comprehensive efforts and more general intervention planning. At this stage, there is a strong need for existing systems to tackle various challenges in the resilience field, such as disaster prevention, mechanical theory, material property, applied technology, system innovation, assessment strategy, interaction effect, decision-making, etc. This general task requires resilience evaluation in a more comprehensive view and intervention planning at the lowest possible cost in its life cycle, which ranges from the inherent resilience of the entire system to the provision of evidence-based strategies for optimizing infrastructure resilience.

From the above perspective and under the promising background, this topic, namely, 'Resilient Civil Infrastructure' is established, which seeks to contribute to the resilient civil infrastructure through enhanced scientific and multi-disciplinary works, and aims to improve knowledge and performance in resilient civil infrastructure under the new normal of urban security risks. The potential topics include (but are not limited to): methodology for resilience assessment and quantification; probabilistic theory and method for resilient infrastructure; resilient construction materials; innovative resilient structures; multiple-hazard effects on resilience; resilient community and smart city; structural resilience and service life extension; design optimization for resilient structure; resilient management and performance improvement; interaction between resilient structures and environment. We have many challenges to address, but by co-working locally, regionally, nationally and globally, we can make great improvements and we will realize the expected outcomes in resilient civil infrastructure.

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