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SEISMIC VULNERABILITY ASSESSMENT AND RETROFITTING OF REINFORCED CONCRETE BRIDGE BY RC JACKETING

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Abstract- Seismic vulnerability assessment of Reinforced Concrete (RC) bridges is of paramount importance in developing countries due to poor design and construction practices, especially in an earthquake-prone zone. A case study of a typical bridge in Pakistan was carried out and results were analyzed. The overall aim of this research was to perform an equivalent static analysis of the existing bridge and measure its adequacy against existing loading conditions and new seismic requirements. This paper aims to highlight the use of SAP2000v14 in seismic analysis of the RC bridge piers, in the existing as well as post remedial measures stage. The bridge was modeled on the software as per existing structural parameters and loading was applied as per relevant seismic criteria which indicated that the bridge was under-designed. The goal was the introduction of an effective remedial measure to accommodate seismic loading in the structural design, which in this case was retrofitting in the form of RC jackets, the results were successful.

Keywords- Reinforced Concrete Bridge, Earthquake-Prone Zone, SAP2000v14, Retrofitting.

1 Introduction

Developing countries like Pakistan with high seismic hazards, poor design, and construction practices require an in-depth special seismic vulnerability assessment of their Reinforced Concrete (RC) bridge stock having different structural systems [1]. Most of the existing RC bridges in Pakistan are gravity-loaded design RC structures. A significant portion of these RC bridges is pre-stressed reinforced concrete structures [2]. Most of these bridges have low lateral load resistance and suffer from ductility issues. Low strength concrete, aging, bad design, inappropriate detailing, and poor construction practices are the components that play a substantial role in structural damages and eminent failures during an earthquake that should be addressed in vulnerability assessment [3][4].

Many recent vulnerability assessment studies focused on the bridges of the developed countries, which generally comprise good quality and code conforming RC bridges [5][6]. These vulnerability studies are not feasible for bridge stocks of the developing countries and can underestimate the damage potential of highly fragile RC bridges to a large extent [7]. The post-Kashmir earthquake seismic hazard studies have predicted higher seismic hazard in different parts of the country indicating high vulnerability of various civil infrastructure which calls for seismic vulnerability assessment of other civil infrastructure [8]. The current work focused on estimating the performance of a case bridge against the new seismic demand of the area. The bridge was found deficient and a feasible technique of retrofitting was proposed for the low strength existing RC bridge piers to meet with declared seismic hazard.

2 Research Methodology

A high-intensity earthquake was recorded in Jatlan by the Pakistan Metrological Department (PMD), in September 2019. According to the official reports, the earthquake in Jatlan caused severe damages to domestic structures including homes, multi-story buildings, and other infrastructures. A typical existing Reinforced Concrete (RC) bridge in the vicinity of the affected region in Pakistan was selected for a case study to investigate whether the considered bridge is safe or not as per the declared seismic zone requirements of the region. The bridge was modeled as per the existing structural drawings prepared by the Bridge Directorate Highway Department of Punjab, Pakistan. Material properties i.e. concrete strength, yield strength for steel, and section properties i.e. girders and piers, were selected as per the existing drawings. Static linear analysis was performed after the input of required loading conditions. Software results were analyzed and it was concluded that the structure is under-designed. Accordingly, retrofitting by RC jacketing was carried out.

2.1 Case Study.

A pre-stressed I-girder bridge located on Dina-Rohtas Road near Rohtas Fort, in the seismic zone 2B of Pakistan was selected as a case study. This bridge consists of two traffic lanes, seven spans of 103.36 ft. (31504.13 mm), and 60 ft. (18288 mm) high piers of 5.5 ft. (1676.4 mm) diameter. Bridge was modeled using SAP2000 v14 software as per the structural drawings. There were no parametric variations along the length of the bridge.

Based on Peak Ground Acceleration (PGA) values, Pakistan is divided into five seismic zones in line with the Building code of Pakistan (BCP 2007) [9]. The Building Code was revised in 2007 and seismic zoning was changed and new Zones were defined as shown in Table 1.

Table 1: Seismic Zones (BCP 2007)

Seismic Zones	**Peak Horizontal Ground Acceleration**
1	0.05 to 0.08g
2A	0.08 to 0.16g
2B	0.16 to 0.24g
3	0.24 to 0.32g
4	> 0.32g

The case bridge is located on the PGA intensity line of 0.2g, as per BCP 2007 PGA contours map. Therefore, the values of the seismic coefficients $\mathbf{C_a}$ and $\mathbf{C_v}$ against seismic zone factor Z, **0.2** were considered.

