Editorial. The crux in bridge and transport network resilience - advancements and future-proof solutions

Original
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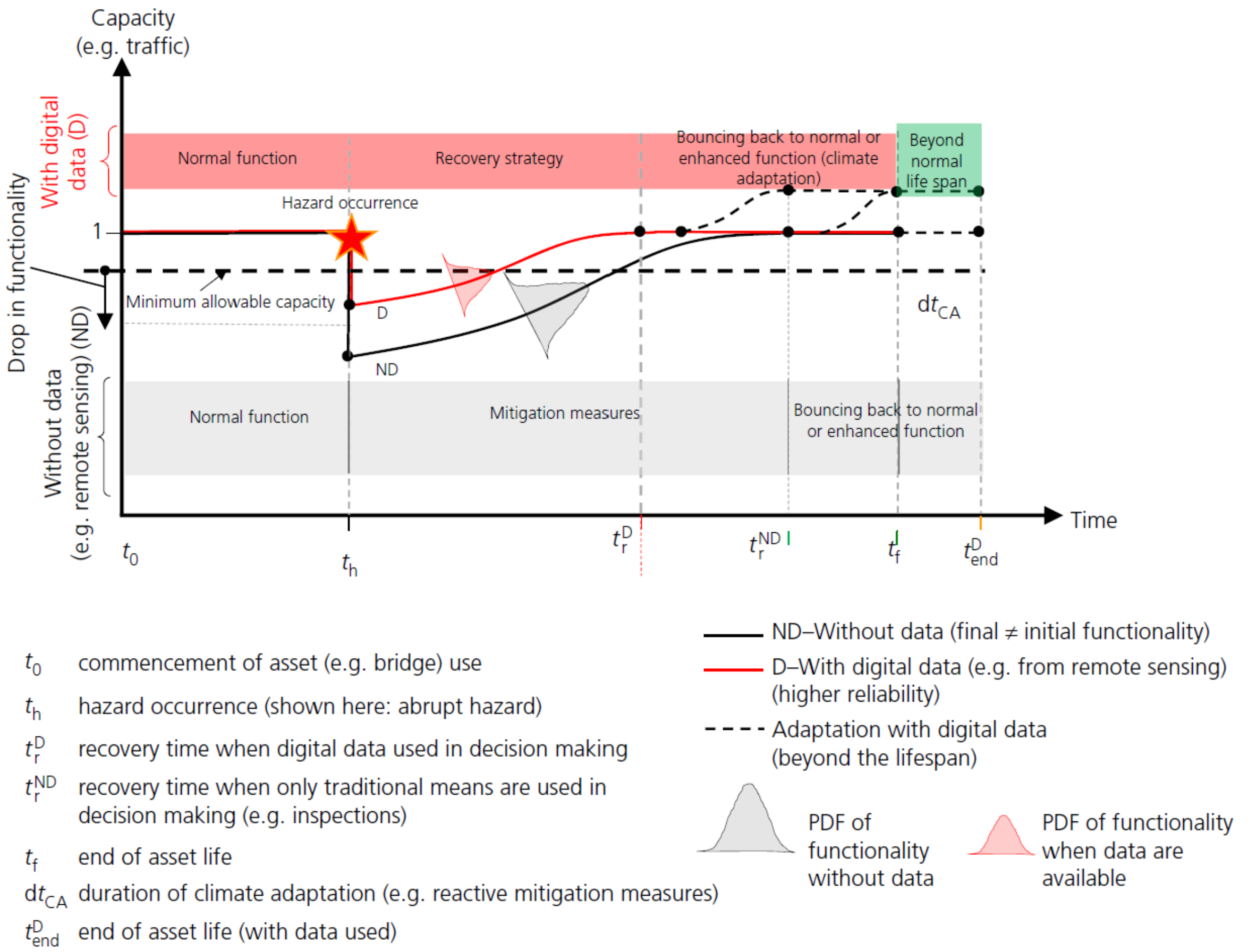

Figure 1. Resilience curves of critical transport assets throughout their lifecycle due to natural hazards with or without the deployment of digital data (Mitouls et al., 2021).

The second manuscript of the issue (Blagojević et al., 2021) focuses on the community disaster recovery approach that accounts for community components' accessibility for repair using a demand–supply framework. It is illustrated on a virtual community with 3600 inhabitants supported by several interdependent infrastructure systems (Figure 2).

