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Seismic assessment method for existing reinforced concrete bridges in Albania

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Abstract

Bridges are one of the main and most vulnerable components on the transport infrastructure network, due to aggressive environment, degradation during the years of service, steel corrosion, etc. A considerable number of existing Albanian bridges have been designed and constructed before 1989 year, according to the former design code. Nowadays the design seismic code and their requirement are change. Therefore we need to assess the seismic performance of bridges under different seismic loadings in different levels of reliability regard in requirements of new standards to seismic actions. Developing a fragility curve for assessing bridge performance is an effective methodology in the evaluation of vulnerabilities of existing reinforced bridges. This study concerns providing a new method of seismic bridge assessment for bridge typology in Albania utilizing fragility curves, considering columns as the most vulnerable component. Ductility analysis for circular section piers is estimated by moment-curvature curves. The proposed method is also illustrated by two application assessment presented the step by step procedure.

Key words: seismic assessment, fragility curve, reinforced bridges, moment curvature

1 Introduction

Most of the existing Albanian bridges have been designed according to former design codes, with no regard for requirements of new standards to seismic actions. Therefore we need to assess the seismic performance of bridges under different seismic loadings. The current European seismic code does not offer a procedure for seismic assessment of bridges, The European standard EN 1998-3, Part 2 focuses primarily on the seismic design of new bridges, [1]. A new seismic assessment procedure for column bridges is presented in the study. This paper aims of providing a new probabilistic framework for seismic assessment of highway/railway bridges after an earthquake by fragility curve [2]. The linear response spectrum analysis and the nonlinear static pushover methods are combined in this procedure through various assessment levels and appropriate checks. The assessment is performed for the existing reinforced concrete bridge with the column, girders, (multi-span simply supported bridges in Albania) [2]. This study is focused on performance assessment of reinforced concrete existing bridge (multi-span simply supported girder bridges) using fragility curves [2, 3]. The bridges are located in the strategic road network in the "Elbasan" and "Mifoli" Estacada bridge.

2 Seismic assessment procedure for existing reinforced-concrete bridge

The seismic assessment framework is set up of four-step:

Step 1. Collection of data on geometrical properties of structural and non-structural elements which may affect the structural response, including structural details, such as the amount and detailing of reinforcement, concrete cover, a connection between members and their position on the seismic tectonic map, importance, etc.

Step 2. Determination of the load-displacement characteristics at the top of the piers on a simplified model for column bridge bents. Based on the moment *vs.* curvature curves determined in two simplified analytical methods and on an assumption for the length of the plastic hinge, load-displacement curves for the top of the piers, considering the different maximum lateral displacement (ductility) levels, are constructed [4, 5].
Assessment of damaged stage based on available plastic rotation capacity, member ductility capacity, demand/capacity ratio, and the probabilistic point of view.

Step 3. Generation of analytical fragility curve obtained from the log-normal distribution of probability density function and the cumulative log-normal distribution.

Step 4. Assumption of the performance of the bridge.

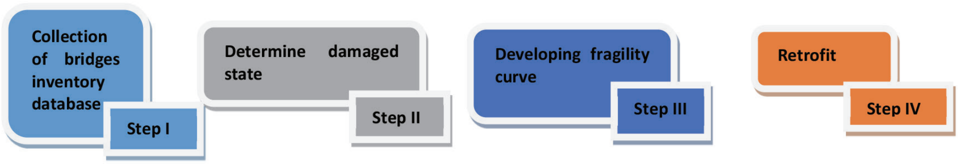

Figure 1. Framework study proposed on the seismic assessment of reinforced existing bridges during a seismic event

3 Analytical bridge fragility methodology for seismic assessment

Fragility is defined as the conditional probability that a structure or a structural component would meet or exceed a certain damage level for a given ground motion intensity [4]. Analytical methods allow both probabilistic demands (D) and capacities (C) to be derived and subsequently used to generate relevant fragilities. When the demand and capacity models follow a lognormal distribution the fragility curves takes the form of the below equation [6, 7, 8]:

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

The log-normal distribution has a probability density function as follows.

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

The cumulative log-normal distribution is obtained by integration of the area below the density function as shown in equation (3).

$$f(x,\mu,\sigma)=\frac{1}{x\sigma\sqrt{2\pi}}\int_0^x\frac{e^{-(\frac{(\ln(x)-\mu)^2}{2\sigma^2})}}{t}dt \tag{3}$$

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.