2.2 Modeling Details.

Modeling was done as per the structural drawings prepared by the concerned department of Pakistan. Girders, Deck slabs, and diaphragms were prestressed members. All the load combinations were taken from the Government of West Pakistan Code of Practice for Highway Bridges (WPCPHB-1967) [10]. The case bridge was designed as per the WPCPHB assuming seismic loads as 2%, 4%, and 6% of dead loads for different foundation conditions. The effect of the live load was ignored. The material properties used for the modeling of the existing bridge were according to the structural design data and the key details are shown in Table 2. Girders, Piers, and transoms were modeled by using these details.

Table 2: Properties of Materials

Concrete Strength for piers (28 days compressive cylinder strength)	3200 psi (22063.2 kPa)
Concrete Strength for prestressed members (28 days cylinder strength)	4400 psi (30336.9 kPa)
Steel Yield strength	60000 psi (413685.4 kPa)

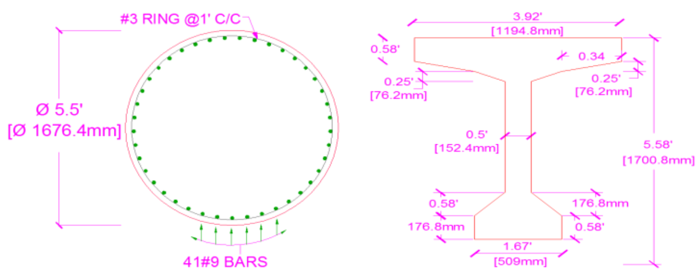
For analysis of the case bridge, the soil profile type S_D (stiff soil) was considered. The values of seismic coefficients C_a and C_v for seismic zone factor Z, **0.20** relevant to the soil profile type were 0.28 and 0.40 respectively (BCP 2007). The structural ductility was considered by the Response modification factor (R) as per BCP 2007-Table 5.13 [9]. In the modeling, bearings on the pier head were considered as link elements, and bearings on the abutment sides were modeled as springs. The values of lateral, vertical, and rotational spring stiffnesses for elastomeric bearing pads on the abutment sides are shown in Table 3 [11].

Table 3: Spring Stiffnesses on the Abutment Sides

Direction	Spring stiffness, K
Lateral	1755 (KN/m)
Vertical	1143752 (KN/m)
Rotational	16270 (KNm/m)

2.3 Model.

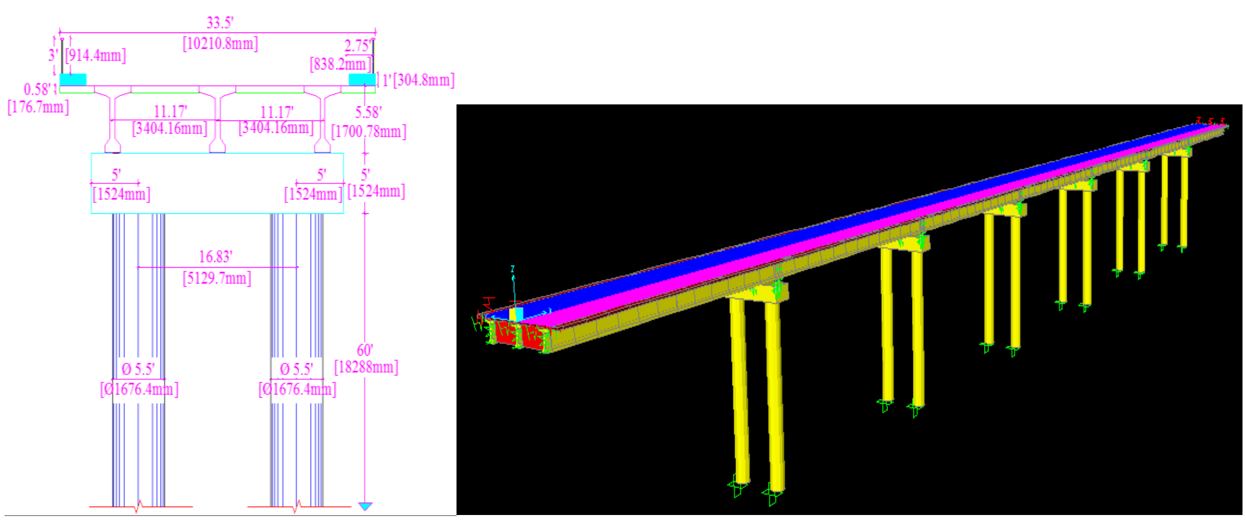
The structural drawings of some key components of the existing bridge are shown in Figure 1.



1a) Pier 1b) I-girder

Figure 1: Cross-sections of pier and girder

After modeling all the components on SAP2000v14, the x-section of the bridge structure and perspective view of the 3-D model is shown below in Figure 2a and 2b respectively.