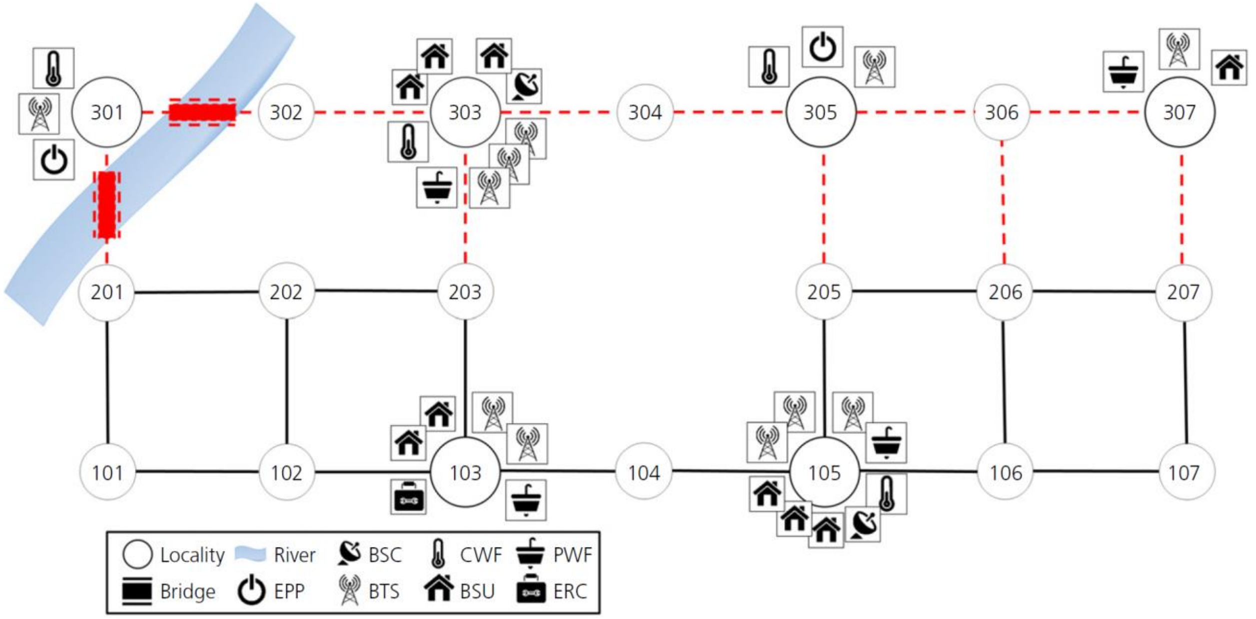

Figure 2. Case study of a virtual community, with complete interruption of networks' branches - red dashed lines (Blagojević et al., 2021).

The third contribution (Lentile et al. 2022) provides a methodology to evaluate the influence of road links in the risk assessment and management strategies of critical transport infrastructures. The methodology is applied to a Spanish motorway, the main case study of the paper. An index to quantify the serviceability losses is developed and presented, combining the results of road link failure scenarios based on the shortest paths and travel times to estimate road network resilience.

The increasing flood-induced damage to bridges due to climate change and rising urbanisation hazard is deepened by the fourth contribution of the Themed Issue (Degan Di Dieco et al., 2022). A taxonomy of 20 attributes for riverine roadway bridges susceptible to flood hazards is proposed, and subsequently verified by considering three bridge datasets in the UK.

Several resilience metrics have been proposed in the literature. In the fifth article of the Themed Issue Argyroudis (2022) reviewed these methods and metrics and provided practical applications and a worked example to facilitate their use by engineers and researchers whilst putting emphasis on the main properties of resilience, i.e., robustness, redundancy, resourcefulness and rapidity. The main steps of resilience assessment for transport infrastructure, such as bridges, are discussed and the use of fragility and restoration functions to assess the robustness and rapidity of recovery is demonstrated. Practical examples are provided using a bridge exposed to scour effects as a benchmark, discussing different aspects of resilience-based decision making and their impact at the network level, as shown in Figure 3.

