Sarpol-e Zahab Earthquake Damages to Roadway Bridges

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ABSTRACT

A strong earthquake with moment magnitude of 7.3 occurred near the city of Sarpol-e Zahab in western Iran on November 12, 2017. The earthquake epicenter was located 10 km from Ezgeleh and 37 km from Sarpol-e Zahab. In this paper, damages to bridges located within 100 km from the epicenter are evaluated based on the field survey conducted one month after the earthquake. Bridges in the seismically affected cities and on primary roads leading to the city of Sarpol-e Zahab were inspected during the field survey. None of the inspected bridges were severely damaged, and they were all in service immediately after the earthquake. The observed damages were mostly minor in form of minor cracking across the decks, detachment of soil and abutments, and cracking of abutments. Some bridges were moderately damaged due to settlement and rotation of abutments which resulted in significant cracking of the deck. Damages occurred mainly in the abutments and to a lesser degree in the decks. Bridge bents in multi-span bridges did not experience any visible damage. This study indicates that concrete superstructures were more vulnerable than superstructures with steel girder. It also indicates that bridges with masonry abutments were more vulnerable than those with concrete abutments. Compared to single span bridges, the state of damage in multi-span bridges were more severe

Keywords:
Sarpol-e Zahab earthquake; Bridges; Damages; Abutment; Cracks

1. Introduction

On November 12, 2017, a major earthquake with the moment magnitude of 7.3 occurred in Kermanshah province, Iran. The epicenter of this event was located at 34.88°N and 45.84°E, near Iran-Iraq border with a depth of 18 km. The epicenter was about 10 km from the town of Ezgeleh and 37 km from the city of Sarpol-e Zahab. Seismological aspects of this major earthquake have been studied by several researchers [1-3]. This paper presents the result of a field study on seismic performance of roadway bridges during this earthquake. Bridge damages were recorded during a field survey one month after the earthquake. Bridges in the cities located within 100 km distance from the epicenter (Kerend, Sarpol-e Zahab, Qasr-e Shirin, Ezgeleh, Javanrud, Ravansar) and bridges on primary roads leading to the city of Sarpol-e Zahab were inspected. This study does not cover bridges on secondary roads.

The earthquake was recorded by 104 stations of Iran Strong Motion Network (ISMN) in the western and central provinces. The strongest ground motion was recorded at the Sarpol-e Zahab station with Peak Ground Acceleration (PGA) of 0.68g [3].

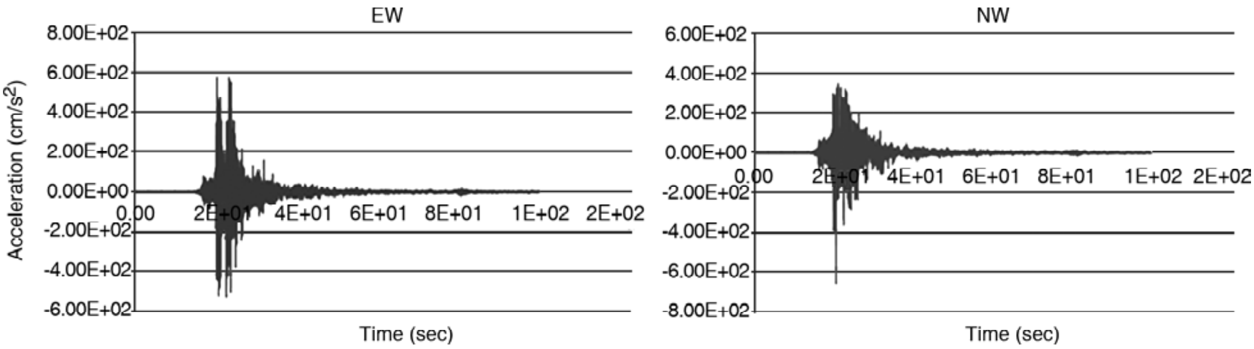

Figure 1. Acceleration history of Sarpol-e Zahab earthquake.

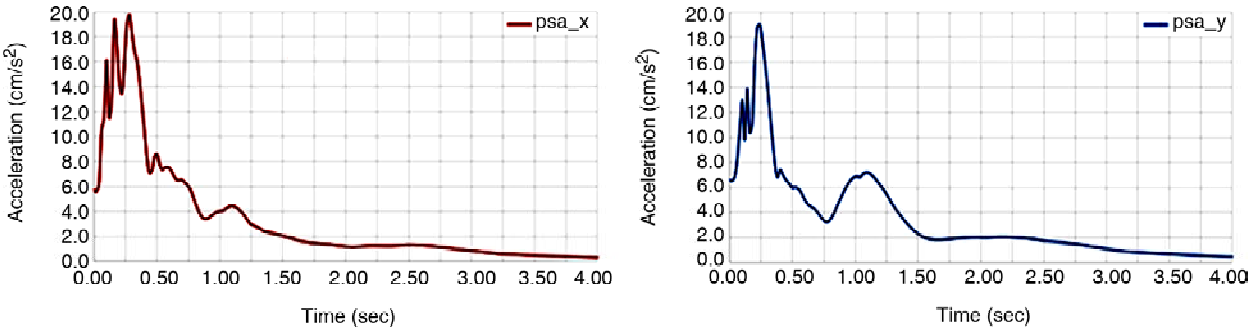

Figure 2. Spectral acceleration of Sarpol-e Zahab earthquake.

