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Evaluation of Seismic Damage for Gisha Bridge in Tehran by HAZUS Methodology

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***Abstract*—**Transportation is of great importance in the current life of human beings. The transportation system plays many roles, from economical development to after-catastrophe aids such as rescue operation in the first hours and days after an earthquake. In after earthquakes response phase, transportation system acts as a basis for ground operations including rescue and relief operation, food providing for victims and etc. It is obvious that partial or complete obstruction of this system results in the stop of these operations. Bridges are one of the most important elements of transportation network. Failure of a bridge, in the most optimistic case, cuts the relation between two regions and in more developed countries, cuts the relation of numerous regions. In this paper, to evaluate the vulnerability and estimate the damage level of Tehran bridges, HAZUS method, developed by Federal Emergency Management Agency (FEMA) with the aid of National Institute of Building Science (NIBS), is used for the first time in Iran. In this method, to evaluate the collapse probability, fragility curves are used. Iran is located on seismic belt and thus, it is vulnerable to earthquakes. Thus, the study of the probability of bridge collapses, as an important part of transportation system, during earthquakes is of great importance. The purpose of this study is to provide fragility curves for Gisha Bridge, one of the longest steel bridges in Tehran, as an important lifeline element. Besides, the damage probability for this bridge during a specific earthquake, introduced as scenario earthquakes, is calculated. The fragility curves show that for the considered scenario, the probability of occurrence of complete collapse for the bridge is 8.6%.

***Keywords*—**Bridge, Damage evaluation, Fragility curve, Lifelines, Seismic vulnerability.

I. Introduction

URBAN societies are severely prone to earthquakes and the average number of these damages is increasing. As it can be seen in the first decade of the 21th century, more than 680000 people have died in earthquakes. Experiences from previous earthquakes show that one of the main reasons of the high casualties in earthquakes is the delay in rescue and relief operation. This delay is almost due to inappropriate performance of bridges which are among the most important parts of a transportation system.

Seismic vulnerability assessment in latest years shifted to utilize fragility curves as a tool and measure for damage evaluation of structures [1], [2].

One of the most common methods for evaluation of damage to a transportation system is the HAZUS method which is designed and developed by Federal Emergency Management Agency (FEMA). The GIS based methods like HAZUS method enabled cities and societies to assess and evaluate the induced losses from catastrophes like earthquake, flood and storms.

The first version of this system for earthquake damage and loss estimation was developed in 1997. Then FEMA in 1999 represented the final version of this software package which is capable of estimating earthquake, flood and storm damages and losses. HAZUS-MH is compatible with GIS software and uses this software perfectly to show hazard input data and physical and financial loss estimation results for buildings and infrastructures.

Damage and loss estimation results include seismic hazard maps, probabilistic map of structural and Non-structural damages to the buildings and lifelines, fire following earthquake, inundation map, the volume of produced debris, social and direct and indirect financial losses[2].

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II. HAZUS Damage Evaluation Method for Bridges

HAZUS Method for damage evaluation of bridges needs several input data. This data are briefly mentioned below:

- Geographical location of the bridge (longitude and latitude)
- Brides classification
- Spectral acceleration at 0.3 and 1 sec
- Permanent Ground Deformation (PGD)
- Peak Ground Acceleration (PGA)
- Soil type in the site (for calculation of amplification factor)

Bridges can be classified according to the following properties:

- Seismic Design
- Number of bridge spans (single- span or. multi-span bridge)
- Structure type (concrete , steel , …)
- Pier type (single column bents, multiple column bents, pier wall)
- Abutment type
- Span continuity

TABLE I
A PART OF HAZUS BRIDGE CLASSIFICATION SCHEME [4]

