Seismic Behavior of Composite Simply Supported Bridge Decks supported on Elastomeric Bearings

Sara k AL Rubaee¹ and Ammar A Abdul Rahman²

¹Civil Engineering Department, AL-Nahrain University, Baghdad, Iraq. Email: saraka94@yahoo.com
²Civil Engineering Department, AL-Nahrain University, Baghdad, Iraq. Email: ammar.arahman@yahoo.com

Abstract. This paper studies the behavior of bridges’ superstructure under seismic action. The bridge under investigation is one of the typical bridges usually used in overpasses in Iraq, which is made of simply supported steel built up girders and reinforced concrete deck slab isolated from the substructure by elastomeric bearing pads. A three-dimensional finite element model was developed using CSI Bridge Software. Time history analysis was carried out using true-recorded earthquake took place in Iraq near the city of Halabja in 2017. The results of the analysis show that the displacements of the elastomeric bearing pads under transverse seismic loading are much higher than the permissible displacements’ limit which will produce failure of these bearings and potential failure of the bridge superstructure.

1. Introduction
Simply supported composite bridge decks is usually used for overpasses inside Iraqi cities. This type of deck consists of reinforced concrete deck slab resting over longitudinal girders (built-up steel girders) and connected with the concrete deck slab by shear connectors to insure the composite action between steel and concrete. Most researches on bridges under seismic loading concentrates on the seismic behavior of the bridge substructure such as the piers including the cross heads and foundation since these elements are in contact with soil and transfer the loads from the seismic activity to the whole bridge. It is necessary to study the behavior of the bridge superstructure under seismic loading and to develop retrofit strategies against it. Saadeghvaziri in 2008 [2] studied the seismic behavior and capacity/demand analysis in order to evaluate the seismic vulnerability of three multi-span simply supported bridge and to develop retrofit strategies and investigate the effect of a parameter on the seismic performance on bridges such as steel bearing, and the impact between girders. Zasiah and Nazmus in 2010 [3] made a seismic analysis of three span deck girder bridge. The analysis carried out was by using the software package ANSYS in a two-step procedure. The first step was by using equivalent static earthquake loading and the second step by using response spectrum analysis and made a comparative study between the two analyses. Cardone, D., Perrone and S. Sofia in 2011 [4] proposed multi-performance seismic device based on super-elastic SMA “Shape memory alloy”. They used this device in seismic retrofit of simply supported and continuous bridge decks to investigate the behavior of bridge deck before and after retrofitting using nonlinear time history analysis through SAP2000 software.
2. Bridge Description
AL-Batha Bridge is one of the typical common simply supported bridges used in Iraq, which located in AL-Nasiriya city southern Iraq. It consists of two spans with total length of 53m designed by the supervisor of this work, as illustrated in figure 1.
Each span is 26.5m in length and a carriageway width of 12.75 m with two sidewalks of 1.775 m each, figure 2. The bridge deck consists of reinforced concrete slab 220mm thick and seven built-up steel girders. Figure 3 shows the dimensions of the steel girder. The steel girders rest on elastomeric pads without any other lateral stiffness except end steel diaphragms to connect the steel girders together. Shear connectors made of steel channels are used to connect the deck slab with the girders which gives complete connection between the steel girders and the deck slab.

3. Finite Element Modeling
The three dimensional modelling of the bridge superstructure was developed using finite element software CSI Bridge, as shown in figure 4. Steel built-up girders were modelled using homogenous shell elements. Concrete deck slab with its reinforcements were modeled using 4-node layered shell element, which has six degrees of freedom per node. The reinforcement in the concrete deck was modeled as a smeared layer of steel “equivalent area of each reinforcement bar divided by reinforcement bar spacing”, as illustrated in figure 5. Complete bond between the top flange of the built up girder and the R.C. deck slab was assumed to represent shear stud connector. Elastomeric bearing pads were modeled as hysteretic isolator link element and the 8-node solid element was used to model the supporting concrete box below the bearing. Frame element was used to model the v-type steel bracing for the end and intermediate diaphragms. Table 1 shows the properties of the materials used in modelling the deck.
Figure 3. Detail and dimensions of built-up steel girder.

Figure 4. Finite element modeling of composite simply supported bridge deck.

Figure 5. multi-layered shell element that used to model the reinforcement concrete deck slab of bridge.

