Seismic Protection of Cable-Stayed Bridge Using Supplemental Devices

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Abstract*— *Cable stayed bridges are the most flexible bridge and getting popularity because of its economy for longer spans and aesthetics. The traditional approach to seismic hazard mitigation is to design structures with sufficient strength capacity and the ability to deform in a ductile manner. Alternatively, newer concepts of structural control have been growing in acceptance as design alternative for earthquake hazard mitigation. The control systems can be used as base isolators to achieve different objectives or performance goals ranging from a life safety standard to a higher standard that would provide damage control. The Primary objective of this study is to improve the performance of cable stayed bridge under seismic loadings. The study enhances using the energy dissipation devices as a promising to passive control technique, to help control the dynamic properties of the bridge structure. Comparison of dynamic behaviour of isolated and Non-Isolated Bridge with and without the Bearing Under three different earthquake motion has been conducted. The 3D bridge model is prepared on CSIBridge software and bridge is analyzed seismically by El-Centro, Loma Prieta and Landers Earthquake. The bridge response in terms of Comparison of different parameters of cable stayed Bridge under seismic loading - time period and natural frequency, Displacement at top of tower, Displacement at mid-point of deck, Moment at tower base Connection with base isolation.

Index Terms*— *Cable-stayed bridges, Seismic Behaviour, Non- linear seismic behaviour, Passive Control, Elastomeric Bearing

I. INTRODUCTION

In the last decades cable-stayed bridges have gained popularity throughout the world for spans up to approximately 1 km due to their appealing aesthetics, fast construction, and efficient use of structural materials leading to small structural members and light appearance, and increased stiffness when compared to suspension bridges. This type of structure, characterized by a long fundamental period, large flexibility, light weight and low structural damping (Ali HM, Abdel-Ghaffar AM 1995), is quite vulnerable to large amplitude oscillations when excited by earthquake ground motions. A number of studies have been performed in the past related to the seismic behaviour of cable-stayed bridges. The seismic response of a cable-stayed bridge depends to a great extent on how the bridge deck is connected to the tower and the piers. Rigid connections limit the deck horizontal displacements under earthquake action but unavoidably increase the transmitted forces between the superstructure and the substructure. There is a general agreement in the convenience of permitting certain relative movement of the deck at the pier and tower locations, to reduce the internal forces at the base of these elements but, due to the low inherent damping, important horizontal displacements are to be expected in that location. (Martínez-Rodrigo 2015)

Cable-stayed bridges are very important engineering structure due to the high costs and logistical importance. The failures of the bridges during earthquakes result in significant consequences. Hence, it strengthened against to earthquake is an important issue. If the fundamental period of structure is lengthened or energy dissipating of structure is increased, the seismic forces on bridge may be reduced. Thus, seismic isolation system may be an alternative approach to protect bridges from damages of severe earthquakes.

Although many efforts were made over the past decades to understand the dynamic behavior of cable-stayed bridges, very little has been reported in the literature about their seismic response-control analysis. The application of the Vibration Control Theory on cable-stayed bridges began more than 20 years ago, with the incorporation of the first seismic isolation devices. Since then, their improvement has not stopped, but the incorporation of this technology to cable-stayed bridges has been slow. Many control devices have been tested applying analytic and/or experimental methodologies, but from a seismic point of view, only a few cable-stayed bridges include advanced protection systems, maybe due to their satisfactory performance during recent earthquakes and the lack of specific regulations for their design and construction. Thus, new passive protection technologies, introducing seismic isolation and energy dissipation devices, began to be used with seismic purposes only a few years ago, as in the Cape Girardeau Bridge (USA) and the Rion – Antirion Bridge (Greece). In fact, constant research and experimentation has allowed a great progress for the new seismic devices whose performance characteristics are better known, with more capabilities to be employed on large structures, according to the new tendencies.