Class	NBI Class	State	Year build	Length less than 20 m	K_{3D}	Design	Description
HWB2	All	California	>=1975	N/A	Equation -1	Seismic	Major Bridge
HWB5	All	California	<1975	N/A	Equation -1	conventional	Single Span
HWB5	101-106	Non- California	<1990	N/A	Equation -1	conventional	Multi column concrete with simple bearing
HWB9	205-206	California	>=1975	N/A	Equation -3	Seismic	Single column, continuous concrete with box girder
HWB11	201-206	Non- California	>=1990	N/A	Equation -3	Seismic	Continuous concrete
HWB14	301-306	Non- California	>=1990	N/A	Equation -1	Seismic	Multi-column, metallic with simple bearing
HWB15	402-410	California	<1975	No	Equation -5	conventional	Continuous metallic
HWB19	501-506	California	>=1975	N/A	Equation -1	Seismic	Multi column, pre-stressed concrete with simple bearing
HWB22	601-607	Non- California	<1990	N/A	Equation -2	conventional	Continuous concrete
HWB25	301-306	California	<1975	Yes	Equation -6	conventional	Multi column, metallic with simple bearing
HWB26	402-410	Non- California	<1990	Yes	Equation -7	conventional	Continuous metallic
HWB28							Other unclassified bridges

TABLE II
COEFFICIENTS FOR CALCULATION OF K3D [4]

Equations number	A	B	K_{3D}
Equations-1	0.25	1	$K_{3D} = 1 + 0.25/(N-1)$
Equations-2	0.33	0	$K_{3D} = 1 + 0.33/(N)$
Equation -3	0.33	1	$K_{3D} = 1 + 0.33/(N-1)$
Equation -4	0.09	1	$K_{3D} = 1 + 0.09/(N-1)$
Equation -5	0.05	0	$K_{3D} = 1 + 0.05/(N)$
Equation -6	0.20	1	$K_{3D} = 1 + 0.20/(N-1)$
Equation -7	0.10	0	$K_{3D} = 1 + 0.10/(N)$

According to the above mentioned structural properties, bridges are categorized into 28 classes. Considering the bridge classification, a three digit code is assigned to each bridge. First digit indicates bridges constructed material and the next two digits represent the bridge structural type. For example, the code for a continuous concrete bridge with structural system of box girder is 205[3].

The equation numbers introduced in Table. I indicate the equations for calculation of K3D factor. The general form of these equations is $K_{3D} = 1 + A/(N-B)$, where N is the number of spans and A and B can be obtained by Table. II.

After determination of the bridge type as well as its related equation, fragility curves of the bridge should be drawn. To draw fragility curves (a Log Normal Function), the values of median and standard deviation are needed. Therefore, with regard to the previous earthquakes in United States, median values of Peak Gourd Acceleration as well as their related permanent ground deformation for every 28 classes of bridges are calculated. It should be noted that these fragility curves are standard curves, i.e. the material and structural system of the bridge are just considered in these curves (each row in Table. III indicates one set of curves for different damage states).

TABLE III
PART OF DAMAGE ALGORITHM FOR BRIDGES[4]

	Sa(1.0 sec-g) for Damage Functions due to Ground Shaking				PGD (inch) for Damage Functions due to Ground Failure			
CLASS	Slight	Moderate	Extensive	Complete	Slight	Moderate	Extensive	Complete
HWB2	0.6	0.9	1.1	1.7	3.9	3.9	3.9	13.8
HWB3	0.8	1.0	1.2	1.7	3.9	3.9	3.9	13.8
HWB5	0.25	0.35	0.45	0.7	3.9	3.9	3.9	13.8
HWB9	0.6	0.9	1.3	1.6	3.9	3.9	3.9	13.8
HWB11	0.9	0.9	1.1	1.5	3.9	3.9	3.9	13.8
HWB14	0.5	0.8	1.1	1.7	3.9	3.9	3.9	13.8
HWB15	0.75	0.75	0.75	1.1	3.9	3.9	3.9	13.8
HWB19	0.5	0.8	1.1	1.7	3.9	3.9	3.9	13.8
HWB22	0.6	0.9	1.1	1.5	3.9	3.9	3.9	13.8
HWB25	0.3	0.5	0.6	0.9	3.9	3.9	3.9	13.8
HWB26	0.75	0.75	0.75	1.1	3.9	3.9	3.9	13.8
HWB28	0.8	1.0	1.2	1.7	3.9	3.9	3.9	13.8

In the next step, specific parameters related to the under-studied bridge should be added and new fragility curve for the bridge should be calculated.

