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Izvorni naučni članak

SEISMIC RISK ASSESSMENT BY USING MONTE CARLO SIMULATIONS FOR BRIDGES OF EGNATIA MOTORWAY IN NORTHERN GREECE

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ABSTRACT
The evaluation of fragility curves for bridges represents a critically important step in their seismic damage estimation and protection process. In this paper, a probabilistic methodology concerning the construction of vulnerability curves for the Egnatia Motorway in Northern Greece is presented. Use is made of the Finite Element Method (FEM), the non-linear static pushover procedure, the capacity spectrum method and Monte Carlo simulation techniques for the treatment of various parameter uncertainties. The methodology is applied to obtain the fragility curves of the Egnatia Highway bridges, and especially for the ravine bridge in the Kavala motorway section, East Macedonia, Greece.

KEY WORDS: Vulnerability Functions, Seismic Risk Assessment, Egnatia Highway Bridges, Monte Carlo Techniques

PROCENA SEIZMIČNOG RIZIKA KORIŠĆENJEM MONTE KARLO SIMULACIJE ZA MOSTOVE AUTOPUTA EGNATIA U SEVRNOJ GRČKOJ

REZIME
Evaluacija krivih povredivosti za mostove predstavlja kritički važan korak u proceni njihovog seizmičkog oštećenja i procesu zaštite. U ovom radu predstavljena je probabilistička metodologije koja se odnosi na definisanje krivih povredivosti za autoput Egnatia u severnoj Grčkoj. Korišćena je metoda konačnih elemenata (FEM), postupak nelinearne statičke pušover procedure, metoda spektra kapaciteta i tehnike simulacije Monte Karlo za tretiranje

neizvesnosti različitih parametara. Metodologija je primenjena za dobijanje krive povredivosti mostova autoputa Egnatia, a naročito za most kod Kavale, Istočna Makedonija, Grčka.

KLJUČNE REČI: funkcije povredivosti, procena seizmičkog rizika, Egnatija autoput, Monte Karlo tehnika

INTRODUCTION

The vulnerability analysis of Civil Engineering Structures, and especially for highway bridges, represents a critically important step in their seismic damage estimation and protection process (Liolios et al, 2011). The relevant fragility curves provide the probability that a specific damage level will be exceeded for a given intensity of a seismic event. In this respect, development of vulnerability relationships for both, the existing and under design Civil Engineering structures, is a key element in formulating mitigation and disaster planning strategies in Civil Earthquake Engineering for the estimation of the urban seismic risk (Rossetto & Elnashai, 2003). In combination with seismic hazard analysis at the bridge sites, they can lead to a reliable assessment of the seismic risk of highways. Furthermore, they can even be used by the authorities in charge to prioritize the on site aftershock inspections, in order to check the structural integrity of the bridges subjected to a severe seismic event .

The present paper deals with a simplified analytical methodology for the evaluation of vulnerability curves for bridges. The methodology combines the nonlinear static pushover procedure, the capacity spectrum method (Chopra, 2007), (Moschonas et al, 2009), and Monte Carlo simulation techniques for the treatment of various uncertainties (Dimov, 2008), (Kottegoda & Rosso, 2000). The methodology is applied for establishing fragility curves for an reinforced concrete bridge in the Kavala section of Egnatia Motorway, in the county of East Macedonia, Northern Greece. The Kavala bridge examined herein is a structurally representative one of many bridges in Egnatia Motorway, and in Greece more generally.

Egnatia Odos is a new motorway that crosses Northern Greece in an E-W direction. It is currently the largest and technically the most demanding highway project in Greece, and one of the biggest ones under recent (2006-2010) construction in Europe. Moreover, for the design and construction of Egnatia Motorway, a lot of Applied Science topics are involved, e.g. structural and seismic mechanics, geotechnical and transport engineering, hydraulic and environmental engineering, probabilistic methods, etc. The total length of Egnatia Motorway is about 1000 km and includes about 1900 special structures, (bridges, tunnels and culverts). These structures are expected to withstand several minor or moderate earthquakes during their life, and may be damaged if they are subjected to a major (catastrophic) earthquake. So, the construction of their fragility curves is very significant (ASPROGE, 2007).

METHOD OF ANALYSIS

As was mentioned in the Introduction, the present study focuses on the simplified practical fragility analysis of bridges. Details have been presented in (Liolios et al, 2011). The vulnerability functions, required for the fragility curves, are expressed (Liolios et al, 2011), (Shinozuka et al, 2000) in terms of a Lognormal cumulative probability function in the form of next eq. (1):

$$P_f\left(DP \geq DP_i \mid S\right) = \Phi\left[\frac{1}{\beta_{tot}} \cdot \ln\left(\frac{S}{S_{mi}}\right)\right] \quad (1)$$

Here $P_f(\cdot)$ is the probability of the damage parameter DP being at, or exceeding, the value DP_i for the i-th damage state for a given seismic intensity level defined by the earthquake parameter S (here the Peak Ground Acceleration-PGA or Spectral Displacement-S_d), Φ is the standard cumulative probability function, S_{mi} is the median threshold value of the earthquake parameter S required to cause the i-th damage state, and β_{tot} is the total lognormal standard deviation. Thus, the description of the fragility curve involves the two parameters, S_{mi} and β_{tot}., which must be determined.