II. CABLE-STAYED BRIDGE

The bridge consists of two h-shaped concrete pylons, double-plane fan type cables, and a steel girder bridge deck. The main span is 2200 ft and there are two equal side-spans of 960 ft for a total length of 4120 ft. There are a total of 48 high strength steel cables, 24 supporting the main span and 12 supporting each of the side spans. The deck is 80 ft. Wide measured center to center of cables. It is made of steel box girder the sectional details of each of the pylon have been presented in Figure 2. All SO SHOW THREE-dimensional view of the Cable-stayed Bridge in Figure 1. Each of the pylons consists of two concrete legs, an upper Cross beam connecting the two legs and a lower Cross beam supporting the deck. The cross-sections of the pylon and cross beam have been illustrated in the Figure 1. In the non-Isolated Bridge is defined as having rigid connection at the deck-tower Connection and Hinge at the abutment Connection. The cables comprise of 6.4 mm diameter wires with an ultimate strength of 1600 MPa. They are of four different cross sectional areas: (1) 0.200 ft² (2) 0.195 ft² (3) 0.125 ft² (4) 0.11 ft² (5) 0.095 ft² (6) 0.075 ft² (7) 0.061 ft². The cables are helically wrapped with a polyethylene covering and are grouted and sealed. They are anchored to the deck 160 ft interval. The cables are connected to the pylon top at an interval of 20 ft. [5]

