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SEISMIC RISK ASSESSMENT OF SIMPLY SUPPORTED GIRDERS BRIDGES

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Abstract

Transport infrastructures, such as bridges, located in seismically active regions are potential exposure due to seismic hazards. A bridge collapse can have tremendous consequences because they provide vital links in a transportation system. Cross border region historically is very well known as territory characterized with high seismic risk. For that purpose, this study is related to the identification of seismic hazard cross-border harmonization vulnerability assessment of risk based on defined levels of seismic hazard and definition of reliable risk of simply supported girders bridge, which is main typology scheme. This study presents an analytical method to predict damage exceedance probabilities due to seismic events using the development of fragility curves. The proposed framework is demonstrated by performing case study highway bridges located in cross border Albanian region with Greece and North Macedonia. Bridge hazard identification is defined by established each damage state of probabilistic structural capacity. The damage probabilities of exceedance that structural demand exceeds capacity are analyzed, displaying results in the fragility curves of bridges.

Keywords:

Bridges vulnerability;
Fragility curves;
Vulnerability;
Risk;
Earthquakes.

1 Introduction

Bridges are key components of the road network, especially those located in road axes with high traffic loads, or which are characterized as of strategic importance. Earthquake damage observed worldwide on road bridges has consequent impact on the wider economic and social activities of the affected areas, while their failure can be occurred catastrophic damage (Kawashima and Buckle, 2013), [1]. In any case, the total cost is high and includes, in addition to the restoration of the damage, the cost of indirect losses due to downtime. In the recent years, many methods have been developed internationally for estimating the seismic risk and their social impact, making the seismic risk assessment as realistic as possible, and describing the potential seismic risk scenario (Kwon and Elnashai, 2010) [2].

Earthquakes represent the main natural hazard in the cross-border region. A number of studies have presented seismic risk frameworks for estimating hazards, earthquake scenario by fragility and basic infrastructure risk exposure (Wener 2000, Chang et al. 2000, Han and Davidson, 2012) [3, 4]. Seismic hazard can be usually considered one or more seismic risk scenarios, or by developing regional hazard analysis methodology, while bridges fragility analysis are set especially for important structures and for primary structural typologies (Kiremidjan et. al. 2007b, Stefaniduo and Kappos, 2017, Gidaris and Padgett, 2017), [5, 6, 7].

This study aims of performing the vulnerability assessment for the Albanian main bridge typology, located on cross border region, concerning and the identified levels of seismic hazards. A seismic assessment framework for simply supported bridges is presented, providing probabilistic methodologies for risk assessment of earthquake hazard by fragility curve, which are innovative and appropriate for vulnerability evaluation [8].

A regional exposure database that has been created is based on contemporary practice and research [9, 10]. This exposure model observes all relevant assets in the cross-border region related to the basic transport infrastructure.

2 Seismic risk assessment framework

In the following paragraphs, the methodologies, and the procedures used to evaluate seismic risk for simply supported bridge column typology is presented and described.

2.1 Regional exposure database

For the purposes of this study, a database on bridges situated along the main roads within the cross-border region with North Macedonia and Greece has been created to gather as much information as possible about the bridge network in Albanian country and to gain enough insight into the bridge database from Albanian Road Authority [9]. A total of 191 bridges have been considered. For these bridges basic data have been available. In this case, two categorizations of different type of data have been performed. The first categorization includes basic information on the existence structures - information, bridge location map and total length. The second set of data includes information on the bridge structural system and material. Based on this information bridge classification according to the taxonomy scheme and their span number have been done.

For most of these bridges, there are basic data on the material of which they are constructed, total length, number of spans and structural system. According to type of structural system, the most frequently found bridge types in this region are bridges with simply supported girders with columns pier, then bridges with frame structural system and pre-fabricated truss bridge account for the least number of bridges, Fig. 1.

