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Information-dependent seismic reliability assessment of bridge networks based on a correlation model

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ABSTRACT

The focus of this study is the seismic reliability assessment of bridge networks, which is normally recognised with temporal and spatial variations similar to other engineered systems. The essence of such variation is that the assessment actually changes with available information. The relevant 'information' is clarified here and simply divided into two categories, i.e. the basic properties of the network together with the hazards and the real performance of part of the network. Correspondingly, approaches to an assessment with different categories of information are identified, and the framework for an information-dependent seismic reliability assessment is formulated. The basis for such information-dependent assessment is the description of the dependence structure of the seismic performance of bridges. Here, a correlation model that covers different aspects relevant to bridge performance is derived to play such role and is combined with the fragility analysis of individual bridges to realise the network reliability assessment and the importance measure of components in the priority of information collection. The proposed framework, together with the correlation model, is demonstrated in an example of a traffic network that connects 8 cities by highways with 12 standard reinforced-concrete overpass bridges in California.

1. Introduction

There are many large-scale engineered systems around us, which play important roles in societal activities. The performance of these systems, which are subject to natural hazards, is a concern of our society. Large-scale engineered systems could be individual but large structures, e.g. offshore structures and large bridges. Large-scale engineered systems could also be geographically distributed engineered systems such as power grids and bridge networks. In previous years, significant progress has been achieved in the risk and reliability analysis of the first category, i.e. individual but large structures (see e.g. [1,2] for offshore structures and [3–9] for concrete bridges). Just approximately one and half decades ago, geographically distributed engineered systems first became the concern of scientists as a special type of complex networks (see e.g. [10,11]). The concern gradually motivated scientific research in structural engineering. For example, Dueñas-Osorio and Vemuru [12] studied the effect of cascading failures in the risk and reliability assessment of power transmission systems. Concerning the seismic risk analysis of bridge networks, many studies had been performed in the previous years, such as [13] for the influence of deterioration phenomena, [14,15] for the influence of retrofit solutions on fragility estimate, and [16] for the estimation of costs for seismic retrofit of bridges. Moreover, Bocchini and Frangopol [17] and Zanini et al. [18] presented different techniques of reliability assessment of bridge networks.

Those achievements in the seismic reliability assessment of bridge networks recognised their temporal and spatial varying attributes similar to other engineered systems. The essence of such variation is actually the change in available information. Bridge networks, similar to other geographically distributed engineered systems, generally cover some areas and have their distribution of hazard, material properties, configurations of individual bridges, etc. over a space. Meanwhile, as some earthquake occurs, new information might arrival, which might be incomplete knowledge but the real performance of part of the network. Here the real performance is the condition state of the bridges subject to the earthquake. On the other side, the change of the condition states of the bridges may cause a loss of functionality of the transportation network, which may further disrupt lifeline services and the flow of goods and services in the immediate aftermath, leading to severe economic consequences. Such consequences are not only limited to direct costs of reconstruction and/or repair of bridges, but may also include broader economic losses and changes in the flow of goods and

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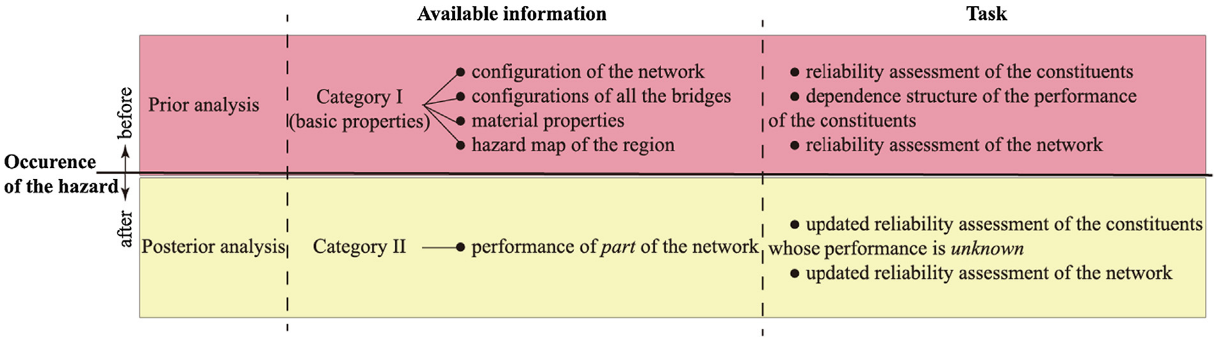

Fig. 1. Tasks of seismic reliability assessment of bridge networks with two categories of available information.

services in the region. The potential huge losses require not only an estimation of reliability of a network without any knowledge of its real seismic performance (prior to the occurrence of an earthquake), but also an accurate and intermediate evaluation of its performance during an incident even with incomplete knowledge for real-time or quasi real-time decision making. All those properties of a bridge network and its exposure, e.g. the configuration of the network and individual bridges, material properties, and characteristics of potential hazards, together with the knowledge of the real seismic performance of part of the network, constitute the information relevant to the seismic reliability assessment of bridge networks.

