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Development of Fragility Curves for Bridges in Korea

By Seongkwan Mark Lee*, Tschangho John Kim, and Seung Lim Kang*****

Abstract

The purpose of this paper is to develop fragility curves for bridges in Korea. Fragility curves are needed for assessing the vulnerability of bridges to unscheduled events and for setting retrofit and/or repair priorities. Research results show that individual bridges suffer different levels of damage, depending not only on the magnitude of earthquake and distance from the epicenter, but also on the structural characteristics of the bridge and the soil type on which it is built. For the construction of bridge fragility curves for Korea, we used data from 1008 expressway bridges and a statistical regression method. The relationships between peak ground accelerations and vulnerabilities were modeled with logistic curve equations using the bridge classification and models by Hwang, Jernigan and Lin. The primary contribution of this research is that this study is the first of its kind that develops fragility curves for bridges in Korea, which can now be used for various applications that analyze the socio-economic impacts of network vulnerability caused by natural and man-made disasters. Finding a logical and rational basis for transforming the structural disruption ratio of a bridge directly to its functional disruption ratio is left for a future study.

Keywords: *earthquakes, fragility curve, bridges, vulnerability estimation*

1. Introduction

Unscheduled events such as an earthquake cause direct damages to transportation networks and have indirect negative impacts on regional and national economies in the long run (Sohn et al., 2003). Recent earthquakes accompanied by catastrophic damages such as Northridge in America (1994), Kobe in Japan (1995), Izmit in Turkey (1999), Chi-Chi in Taiwan (1999), Gujarat in India (2001), Algeria (2003) and southern Iran (2003) suitably demonstrate that the secondary damages to a metropolis caused by a long paralysis of socio-economic activities are far more serious than the direct damages such as disruptions of buildings.

The Korean Peninsula, located on the Circum-Pacific Earthquake Belt, has shown frequent seismic activity; particularly both the eastern and western edges have historically shown intensive seismic activity. The first seismometer was installed in Inchon, Korea in 1905. Since then, the total number of "sensible earthquakes" registering over 3.0 on the Richter scale is a little more than 1,700, of which 48 were catastrophic, i.e. over 5.0 on the Richter scale. About 37% of 723 earthquakes (264 earthquakes) have been recorded as "sensible earthquakes" since the end of 1970 (NEIS, 2006).

The purpose of this paper is to develop fragility curves for bridges in Korea that can be used to explore the various economic impacts of an earthquake, especially impacts on transportation networks. Toward achieving the goal, all spatial data were collected from the 2002 Korea Transport Database (KTDB) of the Ministry of Construction and Transportation (MOCT). Bridge data are based on the 2002 Highway Geographic Information Systems (HGIS) of the Korea Highway Corporation (KHC). For the estimation of bridge vulnerability, Hwang's fragility curves (Hwang and Hou, 1996; Hwang, Jernigan and Lin, 1998; Hwang, Jernigan and Lin, 2000; Hwang, Chiu and Liu, 2001; Jernigan, 1998; and Jernigan and Hwang, 2002) was adopted, modified and implemented.

This paper is composed of three sections: Section 1 is an introduction. Section 2 deals with the vulnerability of bridges. The section consists of four sub parts to explain how bridges are classified and modeled, how synthetic earthquakes are generated, how the damage state is pre-defined, and finally how the fragility curves are derived to describe the bridge damages caused by the earthquake. A brief conclusion is given in section 3.

2. Bridge Vulnerability

Bridges are vulnerable to earthquakes, and damage to bridges can seriously disrupt the function of the traffic network. It takes long time to repair bridges. In addition to direct damage, the indirect damage, such as regional economic loss caused by disruption of the transportation network, is an important social issue (Lee, 2005; Shon et al., 2003).

If one can determine the relationship between an earthquake and the corresponding damage to a bridge, the degree of damage can be estimated by a probability model (Choi, 2002; Jernigan, 1998; Jernigan and Hwang, 2002; Saxena et al., 2000; Shinozuka et al., 2000a). This can be done by using historical earthquakes and the damage caused by them, or by analyzing a synthetic earthquake and its effects on bridges in the laboratory. The

*Member, University of Illinois at Urbana-Champaign (Corresponding Author, E-mail: smlee4@uiuc.edu)
**University of Illinois at Urbana-Champaign (E-mail: tjohnkim@uiuc.edu)
***Member, University of Illinois at Urbana-Champaign (E-mail: kangsl@uiuc.edu)

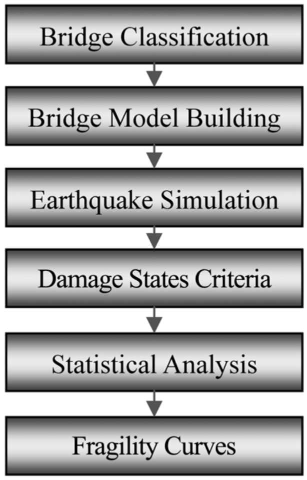

Fig. 1. Common Steps for Deriving Fragility Curves

former can be called as the 'empirical approach[1)]' and the latter the 'analytical approach'. However, because earthquake damage data are very scarce, an analytical method including computer simulation is the only feasible approach for deriving the vulnerabilities (fragility curves[2)]) of highway bridges.

