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Fragility curve development for assessing the seismic vulnerability of bridges in Albania

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Abstract:

Albania is considered a seismic region in Europe. Bridges are one of the main and the most vulnerable components of the transportation system. Therefore they should be functional before and after earthquake action. Using the fragility curve is one of the popular tool in assessing the seismic behaviour of the bridges. The fragility curves are conditional statements, which give the probability of bridge exceeding a particular damage level for a given intensity level. In this study one of the most common bridges type in Albania is assessed. This paper presents a case study of developing fragility curves for simply supported bridges for Vora viaduct. The paper illustrates the use of fragility in verifying the performance objectives of bridge's seismic design. The sources of date needed for this analysis are: bridge design project, ground motion date, geological maps. The analytical modelling and time history analysis were done and the limit states are defined for displacement ductility of bridge's piers and fragility curves were developing during statistical analysis.

Key words: fragility curve, seismic behaviour, transport networks, risk, bridges

Introduction

Bridge structure is the most vulnerable components of the transportation network. Many of highway bridges in Albania are in service for more than 25 years. Many of them were designed with codes without information now available on seismic safety. Seismic requirements have increased in recently codes. Serviceability and safety of bridges before and after earthquake is important to ensure the continuous transport facilities. There is therefore, a need for reliable methods for assessing the seismic vulnerability of existing bridge. Conditional probabilistic statement of bridge damage due to seismic loading, known as fragility curves have been used to evaluate seismic risk for highway bridges. Fragility functions it is conditioned on some parameter which describes the intensity of ground motions. This paper illustrates their generation in post – design as a verification tool and describes the methodology which governs the implementation of the fragility curve.

Analytical bridge fragility methodology

Analytical methods are considered most appropriate for the purpose of design verification. Analytical methods allow both probabilistic demands (D) and capacities (C) to be derived and subsequently used to generate relevant fragilities. When both the demand and capacity models follow a lognormal distribution the fragility curves takes the form of below equation:

$$P\left[D < C \middle| IM\right] = \Phi\left[\frac{\ln\left(S_d / S_C\right)}{\sqrt{\beta^2{}_{d|IM} + \beta^2{}_C}}\right] \quad (1)$$

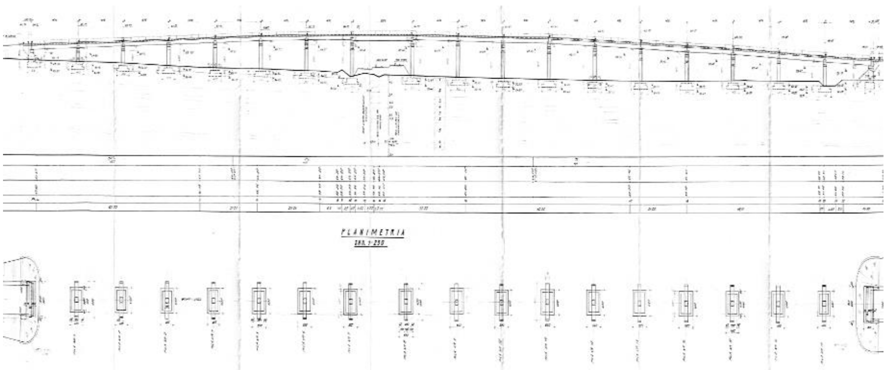
where S_d - is the estimate of the median of seismic demand as function of IM, IM - is the seismic intensity measure, S_C - is the median for the selected limit state, $\beta_{d|IM}$ - is the conditional logarithmic standard deviation of the demand, β_C - is the logarithmic standard deviation of the limit state, Φ […] is the standard normal function .

$S_d = a\ IM^b$ where a and b are the regression coefficients (by Cornell [2002]), which when used in conjunction with an estimate of $\beta_{d|IM}$ referred as a probabilistic seismic demand model (PSDM).

Case Study

Bridge description

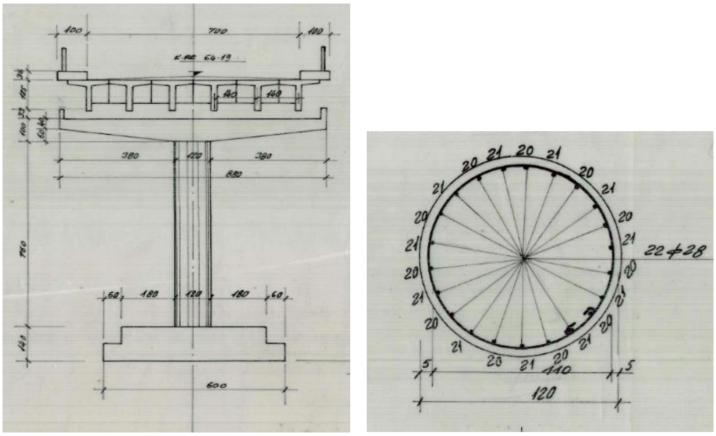
The bridge under consideration is an 18 span simply continuous concrete girders. Each span is 15 m length and an overall length of 313 m. The superstructure consists of by 6 precast beams. The deck width is 9 m. Intermediate supports are provided by one – columns bents and by an abutment at each end. The circular reinforced concrete (RC) bridge columns are 1200 mm in diameter with a concrete compressive strength of 30 MPa. Longitudinal reinforcement is provided by 22 Φ28 (1.2 %) having a yield strength of 430 Mpa. This bridge is modelled in sap 2000 programme. Periods associated with the modes when one considers to be cracked are T=1.2s and T=1.55s. The effects of foundation and abutments are included through translational and rotational springs with respectively properties, considers three rotational and three translational springs which represent the interaction between abutment, soil and foundation. Defining the seismic damage state is an important step in fragility assessement. Fragility curve considering two damage states, which are concrete spalling and longitudinal reinforcement buckling. Refer to figure 1 for the general bridge geometry configuration.