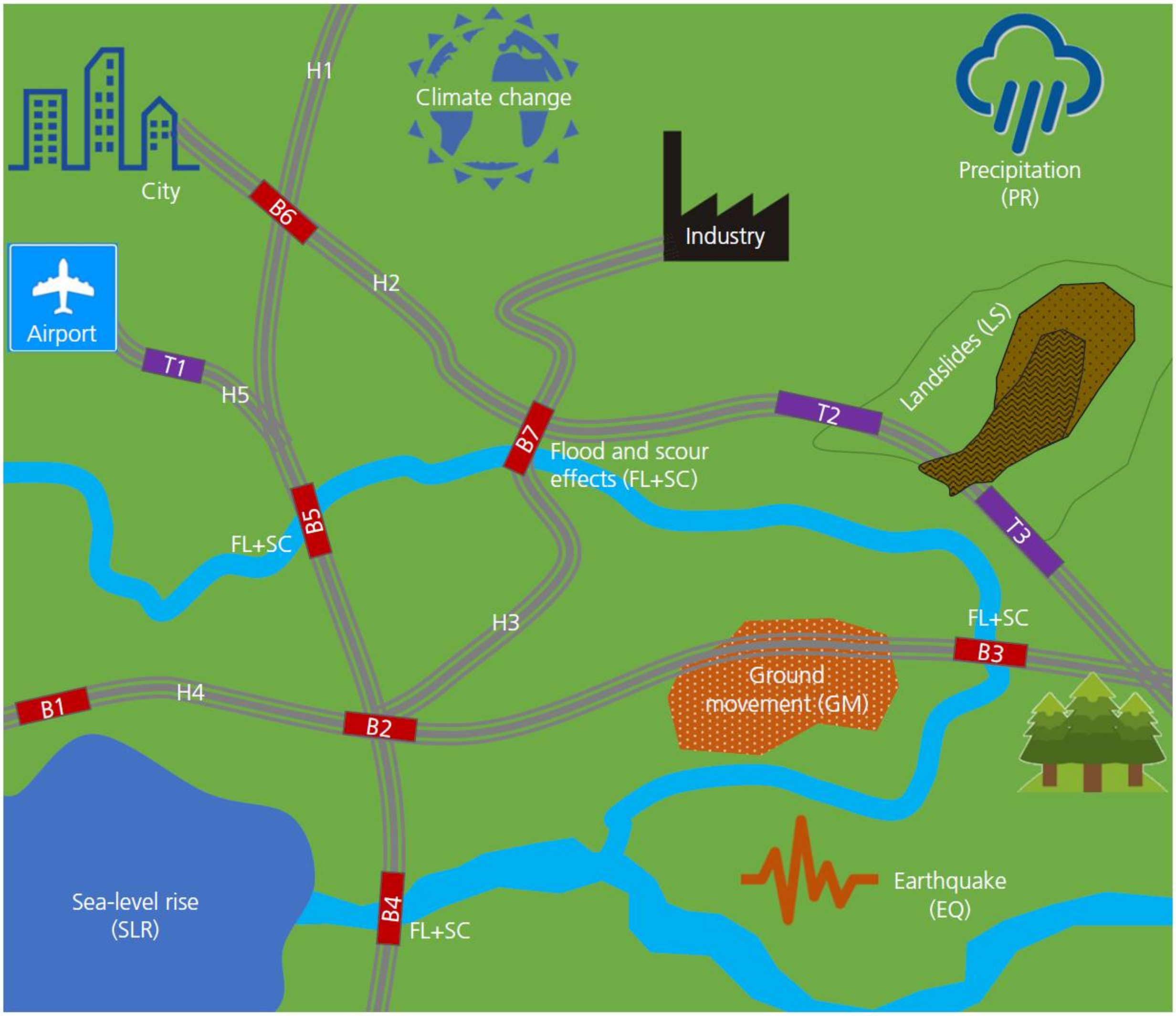

Figure 3. Interconnected transport assets (highway, bridges, tunnels) in multi-hazard conditions (Argyroudis 2022).

The last two contributions focus on two significant case studies. Godazgar et al. (2022) provided a probabilistic resilience curve for the Chemin des Dalles Bridge (CDB) in Quebec, Canada. This model incorporates fragility and restoration profiles available in the literature. In the last paper, Langley (2022) provides the background to the replacement project for the moveable bridge on the A554 Tower Road. The civil, mechanical and electrical designs are described and some of the significant issues encountered during implementation and commissioning are discussed.

Innovation from the papers of this issue

The paper of Mitoulis et al. (2021) introduced two scales in resilience assessment i.e.: (a) small scale – bridge structures and their resilience to multiple and combined hazards and (b) the resilience of large-scale systems, including transport networks. The effects of natural hazards, exacerbated by climate change, potential damage and functionality loss, and relevant mitigation measures for bridges have been discussed along with the assessment of bridge and network vulnerabilities. The paper considers also the critical role of structural control and SHM, which can be useful for planning ordinary (maintenance) and extraordinary post-event interventions to ensure an acceptable level of functionality and safety over time, and facilitate proactive and reactive climate adaptation measures. Large scale simulation platforms have been introduced in Mitoulis et al. (2021), and further detailed in Blagojević et al. (2021). Both are able to reproduce the transport network, but also the critical interdependencies with other infrastructure systems. Blagojević et al. (2021) in particular presents a way to use a demand–supply based community disaster recovery and resilience quantification framework to simulate accessibility of damaged components for repair, using a virtual community of 3600 inhabitants impacted by a virtual disaster. The case study highlights that damage to the transportation network can reduce the ability of a community to mobilise its repair resources. Both papers conclude with the urgent need of realistic validation studies for accurately assessing the ability of numerical modelling and available platforms to capture real-life community disaster resilience.

