ICONHIC2019
2nd International Conference on Natural Hazards & Infrastructure
23-26 June, 2019, Chania, Greece

Bridge vulnerability to flooding: towards an integrated risk model[1]

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1 INTRODUCTION & SCOPE OF WORK

Bridge are crucial points of connection in the transport system, underpinning economic vitality, social well-being and logistics of modern communities. Bridges have especial social and economic importance, since they support access to emergency services (e.g. hospitals) and utilities (e.g. water supply). Bridges are mostly exposed to natural hazards, in particular riverine bridges are vulnerable to flooding. Ultimately, protecting bridges enhances the resilience of cities and communities.

Worldwide countries are setting out national strategies and risk management plans to respond to the increasing flood risk of critical infrastructure. Bridge Management Systems (BMSs) are used to systematically monitor the bridge stock to ensure both safety and performance.

Nonetheless, numerous countries do not use BMSs to make decisions on the risk state; for example, the BMSs adopted in most countries are not linked to a road management system and do not consider the financial consequences of potential performance interruptions (e.g. traffic disruption). As a result, decisions are based on engineering judgement and inspections (*Woodward et al., 2001*).

BMSs present a flexible modular format that could allow the introduction of additional modules according to the users' needs (*Mirzaei et al., 2014*), such as consequence assessment (i.e. the indirect impact of social and environmental costs). This paper is integrating risk management modules into the BMS standard ones, aiming at introducing a new generation of management using Bridge Risk Management Systems (BRMSs). Such risk-based systems would help to identify assets at risk, and optimise the annual spending.

2 METHODOLOGY

The optimal structure of a BMS includes standard modules (*Flaig and Lark, 2000*) (Figure 1). The Inventory Module collects data regarding the bridge stock (location, material, design principles); the Inspection Module collects inspection data to classify the condition state; the Maintenance, Repair and Rehabilitation (MR&R) Module monitors short-term and long-term plans for intervention; finally, the Optimisation Module integrates the previous modules for budget-expenditure forecasts.

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***Figure 1**. The modular structure of a Bridge Management System (BMS).*

The last decades have witnessed the shift from "fighting" natural hazards to "managing" the risk from them (*Merz et al., 2010*). Recent approaches of risk management are based on the methodological framework formed by four modules: hazard, exposure, vulnerability and consequences (*Grossi and Kunreuther, 2005*) (Figure 2).

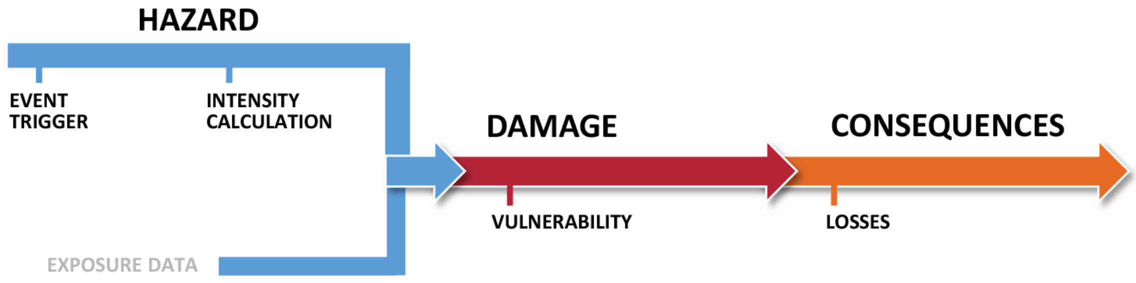

***Figure 2**. Overview of the catastrophe modelling framework, with the four main components: hazard, exposure, damage and consequences (Grossi and Kunreuther, 2005).*

Within a risk perspective, the hazard deals with simulating a range of flooding scenarios where each event is defined by a specific intensity measure (e.g. flood depth, velocity), location and probability of occurrence based on historical data. This study focuses on water-induced phenomena to bridges; however, this risk approach is transferable to other natural hazards (e.g. earthquakes, wind).

The exposure contains details of the location, value and characteristics of the "asset at risk", i.e. bridges potentially subjected to damage or interruption. In the case of infrastructure, this includes the number of users (*Pregnolato et al., 2017*), i.e. traffic volume for the transport sector.

The vulnerability is the susceptibility of exposed elements of being damaged by adverse events (*IPCC, 2012*). The damage estimation consists of evaluating costs and losses, under different load conditions of hazard. Worldwide, Damage Functions (DFs) are recognised as the standard method for urban flood assessment, and a wide range of research is present in the literature (e.g. *Penning-Rowsell et al., 2013*).

3 RESEARCH OUTCOMES AND DISCUSSION

Current BMS modules differ from the "risk modules". In order to advance a bridge management system able to account risk, BMSs can be modified in order to include risk modules and assess risk to bridges in a holistic way (Figure 3), moving towards Bridge Risk Management Systems (BRMSs).

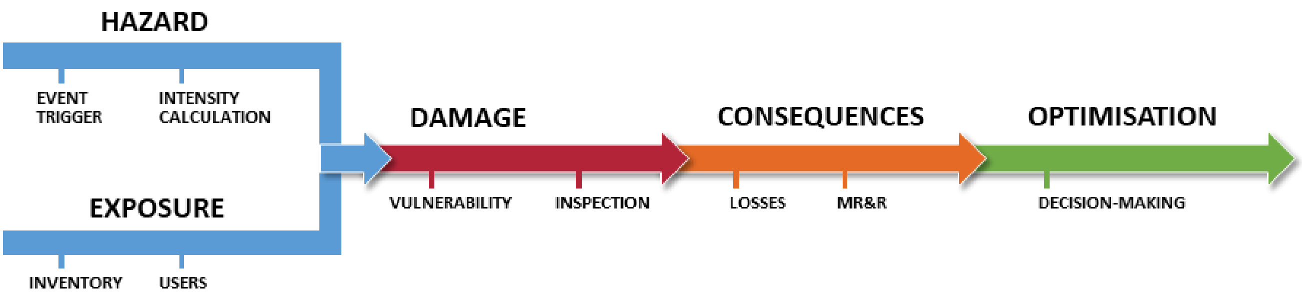

***Figure 3**. The proposed modular structure for an integrated Bridge Risk Management System (BRMS).*

The proposed BRMS aims to capture inventory, number of users and inspection data for each bridge, and integrate them with a range of models to compute the impact of different flooding scenarios (damage model) and analyses options (optimization model) to relieve performance deficiencies and/or to reduce future costs. In fact, an integrated BRMS combines asset inventory, condition information and environmental parameters to assess the costs and benefits of activities, to support management decision-making. This system would permit multi-objective assessment of various aspects including safety, mobility, and environmental sustainability, considering the functional characteristics of a bridge, as well as the occurrence of natural hazards.

An integrated BRMS would enable to identify bridges at higher risk of failure; particularly in a context of natural hazards (like flooding), a holistic risk assessment approach would enable to advance probabilistic analysis and estimate likelihood, type and location of the estimated impact from severe events. Bridge owners should be aware of the risk level of their assets, in order to prioritise certain assets and manage the annual spending.

In the near future, a BRMS will offer a sound basis for assessing current conditions at national scale, and open the conversation towards the estimation of deterioration, future impacts of environmental stresses and potential interventions (e.g. the development of an "adaptation module").

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