Effect of Isolation Systems on a Steel Box Girder Bridge in Tabriz

M. Jamali Golzar & M. Azharian
Sama Technical and Vocational Training College, Islamic Azad University, Sahand Branch, Tabriz, Iran

M.A. Jamali Golzar
Ministry of Energy, East Azarbaijan Regional Watercorp, Tabriz, Iran

SUMMARY:
A very attractive way to improve the seismic performance of a structure is given by the possibility of the energy dissipation. This can be obtained by making use of wide range of isolators on the base of structures. Despite of the using isolators in the bridges around the world, there has been no practical application of those in bridges of Iran. In this research, lead rubber bearing was chosen for a nonlinear time history analytical study. 3D model of a steel box girder bridge was subjected to the seismic motion records of three important earthquakes. For comparison same bridge modelled and analysed with elastomeric bearing system. Results of this paper show that isolator lengthen the period of vibration of the bridge to reduce seismic forces in the substructure. The efficiency of using isolator is demonstrated, not only by reducing the base shear caused by longitudinal ground motions, but also by providing a considerable decrease in the base shear caused by the transverse ground motions.

Keywords: Earthquake, Bridge, Steel Box Girder, Isolator, Lead Rubber Bearing

1. INTRODUCTION

The primary purpose of seismic building codes is to provide a uniform method to determine the seismic forces with enough accuracy to ensure a safe and economical design. Since Iran has been experiencing many violent earthquakes during years, the first seismic code that included some procedures for calculating earthquake loads on steel and reinforced concrete buildings was published in 1968. Strong earthquakes in this country have led to substantial changes in the practice of seismic design and construction in three revisions that have been published in 1988, 1994 and 2006. It was called as Iranian Code of Practice for Seismic Resistant Design of Buildings or Standard No. 2800. Also first revision of Road and Railway Bridges Seismic Resistant Design Code published in 2008. Prior to the introduction of the seismic codes, many structures were designed without adequate detailing and reinforcement for seismic protection. Extensive experimental and numerical studies have been conducted to seismic performance assessment of existing structures and hence retrofitting of them is well acknowledged in earthquake prone countries.

In this paper a steel box girder bridge that has been designed before the publication of third revision of code 2800 is selected as a case study. Since base isolation is one of the most widely accepted techniques to protect structures and to mitigate the risk of life and property from strong earthquakes, this bridge will be evaluated by utilizing lead rubber isolator. The bridge is located in Tabriz, the fourth mega city in Iran and one of historically-rich cities of this country, as well as the capital of Eastern Azarbaijan province. Tabriz is vulnerable to earthquake and during its history; the city has been devastated by earthquakes and rebuilt for several times. With respect to the active faults that make the risk of ground shaking in Tabriz and also its historical earthquakes, code 2800 and also Road and Railway Bridges Seismic Resistant Design Code categorize Tabriz as a city in the region with the highest seismic zone factor. So, the city needs more attention to retrofit its old structures and fortunately there is a high demand for such measures and studies. The reason why the bridge in this study is selected is the proof of such a big demand.

2. DESCRIPTION OF CASE STUDY

This study is conducted on a 228 meter six-span bridge. Superstructure of the bridge was designed of 5 steel box girders and a 20 centimetre reinforced concrete slab that distribute the applied loads to the supporting girders. Steel box girder deck is a common choose in for the bridges with spans between 25 to 40 meters in Iran.

Typical section of the bridge is shown in Fig. 2.1. The width of deck is 18 meter and it has total length of 228 meter that consists of 6 spans each with length of 38 meter. Its piers are designed of reinforced concrete as seen in the figure. The structure of this bridge is upon pinned connection of girders on the piers and abutments.

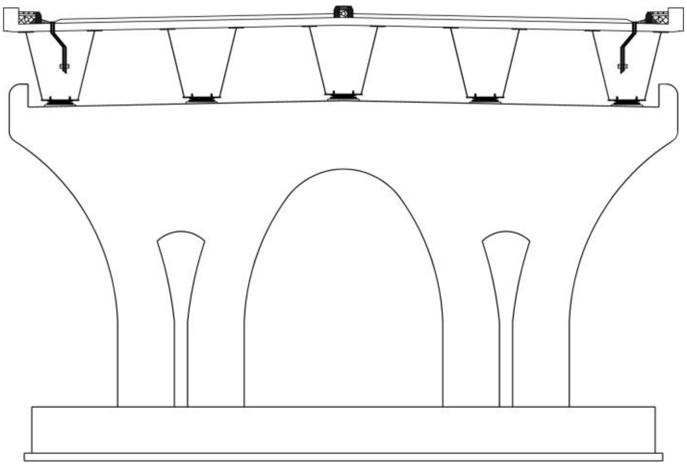

Figure 2.1. Typical section of bridge

3. ANALYSIS PROCEDURE

In this research, the bridge was analysed using Sap2000 program based on the nonlinear three dimensional time history analysis in two cases. First model has elastomeric bearing on the end of its girders and the second model is same but the usage of isolator on its girders. In the modeling of isolators, it has been used LINK elements with the type of rubber isolator.

