EFFECT OF RADIUS OF CURVATURE ON THE SEISMIC RESPONSE OF AN ISOLATED CURVED BRIDGE

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ABSTRACT

Horizontally curved bridges are more demanding than straight bridges in situations like at complicated interchanges or river crossings where geometric restrictions and constraints of limited site space make extremely difficult for adoption of standard straight superstructures. These are also aesthetically pleasing structures as well as these results economically competitive construction costs with regard to straight bridges. In past earthquakes, most of the damages of the bridges occurred due to the failure of the bearings and substructure. Selection of isolation bearings for a curved bridge is a challenging task because of the complexity involved in curved bridges than straight bridges. In the present study, the effect of radius of curvature has been taken in to the consideration and the responses of an isolated curved continuous bridge for seismic loading conditions are determined. Two types of isolation bearings viz. Lead Rubber Bearing (LRB) and Friction Pendulum System (FPS) have been considered.

***Keywords*: Curved Bridge, Friction Pendulum System, Lead Rubber Bearing, Seismic, Isolation**

I. INTRODUCTION

The use of horizontally curved bridges is very important nowadays, especially to avoid a congested traffic and also to solve the limited space requirement in urban traffic conditions. The only problem with these types of bridges is the significant amount of torsion which makes it difficult for design. From the study of damages caused by past earthquakes, it has been found that the performance of bridges is generally governed by the performance of bearings and substructure. Efficacy of isolation bearings, especially in case of curved bridges, is important and selecting a proper isolation bearing is also a demanding task as the performance of a particular type of bearing is affected by radius of curvature of curved bridge. This paper presents a numerical study of the seismic response of a seven-span continuous curved bridge with two types of isolation bearings viz. Lead rubber (LRB) bearing and friction-based bearing (Friction Pendulum System (FPS)). Imperial Valley earthquake ground motion (1940) has been considered in the study and relative performance and efficacy of the two isolation bearings w.r.to the selected earthquake ground motion has been determined in the study.

II. ISOLATION BEARINGS

Various types of isolation bearings are available. However, the present study is limited to a comparative assessment of the seismic performance of the two types of isolation bearings viz. elastomer-based (Lead Rubber Bearing (LRB)) and friction-based bearing (Friction Pendulum System (FPS)).

In case of Lead–rubber bearings (LRBs) (Abrahamson and Mitchell, 2003; Turkington et al., 1989), the rubber provides lateral flexibility to lengthen the period of the structure, and a lead core dissipates energy during cyclic movement due to earthquakes. Friction pendulum system (FPS) is a sliding-based seismic isolator (Dicleli, 2002; Ingham, 2003; Mokha et al., 1991; Wang et al., 1998) with a restoring mechanism. The FPS provides resistance to service load by friction. Once the coefficient of friction is overcome, an articulated slider moves over a spherical surface, which causes the supported mass to rise and provides the restoring force for the system. Friction between the articulated slider and the spherical surface generates damping. The Coulomb damping generated through sliding friction provides energy dissipation in the bearings.

The choice of bearing type in a particular situation is influenced by the cost of the bearing. According to an evaluation (Drozdov et al., 2007) of FPS bearings, LRBs and bearings containing rubber with high damping capability, for the same levels of structural displacement, the FPS bearings were found to be the cheapest.

III. MODELLING AND ANALYSIS

A continuous single-chamber box girder curved bridge has been considered (Yu et al., 2008) (Fig. 1). The total length of the curved bridge is 165 m with two end span of 20 m and five intermediate spans of 25 m. Total nine numbers of bridges has been modelled with the variation range of radius of curvature(R) is from 63 m to ∞ (Straight Line). The cross-sectional area of the box-girder is 3.1 m^2. The longitudinal moment of inertia and transverse moment of inertia of the box-girder are 0.60 m^4 and 16.58 m^4, respectively. The pier has a solid circular section with cross-sectional area of 1.7671 m^2 and moment of inertia of 0.2485 m^4. The height of the pier is 11 m. The piers are resting on rocky strata.

The structure has been modelled using the SAP2000 non-linear software. The superstructure and the piers have been modelled using beam elements with mass lumped at discrete points. Since the piers are resting on rock, these have been modelled as fixed at the base. The abutments have been assumed to be rigid. The isolation bearings have been modelled as link elements. In non-isolated case, the bridge is supported by roller bearings at the abutment and fixed at the base of piers. In isolated case, isolation bearings are used both at abutments as well as between the deck and pier.

Seismic loading has been considered for Imperial Valley earthquake ground motion (1940) with two horizontal orthogonal ground motion components (Table 1 and Fig. 2a and Fig. 2b). The nonlinear dynamic time history of the bridge has been performed for four cases of ground motions viz. (Case 1) PGA 0.31g in global longitudinal (X) direction and PGA 0.21 g in Global transverse (Y) direction; (Case 2) PGA 0.21g in global X direction and PGA 0.31 g in Global Y direction; (Case 3) PGA 0.31g with 45^0 angle w.r.to global X direction and PGA 0.21 g with 45^0 angle w.r.to in Global Y direction; and (Case 4) PGA 0.21g with 45^0 angle w.r.to global X direction and PGA 0.31 g with 45^0 angle w.r.to in global Y direction.