Steps for damage evaluation according to HAZUS Method are represented briefly as following:

First Step: determination of the bridge location (longitude and latitude), class (HWB1-HWB28), number of spans (N), skew angle (α), span width (W), bridge length (L) and maximum span length (L_{max}).

Second step : calculation of ground shaking parameter indexes at the bridge site (PGA, Sa[0.3 sec], Sa[1.0 sec] and PGD)

Third step: calculation of the following modification factors:

$$K_{skew} = \sqrt{\sin(90-\alpha)} \quad (1)$$

$$K_{shape} = 2.5 \times S_a(1.0\text{sec.}) / S_a(0.3\text{sec.}) \quad (2)$$

$$K_{3D} = 1 + A/(N-B) \quad (3)$$

The I_{shape} term is a Boolean indicator. The K_{shape} factor is a modifier that converts short periods (T=0.3 sec) to long periods (T=1.0 sec). When $I_{shape}=0$, the K_{shape} factor is not applied and when $I_{shape}=1$, K_{shape} should be applied.

Fourth step: Modifying the ground shaking medians for "standard" fragility curves in Table. III , estimation of following modification factors :

New median [slight damage] = Old median [slight damage] × Sligh damage factor (4)

if $I_{shape}=0$ then Sligh damage factor = 1

if $I_{shape}=1$ then Sligh damage factor = minimum (1, K_{shape})

New median [moderate damage] = Old median [moderate damage] × K_{skew} × K_{3D} (5)

New median [extensive damage] = Old median [extensive damage] × K_{skew} × K_{3D} (6)

New median [complete damage] = Old median [complete damage] × K_{skew} × K_{3D} (7)

Fifth step: Using new medians with dispersion (standard deviation) of β =0.6 to calculate the damage state probabilities related to ground vibration. Note that Sa (1.0 sec) (listed in table. III) is the parameter to be used in this calculation.

Sixth step: Combination of the damage state probabilities and evaluate of bridge performance.

III. Definitions of Damage States of Bridges

Bridge damages are generally classified into 5 damage states as discussed below [4]:

1) No Damage State (ds1): No damage can be observed in the bridge.

2) Slight/Minor Damage State (ds2) : is defined by minor cracking and spalling in the bearings, cracks in shear keys at abutment, minor spalling and cracks at hinges, minor spalling at the columns (needs slight repair) or minor cracking to the deck.

3) Moderate Damage State (ds3): is defined by columns experiencing moderate shear cracking and spalling (columns are still structurally safe), moderate movement of the bearing bases (less than 2 inch), extensive cracking and spalling of base shear keys, bending bolts and shear keys of all connections, failure of keeper bars without displacement, rocker bearing failure or moderate settlement of the road.

4) Extensive Damage State (ds4) : is defined by column degrading without collapse – shear failure – (column is structurally unsafe), permanent displacements at connections, or major settlement of road, vertical offset of the bearing bases, asymmetric settlement of connections, shear key failure at bearing bases.

5) Complete Damage State (ds5) : is defined by collapse of any column and loose of connection in all bearing supports, imminent deck collapse, tilting of substructure due to foundation failure.

IV. Damage Evaluation for Gisha Bridge

Tehran, as the capital city of Iran with population more than 10 million people (in day time), is located beside several active faults. This city is located in the southern Alborz Mountains and surrounded by active faults. Some of these faults are determined in the maps [5].