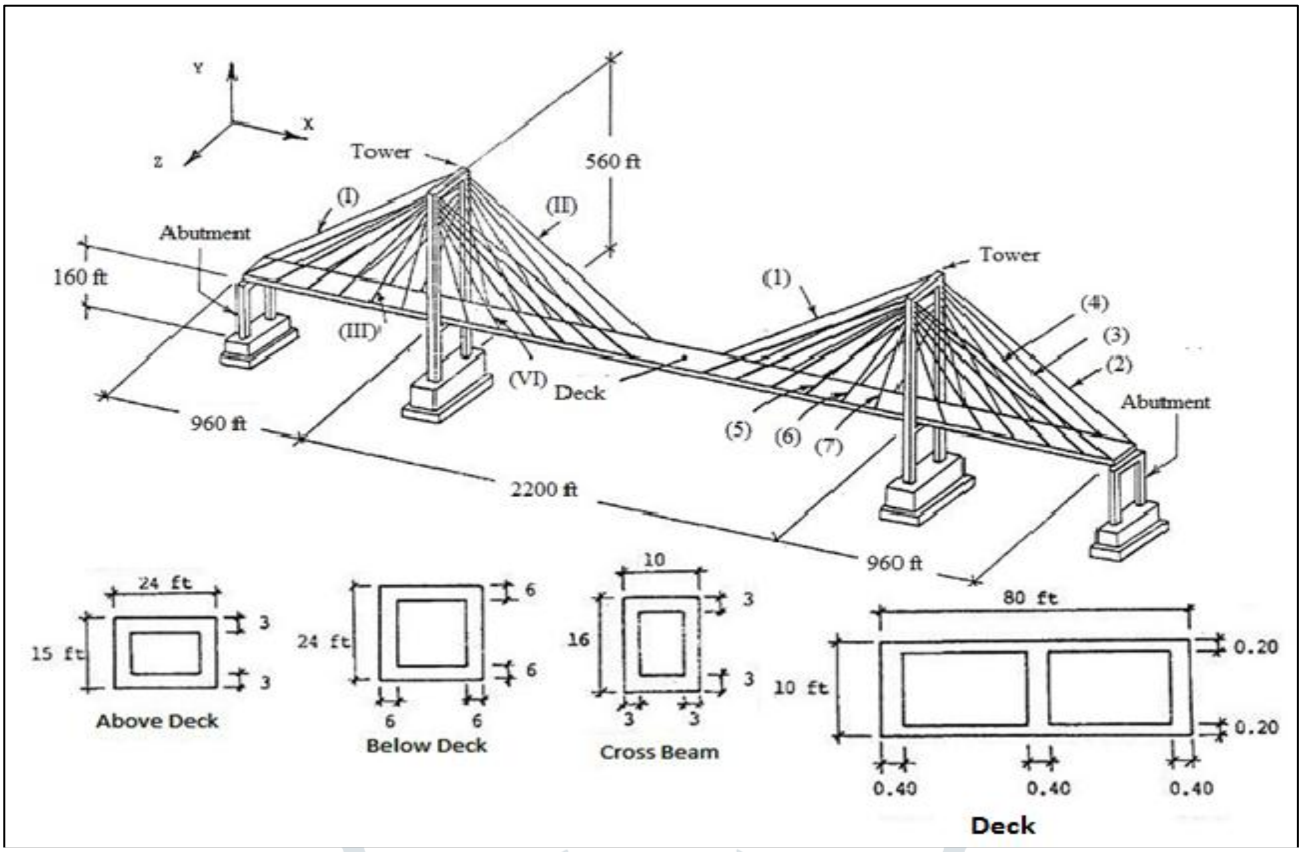


Figure 1 3D view of the Cable-stayed Bridge

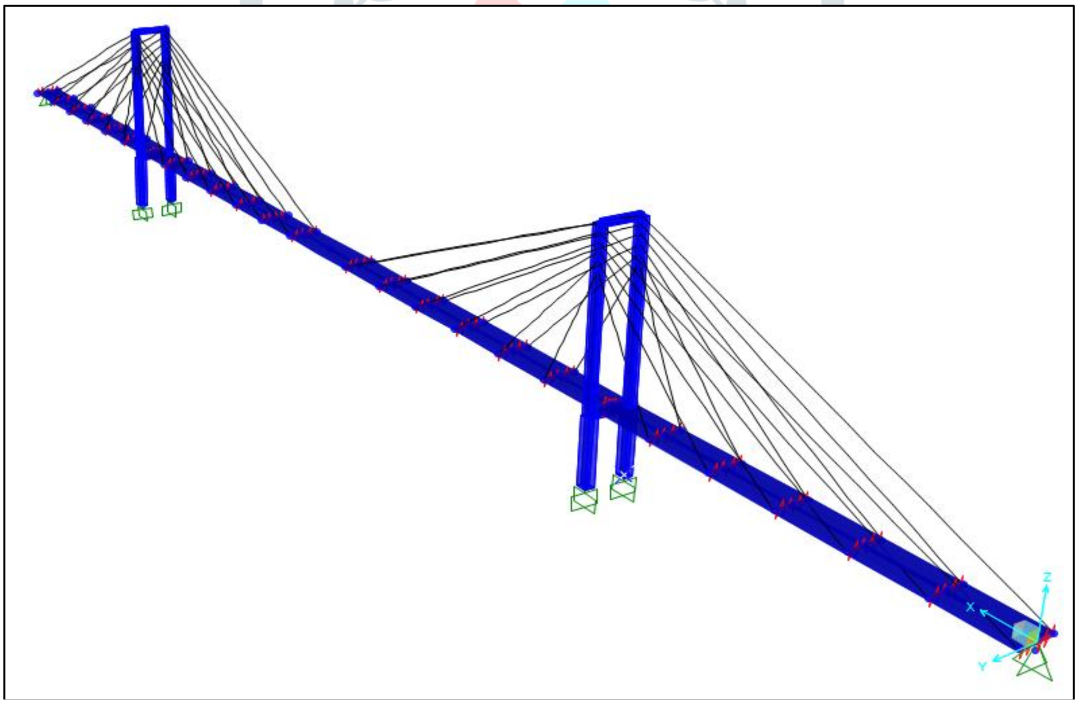


Figure 2 3D Model of the Cable-stayed Bridge (CSI Bridge)

III. NUMERICAL COMPUTATIONS

Nonlinear time history analyses of the isolated and non-isolated bridges are performed in CSI Bridge in order to determine the dynamic behavior of the bridge. 3D FEM of non-isolated bridge is given in Fig. 2. Damping ratio is specified as 5% and the elastomeric bearings selected as an isolator device.

For analysis of cable stayed bridge of time histories are most essential. This required for understanding seismic response of bridge. El-Centro, Loma Prieta and Landers Earthquake time histories have 39.11sec, 60.00sec, and 79.890 sec duration of earthquake. All above three earthquake have different magnitude, different peak ground acceleration (P.G.A) and Different time of occurrence of P.G.A and Time History Input Data show in table 1.