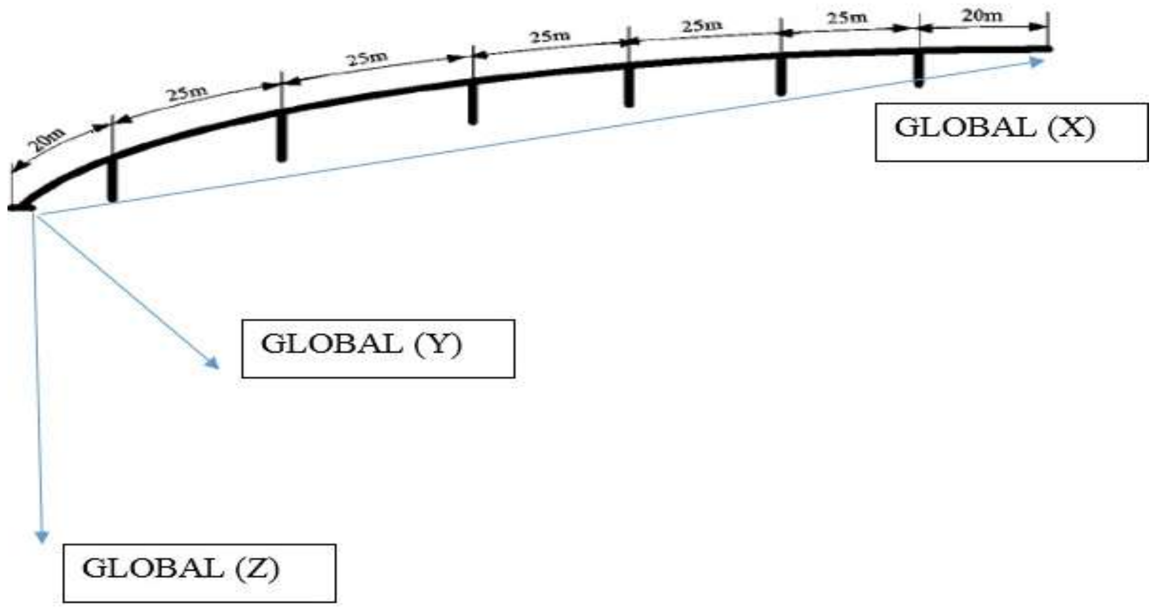

Fig. 1: Structural Pattern of Curved Bridge

Table1 Ground Motion Considered

Event	Mag.	Station	Orientation	PGA (*g*)	Distance-to-fault (km)
Imperial Valley (1940)	7.0	117 El Centro Array #9	IMPVALL/I-ELC180	0.313	8.3
Imperial Valley (1940)	7.0	117 El Centro Array #9	IMPVALL/I-ELC270	0.215	8.3