Seismic records of three most important earthquakes that were recorded close to the north-west of Iran used in time history analyze. Tabas was recorded during the 16th September 1978 with a maximum longitudinal ground acceleration of 0.933g. Naghan was recorded during the 6th April 1977 with a maximum longitudinal ground acceleration of 0.723g. The devastating Bam earthquake was a near source excitation with a large maximum ground acceleration of 0.79g that occurred on 26th December 2003. The longitudinal and transverse components of the original ground accelerations were linearly scaled so that their peak ground accelerations (PGAs) are 0.35g.

4. SEISMIC BASE ISOLATION

There are a couple of mechanisms by which the structural action control is achieved. For instance in the case of passive control, base isolation devices, visco-elastic dampers, tuned mass dampers, liquid column dampers, liquid-mass dampers, metallic yield dampers, and friction dampers have been proposed. Out of the above mentioned methods, base isolation devices have been widely implemented in practice which is used to seismic design of modern structures and retrofit of existing structures. In recent years this relatively new technology has emerged as a cost-effective alternative to conventional seismic strengthening. Whereas conventional fixed-base construction may cause high floor accelerations in stiff buildings and large deformations in flexible buildings, base isolation is realized by decreasing the seismic demand instead of increasing the seismic capacity. This achievement is the result of introduction of a flexible level at the base of structures in the horizontal direction.

Lead rubber bearing known as LRB is comprised of alternate layers of steel and vulcanized rubber with a cylindrical lead core. In this type of isolator appropriate dissipative capability is provided by the lead core. Experimental tests confirm that the force-displacement hysteresis loop of LRB can be reasonably described as a bilinear with an initial elastic stiffness followed by post yield stiffness much lower than the former.

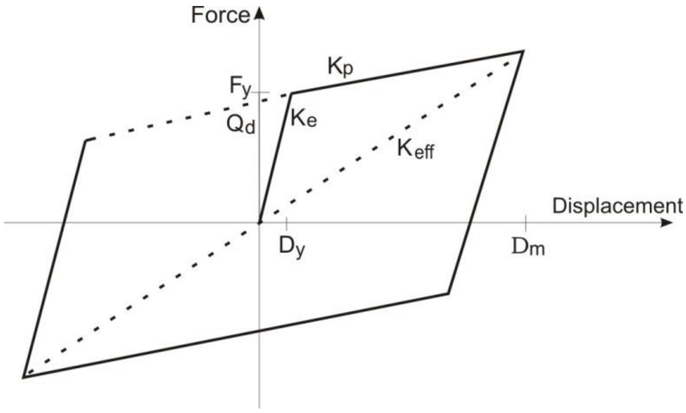

Figure 4.1. Bilinear force-displacement behaviour of LRB

In Iran, Guideline for Design and Practice of Base Isolation Systems in Buildings published last year. In Fig. 4.1 force-displacement behaviour of typical LRB obtained from above mentioned instruction is shown; here K_{eff} defined as effective stiffness of lead rubber isolator by the following formula:

$$K_{eff} = \frac{W}{g}\left[\frac{4\pi^2}{T_D^2}\right] \tag{4.1}$$

Where w = total of dead and live load; g = acceleration of gravity; and T_D = effective period of isolated structure that here it is assumed to be 3 seconds. Also isolator displacement in design earthquake is given by the:

$$D_D = \left[\frac{g}{4\pi^2}\right]\frac{S_1 T_D}{B_1} \tag{4.2}$$

Where B_1 = damping reduction factor which is 1.35 when effecting damping of isolator is 15%; and S_1 equals to:

$$S_1 = A(S+1.5)T_s^{2/3} \tag{4.3}$$

Where according to code 2800, A = seismic zone factor that is 0.35 for entire bridge; and other parameters depend on site soil profile where S = 1.75; and T_S = 0.7. Finally target displacement of isolated structure, D'_D , shall be determined with the formula:

$$D'_D = \frac{D_D}{\sqrt{1+\left[\frac{T_e}{T_D}\right]^2}} \tag{4.4}$$

Where T_e = effective period of fixed base structure. With paying attention to different value of proposed stiffness for LRBs, two different type of this isolator have chosen for evaluation in this paper. The specifications of these LRBs are shown in Table 4.

Table 4.1. Properties of isolators

Property	LRB A	LRB B
Effective stiffness (kg/m)	105000	143000
Initial stiffness (kg/m)	89000	120000
Yield strength (kg)	4400	6000
Effective damping	15%	15%

5. ANALYSIS RESULTS

The analysis is performed for nonlinear static procedure by utilizing isolators with properties which is shown in Table 4.1. For better conclusion, outputs of both models will be compared to a non-isolated bridge that was modelled with the traditional approach in practice of elastomeric bearing.