General bridge geometry. Multi – span simply supported concrete girder bridge .

(RC) Bridge columns. Multi – span simply supported concrete girder bridge[1] .

[1] Railway Overpass of Vora project



(RC) Bridge columns. Multi – span simply supported concrete girder bridge[2] .

Ground Motion Suite

The ground motion suite selected for use in generating the probabilistic demand models are taken from the literature (Seismotectonic ,assessment of seismic risk of Albania 2010, tab. Page 230) for Vora. Consists of 211 recorded of ground motion , at a distance 5 to 15 km and a maximum magnitude of 7. The ground motion suite represents a range of spectral acceleration (1 sec) from 0.08g to 0.635g of the seismic risk with probability 10%/50 [3].

Column Capacities

For this study only the columns are considered deriving the fragility of the bridge. Capacities for the column are taken from research by Berry and Eberhard. They considered two damage states for columns, which are concrete spalling and longitudinal reinforcement buckling.

Equation (2) presents the calculation of the median value for the drift capacity related to concrete spalling.

[2] Railway Overpass of Vora project
[3] Page 230, Seismotectonic, assessment of seismic risk of Albania 2010

$$\frac{\Delta_{spall}(\%)}{L} = 1.6\left(1 - \frac{P}{A_g f'_C}\right)\left(1 + \frac{L}{10D}\right) \quad (2)$$[4]

Equation (3) presents the calculation of drift ratio onset of bar buckling.

$$\frac{\Delta buck(\%)}{L} = 3.5\left(1 + 150\rho_{eff} \frac{d_b}{D}\right)\left(1 - \frac{P}{A_g f'_C}\right)\left(1 + \frac{L}{10D}\right) \quad (3)$$[5]

P- is the axial load

A_g – is the gross –sectional area of the columns

f'_C - is the concrete compressive strength

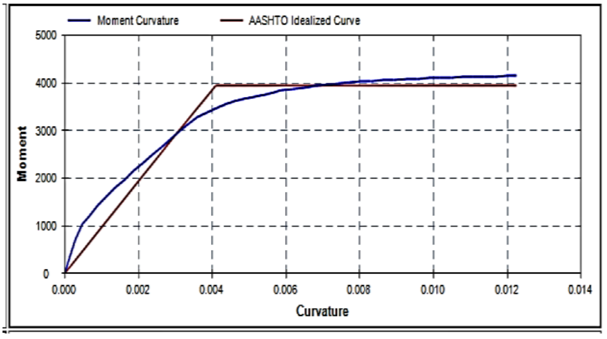
L-is the distance from the top of column to the point of contraflexure

D-is the diameter of the column.

b –the coefficient of variation taken from the literature

Table 1. Parameter values for capacity lognormal distributions.

Column Height (m)	**Spalling**		**Bar buckling**	
	Median Drift (%)	b	Median Drift (%)	b
5.8	1.2	0.35	2.5	0.25
8	1.71	0.35	2.97	0.25



Moment Curvature Analysis

[4] M. Perry & M. Eberhard: Performance Modeling Strategies for Modern Reinforced Concrete Bridge Columns , April 2008

[5] M. Perry & M. Eberhard: Performance Modeling Strategies for Modern Reinforced Concrete Bridge Columns , April 2008

Fragility Curves and Design Verification

The probabilities of exceedance for two damage states, spalling and bar buckling , can be calculated with the equation:

$$P[DS] = \int_{IM} F_{DS}\left(DS|IM\right) f_{IM}(IM)dIM\Big) \tag{4}$$

The log-normal distribution has a probability density function .

$$f(x,\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-(\frac{(\ln(x)-\mu)^2}{2\sigma^2})} \tag{5}$$

The cumulative log – normal distribution is obtained by integration of the area below density function as shown in the equat. (6)

$$f(x,\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \int_0^x \frac{e^{-(\frac{(\ln(x)-\mu)^2}{2\sigma^2})}}{t} dt \tag{6}$$

Where x is the value at which the function is evaluated, μ is the median value of PGA and σ is the log- standard deviation.