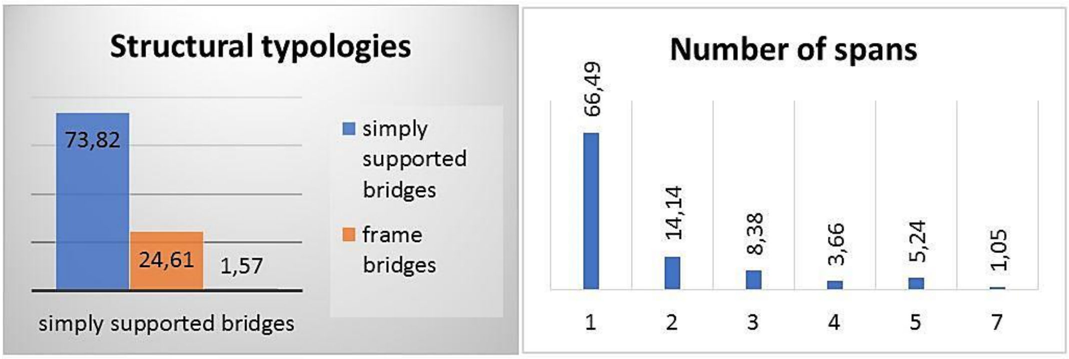

Fig. 1: Percentage presentation of: a) number of bridges from the aspect of structural type; b) number of spans.

As to the number of spans of structures for which there are data, more than half of them, 67 % have 1 span, about 15 % have 2 spans, 8.38 % have 3 span, 3.66 % 4 span, 5.24 % have 5 span, while the greatest number of spans in this region is 7, Fig. 1. As to span length, about 58 % have 20 m span length, 42 % have 30 m span length, Fig. 2.

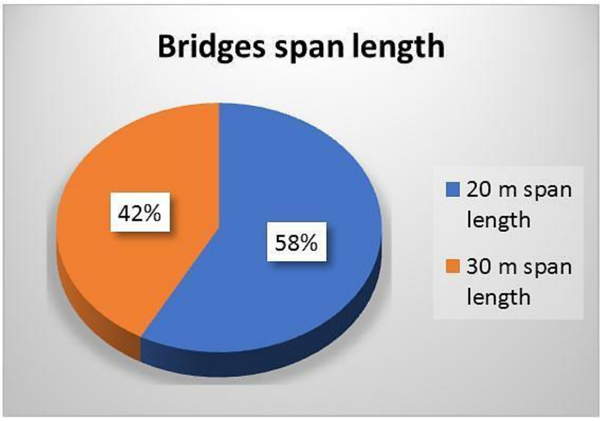

Fig. 2: Percentage of a span length of simply supported bridge.

2.2 Seismic hazard selection

Based on available data on historic seismicity of the Albanian cross border main cities, spatial distribution of Peak Ground Acceleration (PGA) and the Euro-Mediterranean seismic hazard mean model (ESHM13), the probabilistic seismic hazard mapping are established in proposed model for return periods equal to 475 years (10 % exceedance probability in 50 years), 102 years (39 % exceedance probability in 50 years) and 975 years (5 % exceedance probability in 50 years), respectively, for rock site conditions, are given in Fig. 3, [11,12,13].

Fig. 3: Main cities of Albania cross-border area (left) and ESHM13 475 RP map (Mean hazard model).

Probabilistic seismic analysis is performed for Librazhdi and Gjirokaster municipalities that are the region larger cities, and have the highest values of peak ground acceleration PGA related to cross-border areas.

Table 1 shows seismic hazard values (PGA and SA [g]) for 2 municipalities of Albanian cross border area with probability 10 % / 10 years (95 years return period) and 10 % / 50 years (475 years return period) on rock site conditions.

Table 1: Seismic hazard values (PGA and SA [g]) for Librazhdi and Gjirokaster municipalities with probability 10 % / 10 years (95 years return period) and 10 % / 50 years (475 years return period) on rock site conditions, [14, 15].

