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Design and Implementation of Seismic Retrofitting of a Steel Bridge: Case study of Karim-Khan-Zand bridge in Tehran

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Abstract

In order to achieve the maximum utilization of the roadways as well as increasing the service life of the bridges, proper traffic transfer, earthquake resistance and damage resistance of the bridges caused by the passage of time; strengthening and repairing of the bridges are essential. In this study, Karim-Khan bridge was selected as a case study to be repaired and retrofitted. The dynamic response of this bridge was investigated by structural finite element analysis method using SAP2000 software. The three-dimensional geometry of the bridge developed through the software environment and advanced options such as the base contact elements and nonlinear material properties were used to assess the effect of different seismic loads on the structural behavior of the critical bridge components. C / D ratio showed that the columns are not ductile due to geometric configuration when subjected to axial load; while their sections in the longitudinal direction are weak in bending. For this reason, the columns are more vulnerable to collapse during the earthquake. Hence it was concluded that the seismic vulnerability of the bridge is high. Regarding the cost of rehabilitation, which was about 30% of the cost of construction of a new bridge and the traffic problems during the construction of the new bridge, the option of improvement and rehabilitation was approved by the technical and civil deputy of Tehran Municipality.

Keywords: steel bridge, retrofitting, finite element method, seismic performance, damage resistance

1 Introduction

Due to the need to achieve the maximum utilization of the roadways as well as increasing the service life of the bridges, proper traffic transfer, earthquake resistance and damage resistance of the bridges caused by the passage of time; strengthening and repairing of the existing bridges is crucial [1]. By using this approach, the Karim Khan-Sepahbod Qarni and Mirzai Shirazi intersection bridge is one of the repairs and retrofitting options. For this purpose and according to the request of Tehran Municipality, extensive studies have been conducted on the operating conditions and quantitative assessment of the vulnerability of the bridge.

Figure 1: Karim-Khan-Zand bridge view.

General specifications of the bridge

Karim-Khan-Zand Bridge is located in District 6 of Tehran. This bridge is one of the temporary bridges in Tehran, which was built in 1973 by the Belgian company Nobel Spillman. The specifications of the structure are as follows:
• The bridge has 14 spans.
• Bridge columns are made of composite sections in the form of sheet beams. The middle column is with variable cross section and the side columns are fixed cross section.
• The bridge deck is made of steel and is orthotropic.
• Bridge foundations are of surface type.

• The total length of the bridge is 430 meters.

• The width of the bridge is 14.35 meters.

• The bridge has two round-trip routes and no sidewalk.

• The height of the columns varies from 0.70 meters to 5.75 meters.

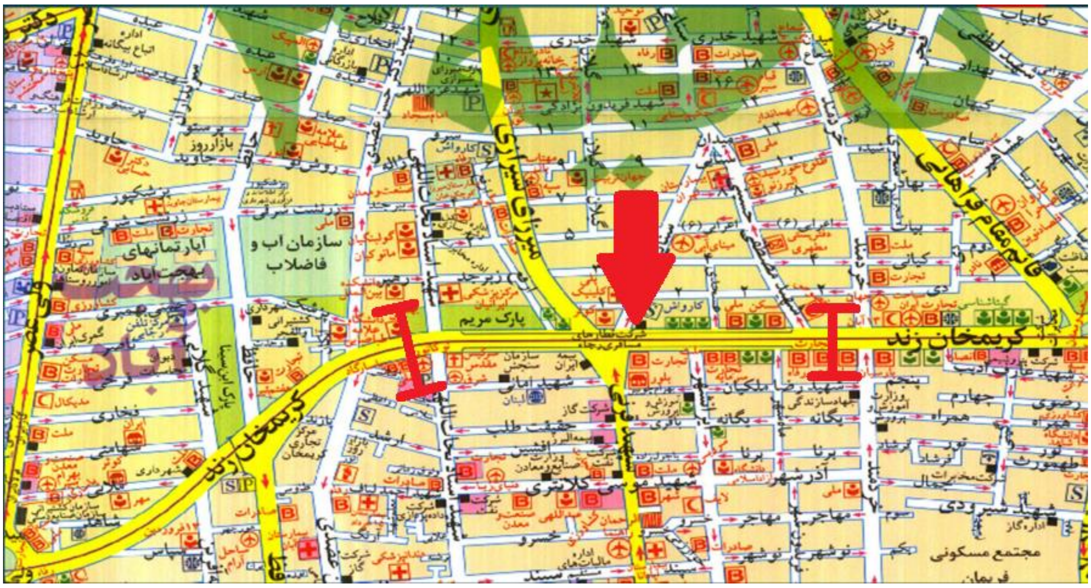


Figure 2: Location of Karim-Khan-Zand bridge.