2a) X-section 2b) 3-D Model View

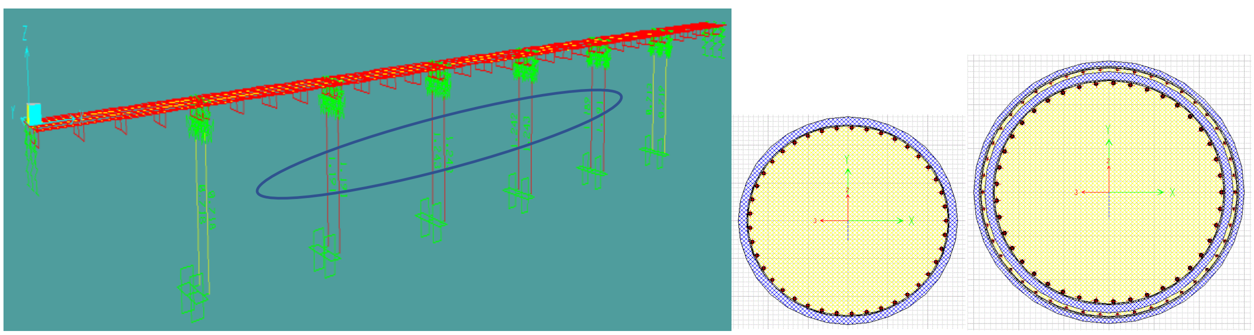
Figure 2: Different Views of Bridge

3 Results and Discussion

Static linear analysis was performed and the model was checked for elastic limits. The seismic forces at the base of each bridge pier and the natural period of vibration are given below.

V_X = 13.55 Kips (60.27 KN), V_Y = 159.54 Kips (709.66 KN), T = 0.73 sec

From the analysis of the data obtained, it was observed that against the load combination, 1.33 Dead+1.33 Earthquake, which is a static load case for seismic forces, the highlighted bridge piers failed in flexure as shown in Figure 3a. The bridge is thus under-designed and vulnerable in the existing seismic zone. It was noted that as per the requirements of WPCPHB, the bridge was designed assuming seismic loads as 2%, 4%, and 6% of dead loads for different foundation conditions. These assumptions do not match with the present seismic demand of the area as PGA estimated in BCP2007 for that area is 20 percent of dead load. The model was then run for the design of the bridge pier for the new PGA requirement. It was noted that the requirement of the longitudinal steel in the bridge pier was 61.142 square inches against the provision of 41.0 square inches in the design. The bridge thus requires additional measures to accommodate this extra demand and there is a need for retrofitting for all the critical members as shown in Figure 3c. To accommodate the required strength for critical members and to compensate for this gap provision of retrofitting through RC Jacketing was proposed.



3a) Flexural Failure Model 3b) Bridge Pier 3c) Bridge Pier with Jacketing

Figure 3: Failed Model and After Retrofitting

The type of proposed retrofitting, in this case, was RC jacketing because the scale of deficiency in the structural strength required a sizeable increase in the flexural capacity of the bridge piers by increasing its cross-sectional dimensions. Further, the material used in RC jacketing is locally and readily available and no extraordinary skilled labor is required for its execution. For a trial, RC jacketing of different thicknesses (3, 4, 5, 6, and 8 inches) were considered in 15 ft lower critical part of the bridge piers and checked for its effectiveness for the case Bridge. The bridge piers were modeled for these additional thicknesses in SAP2000v14 and their efficacy was checked for each thickness of trail RC jacketing. It was concluded that the most efficient thickness of RC jacketing is 0.5 ft (6 inches) with other properties are as shown in Table 4.

Table 4: Reinforcement details for RC Jacketing

Longitudinal Reinforcement	Transverse Reinforcement (Hoops)
46 # 6	# 4 @ 6" c/c

The jacketing of 6 inches thickness when applied up to a height of 15 ft from the base, all the critical members performed well and the structure becomes safe for new seismic demand of the area as shown in Figure 4 [12][13]. The demand/capacity ratios for critical members before and after retrofitting are also shown in Table 5.