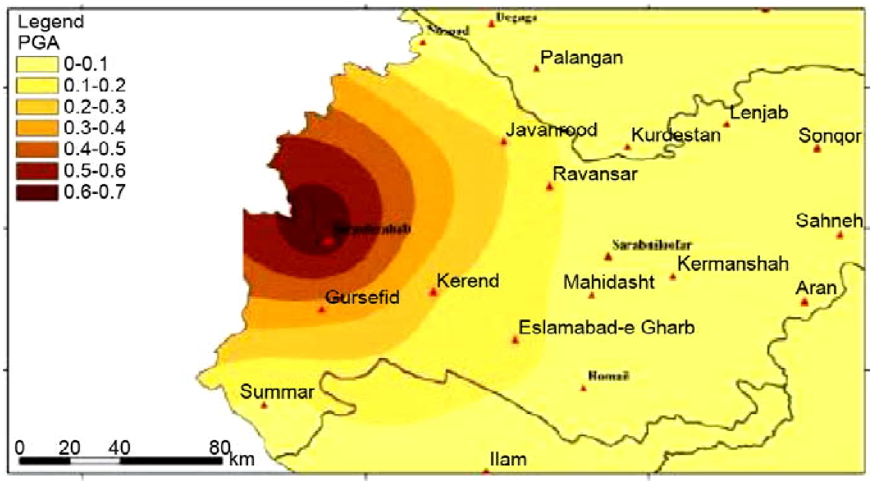

Figure 3. Distribution of Peak Ground Acceleration (PGA) of Sarpol-e Zahab Earthquake [1].

Figure (1) shows the recorded ground acceleration at this station.

Figure (2) shows the spectral accelerations of the recorded ground motion at the Sarpol-e Zahab station. The spectral accelerations indicate directivity pulses in both directions. The pulse-type motion caused by forward directivity is the main characteristics of near-fault ground earthquakes. The pulse period was about 1.1 second as indicated by the local peaks in the spectral accelerations.

Figure (3) shows the distribution of peak ground acceleration (PGA) of the earthquake as reported by IIEES [1]. This distribution was developed using the recorded ground motions at various stations in Iran Strong Motion Network (ISMN).

2. Field Survey

A total number of 32 bridges were inspected during the field survey. They are classified in two general categories. In the first category, the bridges are divided based on type of superstructure, and in the second category, bridges are divided based on

Table 1. Bridge category based on type of superstructure.

A1	Single Span Concrete Slab
A2	Multi Span Concrete Slab
A3	Single Span Concrete Girder
A4	Multi Span Concrete Girder
A5	Single Span Steel Girder
A6	Multi Span Steel Girder

Table 2. Bridge category based on type of abutment.

B1	Bridge with Concrete Abutment
B2	Bridge with Masonry Abutment

type of abutment. Subdivisions are listed in Tables (1) and (2).

Figure (4) shows the location of bridges inspected during the field survey. The bridge label consists of three parts. Part 1 and 2 indicate the types of superstructure and abutment (as per Tables (1) and (2)) and part 3 is the bridge number. For example, bridge with the label A1B2-13 represents bridge number 13 that is a single span concrete slab with masonry abutment.

The first inspected bridge was a single span concrete slab bridge with masonry abutment (A1B2-1) located near Kerend-e Gharb, and the last bridge was a single span concrete girder bridge with concrete abutment (A3B1-32) located at Javanrud. Figure (5) plots the locations of the bridges along with the PGA contours extracted from Figure (3). In this figure, the bridges are categorized based on type of superstructure. Figure (6) plots the location of bridges based on type of abutment. This figure indicates that masonry type abutment was used in most of the bridges.

3. Bridge Damages

Based on the field observations, earthquake damages occurred on bridge decks and/or abutments. No damage was observed on bridge bents. Four damage states are considered for deck and abutment. Description of damage states for the deck is presented in Table (3). In this earthquake, damages to the deck were mostly minor or moderate cracks across the deck. Visible cracks with less

Table 3. Description of the state of damage to the deck.

	Damage States	Description
0	No Damage	No Visible Damage to the Deck,
1	Minor Damage	Visible Cracks on the Top the Deck, Crack width $\leq$ 3mm ,
2	Moderate Damage	Moderate Cracks on the Top of the Deck, Crack width $\geq$ 3mm
3	Extensive Damage	Severe Damage to the Deck

Figure 4. Location of inspected bridges.

