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DEVELOPING FRAGILITY FUNCTIONS FOR ROADWAY BRIDGES USING SYSTEM RELIABILITY AND SUPPORT VECTOR MACHINES

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The resilience of the main road and rail transportation networks across Europe has become increasingly critical in recent years, due to the growing pressure that is put on their use, as well as the exposure to a variety of natural hazards (e.g. earthquakes, landslides, rock falls, floods, etc.) over the large areas covered by these transportation networks. In this context, the European FP7 INFRARISK project aims to develop reliable stress tests on critical road and rail infrastructure through an integrated multi-risk framework that accounts for coupled interdependencies, spatio-temporal processes, cascading effects and time dependent vulnerability.

The analysis of a whole infrastructure system is usually carried out by breaking down the network into a set of components that have similar features or functions in the system (e.g. sets of bridges, tunnels or road pavements in the case of a road network system). The vulnerability and functionality of each of these objects can then be assessed, leading to an estimation of the performance of the network system based on the state of its components. This bottom-up approach has been detailed, for instance, in the recent FP7 SYNER-G project, where an object-oriented architecture has been specifically developed for the seismic analysis of interdependent infrastructure systems (Cavalieri et al., 2012). In the present study, the same logic is used, while focusing also on the assessment of "lower-level" elements, in the sense that road network components such as bridges are decomposed into a set of sub-components like piers, decks or abutments.

This approach has been previously used for the seismic fragility analysis of bridges (e.g. Nielson and DesRoches, 2007; Song and Kang, 2009), where system reliability tools allow the computation of the global fragility of the whole component based on the fragility of its sub-components. A fault-tree analysis of the bridge constitutes a first step to understand the relative contribution of each subcomponent to a given failure mode (i.e. whether some sets of sub-components are to be considered in a series or parallel system). Correlation or independence between the different failure events of sub-components has also to be accounted for (Song and Kang, 2009). This reliability framework is presented here and applied to the more general task of multi-risk analysis, including earthquake-induced events such as geotechnical hazards (i.e. cascading hazards), as well as the likelihood of non-related events like floods (i.e. coincidental hazards). The use of system reliability methods in this context is very relevant as it enables assessment of the specific response of each sub-component to each type of hazard, thus accounting for various combinations of failure modes and damage/functionality states. The final goal is to develop a harmonized set of fragility functions (or fragility functions matrix) that proposes homogeneous damage or functionality states over the range of hazards considered, in order to provide a strong basis for a subsequent infrastructure assessment in a multi-risk context. Using this approach, multi-hazard fragility functions can also be derived (i.e. the probability of damage given the joint occurrence of two or more hazards that are each represented by an intensity measure), as opposed to a juxtaposition of single hazard fragility curves.

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The aforementioned approach is first applied to the well documented and studied model of a multi-span simply supported concrete roadway bridge, as detailed by Nielson (2005). Although this example is typical of the bridges from the Central United States, its simple design and well defined sub-components make it a good candidate for the demonstration of the proposed approach. A finite element model of this bridge is developed using the OpenSees platform and it is subjected to a series of nonlinear time-history analyses. The structural response and specific damage state of each subcomponent can then be recorded in order to derive fragility curves for each of them. Finally, the global fragility curve of the bridge can be aggregated based on the analysis of the individual failure events leading to the different global damage states, while accounting for the correlation between the sub-components' response (see Figure 1).

Secondly, reliability-based analytical fragility curves are derived for the Rio Torto Viaduct located on the A1 Italian highway between Bologna and Florence, which has been selected as a preliminary case-study in the scope of the INFRARISK project, as a portion of the Trans European Transport network (TEN-T network). This old reinforced concrete viaduct has been the subject of several previous studies (e.g. Pinto and Mancini, 2009; Di Sarno et al., 2011) that provide detailed information on the structural subcomponents (e.g. piers, decks, bearing) as well as analytical results based on finite element models. Therefore, the derivation of actual fragility curves for this thirteen-span deck bridge represents a very interesting challenge, especially since the viaduct is located in an area that is prone to both seismic and landslide hazards.