4 Application during assessment of two existing reinforced bridges in Albania

All assessed bridges were designed and constructed before 1991 based on standards in place as of the construction time. These bridges are located in Elbasan and Vlora region, determined as a moderate seismic zone.

The simplified analysis method of seismic response for bridges according to Eurocode and AASHTO standards is given to assume pier capacity. EC8 currently uses moment demand to moment capacity ratios to somewhat guarantee simultaneous failure of piers on bridges [1]. They are assessed for seismic actions utilizing the linear dynamic response spectrum analysis and nonlinear static pushover analysis of the proposed assessment procedure using a simplified model. Two example bridges used for the analysis are shown in Figures 2 and 3.

Bridge 1 (Shkumbini bridge in Elbasan region) is a 10 span simply continuous concrete girders. Each span is 20 m length and an overall length of 200 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 20 Φ20 having a yield strength of 430 MPa, [9].

Bridge 2 (Mifoli estacade in Vlora region) is a 11 span simply continuous concrete girders. Each span is 25 m length and an overall length of m. The superstructure consists of by 6 precast beams. The deck width is 9 m. Intermediate supports are provided by four – columns bents and by an abutment at each end. The circular reinforced concrete (RC) bridge columns are 1000 mm in diameter with a concrete compressive strength of 30 MPa. Longitudinal reinforcement is provided by 20 Φ16 having a yield strength of 430 MPa, [9].

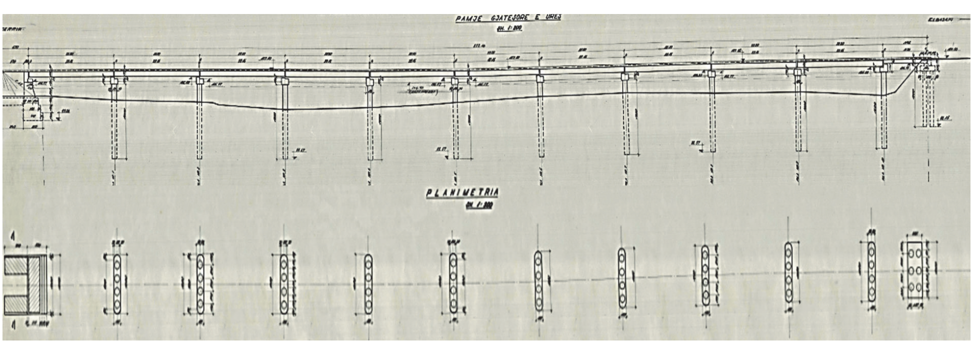

Figure 2. Elevation and Plan View of Shkumbini Bridge 1 ("Design and study Institution of Tirana, Center Technic Inventory of Albania"), [9]

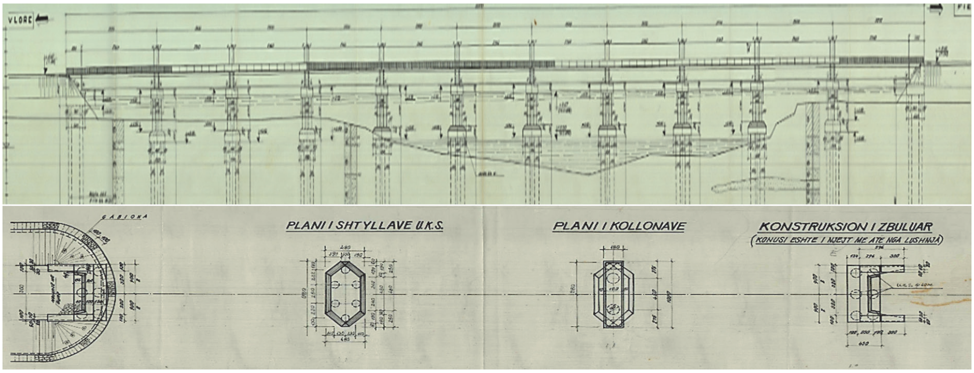

Figure 3. Elevation and Plan View of Mifoli Bridge 2 ("Design and study Institution of Tirana, Center Technic Inventory' Albania"), [9]

A single-column bridge pier model such as the one shown in Figure 4 is used to target the capacity/demand ratio during the design earthquake. The simplified design model is developed based on known dimensions, design details, effective section properties, and design material charachteristics. A summary of cross-section input data for two examples analysis is presented in Table 1.