Seismicity and geotechnical specifications of the area

By examining historical earthquakes and studying recorded earthquakes, it is clear that the study area has a high potential from a tectonic seismic point of view and is highly seismic [2]. Meanwhile, the whole province of Tehran is located in an area with a relative earthquake risk of "very high" (In this case, the Peak Ground Acceleration, PGA, is 0.35 g (according to the third edition of the 2800 standard) [Ref. 3]. Based on studies conducted by the Soil Mechanics Laboratory the type of ground to determine the reflection coefficient of the structure is type II with shear wave velocity of 500-800 m/s (gravel, compact sand, sand stones).

2 Methods

Evaluation of the seismic performance of the bridge

Modelling procedure:

The dynamic response in the present case study was investigated by structural finite element analysis method using SAP2000 software. The three-dimensional geometry of the bridge developed through the software environment and advanced options such as the base contact elements, nonlinear material properties were used to assess the effect of different seismic loads on the structural behavior of the critical bridge components. Figure 3 represents a side view of the three-dimensional model.

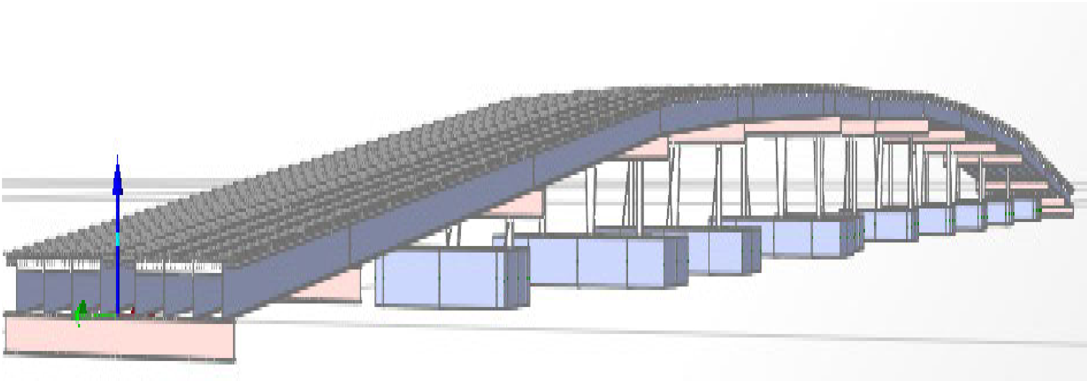


Figure 3: A view of the three-dimensional modelling of the bridge.

Following measures have been taken to evaluate the seismic performance of the structure [4,5,6]:

- Determining the structural and non-structural bridge components in the model and their specifications, parameters and necessary quantities
- Foundation modelling
- Configuration according to the regular or irregular condition of the structure
- Investigation of torsional effects
- Investigation of reversal effects
- Investigation of soil-structure interaction
- Application of the seismic forces using the predicted model
- Comparing the proposed model and the basic assumptions and real structural behavior
- Checking the strength of materials
- Determining the performance of structural components such as beams columns in terms of: Shear control, deformation control and bending control
- Foundation analysis
- Investigation the performance of structural components such as columns, foundations, etc. according to the FHWA acceptance criteria
- Determining final acceptance criteria.

Retrofitting procedure

The main issues and challenges involved in retrofitting phase of the Karim Khan are listed as follows:

A) Operational level problems: Includes noise and bridge vibration with high frequencies associated with the operational activities. The lack of adequate drainage system on the structure and as consequence, the water spillage, led to bridge foundation erosion and several damages to the deck of bridge. Multiple longitudinal and normal joints with difficult maintenance and repair, which were too challenging and affected the quality of operation.

B) Seismic vibration problems: The bridge was not generally designed for any horizontal earthquake forces in both, lateral and longitudinal directions.