Fig. 1 shows the six consecutive steps for deriving bridge fragility curves: classifying objective bridges, building bridge models for analysis, simulating synthetic earthquakes, defining the evaluation criteria for damage states, analyzing statistical probabilities of bridge damage, and drawing fragility curves.

Based on the steps above, there has been some outstanding research on bridge fragility curves, but the final results have always been insufficient. In some cases, the insufficiency resulted from the limitations of computer simulation, but in most cases it came from the paucity of numerical data for bridge models. In this research, the existing fragility curves have been extensively introduced. In particular, this paper focused on the benchmark of the fragility curves of Hwang[3)] and applied them to Korean bridges to explain their vulnerability.

2.1 Bridge Classification and Modeling

The bridge inventory within a study area usually consists of a large number of bridges. Therefore, it is rather difficult, if not impossible, to evaluate the seismic vulnerability of each bridge in detail. In addition to that, even though each bridge has its own structural system, it is well known that the bridges with similar structural characteristics are expected to behave in a similar manner in an earthquake event (Jernigan, 1998). Thus, bridges can be classified into several types to facilitate the generation of bridge models, and analytical bridge models are automatically followed by this classification. Actually, there can be many ways to define and model bridges, but usually two contrasting ways can be considered. One way is to classify bridges according to their attributes. In this case, there may be a predefined bridge classification rule, and various bridge models can be produced based on the rule. The other way is to build mechanical models directly replicating the objective bridges. In this case, the resulting bridge models are very limited.

Saxena et al. (2000) used a mechanical modeling method to classify bridges. Without consideration of type and material of bridges, they modeled just one reinforced concrete bridge that has 12 actual spans. Shinozuka et al. (2000a) used two representative bridges with a precast, prestressed continuous deck in the Memphis area studied by Jernigan and Hwang (1998). Shinozuka et al. (2000b) used the same bridge models in Memphis for a comparison of the capacity spectrum method and the time-history method. Shinozuka, Deodatis, and Saxena (2000c) chose seven sample bridges representing typical California highway bridges. Kim and Feng (2003) modeled the twelve-span precast box girder Santa Clara bridges, which was one of the seven bridges that had been chosen by Shinozuka, Deodatis, and Saxena (2000c). They used the same column model as that of Saxena et al. (2000) since they were evaluating the responses of the bridge under spatially various ground motion rather than the bridge itself. Kim and Shinozuka (2004) used two sample bridges for their fragility curves. As with their former bridge models, they modeled the bridge columns to have nonlinear behavior; that is, a column was modeled to describe both elastic and plastic zones. Choi, DesRoches and Nielson (2003) analyzed the bridge inventory in the Central and Southeastern United States and found that over 90% of the bridges in the CSUS were multi-span simply-supported girder bridges, multi-span continuous girder bridges, or single span bridges, and most of them had either reinforced concrete, prestressed concrete, or steel girders with reinforced concrete decks. Nielson (2003) also mentioned that bridge classification in the reports of the Applied Technology Council (ATC-13, 1985) and of HAZUS (FEMA, 1997). Actually, in the ATC-13 report, all of the bridges are classified as either major or conventional, and HAZUS has 28 classes of bridges. Karim and Yamazaki (2001) considered a simple bridge structure, and two pier models were designed using the 1964 and 1998 seismic design code in Japan. They also modeled two reinforced concrete bridges (isolated or non-isolated), assuming that other conditions, such as the height of the substructure and the length and weight of the superstructure, were unchanged (Karim and Yamazaki, 2003). Lee, Kim and Mha (2003) modeled four different prestressed concrete girder bridges: a three-span simple bridge, a three-span continuous bridge, a six-span simple bridge, and a six-span bridge that was composed of two three-span continuous bridges. They tried to determine the retrofit priority of bridges for earthquakes and to estimate the failure cost of certain components or a whole bridge.

On the advice of Hwang, Jernigan (1998) classified bridges according to a bridge classification system (NBIS/FHWA, 1996) and their own rules. They classified bridges using five-digit code values that described their attributes, including material, design of superstructure, and type and material of bent. A three-digit code was given to the bridges according to the NBIS/FHWA superstructure types, and then a two-digit code was added to describe the bent type/material of the bridge. Table 1 and Table 2

[1] Basoz et al. (1999) achieved an empirical analysis on the 1994 Northridge earthquake by the lognormal regression method, and Shinozuka et al. (2000a) drew empirical fragility curves after analyzing the 1995 Kobe earthquake by the maximum likelihood method.

[2] Fragility curves describe the probability of a structure being damaged beyond a specific damage state for various levels of ground shaking to assess the seismic vulnerability of highway bridges.

[3] Professor, Center for Earthquake Research and Information, University of Memphis.