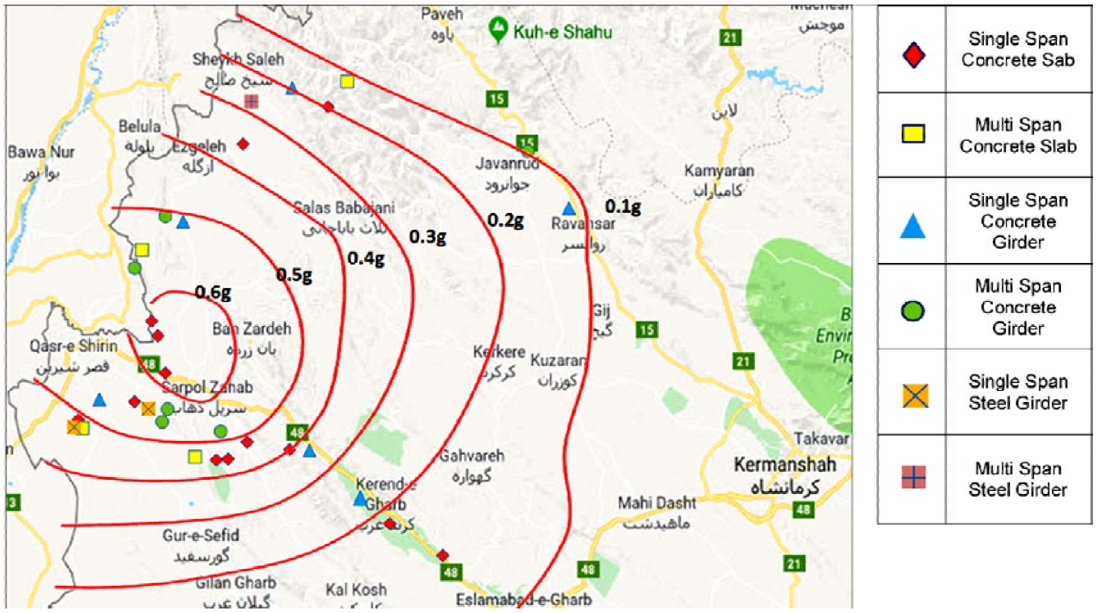

Figure 5. Bridge locations relative to PGA contours (superstructure category).

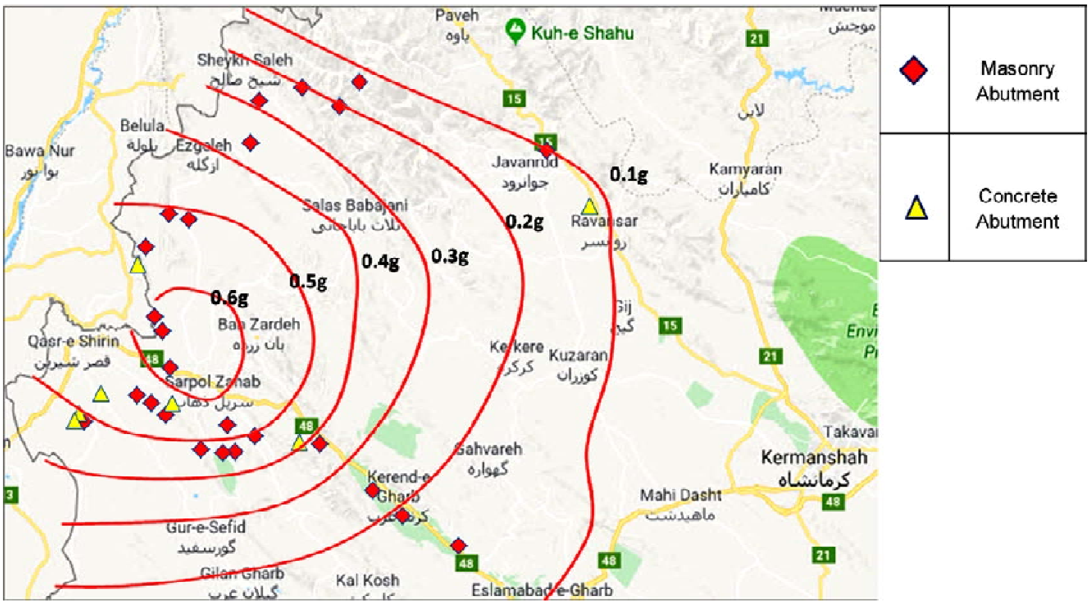

Figure 6. Bridge locations relative to PGA contours (abutment category).

than 3 mm width are denoted as minor damage (level 1) while cracks with larger than 3 mm width are denoted as moderate damage (level 2). No extensive damage to the deck (level 3) was observed in this earthquake.

Description of damage states for the abutment is presented in Table (4). Minor cracking and detachment of soil, visible settlement and rotation of abutment were the various modes of damages in the abutments. Detachment of the soil and minor cracking are denoted as minor damage (level 1) while detachment of wing walls and visible settlement or rotation of the abutment are denoted as moderate damage (level 2). Major settlement or collapse of abutment (level 3) was not observed.

A database for the 32 bridges inspected during the field investigation was developed. The

Table 4. Description of the state of damage to the abutment.