Therefore, the following considerations have been considered in the bridge retrofitting process:
• Flexural retrofitting and improving of the bridge static behavior under vertical static loads
• Seismic retrofitting [10,11] in:
- Longitudinal direction:
The deck two ends are secured on the soil through the diagonal anchor bolts and base plate connection system. A clearance called “seismic gap” is created in the middle of the structure.
- Transverse direction:
The base plate was secured with diagonal anchors and transverse reinforcement was provided for the bridge columns in regions with a high earthquake risk.
• Improvement of thermal stability
Further, the following main steps were taken:
• Execution of piles and foundations in two end zones of the bridge and connection to the bridge deck
• Correction of beam-to-head connections
• The replacement of Neoprene pads under the base plates
• Replacement of fences

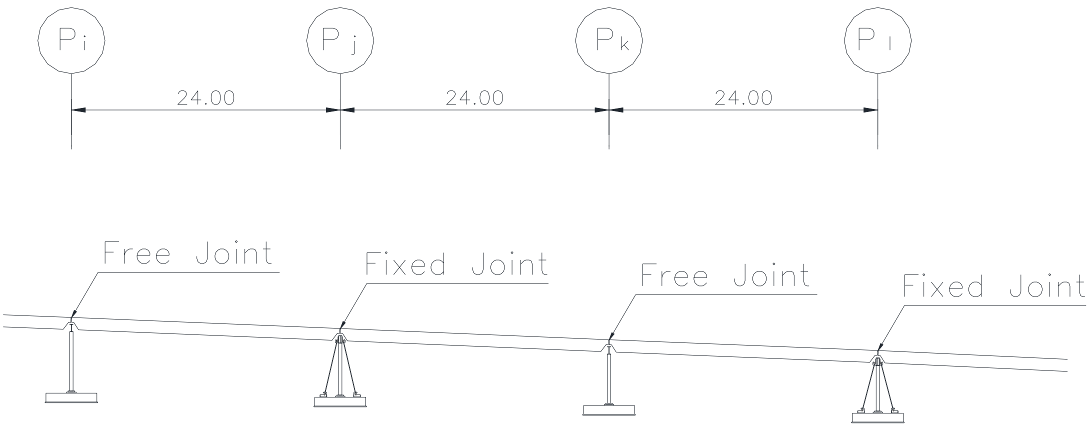


Figure 4: Expected performance of the bridge

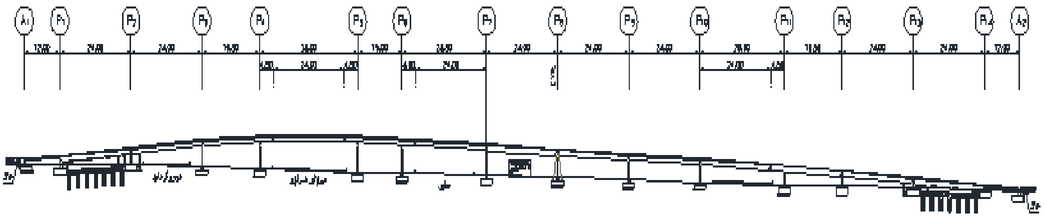


Figure 5: Seismic retrofitting in the longitudinal direction

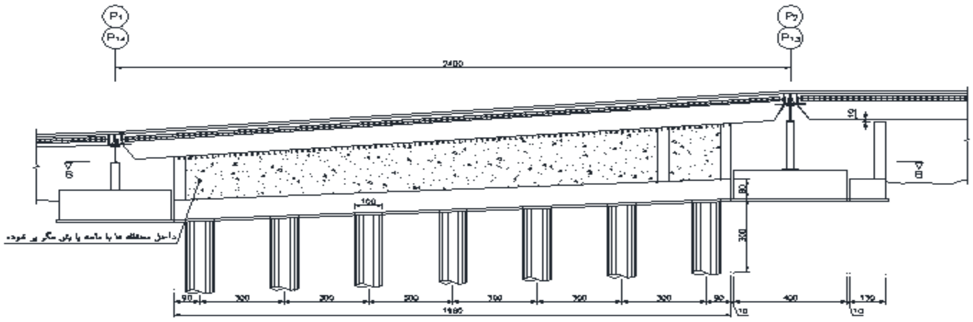


Figure 6: Seismic retrofitting in the longitudinal direction

Figure 7: Locating of piles

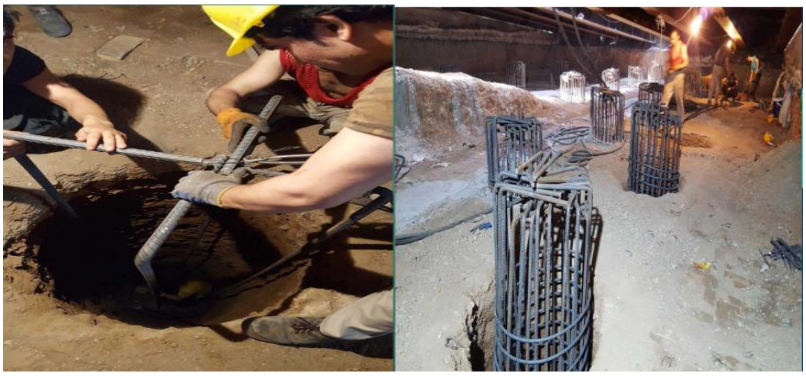


Figure 8: Piles reinforcement

Figure 9: Piles concreting

Figure 10: Scaffolding for the installation of reinforcement plates

Figure 11: Installation of the reinforcement plates

3 Results

Seismic risk assessment of the Karim-Khan highway bridge structure, under the specific earthquake with a certain level of intensity

Evaluation of the structural components according to FHWA [6,7,8] acceptance criteria is based on C/D ratio. According to the C/D ratio table shown in the following table, it is observed that the columns are not ductile due to geometric configuration when subjected to axial load; while their sections in the longitudinal direction are weak in bending. For this reason, the columns are more vulnerable to collapse during the earthquake and more appropriate arrangements must be considered for the longitudinal earthquake than the existing configuration.

According to the risk performance evaluation of the bridge components under seismic loads, it can be said that the columns cannot provide sufficient resistance under the earthquake excitation applied in the longitudinal direction of the bridge and cause seismic vulnerability as well as the flexural inadequacy of the foundations. Therefore, the seismic vulnerability of the bridge is high, however by controlling the longitudinal earthquake along with increasing the damping in the bridge structure or adding additional bracings, appropriate improvement solutions can be reached.