Table 1 Time History Input Data

Earthquake Name	Magnitude	Duration of Earthquake (Sec)	PGA Value (cm/sec2)	Time for PGA (sec)
El- Centro, 1979	6.6	39.11	332.44	2.48
Loma Prieta, 1989	7.0	60.00	174.549	7.320
Landers, 1992	7.5	79.980	148.574	14.82

IV. NUMERICAL RESULTS

PERIOD OF THE BRIDGE

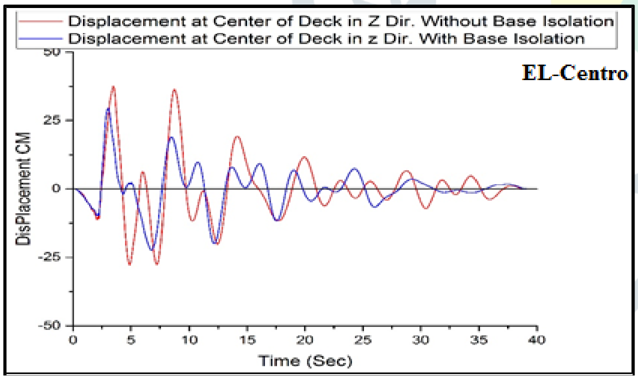
The first 12 Period and Frequency of the isolated and the non- isolated bridges obtained from the modal analyses are given in Table 2. Periods of the isolated bridge are considerably higher than the periods of non-isolated bridge. Isolation devices used on bridge lengthened period of bridge.

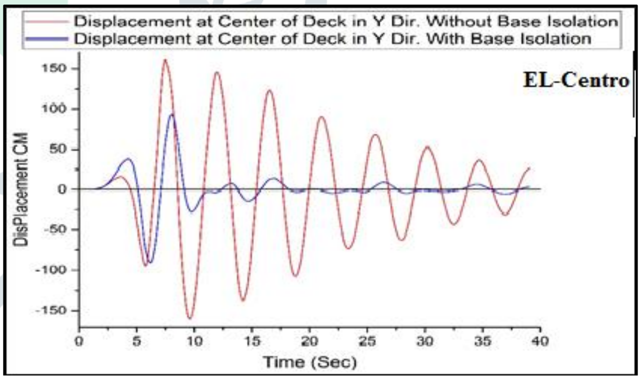
Table 2 Mode Period and Frequency

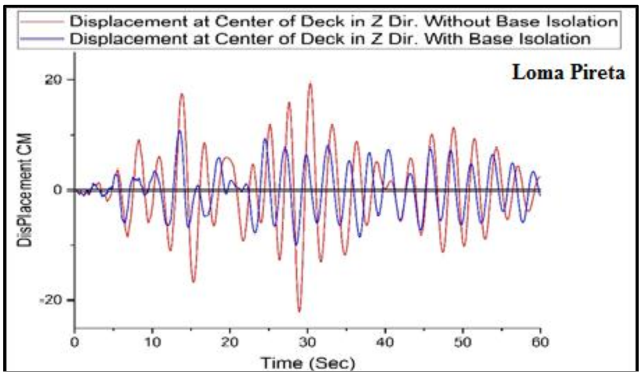
Mode	Without Base Isolation		With Base Isolation	
	Period (sec)	Frequency (Cyc/Sec)	Period (sec)	Frequency (Cyc/Sec)
1	6.354	0.1573	6.758	0.147
2	4.595	0.2176	4787	0.208
3	4.458	0.2243	4.772	0.209
4	4.212	0.2374	4.160	0.240
5	2.999	0.3333	3.034	0.329
6	2.747	0.3640	2.34	0.425
7	2.320	0.4310	1.304	0.766
8	1.329	0.7523	1.259	0.794
9	1.21	0.8242	0.6971	1.434
10	0.853	1.171	0.6242	1.601
11	0.852	1.173	0.268	3.724
12	0.6343	1.576	0.130	7.667