	Damage States	Description
0	No Damage	No Visible Damage
1	Minor Damage	Minor Cracking of Abutment , Detachment of Soil
2	Moderate Damage	Visible Settlement and Rotation of Abutment, Detachment of Wing Wall
3	Extensive Damage	Major Settlement and Collapse of Abutment

information in the database include, bridge structural configuration, damages to the deck and the abutment, bridge location, and the corresponding PGA. The full database is included in a report entitled "Roadway Bridge Damages in November 12, 2017 Sarpol-e Zahab Earthquake." [4]. Tables (5) to (7) present the database for three representative bridges. Table (8) summarizes the technical information and state of damage to the inspected bridges. The approximate age of bridges (year of construction) are included in the chart. The quality of construction was normal. None of the bridges experienced extensive damage (level 3) and damages to the deck and the abutments was either minor (level 1) or moderate (level 2). Moreover, from the 32 inspected bridges, eight bridges did not have any visible damage.

4. Discussion

In this section, damages to the deck, abutment and overall damage of bridges based on damage levels described in Table (3) and (4) are presented. None of the bridges experienced extensive damage (level 3) and damages to the deck and the abutment were either minor (level 1) or moderate (level 2).

4.1. Damage to the Deck

Figure (7) shows the state of damage to the

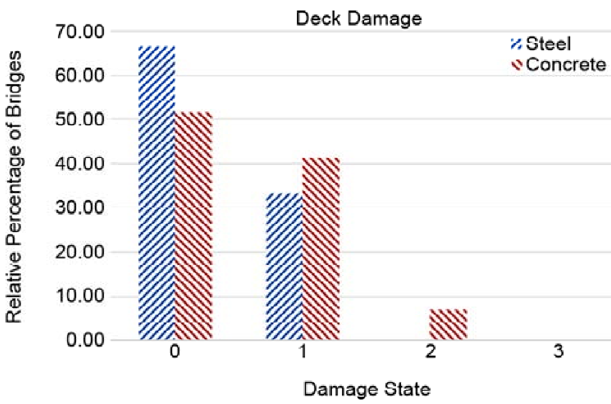

Figure 7. Deck damages at different levels.

Table 5. Bridge A4B2-13.

Location: Sarpol Zahab		
Structure Type: Multi Span Simple Concrete Girder	**River Intersection:** Yes	
Latitude: 34.463518	**Longitude:** 45.856203	

Material and Structural Specifications

Superstructure			Substructure	
Deck	**Type:** Girder	**Width:** 8m	**Bent**	**Type:** Wall
	Material: Concrete	**Span Length:** 32m		**Material:** Masonry
	No. of Spans:3	**Span Length** : 10m	**Abutment**	**Type:** Closed
				Material: Masonry

Damage Comments

- Damage to the Deck and Large Crack on It (a, c) - Subsidence of the Soil of Abutment (b) - Separation of Wing Wall (d)	**Damage Level**	Deck: 1 Abutment: 2	**PGA:** 0.53g

(a)

(b)

(c)

(d)

Table 6. Bridge A5B1-17.

Location: Sarpol-e Zahab to Ghasr-e Shirin					
Structure Type: Single Span Steel Girder		**River Intersection:** Yes			
Latitude: 34.775154		**Longitude:** 45.782817			
Material and Structural Specifications					
Superstructure			**Substructure**		
Deck	**Type:** Girder	**Width:** 10m	**Bent**	**Type:** No Column	
	Material: Steel	**Bridge Length:** 30m		**Material:** -	
	No. of Spans: 1	**Span Length:** 30m	**Abutment**	**Type:** Closed	
				Material: Concrete	
Damage Comments					
- Damage to the Deck and Sidewalk (d) - Damage to the Abutment (a, b) - Rupture of Soil (c)		**Damage level**	Deck: 0 Abutment: 2		**PGA:** 0.48g

(a)

(b)

(c)

(d)

superstructure. As shown in this figure, the concrete superstructures were more vulnerable than the superstructures with steel girder. 52 percent of the concrete superstructures experienced no damage (level 0) as compared to 67 percent for steel girder superstructures, while 48 percent of concrete superstructures experienced minor or moderate damage (level 1 and 2) as compared to 33 percent for steel girder superstructures, which experienced only minor damage (Level 1).

4.2. Damage to Abutment

Figure (8) shows the state of damage to the abutments. As shown in this figure, masonry abutments were damaged more severely than concrete abutments. 27 percent of masonry abutments experienced moderate damage (level 2) as compared to 17 percent for concrete abutments.

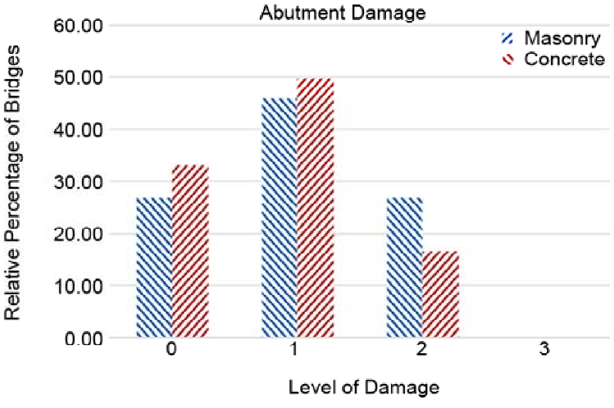

Figure 8. Abutment damages at different levels.