The index proposed by Lentile et al. (2022) has been used to measure the vulnerability of individual road links in a Spanish highway case study in order to obtain a measure of network resilience. A statistical combination of the results, evaluating the median and quartile values of the LoS indices, allows an overall assessment of the vulnerability of the road links and thus of the functionality of the road network by exploiting openly available data and information, such as the structure of the network, using an open-source geographical database.

The verification exercise of the proposed taxonomy in Degan Di Dieco et al. (2022) with three UK bridge datasets shows that the significance of the taxonomy is multi-fold and fills the gap of a specific taxonomy for bridges at flood risk, developing a common language that could uniform data collection and cataloguing of bridges at flood risk. This is of paramount importance in developing resilience models for portfolios of bridges that have similarities and hence reduce the cost of bridge-specific fragility and resilience modelling, toward more efficient management of our transport networks.

Argyroudis (2022) reviews the available resilience metrics and through applications paves the way to their use in bridge and transport network management. This practical paper is useful especially in view of the urgent climate adaptation measures that we need to incorporate into our resilience-based designs for bridges and networks.

The last two contributions with significant case studies include the contributions of Godazgar et al. (2022) and Langley (2022). They provide insights on the seismic resilience of the Chemin des Dalles Bridge (CDB) in Quebec, Canada (Godazgar et al. 2022) and on the requirements, e.g., the need for an integrated multi-disciplinary team of civil, mechanical and electrical engineers to ensure a resilient project development (Langley 2022).

Conclusions - Future-proof solutions including climate projections

Resilience simulation frameworks, tools and metrics, presented in this Editorial, need to travel in time. First, to the past, in the process of validation against recorded events. Second, and often, to the future, think and design bridges for realistic and/or unforeseen climate scenarios. We expect to use resilience simulation models to predict the vulnerability and the recovery of bridges and transportation networks in possible future disasters, to plan retrofits of existing structures, to design new structures and transportation systems, all the while informing operators and the public about the costs and benefits of resilience to their communities.

To do this well, resilience simulators must consider the changes in existing structures due to their use and local environmental effects, as well as the evolution of their service demands and loads due to the changes in our climate, growth of our society and deployment of new technologies. Structural health monitoring and digital twining offer promising ways forward to update and future-proof resilience models of individual structures. Evolution of climate, technologies and society, however, requires comprehensive integration of systemic engineering resilience models with climate, territorial planning and technology forecasting models. The contributions presented herein are the basis for this difficult task.

For more accurate resilience modelling, the focus of research and practice in the future should be on the development of realistic and practical restoration and reinstatement models for bridges and networks – this is currently missing in view of the urgent need for adaptation to predicted climate changes. The interdependencies of transport networks and other critical systems (e.g. energy systems) is another area that requires significant efforts in modelling and quantification as bridges and transport networks reside within other complex and diverse assets, networks and systems, the interoperability of which is vital.

Multidisciplinary solutions are of paramount importance for planning resilient bridges and transport infrastructure and this effort can be complemented with ongoing technological developments. Smart infrastructures of the future, including bridges, will have to be conceived in a holistic context of multi-functionality. Thus the load-bearing structural skeleton will be integrated into a larger context and harmonized with other components (e.g., plant engineering, traffic, environment). Thus, the implementation and development of computational tools and data management algorithms (e.g., machine learning and Big Data), for data sensed by e.g., fiber optics, embedded sensors, miniaturization, are destined to become the backbone of the smart and resilient infrastructure of the future, thus they need to be further developed and calibrated, federated and supported by policy. The goal is to optimise their operation assuming an evolutionary scenario, both with a view to increasing their safety (including with respect to the structural capacity of existing assets) and improving their operation for unforeseen hazards and threats.

Modelling and simulation approaches at small and large scales, underpinned by emerging technologies relating to monitoring have been recognised as critical tools for the resilience assessment of critical infrastructures. In this context, the deployment of virtual simulation environments, that include large inventories of digital twins, and real assets equipped with sensor networks collecting data in real-time from the real world also need to be used in harmony and complement each other. This would alleviate the demand for modelling and obtaining data from resilience specialists, who often develop large-scale models, but are in some cases unable to validate and connect them to real world structures.

Future-proof solutions require adoption of technological and scientific advancements, but what is more important is to nurture the next generation of civil and bridge engineers with the principles of resilience and sustainability and to train them on new technologies. It is therefore necessary to create new integrated and interdisciplinary curricula for the new generation of resilience and sustainability engineers. The same applies for taught modules and curricula on bridges and transport infrastructure, where more specialised knowledge on resilience would be required. Resilience engineering is in its infancy and has been adopted by leading universities and technical institutions, but needs to be consolidated in the future and extended to all academic institutions which offer degrees in engineering.

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