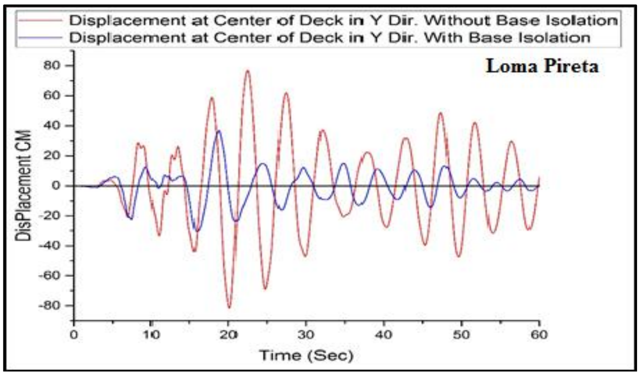
DECK RESPONSE

Maximum vertical displacements of the deck for three earthquakes are given in Fig. 3. Decreasing percentage of vertical displacements for El centro and Loma Prieta earthquake ground motions are 21.26 % and 55.01%, respectively. Increasing percentage of vertical displacements for Lander earthquake ground motions 16.95%. Maximum transverse Displacement obtained from analysis are given in Fig. 4. Decreasing percentage of Maximum transverse Displacement for El centro, Loma Prieta, and Landers earthquake ground motions are 43.86%, 62.59%, and 16.64%, respectively.









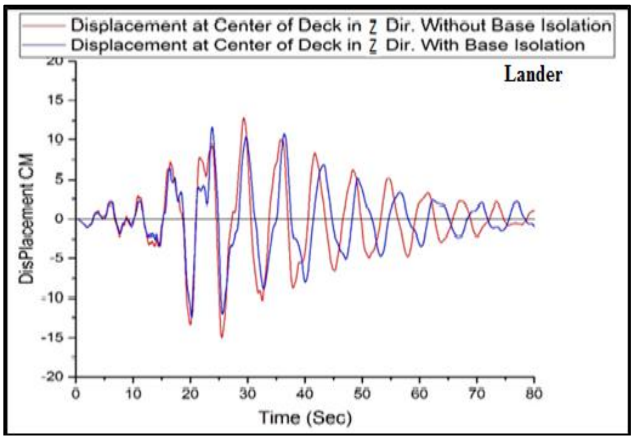


Figure 3 vertical displacements of deck

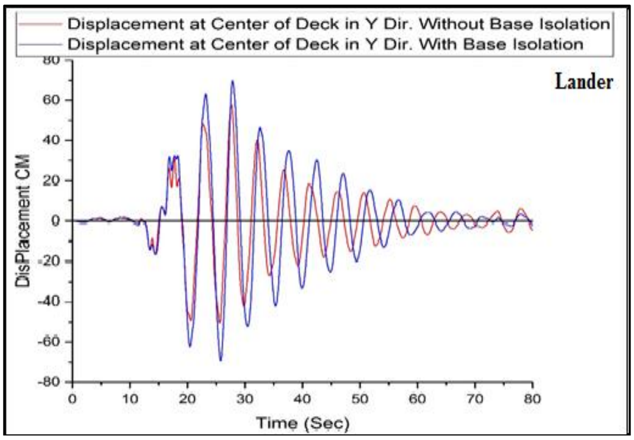


Figure 4 transverse Displacement of deck

Tower response

Top of the bridge tower top displacements on X and Y direction for three earthquakes are given in Fig. 5. Decreasing percentage of X direction Displacement for El centro, Loma Prieta, and Landers earthquake ground motions are 8.08%, 27.08%, and 14.80%, respectively. Decreasing percentage of Y direction Displacement for El Centro, Loma Prieta, and Landers earthquake ground motions are 5.733%, 12.08%, and 8.36%, respectively.

Maximum tower base bending moments in X and Y direction obtained from analysis are given in Fig. 6. Decreasing percentage of bending moments in X direction for El centro and Loma Prieta, earthquake ground motions are 34.58 %, and 35.94%, respectively. Increasing percentage of bending moments in X direction for Lander earthquake ground motions 12.28%. Increasing percentage of bending moments in Y direction for Lander and Loma Prieta, earthquake ground motions are 45.88 %, and 33.04 % respectively. Decreasing percentage of bending moments in Ydirection for El- cento earthquake ground motions 15.11%.