Table 5.1 shows the main period of bridges in three different cases. It is possible to definitively conclude from table that isolators cause a significant increase in the main period of bridges. Also, by utilizing stiff isolator on this bridge, the vibration period of system decrease about 12%.

Table 5.1. Main vibration period of models

Model	Period (Sec.)
Non-isolated bridge	0.93
LRB A-isolated bridge	1.71
LRB B-isolated bridge	1.53

The maximum base shear of the models under longitudinal components of various earthquakes is summarized in Table 5.2. The base shear is reduced about 7% to 13% for the isolated system as compared to the non-isolated system under Tabas earthquake motion. Naghan record generates maximum base shear slightly smaller than Tabas and it is reduced about 19% to 25% for the isolated system as compared to the non-isolated system. This indicates that the isolation systems are quite effective in reducing the earthquake response of the bridge system. In the case of isolated bridges, base shear forces are reduced about 8% when the stiffer isolator is incorporated as compared to the more flexible isolator.

Table 5.2. Maximum base shear of models on the longitudinal direction

Model	Shear (ton) Tabas EQ	Shear (ton) Naghan EQ	Shear (ton) Bam EQ
Non-isolated bridge	1912	1860	1794
LRB A-isolated bridge	1649	1394	1589
LRB B-isolated bridge	1780	1507	1656

Table 5.3 shows the maximum base shear of the bridge under various ground motions on the transverse direction. The base shear is reduced about 25% to 32%, 44% to 49% and 30% to 40% for the isolated system as compared to the non-isolated system under Tabas, Naghan and Bam earthquake motions respectively.

Table 5.3. Maximum base shear of models on the transverse direction

Model	Shear (ton) Tabas EQ	Shear (ton) Naghan EQ	Shear (ton) Bam EQ
Non-isolated bridge	2897	2804	3012
LRB A-isolated bridge	1968	1423	1783
LRB B-isolated bridge	2166	1560	2085

Fig. 5.1 illustrates the longitudinal displacement responses of the isolators for the isolated bridge subjected to Tabas ground motion. It shows that the longitudinal displacement response of the LRB A induced by Tabas ground motion is higher than those by LRB B.

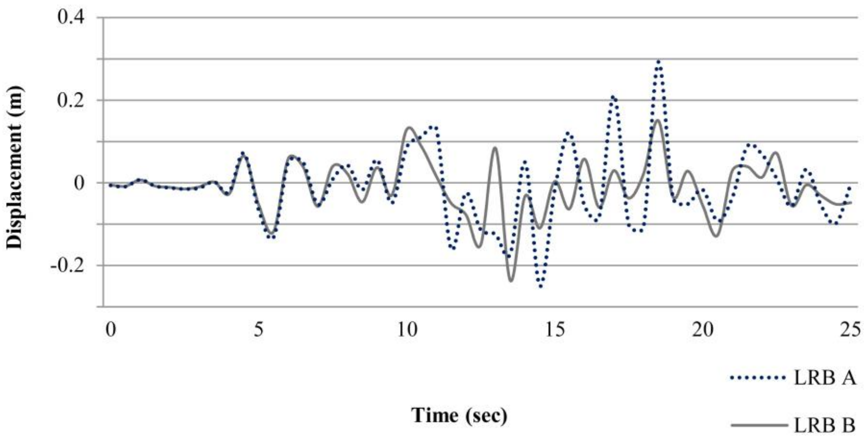

Figure 5.1. Time variation of longitudinal bearing displacement of the bridge isolated by LRB system under Tabas earthquake motion

Fig. 5.2 demonstrate that by utilizing lead rubber bearing on the bridge, maximum shear in longitudinal direction of pier will reduce about 39% to 30%, 40% to 29% and 28% to 15% for the isolated system as compared to the non-isolated system under Tabas, Naghan and Bam earthquake motions respectively.

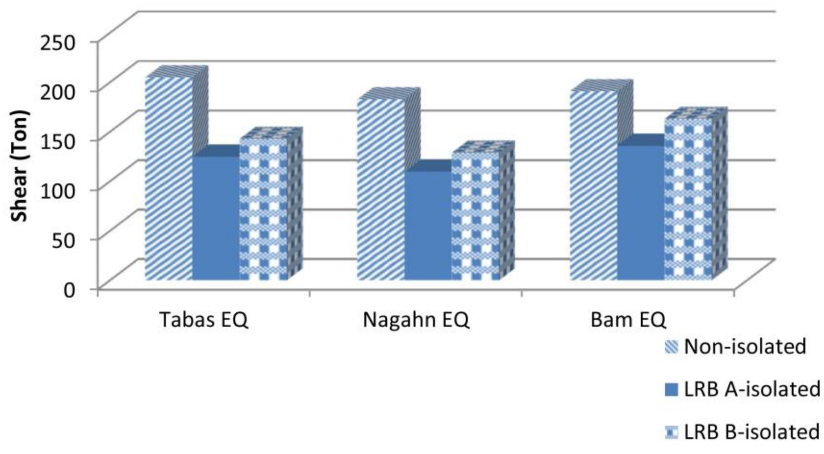

Figure 5.2. Maximum longitudinal shear in one of the piers of the bridge in various bearing condition and under three different strong earthquake motions