	Coordinates		**Probability**	**PGA**	**SA**			
Municipality	N	E		0.01 s	0.2 s	0.5 s	1.0 s	2.0 s
Librazhdi	41.18	20.32	10 % 10	0.141	0.344	0.189	0.09	0.04
			10 % 50	0.254	0.66	0.384	0.193	0.088
Gjirokaster	40.07	20.08	10 % 10	0.115	0.269	0.137	0.07	0.029
			10 % 50	0.242	0.565	0.318	0.159	0.069

2.3 Section moment-curvature analysis

Moment Curvature cross sectional capacities is used to evaluated the behavior of reinforced cross section. A simplified model proposed by Mander for confined and unconfined concrete is used to determine the nonlinear response characteristics of the bridge pier. The procedure of moment-curvature curve analysis considered sectional axial loads into account of the constitutive model [16]. In this study, SE-MΦ software is used to define moment-curvature relationship. Columns are one of the most crucial elements under earthquake loads, and their mechanisms are critical to prevent total structure collapse. Fig. 4 presents a single-column bridge pier model, which is used to target the capacity/demand ratio during the earthquake scenario.

The load-displacement characteristics at the top of the piers are plotted considering the different maximum lateral displacement levels, [17, 18, 19].

Damaged stage assessment is defined on available plastic rotation capacity, member ductility capacity, demand/capacity ratio, and the probabilistic point of view [20, 21].

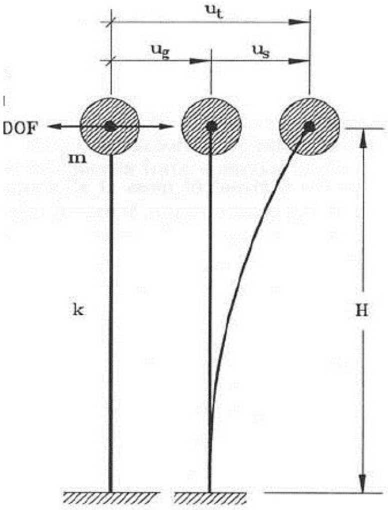

Fig. 4: Simplified bridge pier [16].

2.4 Seismic assessment using fragility curves

The vulnerable conditions of a bridge can be described using fragility functions. A fragility function expresses the conditional probability that a structure reaches or exceeds a damage state when subjected to a given level of the spectral displacement, *Sd*. In this paper, the fragility function is assumed as a log-normal cumulative distribution function, expressed by

$$P[DS|IM] = \Phi[\frac{1}{\beta_{ds}} ln \frac{S_d}{S_{d.ds}}], \tag{1}$$

where *P[DS|IM]* is the probability of exceeding the damage state *DS* at a given level of spectral displacement S_d, Φ[-] is the standard normal cumulative distribution function, $S_{d,ds}$ is the median value of spectral displacement at which the structure reaches the threshold of the damage state, d_s and β_{ds} are the standard deviations of the natural logarithm of spectral displacement for damage state, d_s.

Bridge damage functions are obtained, based on the theoretical background of the damage functions, see Basoz and Mander (1999), [8, 16, 22, 23, 24].

There are several models which can be used to quantify the characterization of damage state and estimation of losses after the earthquakes. One of the models used in this study is HAZUS 99-SR2 developed by Federal Emergency Management Agency FEMA. The status for damage states of the structure after an earthquake is presented on Table 2, [22, 23].

Table 2: Damage state according HAZUS 99-SR2.

Damage state	HAZUS descriptor	Evidence	Ductility factor
1	None	None	0.33
2	Slight	Cracking	1.0
3	Moderate	Large cracks cover spalled	1.67
4	Heavy	Failure of the components	2.0
5	Complete	Partial/total collapse	2.7

Table 3 is given a set of five different damage state and the corresponding drift limits for a typical column introduced by Dutta and Mander, [16].

Table 3: Description of damage state based on drift limits.

Damage state	Description	Drift limits
Almost no	First yield	0.005
Slight	Cracking, spalling	0.007
Moderate	Loss of anchorage	0.015
Extensive	Incipient column collapse	0.025
Complete	Column collapse	0.05

Table 4 gives the median and logarithmic standard deviation/dispersion parameter of simply supported bridges according HAZUS and INFRA-NAT bridges fragility (assumed to follow a lognormal distribution).

Table 4: Mean and deviation fragility parameters for simply supported bridges typology according Hazus and Infranat parameter [22, 23].