The numerous faults around the Tehran city and historical experiences of their activities show that the occurrence of a strong earthquake in the close future is possible. What indicates the fault activity and its seismicity is its observed historical seismicity and geology instances. Investigations show that Niavaran fault, Tarasht fault and Lavizan fault are among the most active faults located near Tehran. It is confirmed that the entire length of Niavaran fault which had been estimated to has 13 kilometer length in past, is 45 kilometer. The recent studies show that the Niavaran fault line is extended to the east and intersects the Mosha fault. This fault is Strike-Slip Fault (Left-Slip Fault) which is shown with straight solid line in the aerial photo. The earthquakes around Niavaran fault are Strike-Slip with little tensile component [6]. Consequently, the Niavaran fault is selected as a scenario fault because of its importance and its unknown activity.

Gisha Bridge (also called Nasr Bridge) is one of Tehran bridges located along the Jalale Ale-Ahmad highway at intersection with Shahid Chamran highway. Jalale Ale-Ahmad highway passes over the Shahid Chamran highway. This bridge is among the longest Tehran roadway steel bridge and also an important lifeline in this city. Gisha Bridge was designed and constructed by Nobels Poelman, a Belgian company, in 1982.

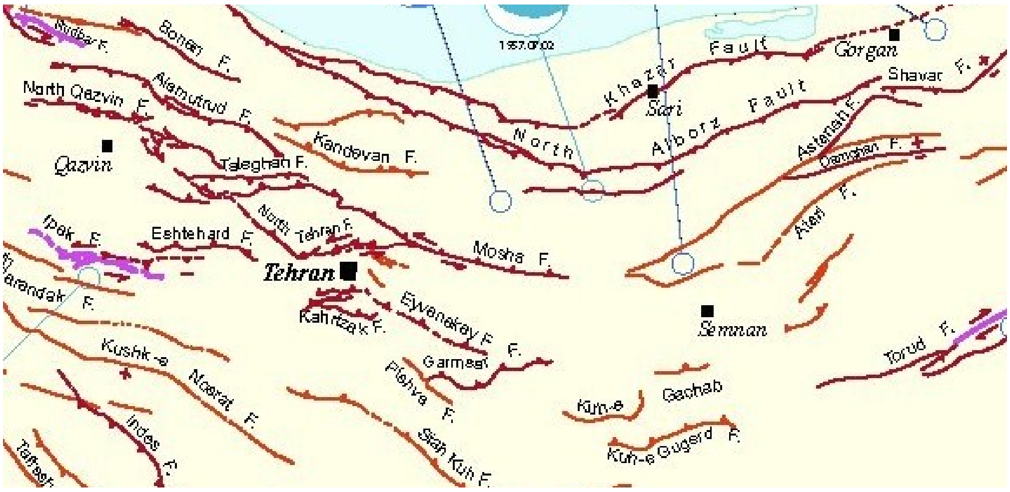

Fig. 1 Distribution of Faults around Tehran City


Fig. 2 Aerial Photo from Gisha bridge in Tehran City

Fig. 3 Left Photo: South view of Gisha bridge, Right Photo: North view of Gisha bridge

The bridge deck material is steel and its structural system is categorized as an orthotropic class. In the main part of the bridge, the loads applied to the deck are transferred to the ground by two piers. This bridge consists of 24 spans with approximate length of 520 meters and has 4 lanes to facilitate automobiles traffic. The length of the longest span is 24 meters and is located where it passes over the Shahid Chamran highway. The skew angle (α) of the bridge is considered to be zero. Abutments of the bridge are infilled and with regard to the Table. 1 in NIBS classification, this bridge is a major bridge and categorized as a HWB2 class. Thus:

$$PGA = 0.094$$
$$New\,Median(Slight) = 0.6$$
$$New\,Median(Extensive) = 0.91$$
$$New\,Median(Complete) = 1.72$$
$$\beta = 0.6$$

Therefore, the fragility curve for Gisha Bridge with above medians and standard deviation equal to 0.6 is shown in Fig. 4.