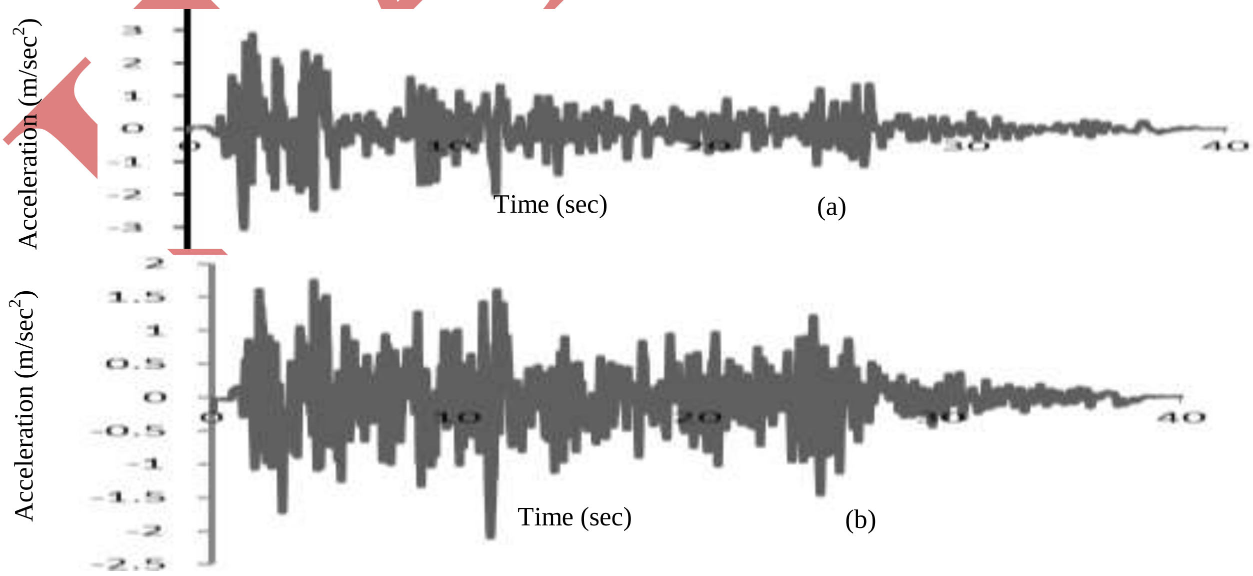

Fig. 2. Ground Motions Considered (a) PGA 0.313g (b) PGA 0.215g.

IV. DESIGN OF ISOLATION BEARINGS

The design of the isolation bearings was done according to different criteria provided in various codes (AASHTO, 999; IRC, 1987) and the literature (Dolce et al., 2007; Priestley et al., 1996). Three parameters are important for the design of the isolation bearings: time period of the isolated structure; the damping ratio of the isolation system; and the level of ground motion. In the present study, the isolation bearings have been designed for the Imperial Valley (1940) earthquake ground motion and the performance of different bearings has been compared. The isolation bearings have been designed for maximum displacement of 80mm.

V. RESULTS AND DISCUSSIONS

The response of the curved bridges with the LRB bearing and FPS bearings has been determined for four different cases as stated above in section 3. The natural period of the isolated structure and damping of the isolation device are the most important parameters affecting the response of the structure. These in turn depend on size and design of the isolation bearings. In the present paper, the isolation time period and damping ratio of the isolation bearings have been considered as 1.5 sec and 20% respectively.

The effect of radius of curvature, the variation range of radius of curvature(R) is from 63 m to ∞ (Straight Line) with corresponding the angle of curvature, denoted as $\beta(^{o})$(referring to Fig. 3)on seismic responses of curved bridges has been determined. In case of responses, the resultant of the responses in the two perpendicular horizontal directions is considered. This is because, the considered bridges are curved bridges and the resultant of the response of perpendicular horizontal directions can be more effective from design consideration of bridges.

From the Figs.4-7, In case of non-isolated bridges it is very clear that with the increase of angle of curvature of bridge the pier 1* displacement increases but in case of isolated LRB the displacement of pier 1 of curved bridges do not increases with the increase of angle of radius of curvature. In case FPS isolated bridges, the pier 1 displacements also do not increases with the increase of angle of curvature of curved bridges. From Figs4-7, it is very clear that the LRB is most effective in reducing the pier displacement of the curved bridges.

From the Figs8-11, In case of non-isolated bridges it is very clear that with the increase of angle of curvature of bridge the pier 1 shear force increases but in case of isolated LRB the shear forces of pier 1 of curved bridges do not increases with the increase of angle of radius of curvature. In case FPS isolated bridges, the pier 1 shear forces also do not increases with the increase of angle of curvature of curved bridges. From Figs 8-11, it is very clear that the LRB is most effective in reducing the pier shear forces of the curved bridges.

From the Figs 12-15, In case of non-isolated bridges it is very clear that with the increase of angle of curvature of bridge the pier 1 shear force increases but in case of isolated LRB the bending moments of pier 1 of curved bridges do not increases with the increase of angle of radius of curvature. In case FPS isolated bridges, the pier 1 bending moments also do not increases with the increase of angle of curvature of curved bridges. From Figs 12-15, it is very clear that the LRB is most effective in reducing the pier bending moments of the curved bridges.