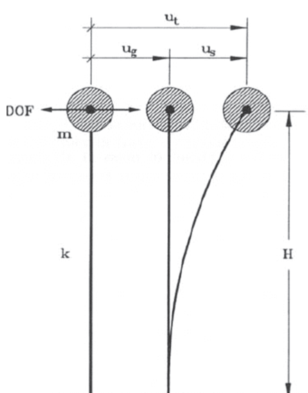

Figure 4. Concrete bridge column [4]

Table 1. Cross section input data for bridge 1 and 2

	Cross section data for bridge 1 and 2	
Axial Force	P_{axial} = 1245 kN	P_{axial} = 1355 kN
Cross section diameter	D = 1200 mm	D = 1000 mm
Reinforcement percent	ρ [%] = 0.5554	ρ [%] = 0.512
Compressive strength	f'c = 25 MPa	f'c = 25 MPa
Seismic mass	m* = 126.9 t	m* = 138 t

5 Moment-curvature curves and damage states

Nonlinear response characteristics associated with the bridge are based on moment-curvature curve analysis taking axial loads into account and uses the constitutive model proposed by Mander for the confined and unconfined concrete [10]. SE-MΦ software is used for the computed moment-curvature relationship [10]. Figures 5 and 6 are shown the plotted curve for bridge 1 and 2 columns.

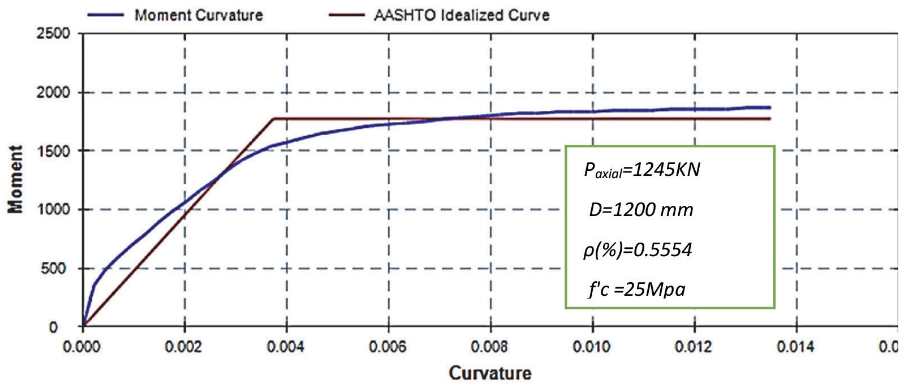

Figure 5. Moment curvature curve for bridge 1 column (SE-MΦ software)

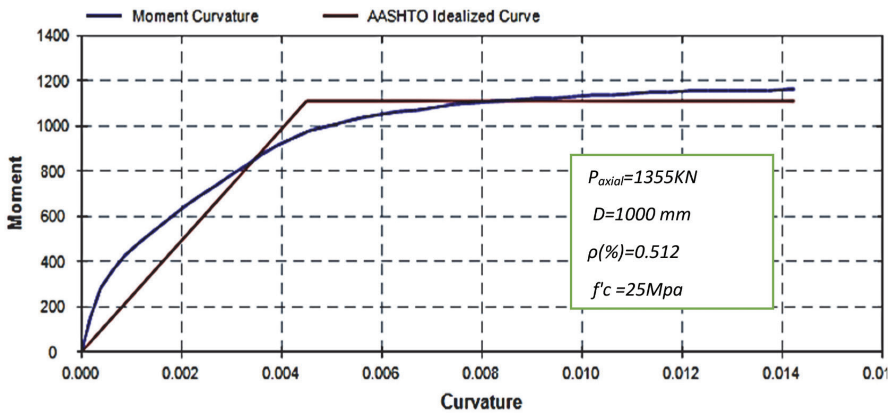

Figure 6. Moment curvature relationship for bridge 2 column (moment curvature SE-MΦ software)