The damage level depends on the input seismic excitation, i.e. the seismic ground acceleration. As well known from Structural Dynamics and Earthquake Engineering (Chopra, 2007), because this input is not known for future earthquakes, the spectral approach is used according to various aseismic building codes, e.g. the Greek Aseismic Code EAK2000.

According to equation (1), the description of the fragility curve involves only two parameters, S_{mi} and β_{tot}. The first parameter S_{mi} is estimated on the basis of the capacity spectrum method (Chopra, 2007), (Moschonas et al, 2009), wherein the demand spectrum is plotted for a range of values of the earthquake parameter S (in spectral acceleration vs. spectral displacement format) and it is superimposed on the same plot with the capacity curve of the bridge. The earthquake parameter used in this study is the peak ground acceleration (PGA).

The second parameter of Eq. (1) is the total lognormal standard deviation β_{tot}, which incorporates the various uncertainties in the seismic demand, in the response and the capacity of the bridge, and also in the definition of the damage index and damage states. So, it takes into account the uncertainties in seismic input motion (demand), in the response and resistance of the bridge (capacity), and in the definition of damage states. This parameter (β_{tot}) can be estimated in the frame of Monte Carlo simulation techniques (Dimov, 2008), (Kottegoda & Rosso, 2000), by realizing a statistical combination of the individual uncertainties, assuming these are statistically independent. Thus, on the basis of Monte Carlo simulations and empirical fragility curves obtained from actual Egnatia Highway bridges damage data in the frame of the research project ASPROGE (2007), the value of β_{tot} was estimated to be equal to 0.60.

THE INVESTIGATED CASE OF THE KAVALA RAVINE BRIDGE IN EGNATIA MOTORWAY.

žIn order to investigate the anti-seismic security of Egnatia motorway bridges, the research project ASPROGE (2007) has been realized, at which A. Liolios had participated. A simplified methodology has been developed for the calculation of the vulnerability curves

of bridges in the presence of seismic stoppers, see (Liolios et al, 2011), (Panetsos & Liolios, 2010). This methodology, using the Finite Element Method (FEM), is based on a modal pushover nonlinear static analysis and on a capacity demand spectrum approach, instead of a time consuming non-linear vulnerability analysis based on dynamic contact mechanics.
The damage states are defined according to Table 1. Five states of damage (i=0 to 4) were defined as a function of the damage ratio $D_i = \delta_i/\delta_y$, where δ_i is the displacement at the target point and δ_y the corresponding yield displacement. Corresponding threshold values D_i , that define the boundaries between the damage states, were also defined. For details concerning the computation steps for obtaining the fragility curves, see (Liolios et al, 2011).

Table 1: Definition of damage states

i Ratio	Damage State	Necessary repair interventions	Duration of interventions	Damage $D_i = \delta_i/\delta_y$
1	No damage	None	----	< 0,7
2	Minor damage	Small scale repairs	< 3days	> 0,7
3	Moderate damage	Repair of struct. Elements	< 3weeks	> 1,5
4	Extensive damage	Reconstruction of Struct. parts	< 3 months	> 3,0
5	Collapse	Reconstruction of bridge	> 3 months	$> \mu_u$

In this work, the seismic vulnerability of a structurally representative bridge of Egnatia Motorway in East Macedonia section has been assessed. This bridge is the 2nd ravine Kavala bridge shown in Fig. 1, with total length 180 m (four 45m long spans of simply supported prestressed beams). Stoppers on the pier's beams were designed to be distant from the superstructure such as to be activated after the exceeding of the maximum spectral displacement.
Details for the geometric and elastic characteristics of the bridge elements are given in (ASPROGE, 2007). The obtained relative vulnerability curves are shown in Figs. 2 and 3.

Fig. 1: The Kavala bridge on Egnatia Motorway, East Macedonia.