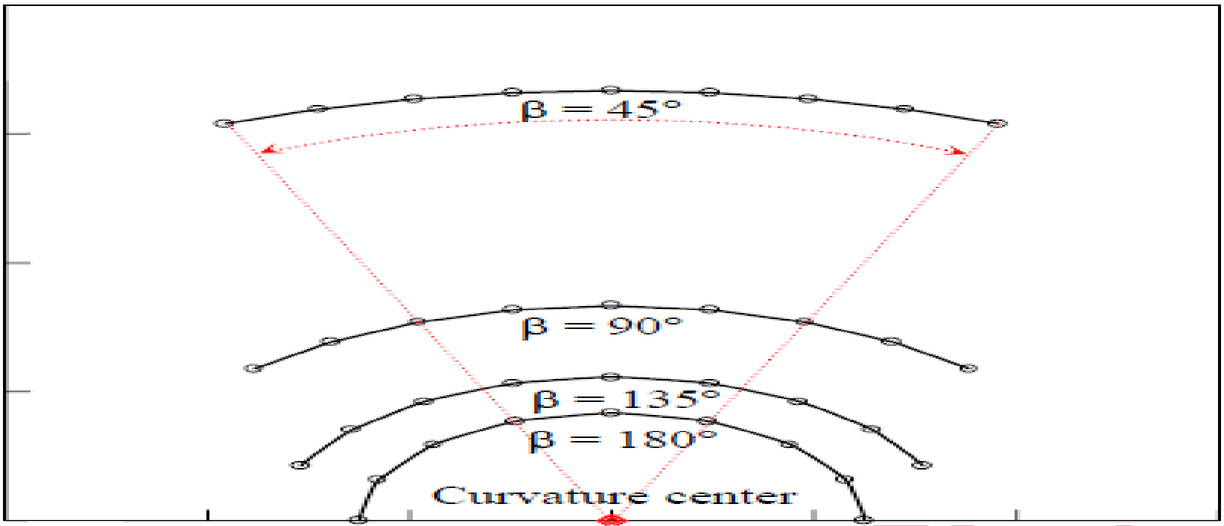

Fig.3. **Schematic Plot of Curved Bridges Under Various Angles of Curvature**.