Damage state	SA (1s in g's) for damage functions due to ground shaking (Hazus parameter)	SA (1s in g's) for damage functions due to ground shaking, 3 span bridges (INFRANAT parameter)	SA (1s in g's) for damage functions due to ground shaking, 5 span bridges (INFRANAT parameter)
Slight	Median = 0.50	-	-
	Deviation = 0.6		
Moderate	Median = 0.8	-	-
	Deviation = 0.6		
Extensive	Median = 1.10	Median = 0.35	Median = 0.32
	Deviation = 0.6	Deviation = 0.48	Deviation = 0.55
Complete	Median = 1.70	Median = 1.24	Median = 1.28
	Deviation = 0.6	Deviation = 0.44	Deviation = 0.56

3 Case study of risk assessment

As mentioned before, the most common types of bridges in cross - border Albanian region with Greece and N. Macedonia are simply supported reinforced concrete column bents with 20 - 30 m span length, which are assumed. Bridges locations are chosen on Librazhdi and Gjirokaster cross border municipalities. The spans are supported by fixed bearing on the bent and by expansion bearings at the other ends on the bents.

The dimensions of circular reinforced concrete (RC) bridge columns are 1200 mm in diameter D, with a concrete compressive strength f'_c of 30 MPa (C30) and a yield strength of longitudinal reinforcement 430 MPa. Concrete material behavior is modelled by employed Mander approach. Cross-sectional properties for case study are shown in Table 5.

Table 5: Section properties of bridge pier.

Axial load for 20 m span length $P_{axial,l}$	$P_{axial,\,l} = 1300$ kN
Axial load for 30 m span length $P_{axial,2}$	$P_{axial,2} = 2500$ kN
Cross effective moment of inertia I_{eff}	$I_{eff} = 0.5\frac{\pi D^4}{64} = 5.08 \cdot 10^{10}\mathrm{mm}^4 = 0.0508\,\mathrm{m}^4$
Modulus of elasticity of concrete E_c	$E_c = 4700\sqrt{f'_c} = 2.57 \cdot 10^4\,\mathrm{MPa}$
Effective stiffness $K_{eff,o}$	$K_{eff,o} = \frac{6 \cdot E_c \cdot I_{eff}}{H^3} = \frac{6 \cdot 2.57 \cdot 10^7 \cdot 0.0508}{10^3} = 7833\,\mathrm{kN/m}$

Moment curvature relationship of circular columns was determined by using SE-MΦ software shown in Fig. 5. The analysis was performed for 1300 kN and 2500 kN axial load, respectively.

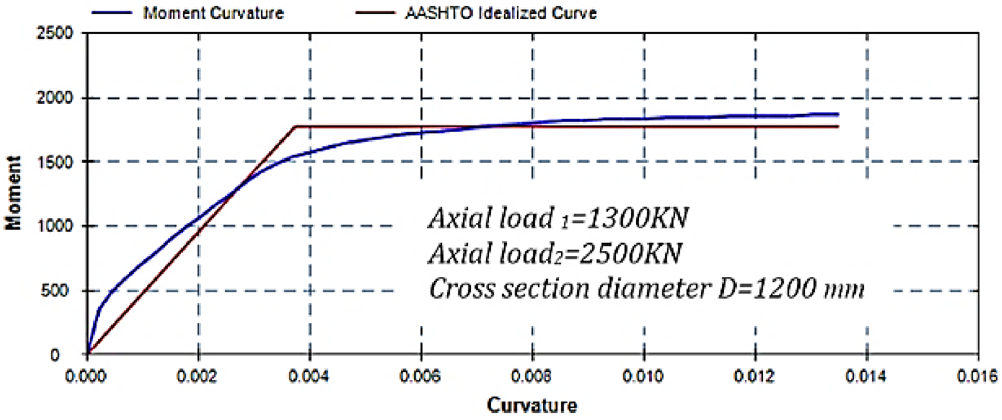

Fig. 5: Moment-curvature relationship of circular section (SE-MΦ).