Table 7. Bridge A6B2-27.

Location : Ezgeleh to Salas Babajani	
Structure Type: Multi Span Steel Girder	**River Intersection:** Yes
Latitude: 34.840319	**Longitude:** 45.901841

Material and Structural Specifications				
Superstructure			Substructure	
Deck	**Type:** Ggirder	**Width:** 7m	**Bent**	**Type:** Wall
	Material: Steel	**Span Length :** 32m		**Material:** Masonry
	No. of Spans: 2	**Span Length :** 16m	**Abutment**	**Type:** Closed
				Material: Masonry

Damage Comments			
- Fault Offset (a)	**Damage Level**	Deck : 0	**PGA:** 0.29 g
- Damage and Separation of Abutment (b, c, d)		Abutment : 2	

(a)

(b)

(c)

(d)

The level 2 damages were mainly due to settlement and rotation of the abutment. The walls of masonry abutments were also damaged significantly in some cases. A comparison of Figures (7) and (8) indicates that the abutments were damaged more extensively than the decks.

4.3. Overall Bridge Damages

As mentioned before, the observed bridges in field survey were classified in two general categories (Tables 1 and 2). To evaluate the overall bridge damage, the highest damage level, observed for the deck and abutment is considered as the overall bridge damage. The surveyed region was divided to three zones by its hazard level and PGA and the overall bridge damages in each zone are evaluated separately. Low hazard zone are regions with PGA less than 250 cm/s^2, moderate hazard zone are regions with PGA between 250 cm/s^2 and 500 cm/s^2 and high hazard zone are regions with PGA larger than 500 cm/s^2.

Figures (9) to (11) show the overall bridge damage level in low hazard zone, moderate hazard zone, and high hazard zone respectively. Figure (9) shows that in the low hazard area (PGA< 250 cm/s^2) five bridges experienced minor damage (level 1). Figure (10) indicates that in the moderate hazard area (250 cm/s^2 < PGA < 500 cm/s^2) three bridges experienced minor damage and three bridges were moderately damaged. Figure (11) shows that all bridges located in the high hazard area (PGA > 500 cm/s^2) experienced either minor or moderate damages.

Overall damages to single span bridges and multi-span bridges are also evaluated separately. Figures (12) and (13) show the overall bridges damages to single span bridges and multi-span bridges in the three hazard zones. Figure (12) shows that 38% of single span bridges experienced no damage, 43% experienced minor damage (level 1) and 19% experienced moderate damage (level 2). Figure (13) shows that 55% of multi span bridges experienced minor damage (level 1) and 45% experienced moderate damage (level 2). This indicates that multi span bridges were more vulnerable in comparison to single span bridges.

Table 8. Bridge configurations and state of damage.

Bridge Name	PGA	Type	Number of Span	Span Length (m)	Damage Level		Year of Construction
					Deck	Abutment	
A1B2-1	0.15g	Single Span Concrete Slab	1	11	0	0	2006
A1B2-2	0.2g	Single Span Concrete Slab	1	10	0	0	2010
A3B2-3	0.25g	Single Span Concrete Girder	1	15	0	0	1980
A3B2-4	0.38g	Single Span Concrete Girder	1	8	0	0	2010
A1B1-5	0.4g	Single Span Concrete Slab	1	6.5	0	0	2010
A1B2-6	0.48g	Single Span Concrete Slab	1	6	0	0	2010
A1B2-7	0.45g	Single Span Concrete Slab	1	5.5	0	0	2010
A1B2-8	0.44g	Single Span Concrete Slab	1	6	0	0	2010
A2B2-9	0.45g	Multi Span Concrete Slab	4	10	1	1	2012
A4B2-10	0.51g	Multi Span Concrete Girder	2	10	1	2	2012
A4B1-11	0.55g	Multi Span Concrete Girder	2	8	0	1	2012
A1B2-12	0.61g	Single Span Concrete Slab	1	10	2	1	2012
A4B2-13	0.53g	Multi Span Concrete Girder	3	10	1	2	2012
A1B2-14	0.54g	Single Span Concrete Slab	1	8	0	1	2012
A3B1-15	0.55g	Single Span Concrete Girder	1	10	1	1	1998
A2B2-16	0.48g	Multi Span Concrete Slab	3	10	2	2	2006
A5B1-17	0.48g	Single Span Steel Girder	1	30	0	2	1998
A1B1-18	0.49g	Single Span Concrete Slab	1	12	1	1	2006
A5B2-19	0.54g	Single Span Steel Girder	1	40	1	2	1998
A1B2-20	0.68g	Single Span Concrete Slab	1	8	1	1	2010
A1B2-21	0.65g	Single Span Concrete Slab	1	9	0	1	2010
A4B1-22	0.58g	Multi Span Concrete Girder	2	6	1	1	1970
A2B2-23	0.55g	Multi Span Concrete Slab	2	8	1	1	1970
A4B2-24	0.51g	Multi Span Concrete Girder	3	10	1	2	1970
A3B2-25	0.51g	Single Span Concrete Girder	1	10	1	2	1970
A1B2-26	0.37g	Single Span Concrete Slab	1	7	1	1	1970
A6B2-27	0.29g	Multi Span Steel Girder	2	16	0	2	1970
A3B2-28	022g	Single Span Concrete Girder	1	9	0	1	1970
A1B2-29	0.21g	Single Span Concrete Slab	1	8.5	0	1	1970
A2B2-30	0.18g	Multi Span Concrete Slab	2	8	0	1	1970
A4B2-31	0.12g	Multi Span Concrete Girder	2	10	0	1	1970
A3B1-32	0.11g	Single Span Concrete Girder	1	13	1	0	2016