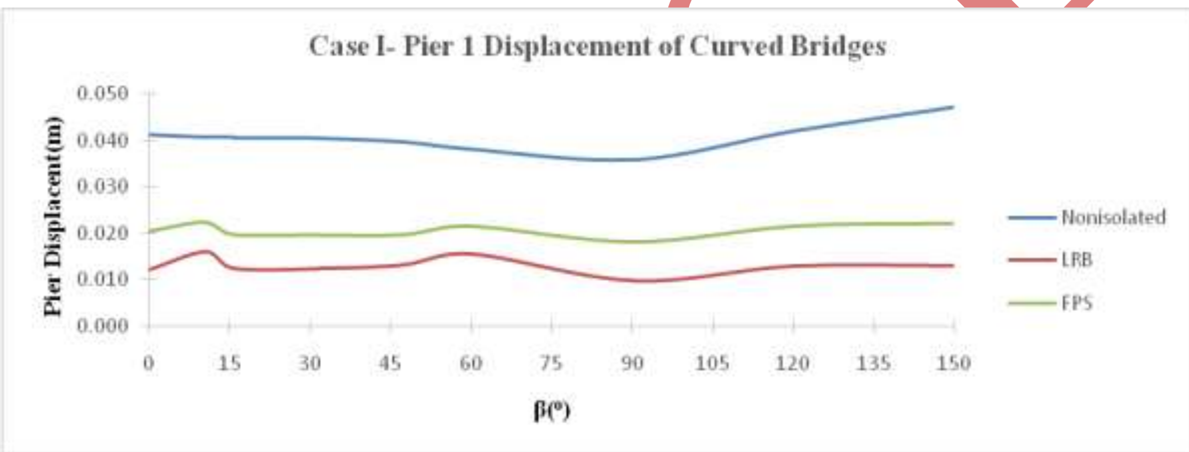

Fig.4. **Case I- Pier 1 Displacement of Curved Bridges**

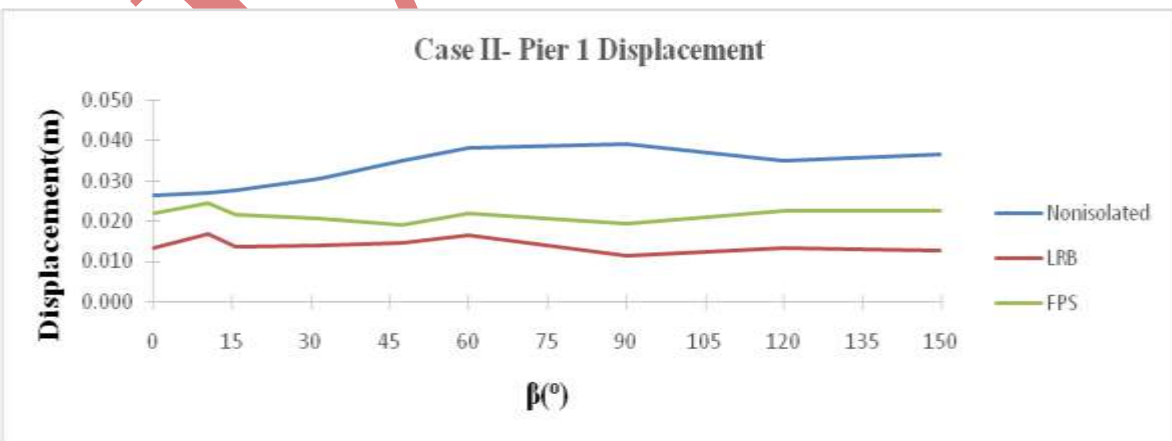

Fig. 5.**Case II- Pier 1 Displacement of Curved Bridges**

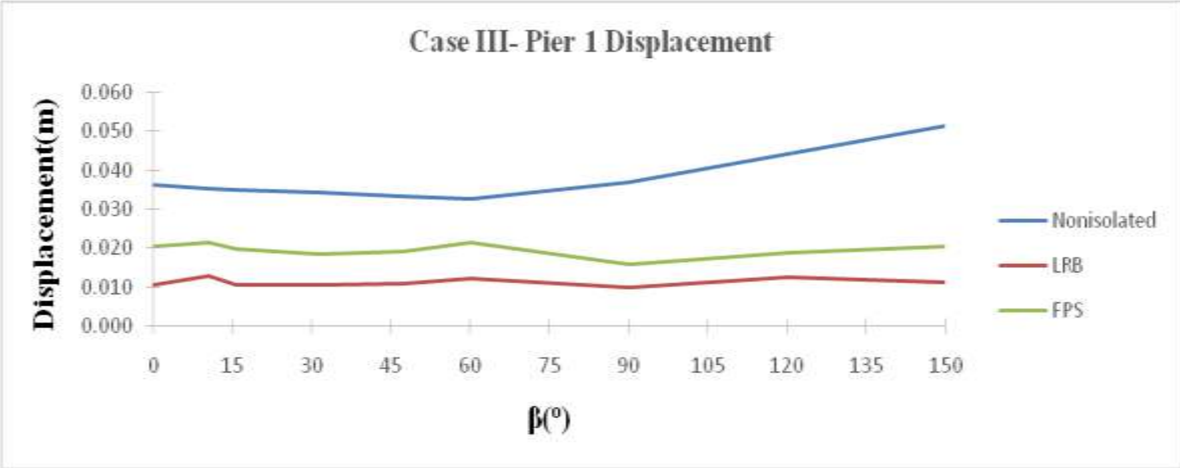

Fig.6. Case III- Pier 1 Displacement of Curved Bridges

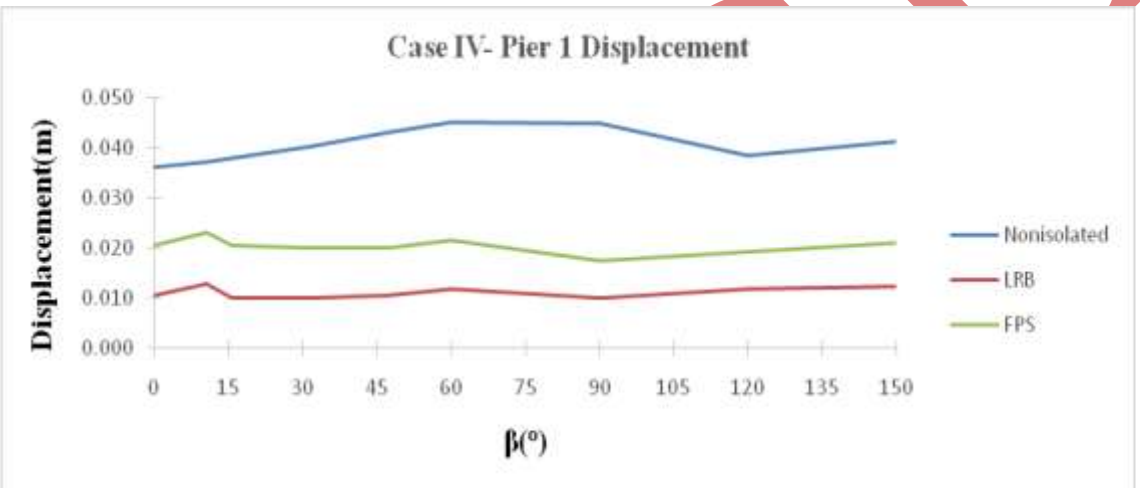

Fig. 7. Case IV- Pier 1 Displacement of Curved Bridges

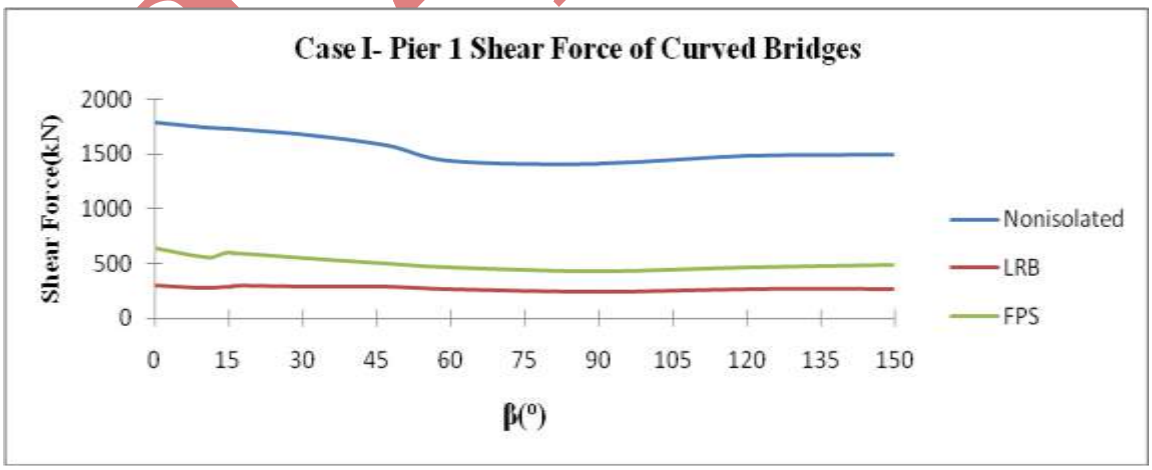

Fig. 8. Case I- Pier 1 Shear Force of Curved Bridges

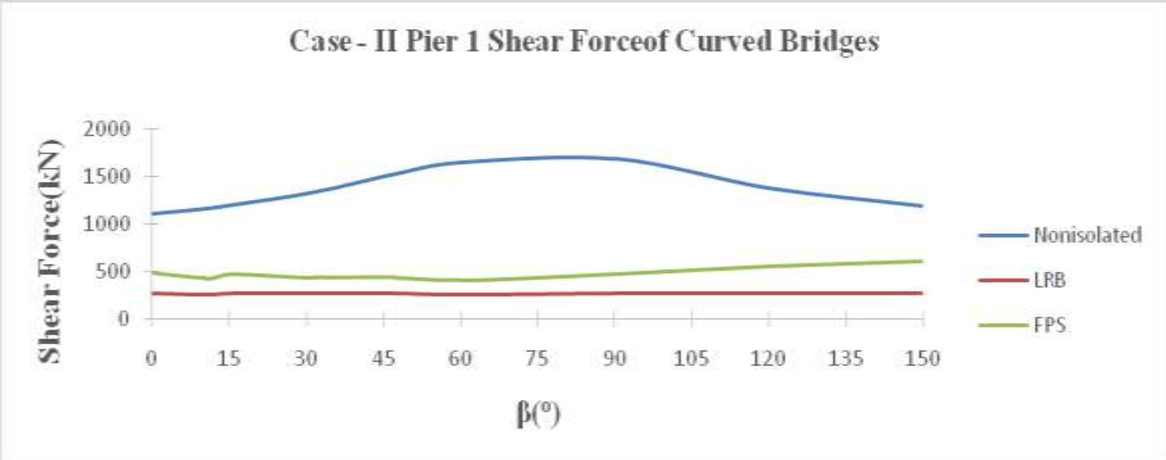