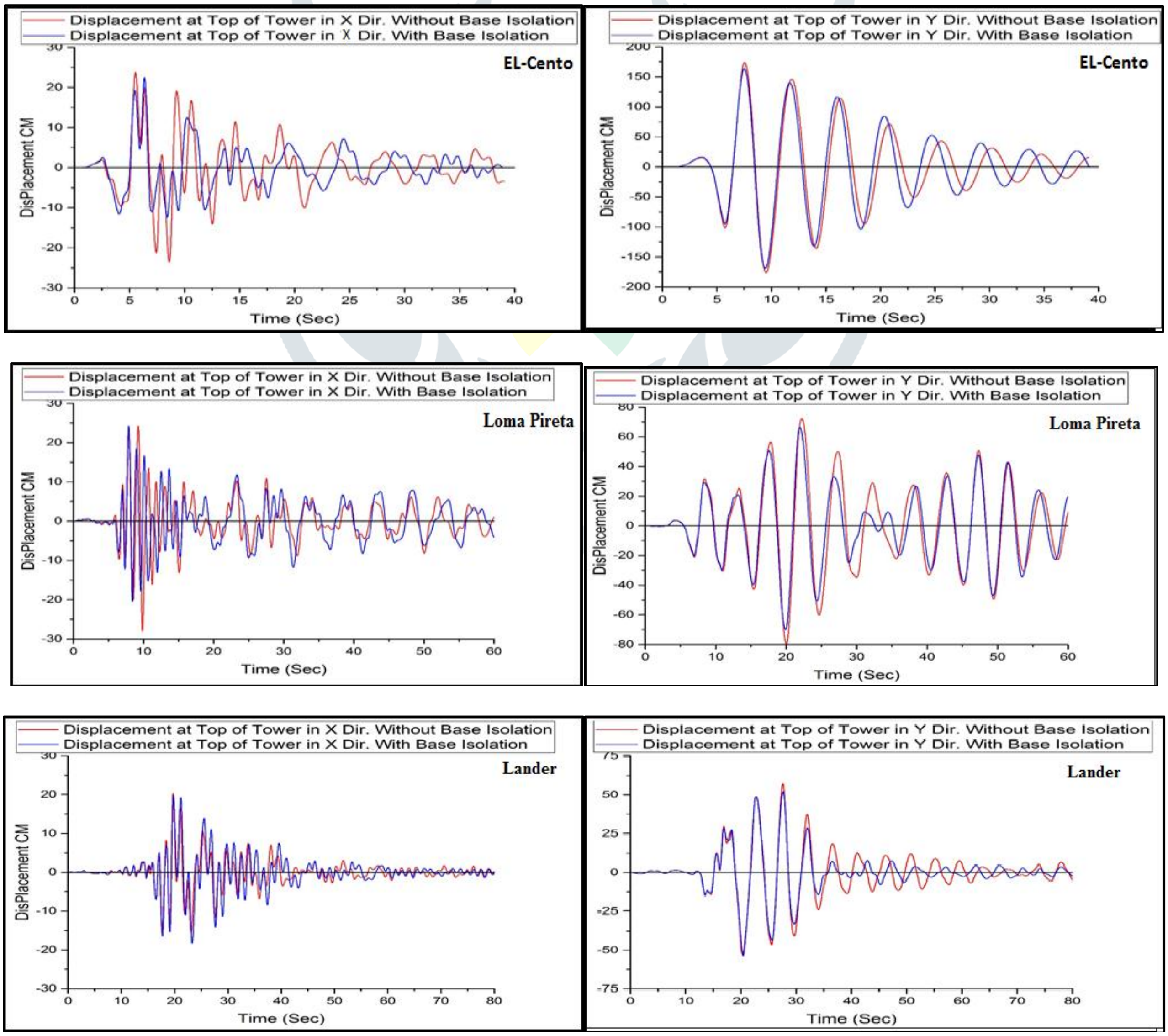


Figure 5 Displacement at Top of Tower

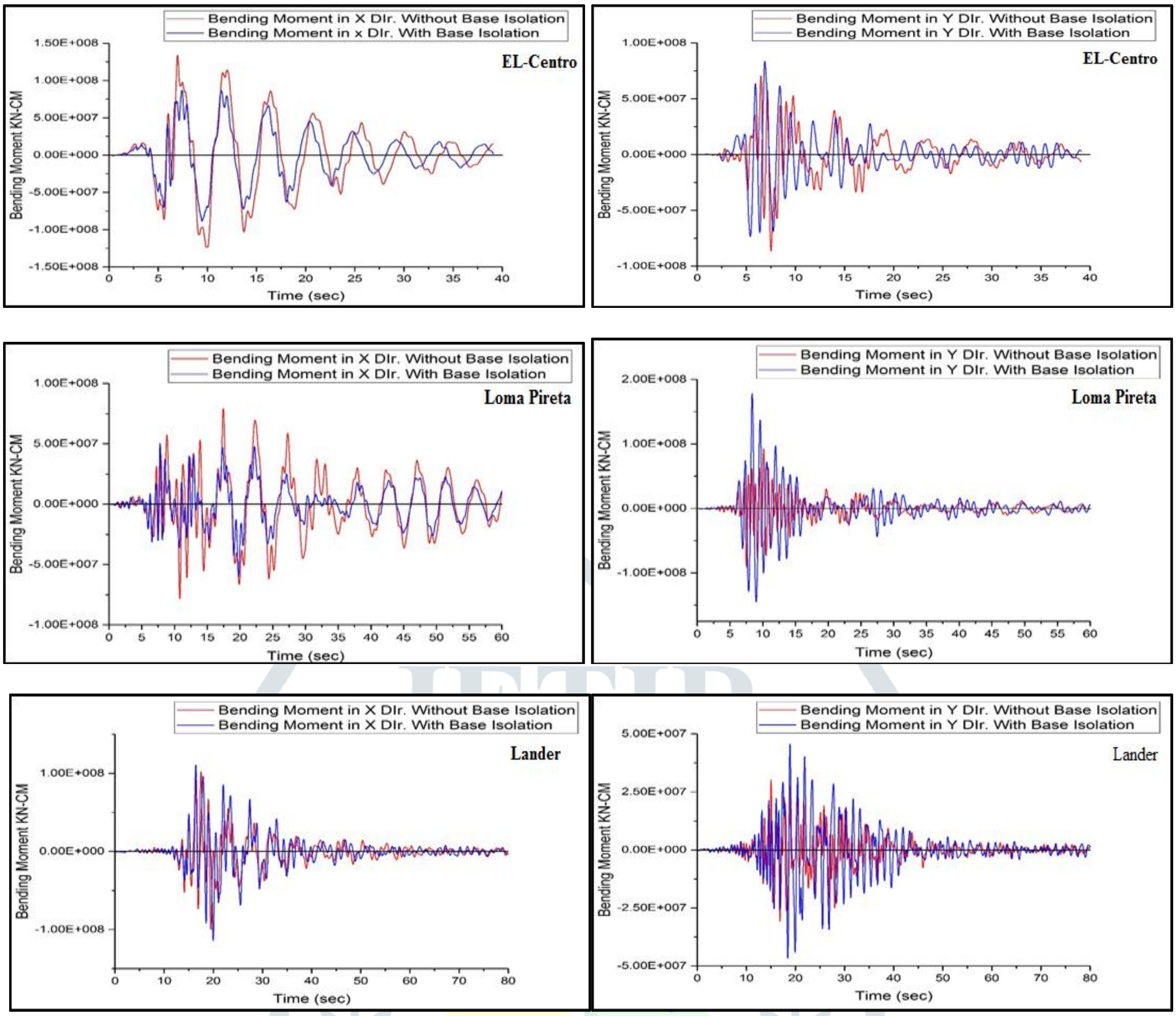


Figure 6 Bending Moment at Base of Pylon

V. CONCLUSIONS

Finite element model of the isolated and non-isolated bridges are created with CSI Bridge. Nonlinear time history analysis is performed in order to investigate effectiveness of the seismic isolation systems on the bridge. The main conclusions of this study can be summarized as;

Isolation system increased periods of the bridge significantly. Increasing of the bridge period provide decreasing of transferred acceleration so internal reactions of the bridge decrease as well.

In cable stayed bridge with base isolation system, Displacement & Bending moment decrease with respect to without base isolation system in case of El-Centro & Loma Pireta Earthquake.

In cable stayed bridge with base isolation system, Displacement & Bending moment increase with respect to without base isolation system in case of Lander earthquake. This is due to structure natural frequency is 0.145 is near equal to earthquake frequency 0.146.

The results show that usage of the isolation devices offers some advantages for the internal forces on the deck for the considered isolated bridge as per the non-isolated bridge. Finally, it should be noted that isolation system is more effective when the bridges are subjected to earthquake.

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