Ultimate, yield moment and curvature (M_u, $M_{y,}$ φ_u, φ_y) values are taken from the curve with respective values for Bridge 1 shown in equations (4) and (5):

$$Mu = 1861 Kn.m,\ \varphi\ u = 0.01351 \frac{rad}{m} \tag{4}$$

$$My = 1298\, Kn.m, \varphi y = 0.00275 \frac{rad}{m} \tag{5}$$

Ultimate, yield moment and curvature (M_u, $M_{y,}$ φ_u, φ_y) values are taken from the curve with respective values for Bridge 2 shown in equations (6) and (7):

$$Mu = 1159\, Kn.m, \varphi u = 0.01425 \frac{rad}{m} \tag{6}$$

$$My = 848.5\, Kn.m, \varphi y = 0.003453 \frac{rad}{m} \tag{7}$$

The column displacement ductility factor capacity for Bridge 1 is calculated in equation (8):

$$\mu_\Delta = \frac{\Delta u}{\Delta y} = 1 + \frac{\Delta p}{\Delta y} = \frac{86.4}{32.4} = 2.66 \tag{8}$$

The column displacement ductility factor capacity for Bridge 2 is calculated in equation (9):

$$\mu_\Delta = \frac{\Delta u}{\Delta y} = 1 + \frac{\Delta p}{\Delta y} = \frac{156.3}{69.8} = 2.2 \tag{9}$$

Based on output data and respective spectral acceleration are computed seismic force, displacement, and ductility for each case. Table 2 presents a results summary. Table 3 shows the spectral accelerations and maximum ground acceleration for 10 %/10 and 10 %/50 year probability on Elbasan and Vlore position. Spectral of uniform hazard for 10 %/50 probability or 475-year repetition is given in figure 7 [11].

Table 2. A summary of computed results

Time [s]	Spectral coefficient Sa	Seismic force E_i [kN]	Stiffness K_{eff}[kN/m]	Displacement [mm]	Ductility displacement μ
Bridge 1					
2s	0.098	122.01	23043	5.294883	0.413663
1s	0.222	276.39	23043	11.99453	0.937073
0.5s	0.435	541.575	23043	23.5028	1.836156
0.2s	0.727	905.115	23043	39.27939	3.068702
Bridge 2					
2s	0.072	97.56	24163	4.037578	0.377344
1s	0.166	224.93	24163	9.308861	0.869987
0.5s	0.33	447.15	24163	18.50557	1.729492
0.2s	0.581	787.255	24163	32.58101	3.044954

Table 3. Spectral accelerations and maximum ground acceleration for 10 %/10 year and 10 %/50 year probability, [11]

Position	Coordinate		Probability	PGA	Sa			
	V	L		0.01s	0.2 s	0.5 s	1.0 s	2.0 s
Elbasan	41.12	20.05	10 %10 10 %50	0.162 0.296	0.375 0.727	0.21 0.435	0.102 0.222	0.044 0.098
Vlorë	40.46	19.48	10 %10 10 %50	0.121 0.249	0.281 0.581	0.144 0.33	0.073 0.166	0.03 0.072

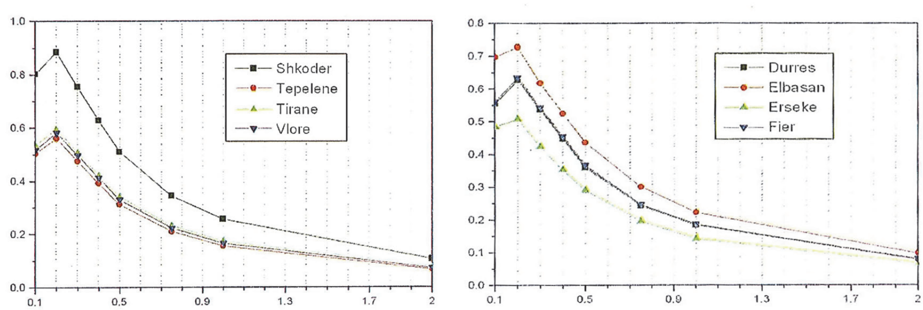

Figure 7. Spectral of uniform hazard for 10 %/50 year probability, [11]

A summary of the computed values in example is shown in table 4. Table 4 is divided into four columns. The first and third column gives the spectral acceleration of the bridge 1 and bridge 2. (*S* is a parameter conceptually related to seismic demand at the site where the bridge is located). The second and four column gives the damage state of the Bridge 1 and 2 assumed from the demand and the capacity model, and moment-curvature section analysis. As shown in Table 4, for spectral acceleration values lower than 0.2 g is no damage or slight damage. Higher values of spectral acceleration of over 0.4 g show moderate damage.