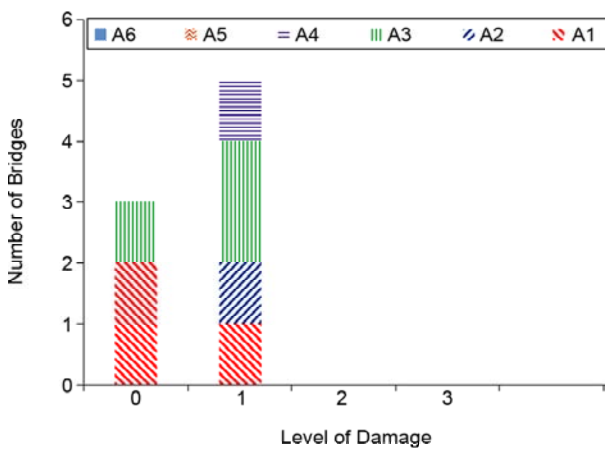

Figure 9. Bridges damage for low hazard zone.

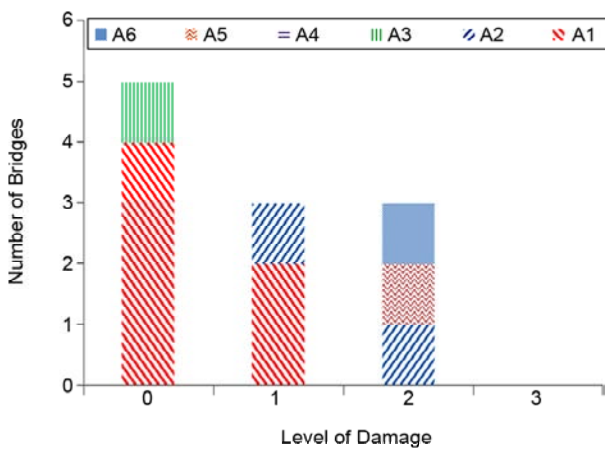

Figure 10. Bridges damage for moderate hazard zone.

5. Analytical Evaluation

Field survey of bridges located within 100 km from the epicenter indicated that bridge bents did not experience any visible damage, and bridge damages were either minor or moderate in form of detachment of soil and abutments, cracking of abutments, cracking across the decks, and settlement and rotation of abutments. In many cases cracking across the deck was due to settlement and rotation of abutments. Thus, the abutments were the critical bridge components and high seismic demands on abutments were the source of damage in the more severely damaged bridges. The analytical evaluation presented in this section would be concentrated on the seismic response of the abutments. Table (9) lists the technical information related to the seismic demands and damage levels of the abutments. Seismic demands on the abutments are calculated using peak ground accelerations at bridge locations and tributary mass of the decks.

Figure (14) shows the seismic demands on the bridge abutments. This figure indicates that except for two relatively long span bridges (Bridges no. 17 and 19), seismic demands on abutments are less than 4.3 ton/m. Seismic demands on abutments of the two long span bridges are approximately

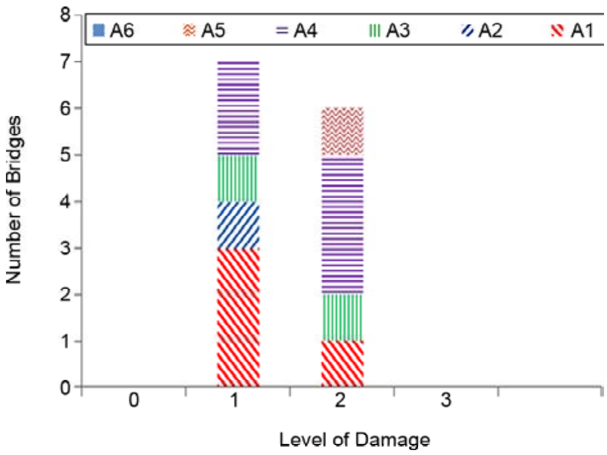

Figure 11. Bridges damage for high hazard zone.