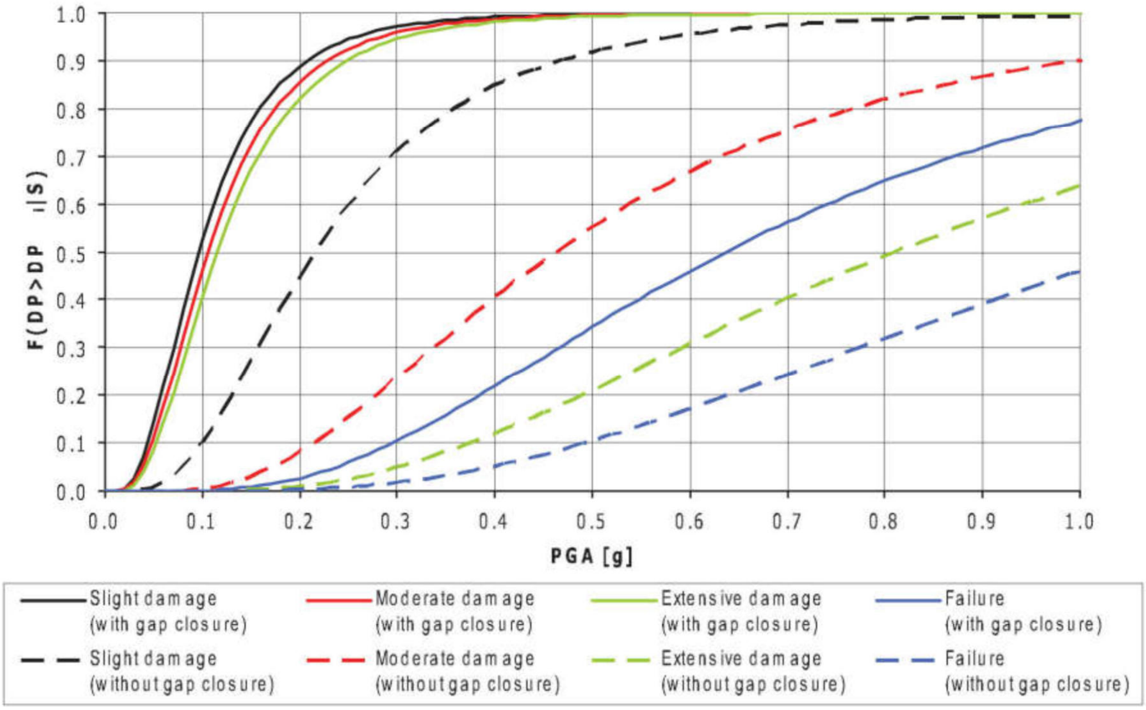

Fig. 2. Fragility curves of the Kavala Ravine bridge: Longitudinal direction.

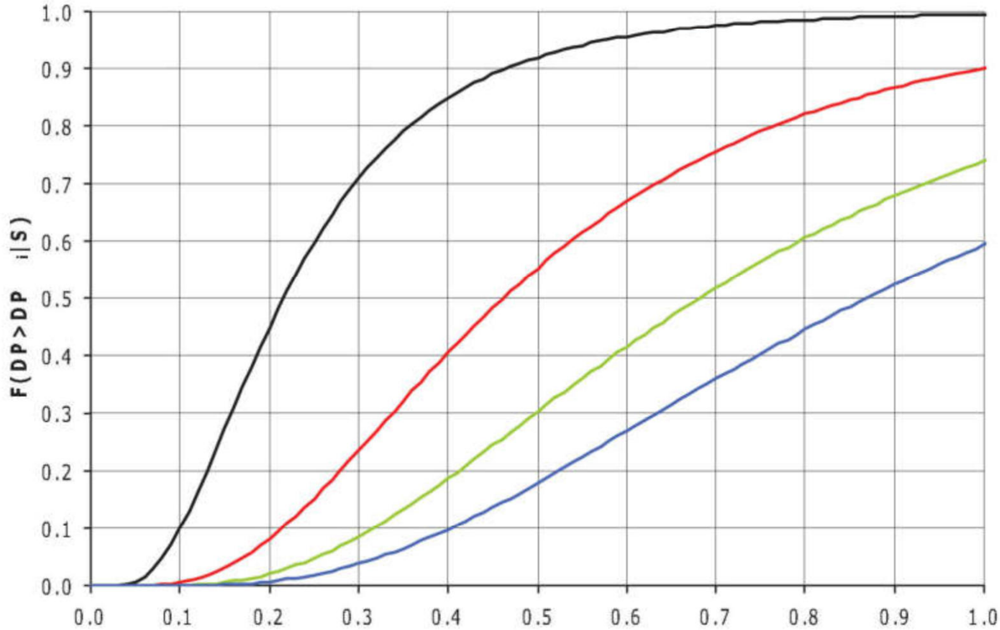

Fig. 3. Fragility curves of the Kavala Ravine bridge: Transverse direction.

CONCLUDING REMARKS

A simplified analytical methodology for the evaluation of vulnerability curves for bridges has been presented.. The methodology combines the nonlinear static pushover procedure, the capacity spectrum method and Monte Carlo simulation techniques for the treatment of various uncertainties. Application of the proposed methodology has been realized for establishing fragility curves for an reinforced concrete bridge in the Kavala section of Egnatia Motorway, in the county of East Macedonia, Northern Greece.

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