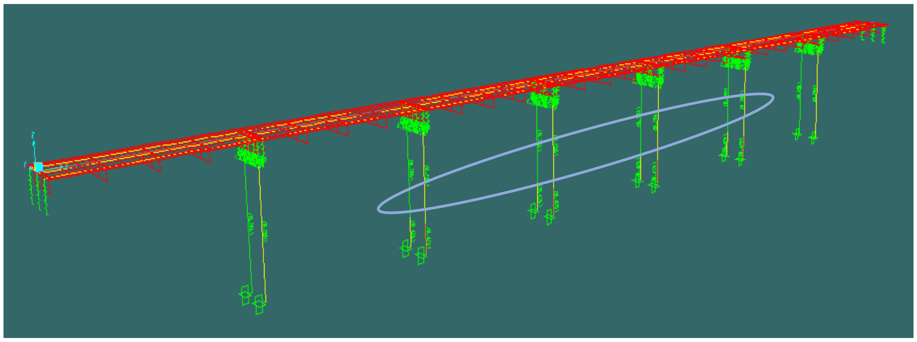


Figure 4: Model after Retrofitting

Table 5: Demand/Capacity ratios for Critical Members

Pier	Demand/Capacity ratios before retrofit	Demand/Capacity ratios after retrofit
2	1.088	0.842
3	1.322	0.886
4	1.322	0.886
5	1.088	0.842

4 Applicability of Research

In Pakistan, after the Kashmir (2005) earthquake, seismic zoning has been revised. Before this major earthquake, the bridges were designed as per the Government of West Pakistan Code of Practice for Highway Bridges (WPCPHB-1967) [10]. Therefore, most of the existing bridges are susceptible to major seismic damages and need strengthening to enhance their strength against the present seismic demand. As the existing RC bridge piers are deficient in flexural strength. The obtained results reveal that the technique for retrofitting thus used i.e, RC jacketing has a greater impact in fulfilling the required flexural strength of all critical bridge piers.

5 Conclusion

From the conducted study it has been concluded that

- The required longitudinal reinforcement area for the bridge piers in the present seismic zoning of Pakistan is more than the provided area.
- There is a need for retrofitting for all the critical members to enhance their load-carrying capacities to accommodate the revised seismic requirements of the area.
- All the critical members fulfill the required criteria when RC Jacketing of thickness 0.5 ft (6 inches) with forty-six bars of # 6 are provided to compensate for the reinforcement gap and applied up to 15 ft bottom depth of piers for case bridge.

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References

[1] S. Ahmad, K. Pilakoutas, Q. U. Z. Khan, and S. Mehboob, "Seismic Demand for Low-Rise Reinforced Concrete Buildings of Islamabad–Rawalpindi Region (Pakistan)," *Arab. J. Sci. Eng.*, vol. 43, no. 10, pp. 5101–5117, 2018.

[2] M. Waseem and E. Spacone, "Fragility curves for the typical multi-span simply supported bridges in northern Pakistan," *Struct. Eng. Mech. An Int. J.*, vol. 64, no. 2, pp. 213–223, 2017.

[3] M. Zain, M. Usman, S. H. Farooq, and T. Mehmood, "Seismic vulnerability assessment of school buildings in seismic zone 4 of Pakistan," *Adv. Civ. Eng.*, vol. 2019, 2019.

[4] H. Aryan, "Seismic Resistant Bridge Columns with NiTi Shape Memory Alloy and Ultra-High-Performance Concrete," *Infrastructures*, vol. 5, no. 12, p. 105, 2020.

[5] K. Aljawhari, F. Freddi, and C. Galasso, "State-dependent vulnerability of case-study reinforced concrete frames," in *COMPDYN 2019 Proceedings*, 2019, vol. 7.

[6] T. Rossetto and A. Elnashai, "Derivation of vulnerability functions for European-type RC structures based on observational data," *Eng. Struct.*, vol. 25, no. 10, pp. 1241–1263, 2003.

[7] M. Pregnolato, "Bridge safety is not for granted–a novel approach to bridge management," *Eng. Struct.*, vol. 196, p. 109193, 2019.

[8] A. Q. Bhatti and H. Varum, "Application of Performance Based Nonlinear Seismic Design and Simulation Static Pushover Analysis for Seismic Design of RC Buildings," in *Proceedings of the 15th World Conference on Earthquake Engineering, 15WCEE, Lisbon*, 2012, pp. 24–28.

[9] Seismic Provisions, "Building Code of Pakistan (Seismic Provisions 2007)," p. 303, 2007.

[10] "Government Of West Pakistan Highway Department Code Of Practice," 1967.

[11] C. Akogul and O. C. Celik, "Effect of elastomeric bearing modeling parameters on the Seismis design of RC highway bridges with precast concrete girders," in *Proceedings of the 14th World Conference on Earthquake Engineering*, 2008, pp. 13–28.

[12] M. Suarjana, D. D. Octora, and M. Riyansyah, "Seismic Performance of RC Hollow Rectangular Bridge Piers Retrofitted by Concrete Jacketing Considering the Initial Load and Interface Slip.," *J. Eng. Technol. Sci.*, vol. 52, no. 3, 2020.

[13] A. Reggia, A. Morbi, and G. A. Plizzari, "Experimental study of a reinforced concrete bridge pier strengthened with HPFRC jacketing," *Eng. Struct.*, vol. 210, p. 110355, 2020.