4 Conclusions and Contributions

Target Costing and Value Engineering

The initial estimation of the destruction of the current bridge and the construction of a new one was about 350 billion Rials, while the seismic retrofitting and strengthening of the bridge were estimated at about 94 billion Rials.

30X	P	M2	M3	pcr	MX	MY	p/pcr	mMX	mMy	D/C tot	C/D Tot
3-1	-199.65	-4.70	-93.97	561.58	134.27	36.00	0.36	1.2	1.2	2.13	0.47
3-2	-85.91	-3.05	-150.35	531	496	44.00	0.16	1	1	2.31	0.43
3-3	-46.94	-5.44	-93.97	561.58	134.27	36.00	0.08	2	2	1.15	0.87
4-1	-185.45	-64.20	-256.65	530.78	134.27	36.00	0.35	1.2	1.2	1.95	0.51
4-2	-17.02	-59.45	-408.29	497	496	44.00	0.03	1	1	2.70	0.37
4-3	121.72	-64.35	-256.65	530.78	134.27	36.00	0.23	1.2	1.2	1.83	0.55
5-1	-308.87	1.80	-251.65	513.41	134.27	36.00	0.60	1	1	3.45	0.29
5-2	-112.18	1.68	-438.15	478	496	44.00	0.23	1	1	3.28	0.31
5-3	-8.75	0.83	-251.63	513.41	134.27	36.00	0.02	2	2	1.44	0.69
6-1	-250.43	-43.25	-363.99	494.91	134.27	36.00	0.51	1	1	3.46	0.29
6-2	-25.91	-41.41	-599.49	457	496	44.00	0.06	1	1	3.57	0.28
6-3	156.64	-43.40	-363.99	494.91	134.27	36.00	0.32	1.2	1.2	2.33	0.43
7-1	-233.37	-42.24	-345.82	483.91	134.27	36.00	0.48	1.2	1.2	2.91	0.34
7-2	-22.32	-40.50	-570.29	457	496	44.00	0.05	1	1	3.56	0.28
7-3	153.43	-42.37	-345.82	483.91	134.27	36.00	0.32	1.2	1.2	2.30	0.43
8-1	-435.59	-1.04	-478.31	494.91	134.27	36.00	0.88	1	1	4.40	0.23
8-2	-143.77	-0.78	-779.58	445	496	44.00	0.32	1	1	4.16	0.24
8-3	64.74	-2.75	-478.31	494.91	134.27	36.00	0.13	2	2	1.89	0.53
9-1	-257.64	-43.84	-386.69	494.91	134.27	36.00	0.52	1	1	3.47	0.29
9-2	-25.66	-42.19	-629.40	457	496	44.00	0.06	1	1	3.57	0.28
9-3	170.46	-44.04	-386.69	494.91	134.27	36.00	0.34	1.2	1.2	2.36	0.42
10-1	-222.55	-53.22	-314.02	512.74	134.27	36.00	0.43	1.2	1.2	2.62	0.38
10-2	-24.59	-50.69	-508.33	477	496	44.00	0.05	1	1	3.11	0.32
10-3	138.07	-53.42	-314.02	512.74	134.27	36.00	0.27	1.2	1.2	2.06	0.49
11-1	-204.77	-68.21	-262.79	532.7	134.27	36.00	0.38	1.2	1.2	2.31	0.43
11-2	-24.45	-63.54	-422.42	499	496	44.00	0.05	1	1	2.68	0.37
11-3	118.45	-68.38	-262.79	532.7	134.27	36.00	0.22	1.2	1.2	1.80	0.56
12-1	-155.77	-8.14	-40.04	565.56	134.27	36.00	0.28	1.2	1.2	1.86	0.54
12-2	-85.11	-5.25	-65.36	535	496	44.00	0.16	1	1	2.25	0.44
12-3	-80.18	-7.40	-40.05	565.56	134.27	36.00	0.14	1.2	1.2	1.73	0.58

