Comparative Study to Determine Seismic Efficiency of Various Bridge Bearings

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Abstract - Bridges play a vital role in transportation network, hence their seismic efficiency plays a crucial role. Seismic base isolation is an important technique to reduce the seismic vulnerability by increasing the seismic demand of the structure. Base isolators functions by decoupling the superstructure from substructure during an earthquake. The lateral forces acting on the superstructure are reduced by shifting their fundamental period from the time predominant period of ground motion and thereby providing additional damping. In this paper, Triple Friction Pendulum System (TFP) and Lead Rubber Bearing (LRB) are taken for comparative study in a box girder concrete bridge. A response spectrum analysis is carried out to determine the displacement happening in the base isolators and thereby determining the seismic efficiency of the isolators. The modelling and analysis is carried out using the CSI Bridge software.

Keywords: Concrete Box Girder, Base isolators, Response Spectrum Analysis, CSI Bridge

Introduction

Destructive earthquakes and other induced vibrations on structures have led to the need of development of an system to mitigate such hazards on structures. Several researches has been happening in the past few decades on how to mitigate the earthquake effects on structures. An innovative idea for seismic base isolation was coined by William Robinson in 1974 with the invention of Lead Rubber Bearing (LRB) device. Seismic base isolation is considered as a passive protection system. It reduces the effect of earthquake by providing decoupling the superstructure from substructure making the structural acceleration less than that of the ground acceleration during the event of an earthquake. Earthquakes have a catastrophic effects on bridges, hence the seismic isolation of bridges are of crucial importance. Several researches were carried out in the field of seismic base isolation leading to the development of devices like High Damping Rubber Bearing (HDRB) system, Friction Pendulum System (FPS) etc. Sabahmer et al. (2015) states seismic base isolation depends on a lot of factors including length of span, no of continuous span of bridges, seismicity of the area etc. This paper does a comparative study between two base isolators Lead Rubber bearing (LRB) and Triple Friction Pendulum System (TFPS) on a concrete box girder bridge using response spectrum analysis in CSI Bridge software.

1. Lead Rubber Bearing (LRB)

LRB was introduced in 1970's for the seismic base isolation of bridges. Basic components of an LRB includes lead plug, rubber and steel which are placed in layers. The rubber provides flexibility through it's ability to move. The Lead was chosen because of its plastic property while it may deform with the movement of the earthquake, it will revert to its original shape, and it is capable of deforming many times without losing strength. During an earthquake, the kinetic energy of the earthquake is absorbed into heat energy as the lead is deformed. Using layers of steel with the rubber means the bearing can move in a horizontal direction but is stiff in a vertical direction.

Fig.1(a): Cross section of an Lead Rubber Bearing system

2. Triple Friction Pendulum System

Triple friction pendulum system has four sliding surfaces that are stacked. Two of the sliding surfaces are identical which provides three distinct pendulum systems. Triple...
Friction can be developed to achieve multiple performance objectives subjected to different levels of ground motion. The working principle of a friction pendulum system is similar to that of a simple pendulum. The articulated slider moves along a concave surface causing the structure to move in simple harmonic motion during the event of an earthquake Kravchuk et al.(2016). During the event of an earthquake the building tends to slide along the concave inner surface leading to the increase in natural period of the building. A dynamic frictional force is created by the friction interface leading to an energy dissipation during an earthquake event. Fig.2 shows the section a curved/spherical friction pendulum.

Fig.2: Sectional View of Friction Pendulum System

I. METHODOLOGY

A. Modelling

Case study bridge is a 40m span concrete box girder bridge[1]. The total width of the deck section is 12m. Crosssection of the box girder bridge is being shown in the figure below.

Fig 3: Cross sectional view of the deck section (all dimensions are in mm)

The 3D model of the box girder bridge modelled in Csi bridge software is shown in the figure below. The deck section concrete material was assigned with M40 grade concrete and the rebars were assigned HYSD415.

B. Loading

Based on the carriage way width of the deck section calculated as per IRC-6(2014) specification and the span of the bridge, two lanes of class A and one lane of class 70R are defined. The moving live load was defined as multi step static load for the analysis (Fig.5). Footpath live load was also considered for the analysis. The other loads taken for the analytical purpose included the dead load and crash barrier load (Taken as superimposed dead load). Fig.6 provided below shows the load cases defined.

Fig.5: Vehicle load definition

Fig.6: Load cases defined for analysis

C. Response spectrum analysis

In this research response spectrum analysis was chosen to evaluate the performance of the base isolation system. The response spectrum was defined with an effective damping ratio of 0.05 based on IS1893.
For normal bridges:
Importance factor, $I=1$ [Table 2: IS1893: Part-3]
Response reduction factor, $R=3$ [Table 3: IS1893: Part-3]
Zone factor is taken as 0.36 (Severe condition)

D. Base Isolation

Two types of base isolation system are considered for this case study, which are Lead Rubber Bearing (LRB) and Triple Friction Pendulum system (TFP). The bearings are assumed to be spherical in shape. The parameters required for the design of bearings like rotational inertia, effective stiffness and effective damping are calculated based on the AASHTO LRFD (2011) [2]. The values of stiffness and masses were calculated for different types of bearing isolators for its definition.