The present article aims to formulate a framework for an information-dependent seismic reliability assessment of bridge networks to facilitate the further risk analysis. Before occurrence of the hazard, only the basic properties of the bridge network and the characteristics of potential hazards are available but there is no information of the real seismic performance of the bridge network. A reliability assessment is still necessary for such purpose as design, inspection, and maintenance optimisation. In the previous decade, a framework for a performance-based earthquake engineering (PBEE) was developed and implemented by researchers at the Pacific Earthquake Engineering Research (PEER) Center. The so-called PEER framework is discussed in detail in [19,20]. It provides the basis for reliability assessment of individual engineered structures. For example, in 2008, Mackie et al. [21] applied the PEER framework to a probabilistic performance-based evaluation of benchmark concrete bridges. However, the framework does not directly address the reliability assessment of networks of such structures. That is, the probabilistic modelling of individual bridges is not enough for the reliability assessment of bridge networks and the dependence structure of the performance of bridges should be considered. For the dependence structure, a correlation model that covers all aspects relevant to the seismic performance is derived here first. The proposed correlation model would be combined with the probabilistic model of the performance of individual bridges to formulate the probabilistic model of the performance of bridge networks. As soon as some earthquakes occur, the performance of some parts of the network would be updated and the reliability could be assessed with the input of this new information by formulating a Bayesian probabilistic model. Moreover, based on the assessment with different categories of information, the relative 'important' components, whose real seismic performance has a high priority to be collected to make the reliability assessment and estimation of the consequence accurately and immediately, need to be identified. Here, measuring or comparing the importance of the components quantitatively will be introduced further. The measure of importance of component information is also a crucial matter for the seismic emergency management by the stakeholders, in which the interaction with the surrounding built environment such as jutting buildings might be considered (see e.g. [22–24] for references and further reading).

An application of the proposed framework is demonstrated using a traffic network presented in [25], which connects 8 cities by highways with 12 standard reinforced-concrete overpass bridges in California, where the seismic performance of individual bridges and the entire network would be analysed. The influence of given information on the seismic performance of some bridges on the others would be also illustrated.

2. Information relevant to seismic performance analysis of bridge networks

2.1. Categorisation of information and corresponding tasks of seismic reliability assessment

In the assessment of the performance of bridge networks subject to seismic hazards, similar to other infrastructure systems, a big challenge is the lack of knowledge. That is, there are uncertainties in all relevant aspects of the performance and basic properties of networks, such as structural configurations and material properties, together with hazards. Considering the potential severe consequences caused by bridge network damages, as mentioned above, their reliability assessment should be renewed depending on the arrival of available new information that can facilitate an accurate risk analysis. The duration of an earthquake is short and damages to the network constituents are generally obvious. The only problem is that the collection of information relevant to the performance of bridge networks takes some time, which could lead to severe consequences due to delayed actions. The information could be simply divided into two categories: the basic properties of the network together with its exposure, and the knowledge of the real seismic performance of part of the network. Following this categorisation, the procedure for seismic reliability assessment of bridge networks could also be divided into two phases as illustrated in detail in Fig. 1 considering the special characteristics of bridge networks. At first, the bridge network is built and it does not have any hazard. At this stage, the available information could only be the first category, i.e. the basic properties of the bridge network and the characteristics of potential hazards. Note that here, we may take some indicators from these relevant aspects of basic properties and know the exact values of those indicators or their values with errors, that is, their respective probabilistic descriptions. Generally, hazard maps of the region where the network is located would be also available. Based on this information, it is possible to obtain fragility curves of bridges, as the constituents of the network, following the PEER framework (see [19,20]). Then, their respective reliability can be assessed for future potential seismic hazards, which are represented by a combination of a series of scenarios that correspond to the hazard maps. Furthermore, a dependence structure inside the network needs to be defined for the network analysis so that the fragility curve of the entire network can be drawn and a reliability assessment for the network can be implemented. At some point, when some earthquakes occur, bridges may be damaged. The arrival of information on the performance of components makes the assessment move to a new phase. However, the problem here is that the new information would not be perfect generally. It is difficult to know the performance of the entire network immediately considering