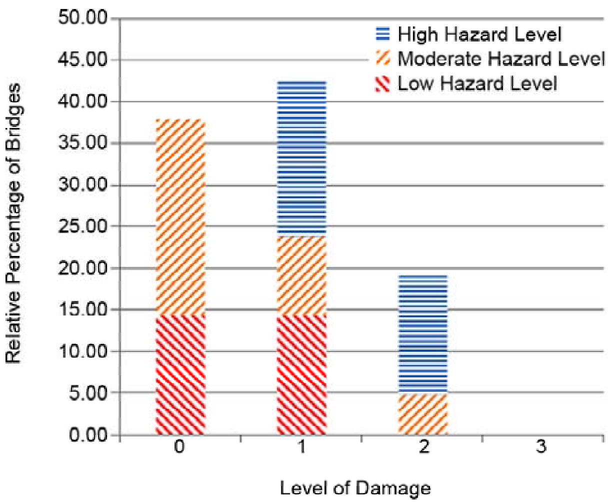

Figure 12. Bridges damage for single span bridges.

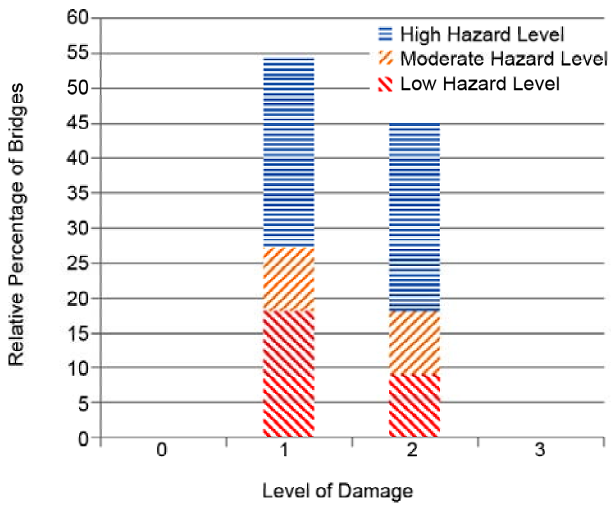

Figure 13. Bridges damage for multi span bridges.

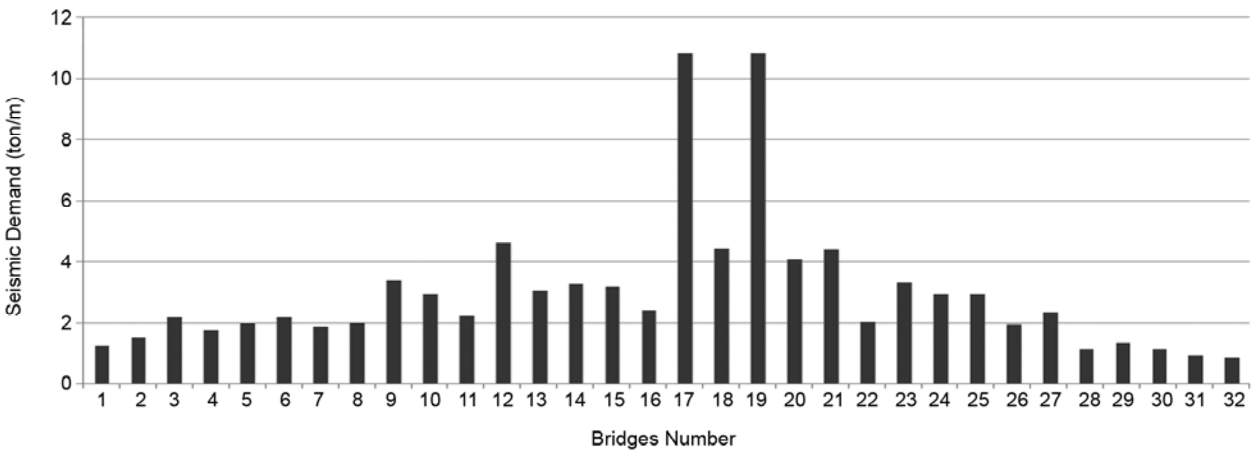

Figure 14. Seismic demands on the abutments.

Table 9. Bridge dimensions and seismic response of abutments.