According to computed results from SE-MΦ, yield displacements Δ_{yi} for 1300 kN and 2500 axial load are given on equation 1 and 2:

$$\Delta_{yi} = \frac{E_i}{K_{eff,o}} = \frac{M_y}{H \cdot K_{eff,o}} = \frac{1700}{10 \cdot 7833} = 21.7\ mm, \tag{2}$$

$$\Delta_{yi} = \frac{E_i}{K_{eff,o}} = \frac{M_y}{H \cdot K_{eff,o}} = \frac{2700}{10 \cdot 7833} = 34.4\ mm, \tag{3}$$

where M_y is yield moment obtained from computed results, H is column height, $K_{eff,o}$ is effective stiffness.

Table 6 shows computed values of spectral and ductility displacement according spectral coefficient and yield displacement for 20 and 30 span length bridges, respectively. Table 7 shows mean and deviation fragility parameters for spectral displacement.

Table 6: Spectral and ductility displacement values.

Librazhdi municipality bridges with 20 - 30 m span length					
Time [s]	**Spectral coefficient SA**	**Seismic load E_i [kN]**	**Spectral displacement [mm]**	**Ductility displacement μ**	**Ductility displacement μ**
				20 m span length	**30 m span length**
2 s	0.088	114.4	14.60	0.67	0.42
1 s	0.193	250.9	32.03	1.48	0.93
0.5 s	0.384	499.2	63.73	2.94	1.85
0.2 s	0.66	858	109.54	5.05	3.18
Gjirokaster municipality bridges with 20 - 30 m span length					
2 s	0.069	172.5	22.02	1.01	0.64
1 s	0.159	397.5	50.75	2.34	1.48
0.5 s	0.318	795	101.49	4.68	2.95
0.2 s	0.565	1412.5	180.33	8.31	5.24

Table 7: Mean and deviation fragility parameters for spectral displacement.

Damage state	**Slight**	**Moderate**	**Heavy**	**Complete**
Median spectral displacement [cm]	0.7	1.5	2.5	5
Log-standard deviation β	0.6	0.6	0.6	0.6

Fig. 6 and 7 displays the mean fragility functions (based on the mean value of the median/logarithmic mean and mean value of the dispersion/logarithmic standard) of spectral displacement and spectral acceleration.

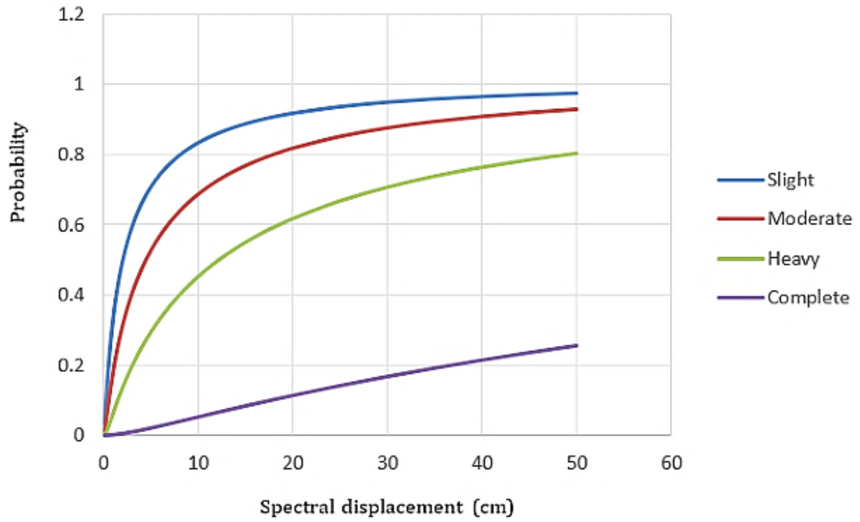

Fig. 6: Spectral displacement bridges fragility curve.

The bridges would be situated in slight damage fragility zone with more than 50 % probabilities for 2.5 cm modal displacement, more than 50 % probabilities to have moderate damage for 5 cm modal displacement. There are more than 50 % probabilities to be situated in heavy damage fragility zone for spectral displacement more than 13 cm spectral displacement.