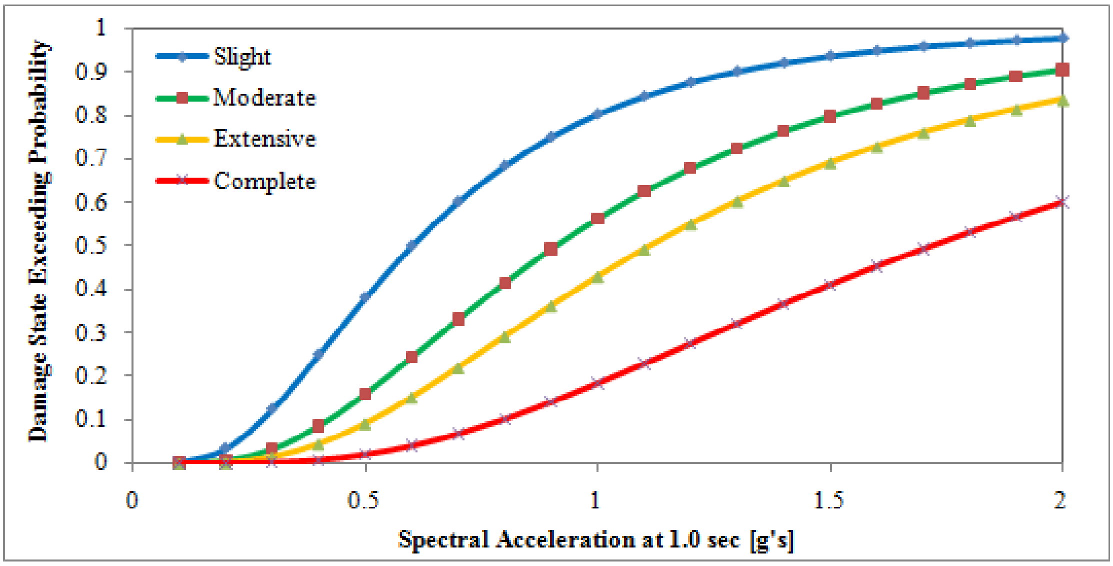

Fig. 4 Fragility curve for Gisha bridge

The earthquake scenario is considered as an earthquake with magnitude of 7 in Richter scale which release its energy at a point at Niavaran Fault with geographical location of 548158 as longitude and 3967442 as latitude in UTM coordination system. Consequently, the spectral acceleration is equal to:

$$S_a(0.3\ \ s) = 1.18\ \ g$$
$$S_a(1.0\ \ s) = 0.76\ \ g$$

Therefore, the probability of entering to the five mentioned damage state for Gisha Bridge are:

$$P_{Complete} = 0.086$$
$$P_{Extensive} = 0.260 - 0.086 = 0.174$$
$$P_{Moderate} = 0.379 - 0.260 = 0.119$$
$$P_{Slight} = 0.650 - 0.379 = 0.271$$
$$P_{No\ \ Damage} = 1 - 0.650 = 0.350$$

V. Conclusion

Fragility curve is an appropriate tool for evaluation of bridges damage. These curves estimate the probability of the occurrence of damage limit states or exceeding from that as a function of ground motion parameters. The results of the pilot study and the evaluated fragility curves indicate that the probability of occurrence of no damage in the bridge under scenario earthquake is 35%. It also shows that the probability of occurrence of slight, moderate and extensive damage are 27%, 11.9% and 17.4%, respectively. Moreover the probability of occurrence of complete damage is 8.6%. In fact, the fragility curves can be used to evaluate if the capacity of a bridge is enough for the considered scenario or not. Considering the negligible probability of the complete damage, it is shown that Gisha Bridge has rather good capability to sustain the considered earthquake loads.

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