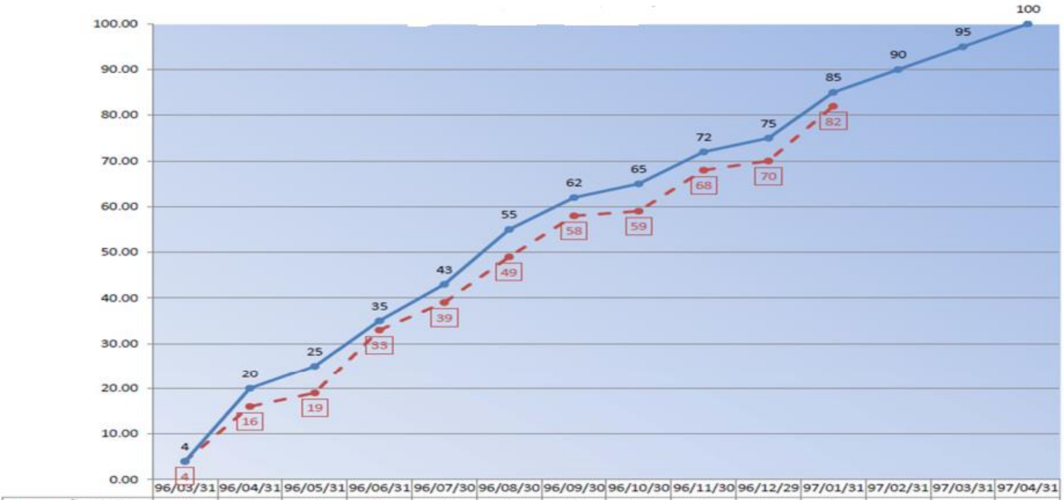
Table 1: Available capacities and determination of C / D ratio for load combination DL + EY + 30% EX (units are ton-meters).

Regarding the cost of rehabilitation, which was about 30% of the cost of construction of a new bridge and the traffic problems during the construction of the new bridge, the option of improvement and rehabilitation was approved by the technical and civil deputy of Tehran Municipality.

The option of constructing an underpass was also considered. However, due to the passage of the 6-metro line tunnel and the passage of various facilities such as power cables, high pressure, gas pipes and water supply pipes of 1400 mm, etc., as well as severe disruption in traffic at the construction time, it was abandoned.

Executive operations volumes	
Steel works with rebars	220 tons
Heavy steel work	80 tons
Situ concrete	2500 m3
Preparation of neoprene	250 dm3
Excavation and drilling piles	3000 m3
Loading and transporting materials obtained from earthworks	34000 m3
Concrete demolition	270 m3
Asphalt destruction	5180 m2

Table 2: Executive operations volumes



	96/03/31	96/04/31	96/05/31	96/06/31	96/07/30	96/08/30	96/09/30	96/10/30	96/11/30	96/12/29	97/01/31	97/02/31	97/03/31	97/04/31
پیشرفت واقعی	4	16	19	33	39	49	58	59	68	70	82			
پیشرفت برنامه ای	4	20	25	35	43	55	62	65	72	75	85	90	95	100

Figure 12: Chart of retrofitting operations' progress

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