Table 8 gives mean and deviation fragility parameters used in this study for spectral acceleration.

Table 8: Mean and deviation fragility parameters for spectral acceleration.

Damage state	Slight	Moderate	Heavy	Complete
Median spectral acceleration *g*	0.1	0.15	0.2	0.35
Log-standard deviation *β*	0.6	0.6	0.6	0.6

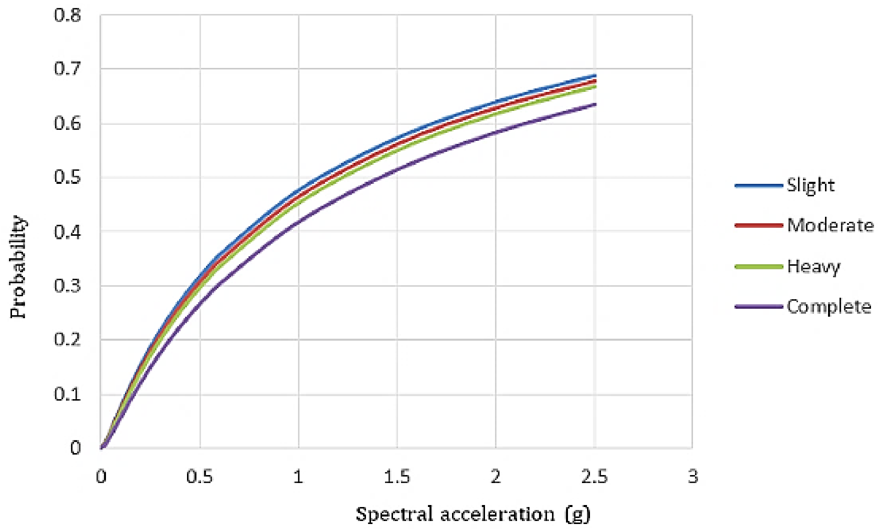

Fig. 7: Spectral acceleration bridges fragility curve.

The bridges would be situated in complete damage fragility zone with more than 30 % probabilities for 0.6 g value of spectral acceleration. There are more than 30 % probabilities to be situated in heavy damage zone for spectral acceleration coefficient 0.5 g, and more than 50 % probabilities to be situated in complete fragility zone for spectral acceleration coefficient 1.5 g.

4 Conclusions

This paper aims at providing a seismic risk framework to evaluate vulnerability assessment of the most common type bridges typologies located on cross-border Albanian region among the Greece and N. Macedonia countries, concerning the identified levels of seismic hazards based on developed models. For the purposes of the study, a data base on bridges situated along main roads within the frames of the cross-border region has been created. In this study, only structures in larger cities related to cross-border areas and serving a larger number of users have been considered. From the territory of Albania, a total of 191 bridges along main roads leading to border crossings on N. Macedonia and Greece countries have been considered. Most of the bridge structures in the considered region are constructed of reinforced concrete, simply supported girder typology with column bents. In this study, simplified pier model is used to determine the behavior of the structure and damage state level assessment.

The fragility functions of simply supported bridges subjected spectral displacement and spectral acceleration exposure hazards are derived considered fragility functions lognormal standard parameters based on column component structure ductility levels.

The study finds that the bridges would be situated in slight damage zone with more than 50 % probabilities for 2.5 cm modal displacement, more than 50 % probabilities to have moderate damage for 5 cm modal displacement. There are more than 50 % probabilities to be situated in heavy damage zone for spectral displacement more than 13 cm spectral displacement. If the analysis results are compared, column piers are significantly affected under ground shaking when modal displacement would be more than 5 cm on the top of bridge pier. The bridges would be situated in complete damage fragility zone with more than 30 % probabilities for 0.6 g value of spectral acceleration. There are more than 30 % probabilities to be situated in heavy damage zone for spectral acceleration coefficient 0.5 g, and more than 50 % probabilities to be situated in complete fragility zone for spectral acceleration coefficient 1.5 g.

This study has conclude that need more research in risk evaluation subject, as well as fragility methods is a reliability tool assessment, and quite limited studies are available for Albanian bridges typology.

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