Table 1. The material properties of composite deck.

| Material       | Concrete  | A50 Steel |
|----------------|-----------|-----------|
| $E_C$          | 27805.57 MPa | $E_S$ 200000 MPa |
| $f_c'$         | 35 MPa    | $f_s$ 345 MPa    |
| $\nu$          | 0.19      | $\nu$ 0.3       |
| $\gamma_C$     | 24.5 KN/m$^3$ | $\gamma_s$ 78.6 KN/m$^3$ |
3.1 Elastomeric Bearing Pads
The elastomeric bearing pads are designed to transmit the forces from the superstructure to substructure and receive translations and rotational displacements by elastic deformation. Main action is like a hyperelastic body. It consists of natural rubber with steel plates inserted inside the rubber making it as layers of rubber, as shown in figure 6. Two nodes hysteretic rubber isolator link element was used to model the elastomeric pads with stiffness in three directions which composite of six springs (axial, shear, pure bending, and torsion), as shown in figure7. This element provides non-linear properties for two horizontal directions and linear properties for remaining axial and three rotational directions.

The top and bottom faces of the elastomeric bearing pads are actually covered by epoxy resin with no bolt to fix the pad in place, which is modelled as a rigid spring element with high stiffness.

The hysteresis curve produced under actual lateral displacement of an isolator is a combination of linear-elastic and elastic-perfectly plastic force-displacement relationship. Rectangular hysteresis curve will not be produced by an isolator, which has a curve translation on unloading and reloading. Equivalent bi-linear approximation was used for the analysis to define the isolator properties such that damping is defined equal to the area under hysteresis curve in figure 8, as calculated below:

\[
\beta = \frac{1}{2\pi} \left( \frac{4Qd}{K_{Heff}} \right) \left( \frac{\Delta_m - \Delta}{\Delta^2} \right) \tag{1}
\]

Lateral stiffness of bearing pads was determined from the following equation depending on hysteresis curve based on empirical data [1] with a given properties shown in table 2.

\[
K_{Heff} = K_d + \frac{Q_d}{\Delta} \tag{2}
\]

Where: \(K_d\) post-elastic stiffness, \(Q_d\) characteristic strength, \(\Delta\) specific displacement, \(\Delta_m\) maximum displacement.
The vertical stiffness of elastomeric bearing pads depend on reducing the area of rubber, which is calculated based on the overlapping area of bearing between the top and the bottom portion at a specific displacement.

\[ K_v = \frac{E_c A_r}{T_r} \]  

(3)

Where: \( A_r \) reduce area of bearing, \( E_c \) compressive modulus is a function of material constant and shape factor of isolator, \( T_r \) total thickness of elastomer.

\[ E_c = E[1 + 2KS^2] \]  

(4)

\[ A_r = A_b \left[ 1 - \left( \frac{\Delta B_b}{w_b} + \frac{\Delta w_b}{w_b} \right) \right] \]  

(5)

Where: \( E \) elastic modulus, \( K \) material constant, \( S \) shape factor, \( A_b \) bounded area, \( B_b \) \( w_b \) bounded dimension.

**Table 2. Properties of isolator.**

| Elastomer Properties | Shear strain\( \% \) | 50 | Isolator Dimension | Rubber cover thickness | 2.5 |
|----------------------|----------------------|----|-------------------|------------------------|-----|
| Shear modulus, \( G \) | 0.000707 | No. of rubber layer | 4 |
| Material constant, \( k \) | 0.7 | Rubber layer thickness, \( t_r \) | 9.5 |
| Elastic modulus, \( E \) | 0.00263 | No. of steel plate | 5 |
| Bulk modulus, \( E_\infty \) | 1.5 | Steel plate thickness, \( t_s \) | 4 |
| Damping | 0.05 | Total height, \( H \) | 63 |
| Gravity | 9810 | Total elastomer thickness, \( T_r \) | 38 |