Fig. 9. **Case II- Pier 1 Shear Force of Curved Bridges**

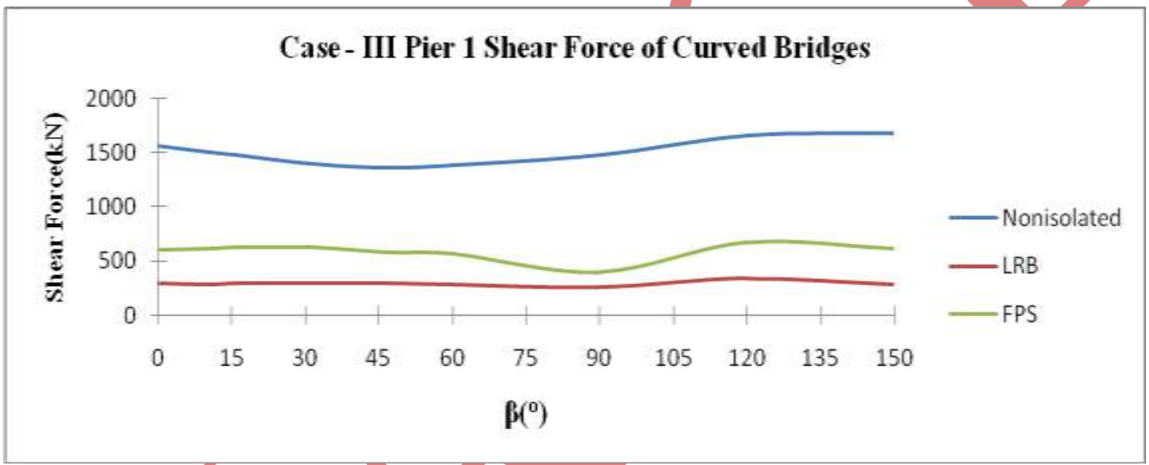

Fig. 10. **Case III- Pier 1 Shear Force of Curved Bridges**

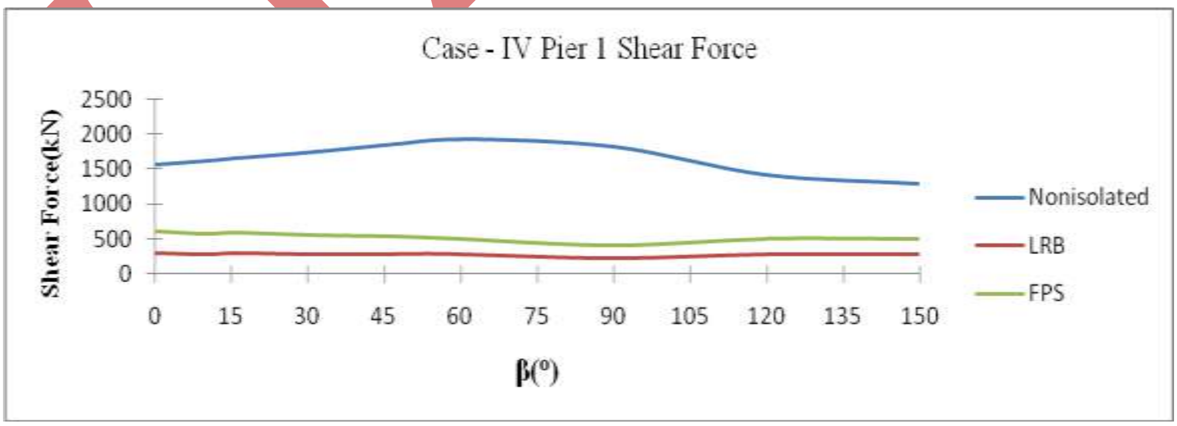

Fig. 11. **Case IV- Pier 1 Shear Force of Curved Bridges**

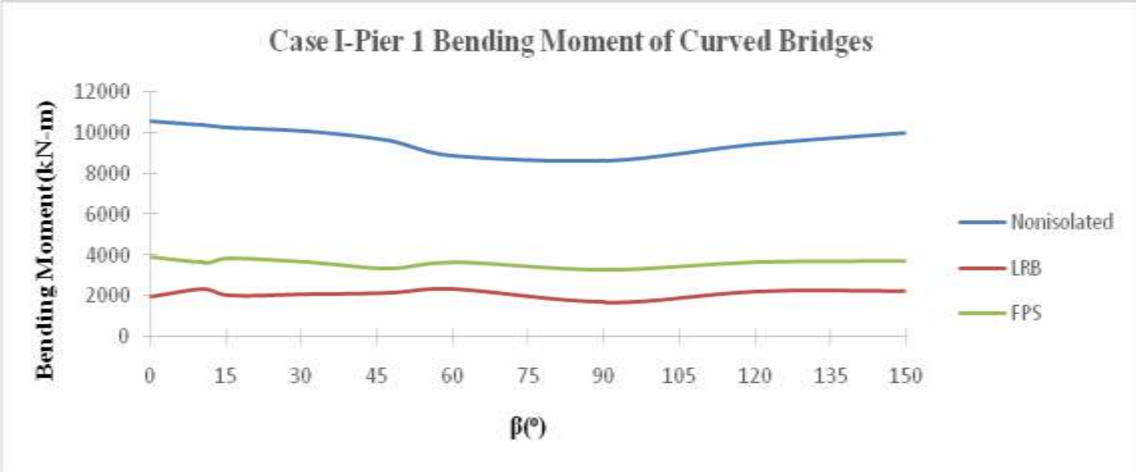

Fig. 12. **Case I-Pier 1 Bending Moment of Curved Bridges**

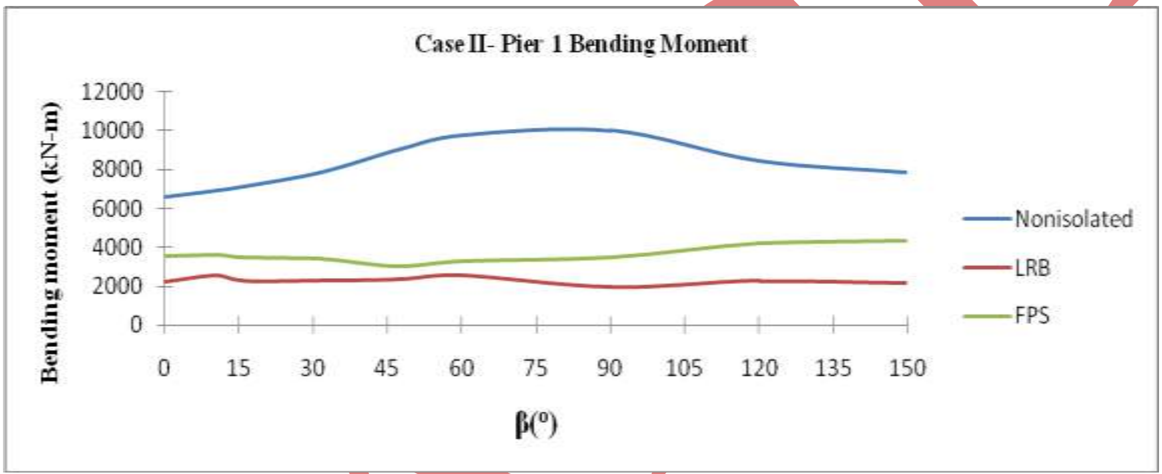

Fig.13. **Case II-Pier 1 Bending Moment of Curved Bridges**

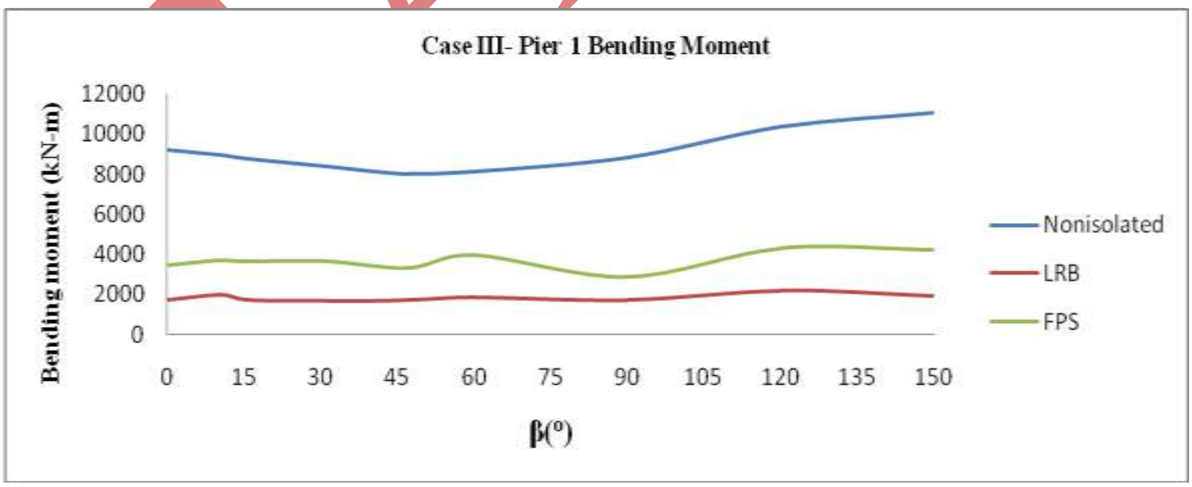

Fig.14. **Case III-Pier 1 Bending Moment of Curved Bridges**