For this case the value of μ, σ are taken as below:

σ=0.6

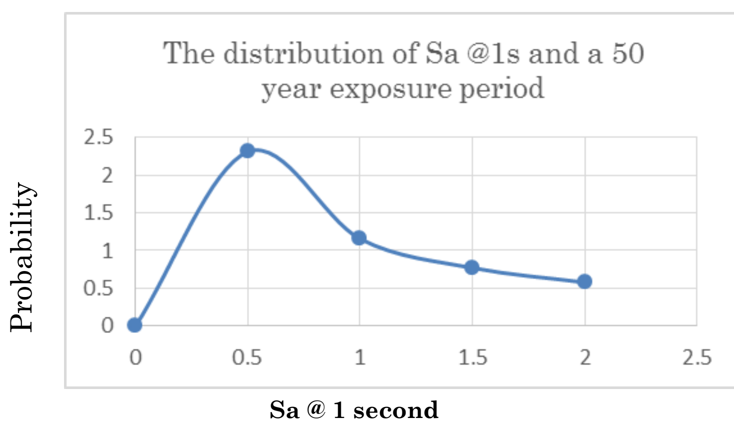


Figure 5. The distribution of Sa- acceleration for soil type E and a 50 year of exposure period

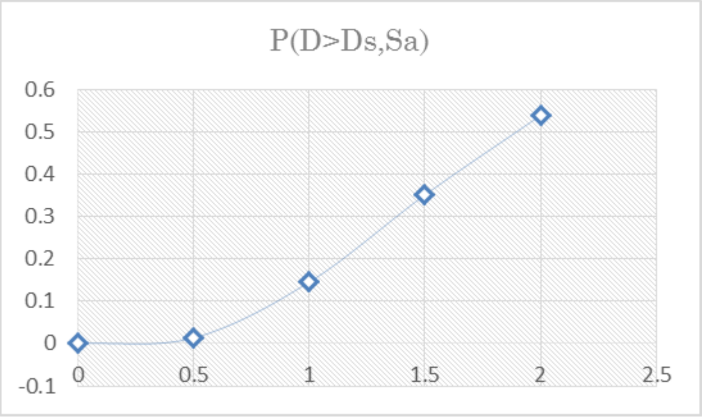


Figure 6. Fragility curve for minor - analitycal state

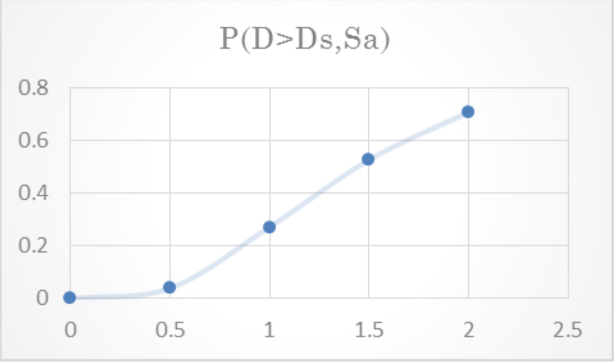


Figure 7. Fragility curve for moderate - analitycal state

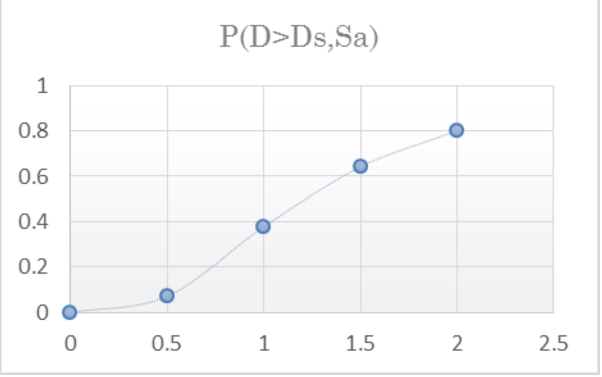
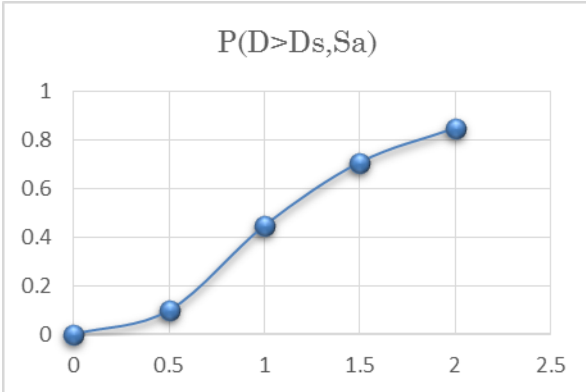


Figure 8. Fragility curve for major - analitycal state



Sa @ 1 second

Figure 9. Fragility curve for collapse - analitycal state

Conclusions

The generation of fragility curve for bridges are useful in evaluation the vulnerability assessment, disaster response planning and evaluation of loss of functionality in transportation infrastructure. This study illustrates the use of fragility curves in post design verification of existing bridges and propose an probabilistic method to get on fragility curve for the pier bridge . It presents a case study for simply concrete girders bridges type in Albania. Fragility curves are generated using an analytical approach taking consideration the estimated seismic hazard for the selected site. Columns are proposed to be the most vulnerable component of the bridges structure, and their height is a very important parameter for the evaluation of damage state. Post design fragility curves are useful for verifying design assumptions against specific performance objectives.

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