**Elastomer Properties**

| Vertical Stiffness | Shear strain\( \% \) | 50 | Isolator Dimension | Rubber cover thickness | 2.5 |
|-------------------|----------------------|----|-------------------|------------------------|-----|
| Bounded area, \( A_b \) | 0.06 | Characteristic strength, \( Q_d \) | 305.1 |
| Bounded perimeter | 0.0769 | Post-elastic stiffness, \( K_d \) | 457.05 |
| Shape factor, \( S_i \) | 3.05 | Elastic stiffness, \( k_e \) | 25351.27 |
| Reduce area of rubber | 0.05016 | Effective stiffness, \( K_{H eff} \) | 7898.50 |
| Vertical stiffness of isolator, \( K_v \) | 48683.976 | Area of hysteresis loop, \( A_h \) | 33453 |
| Moment of inertia, \( J \) | 3.255E0-4 | Equivalent viscous damping, \( \beta_{eff} \) | 0.4 |

### 4. Seismic Analysis of Bridge Superstructure.

Seismic analysis of the typical simply supported bridge superstructure in Iraq was carried out using nonlinear time history analysis and the equation of motion in this analysis was performed, using direct integration method in order to study the behavior of superstructure under seismic loading. In this study, the response of the structure was evaluated at each step and at the end of any step, the equation of motion was investigated.

The input data of loading was a function of acceleration - time history figure 9. In this study, the earthquake hit Iraq-Iran border 30 km southwest of Iraqi city of Halabja on 12 November 2017 with a magnitude 7.3 Mw as recorded by International stations and with 4.9 Mw as recorded at the station of Baghdad was used in this study as the input seismic activity. This earthquake was chosen for the following reasons:

- To investigate the behavior of typical bridge superstructure under true recorded earthquake happened in Iraq.
- It is the largest earthquake recorded in Iraq until the date of preparing this study that felt clearly and strongly in Baghdad.
Figure 5. Iraq-Iran recorded acceleration time history in Baghdad, north-south (Y) direction.

5. Analysis Results

The response obtained from the bridge superstructure analysis was defined in terms of displacements limits under the effect of self-weight load and earthquake ground motion, which was applied in the transverse direction of the bridge deck, because the stiffness of the superstructure under lateral load is not enough to produce the required lateral resistance and makes it the point of research and inspection. Elastomeric bearing pads were the weakest component of the bridge superstructure and the failure of the bearings governed the behavior of superstructure under the effect of the earthquake. When the displacement of such bearing exceeds the permissible limit, steel girder slip from its place and the superstructure susceptible to toppling. The maximum lateral displacement of elastomeric bearing pads approaches 261.3mm occurred in the bearings, consequently instability of these bearings in transverse direction due to excessive displacements. The maximum transverse displacement of steel girder due to seismic loading approached to 388.9mm occurred in the bottom web of the left exterior girder. Figure 10 showed the maximum and minimum displacements of superstructure component A) elastomeric pads, B) in steel girder. Maximum longitudinal stresses due to the same loading in the bottom flange of steel girder is relatively higher than that in the top web with a magnitude of 381.0 mm due to the connection with bearings. Finally, maximum stresses in the deck slab when subjected to the earthquake was presented. Figure 11 shows the distribution of stresses in a) reinforcement concrete deck slab, b) 7-steel girders.

Figure 12 shows how the steel girders slipped from their positions during the effect of applying the earthquake to the superstructure of the bridge.
Figure 10. Maximum and minimum displacement of superstructure component (a) elastomeric pads, (b) top and bottom web of steel girder
Figure 11. The distribution of stress in: (a) seven-steel girder, (b) reinforcement concrete deck slab.

6. Conclusions and Recommendations
From this analysis, the bearings were under deformations exceed the acceptable limit (30.5mm) according to the specification of bearing pads manufacturer. This conclusion demonstrate that under such a magnitude of earthquake not exceeding 5.0 Mw the typical simply supported bridge superstructure will fail due to the failure of elastomeric pads which is the main connecting part of the superstructure with the substructure which governs the whole behavior. Consequently, a retrofit strategy such as shape memory alloy, bombers, and restrained component or pads should be used to prevent superstructure from toppling for this type of bridge decks.
The bumpers are a restrainer block installed between the steel girders in order to prevent them from dropping from the elastomeric pads and piers during seismic loading. It remains in elastic range and produces reaction force for restraining the displacement of a steel girder to reduce seismic response. This type of proposed section is recommended to use, which provides energy dissipations capacity. It is not difficult to build on a crosshead of a pier and not expensive compared to other dissipations devices. FEA of this type of restrainer will be investigated in the future through complete analysis of such new deck configuration.

**Figure 12.** Steel Girders out of their positions after the Earthquake.

**References**

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