Bridge Name	PGA (g)	Span Length (m)	Bridge Width (m)	Deck Weight (ton)	Seismic Demand on Abutment (t/m)	Abutment Damage Level
A1B2-1	0.15	11	7	115.5	1.23	0
A1B2-2	0.2	10	7	105	1.57	0
A3B2-3	0.25	15	14	241.5	2.15	0
A3B2-4	0.38	8	6	55.2	1.74	0
A1B1-5	0.4	6.5	6	58.5	1.95	0
A1B2-6	0.48	6	7	63	2.16	0
A1B2-7	0.45	5.5	6	49.5	1.85	0
A1B2-8	0.44	6	6	54	1.98	0
A2B2-9	0.45	10	5	75	3.37	1
A4B2-10	0.51	10	15	172.5	2.93	2
A4B1-11	0.55	7	10.8	86.9	2.21	1
A1B2-12	0.61	10	6	90	4.57	1
A4B2-13	0.53	10	8	92	3.04	2
A1B2-14	0.54	8	6	72	3.24	1
A3B1-15	0.55	10	8	92	3.16	1
A2B2-16	0.48	10	7	70	2.40	2
A5B1-17	0.48	30	10	450	10.88	2
A1B1-18	0.49	12	6	108	4.41	1
A5B2-19	0.54	40	10.5	420	10.82	2
A1B2-20	0.68	8	7	84	4.08	1
A1B2-21	0.65	9	8	108	4.38	1
A4B1-22	0.58	6	6	41.4	2.01	1
A2B2-23	0.55	8	6	72	3.32	1
A4B2-24	0.51	10	6	69	2.93	2
A3B2-25	0.51	10	8	92	2.93	2
A1B2-26	0.37	7	6	63	1.94	1
A6B2-27	0.29	16	7	112	2.32	2
A3B2-28	0.22	9	8	82.8	1.13	1
A1B2-29	0.21	8.5	6	76.5	1.33	1
A2B2-30	0.18	8	7	84	1.13	1
A4B2-31	0.12	10	10	150	0.91	1
A3B1-32	0.11	13	10	149.5	0.82	0

10.8 ton/m. These two bridges are single span steel girder bridges with span lengths of 30 and 40 meters. They experienced relatively high seismic intensity (PGA = 0.48 g and 0.54 g) and the abutments experienced level 2 damages as indicated in Table (9). The span lengths for the rest of bridges are less than 16 meters.

Figure (15) which correlates the seismic demand with the damage level indicates that the level of damage increases with increasing seismic demand. Based on these data, a threshold for seismic demand on abutment is defined beyond which the abutment may experience level 2 (moderate)

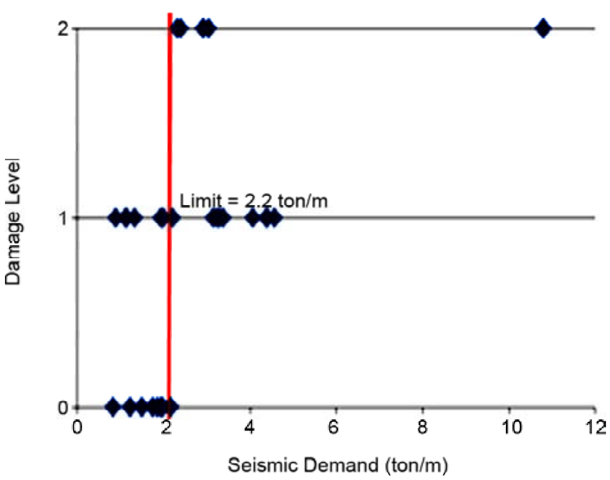

Figure 15. Abutment damage level vs. seismic demand.

damage. The corresponding limit for seismic demand on abutment is 2.2 ton/m. Figure (15) indicates that below this limit, none of the bridges experienced moderate damage (level 2) and only 15% of bridges experienced minor damage (level 1).

6. Conclusion

Bridges located within 100 km from the epicenter of Sarpol-e Zahab earthquake are surveyed for earthquake damages in superstructure and sub-structure. The general conclusions resulted from this survey are as follows:

- Despite the large magnitude of Sarpol-e Zahab earthquake, none of the bridges were severely damaged. They were all in service after the earthquake.
- The inspected bridges showed acceptable behavior during the severe earthquake mainly because they were mostly single span bridges, and the few multi-span bridges had relatively short spans.
- The observed damages were mostly minor in form of minor cracking across the decks, detachment of soil and abutments, and minor cracking of abutments. There were a few bridges that were moderately damaged due to settlement and rotation of abutments which resulted in significant cracking of the superstructure and masonry abutment walls.
- The abutments were the critical bridge components, and high seismic demands on abutments were the primary source of damage in the moderately damaged bridges.
- A threshold for seismic demand on abutment is established beyond which the abutment may experience moderate damage. The corresponding limit for seismic demand on abutment is 2.2 ton/m.
- None of the bridge bents were damaged during this earthquake.
- Masonry abutments were more vulnerable than concrete abutments.
- Multi-span bridges were more vulnerable than single span bridges.
- Steel girder bridges were less vulnerable than concrete bridges.

References

1. International Institute of Earthquake Engineering and Seismology (2017) *Report of November 12, 2017 Sarpol-e Zahab Earthquake*. IIEES Report, Rev. 5 (in Farsi).

2. Zare, M., Kamranzad, F., Parcharidis, I., and Tsironi, V. (2017) *Preliminary Report of Mw 7.3 Sarpol-e Zahab, Iran Earthquake on November 12*.

3. Farzanegan, E., Pourmohammad Shahvar, M., Eshaghi, A., Mirsanjari, M., Abdollahi, H., and Mirzaee, H. (2017) *Report of the November 12, 2017 Sarpol-e Zahab, Kermanshah Province Earthquake*. BHRC Report.

4. Vasseghi, A. and Taghinia, A. (2018) *Roadway Bridge Damages in November 12, 2017 Sarpol-e Zahab Earthquake*. IIEES Report.