II. ANALYSIS

In the present study, a bridge is modelled and analysed first with normal elastomeric bearings and results are found out. Based on the load coming onto the bearings, two types of bearings which are Triple Friction Pendulum system (TFP) and Lead Rubber Bearing (LRB) are defined. These bearings are assigned as link/support properties and two separate models for each bearing are made and analysed. Response spectrum analysis is carried out to determine the seismic efficiency of the bearings. The forces, moments and displacements values are to be obtained in the results and these are compared to find the effectiveness of each type of base isolator and their importance.

III. RESULTS

The earthquake analysis with all types of bearings in each model was carried out and the solution is to be discussed as follows.

Since the main objective of this paper is to study the efficiency of the base isolators which is important for earthquake analysis, only results for earthquake cases will be studied to obtain a conclusion. The X direction considered in the model is the direction along the longitudinal axis of the bridge, that is span and the Y direction is the direction perpendicular to the longitudinal, that is the transverse direction of the bridge.

<table>
<thead>
<tr>
<th></th>
<th>FPS</th>
<th>LRB</th>
<th>NORMAL</th>
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</thead>
<tbody>
<tr>
<td>AXIAL FORCE</td>
<td>4.36E-05</td>
<td>3.15E-04</td>
<td>1.68E-04</td>
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<tr>
<td>SHEAR VERTICAL(V2)</td>
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<tr>
<td>LONGITUDINAL DISP.</td>
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<tr>
<td>TRANSVERSE DISP.</td>
<td>9.8362</td>
<td>0.6592</td>
<td>0.283</td>
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</table>

Table 1: Forces and Displacements for Earthquake in X directions (kN-mm)

The forces and displacements are briefly explained as follows:

i. Axial Force

The Axial force was found to be maximum in the model with LRB bearing and minimum in case of FPS isolator for earthquake in X direction. The axial force was found to be maximum in normal bearing and minimum in FPS for earthquake in Y direction.
ii. Shear Force

The forces were found to be minimum in case of FPS isolator and maximum in LRB isolator. All the dead loads and other loads get transferred to the substructure through the bearings as reaction or moments. When more number of bearings are placed under the girders, lesser reaction will be transferred to each bearing and hence the dimensions of the bearings can be reduced.

iii. Moments and Torsion

The moments and torsion are found to be minimum in FPS base isolator whereas it was found to be maximum in LRB for earthquake in X direction and maximum in normal bearings for earthquake in Y direction. Lesser the moments more economical the section hence the type of base isolator bearing giving lesser values will be more effective.

iv. Displacements

The displacement values need to be within limits in any cases. Since the earthquake is generally applied in horizontal direction, the values of transverse and longitudinal displacement play more important role than vertical displacement. The transverse displacement was found to be higher in case of FPS isolator which indicates that the distance between the superstructure and the substructure is more during earthquake and hence the effect of ground motion during earthquake is reduced in the superstructure. In some cases the displacements in LRB isolator are found to be higher.

IV. CONCLUSIONS

Graph 1: Comparison of forces for Earthquake in X direction

Graph 2: Comparison of forces for Earthquake in Y direction

From the comparative study carried out between the different types of base isolator bearings with the normal bearing, the following conclusions can be drawn:

a) From the horizontal shear force for earthquake in X direction, we can see that the value is maximum in FPS isolator and minimum in normal bearing compared to that of LRB isolator bearing. Since the force is more in case of FPS it will cause more load on the substructure.

b) From the moment about horizontal axis for earthquake in X direction, we can see that the moment is minimum for FPS and maximum for LRB isolator bearing.

c) From the transverse displacement graph for earthquake in X direction, we can see that the value is high for FPS isolator since the base isolation takes place. The substructure moves in the transverse direction whereas the superstructure does not get much affected and hence the displacement is high.

d) From the horizontal shear force for earthquake in Y direction, we can see that the value is maximum in normal bearing and minimum in FPS isolator bearing compared to that of LRB isolator bearing. Since the force is least in case of FPS it will be more effective than others.

e) From the moment about horizontal axis for earthquake in Y direction, we can see that the moment is maximum for FPS and minimum for normal bearing compared to LRB isolator bearing.
f) From the longitudinal displacement graph for earthquake in Y direction, we can see that the value is high for FPS isolator since the base isolation takes place. The substructure moves in the transverse direction whereas the superstructure does not get much affected and hence the displacement is high.

After comparing all the forces, moments and displacements for FPS, LRB and normal bearings we can see that different bearings have different advantages at various points. But the maximum effective that be concluded as the FPS bearing isolator which will help the bridges to have minimum damages during the earthquake. LRB isolator bearing is the second most efficient type of bearing isolator that will allow less forces to transmit through the bearing from the substructure to the superstructure.

V. REFERENCES