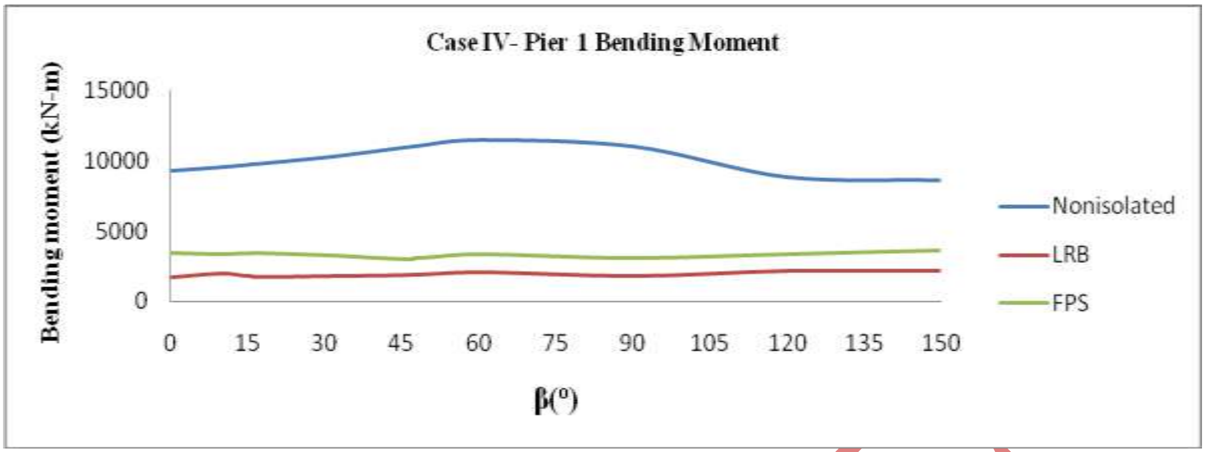

Fig.15. Case IV-Pier 1 Bending Moment of Curved Bridges

VI. COCLUSIONS

In the present study, effects of isolators on the response of curved bridge with varying radius of curvatures are investigated. Some of the findings of the present study are as follows:

1. The use of Isolator in curved bridges would induce better performance on pier displacement and pier forces reduction.

2. LRB is found to be more effective in reduction of Pier displacement and pier forces than FPS.

3. The responses of bridge isolated with LRB are insignificant w.r.to the angle of curvature of the bridge.

4. Based on the present study, a general conclusion on the selection of the isolation bearing cannot be drawn as that involves a lot more investigation. Within the scope of the present study, valid for the considered ground motion only, any of the above systems can be used depending on the availability of skill and cost considerations for local conditions.

VII. ACKNOWLEDGMENTS

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