In parallel to these analytical developments, it is proposed to investigate the propagation of epistemic uncertainties through the construction of Bayesian Networks at the bridge-level. This procedure is also helpful to calibrate and adjust the actual influence of the sub-components' states on the global performance component, potentially leading to some simplifications in the reliability analysis.

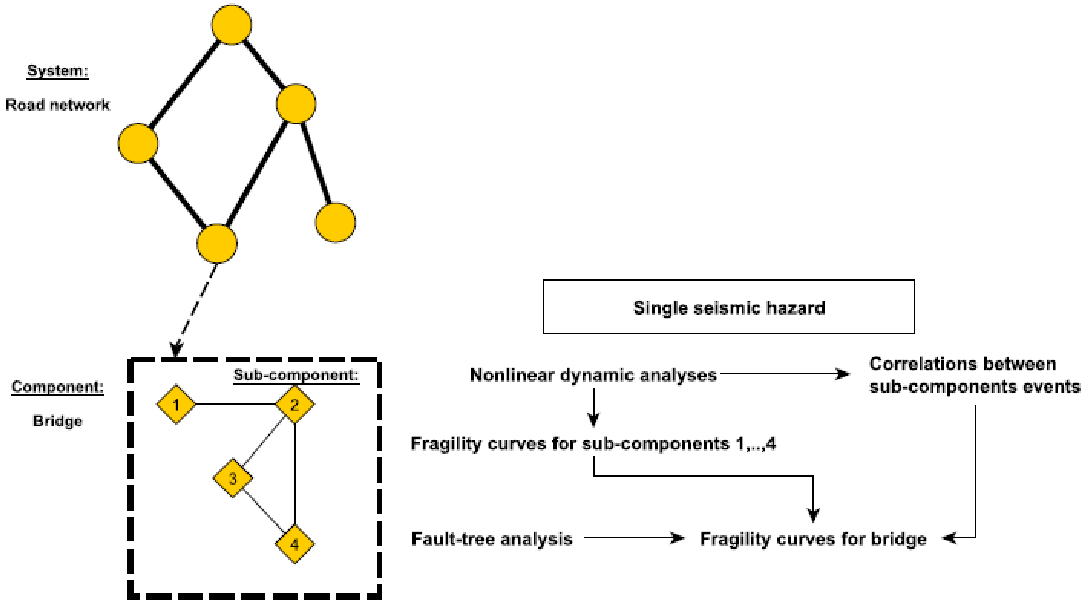

Figure 1. Outline of the proposed approach to derive analytical fragility functions for roadway bridges subjected to seismic hazard

Finally, as stated above, this is a bottom-up approach to modelling the fragility of the network as a whole. An alternative and complimentary approach is to produce a top-down model of system resilience. By constructing a spatio-temporal database relating recorded instances of hazard events (including location and magnitude), network performance and a suite of environmental, topographic and climatic variables it is possible to predict how the network will respond to a range of hazards. This is an empirical means of modelling resilience and as such is limited by data availability and quality. The proposed component-based, fragility curve models will contain a great deal of detailed information about the system, whereas the empirical modelling approach will validate its predictions using observed data and include spatially explicit environmental information which could impact on system performance in the real world (Nateghi et al., 2011).

The empirical model proposed for this study is support vector machines (SVMs). SVMs perform classification (and regression) by constructing N-dimensional hyperplane that optimally separates data into categories (Hearst et al., 1998). For example, if we wish to separate data into two classes, we would like to find a threshold which could discriminate between the two. The simplest example of this would be a straight line in two-dimensional space, or a hyperplane in higher dimensional space. The SVM tries to find the optimal separating hyperplane that gives the largest separation between classes (Vapnik, 1998). For scenarios, such as infrastructure, where there are a huge number of interacting variables to consider, SVMs transform data to make it linearly separable and hence can handle highly complex datasets. This approach has been successfully applied to the spatio-temporal prediction of tornado occurrence (Adrianto et al., 2009) and landslide susceptibility (Ballabio and Sterlacchini, 2012). It is the proposal of this study that the two modelling techniques are complimentary. The SVM models can be used to investigate at the system as a whole, offer empirical validation and potentially attribute any anomalous results to external environmental factors. In turn, the fragility curve models will provide component-level explanation of the performance of transport infrastructure give hazards of different magnitudes.

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