In Fig. 5.3 maximum shear in longitudinal direction of abutment is shown. It looks like that shear in abutments reduces about 50% to 44%, 52% to 37% and 45% to 34% for the isolated system as compared to the non-isolated system under Tabas, Naghan and Bam earthquake motions respectively. It seems that the bridge which is isolated by more flexible LRB devices, namely LRB A have better result in reduction the internal forces on the piers and abutments.

Fig. 5.4 presents maximum moment in one of the piers of the bridge in various bearing condition and under three different strong earthquake motions. Similar to the effects of isolator on the shear, it reduces about 50% to 47%, 40% to 35% and 44% to 29% for the isolated bridge as compared to the non-isolated bridge respectively.

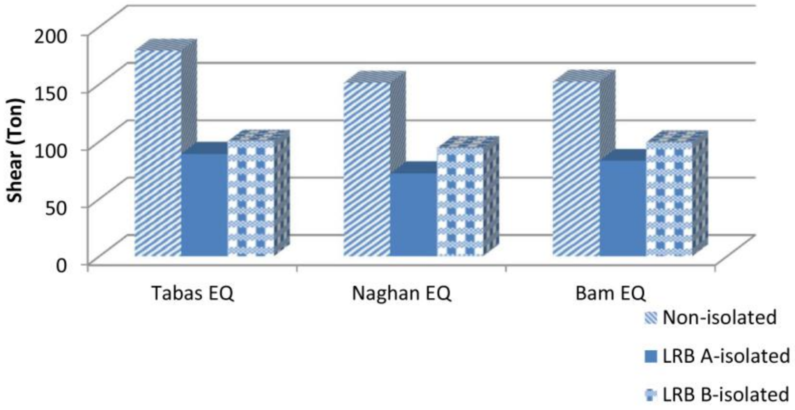

Figure 5.3. Maximum longitudinal shear in abutments of the bridge in various bearing condition and under three different strong earthquake motions

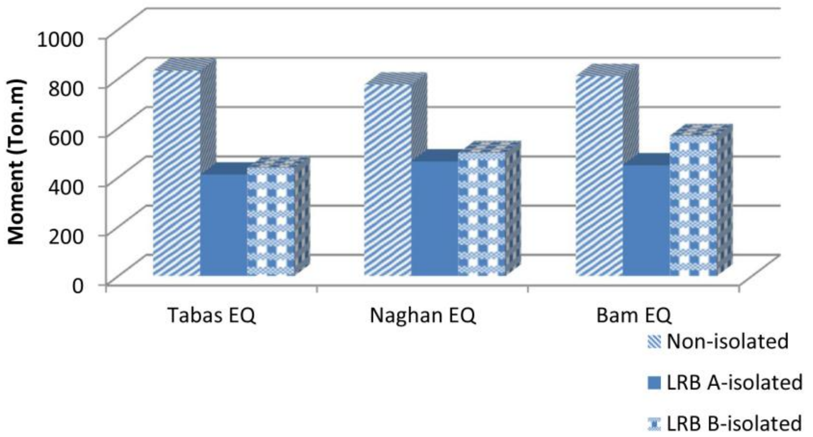

Figure 5.4. Maximum moment in one of the piers of the bridge in various bearing condition and under three different strong earthquake motions

6. CONCLUSION

In this paper behaviour of a steel box girder bridge was investigated by applying three strong ground motion records of Iran in three different bearing conditions. First one had common bearing system namely elastomric bearing, second model had LRB isolators on its girders with certain stiffness and third model had LRB isolators with more stiffness. First of all, Analysis results show the efficiency of seismic isolations in increasing the vibration period of structure.

Furthermore, the displacement and base shear response for entire bridge was strongly depend on the value and the energy of the ground motions. Lead rubber isolator had magnificent effect on reducing the base shear up to 50% in some cases. Its another service were concern to the internal forces of the substructure. In this case at least 28% and 40% reduction in the shear and moment forces of piers reported respectively. Also it can be concluded that flexibility of bearing systems is so important in improving seismic behaviour of bridges under earthquake ground motion and it must be selected wisely. Large stiffness isolators are not suitable under some earthquake ground motions.

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