Table 4. Damage state level

Bridge 1	Damage state	Bridge 2	Ductility displacement limits
Sa(0.2s) = 0.635g	Moderate	Sa(0.2s) = 0.581g	Moderate damage
Sa(0.5s) = 0.435g	Slight damage	Sa(0.5s) = 0.33g	Slight damage
Sa(1s) = 0.222g	Slight damage	Sa(1s) = 0.166g	No damage
Sa(2s) = 0.098g	No damage	Sa(2s) = 0.072g	No damage

6 Fragility analysis

The fragility curves for Bridges 1 and 2 associated with four damage states (no damages, minor damages, controlled damages, collapse) which have been determined in section 5 are plotted in Figures 8 and 9, respectively, as a function of peak ground acceleration. These curves are developed using pushover and time history analyses for simplified bridge models.

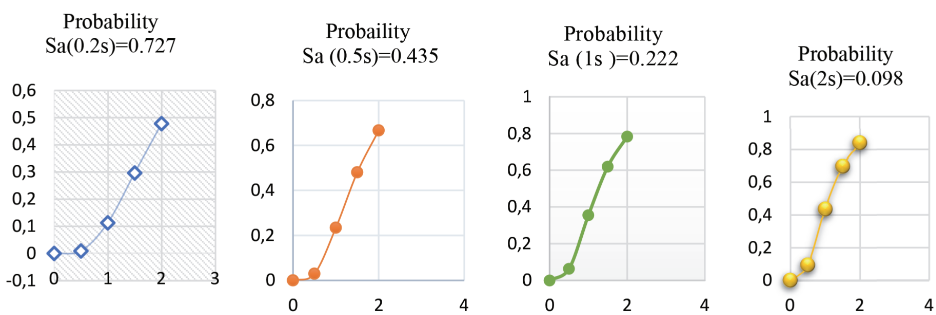

Figure 8. Fragility curve for Shkumbini bridge

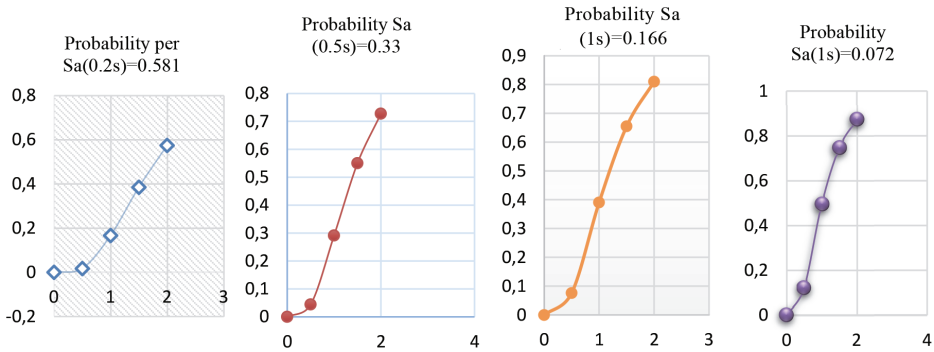

Figure 9. Fragility curve for Mifoli estacade bridge

7 Conclusion

The study is providing a new probabilistic method and step by step procedure for seismic assessment caused by seismic loadings and aims to provide useful information of damage state after an earthquake. This paper presents the seismic fragility analysis for a typical Albanian bridge designed before the 1989 year (Elbasan bridge and Mifoli Estacade).

The ductility capacity is determined based on moment-curvature section analysis and displacement-based design methodologies, considering the column as the most vulnerable component of the bridge. For different values of spectral acceleration are assessed damages state of column bridge for capacity/demand ratio and probability exceeding of damaged state, developing fragility curve.

It is observed from the results of the fragility analysis that these typical bridges in Albania have more than 50 % probability of exhibiting slight damage, controlled damage, and collapse when subjected to earthquakes with PGAs equal to 0.187g; 0.33g; 0.581g; 0.635g for each of the four damage states, respectively.

The authors conclude that the presented seismic assessment procedure could easily find its place as an everyday tool in retrofit and seismic design decision making for reinforced concrete column bridges.

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