Seismic Analysis of Isolated and Non-isolated Railway Bridges with Slab Track—A Comparative Study

A. Shivaraj, G. Sudarshan, G. Sridevi, and B. Umesh

1 Introduction

Highway and railway bridges are vital components in the infrastructure of transportation networks. These structures experience significant structural and non-structural damage during the earth quake. Earthquake can cause damage not only on account of the shaking of the super structure but also due to permanent lateral displacement because of either soil settlements or ground lateral displacements. It is, therefore, important to take necessary precautions in the planning and design of structures so that they are safe against such secondary effects also. The damage caused to these structures during earthquakes engenders the functionality of the railways, thus leading to significant losses. The behavior of a railway bridge system depends on the interaction of the three subsystems: the rolling stock, the rail track, and the subsoil. The nonlinear behavior of these subsystems makes the assessment of the system, as a whole, very complex. The base isolation attempts to decouple the structure from the damage caused due to ground movement at the time of earthquake.

Xiang and Li [1] conducted a practical test to identify the sliding behavior of LRB with specific configurations in China. Shen et al. [2] introduced a new seismic isolation system.

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Yuan et al. [3] conducted real-time hybrid simulation tests on a multi-span continuous highway bridge under different seismic ground motions.

Research has shown that traditional isolation methods are efficient in reducing the harmful effects of earthquakes on bridges [4], among various low-loss flexible design options.

Haque et al. [5] analyzed the seismic response of a base-isolated highway bridge with seismic responses of a base-isolated highway bridge with different isolators. Non-linear dynamic analysis of the multi-span bridge was carried out with three types of LRB, namely, natural, high dumping, and lead rubber bearing. The impact of laminated rubber bearings on significantly reducing the reaction of rigid bridge systems is significant.

Di Sarno [6] carried out the comprehensive linear and nonlinear dynamic analyses of a typical railway bridge system. The introduction of lead rubber bearings greatly improved the earthquake bridge response; however, the isolation equipment does not meet the serviceability requirements because of the rails. Steel dampers as isolators are recognized as an advantageous construction system in terms of service efficiency and final boundary states. Dimitriadou [7] studied the seismic performance of a bridge with LRB provided at the top of the pier. The dynamic response was studied before and after the introduction of lead rubber bearings. As peak ground acceleration (PGA) levels increase, the bridge response in the piers increases with the corresponding values in the rest of the deck at the same level. Couture Zella et al. (2014) studied the effect seismic isolation system of a bridge for Kobe earthquake of 1995 in both lateral and longitudinal directions.

Alberto et al. [8] analyzed the effects of the isolation devices on the Post-Yielding Stiffness. Four different yielding forces of the hysteric damper (Fy) were considered, keeping the stiffness properties constant. The behavior of the bridge is analyzed for maximum and residual displacements by changing the device's yielding force.

1.1 Need of Seismic Isolation in Bridges

Isolation systems do not absorb seismic energy, but instead dissipate it through the dynamics of the system. In this way, a structure is separated from its foundation, and superstructure of the bridge is separated from the piers.

In bridges, the concept of decoupling is very different than in buildings. In bridges, most of the load is concentrated in a parallel plane, superstructure.

1.2 High Damping Rubber Bearings

HDRB reinforces rubber sheets and steel plates in the isolator. These components allow HDRB to separate the bridge superstructure from the substructure due to its high horizontal orientation and allow up to 16% of the energy dissipation. Effective

HDRB isolators have the ability to transmit vertical loads due to live loads, dead loads and accidental impacts, the capacity to support horizontal loads by allowing very little displacement relative to the ground. HDRB does not damage the remaining structure due to its elastic response to high magnitude earthquakes without interruption in structural performance.

1.3 Slab Track (Ballastless Track)

A slab track means that the ballast is recoupled by a reinforced concrete slab track that transmits load and enhances stability. It is, also known as ballastless track, a modern form of track used for high-speed lines, heavy rail, and tram systems. Slab track technology offers higher performance and longer service life than traditional ballasted track.

1.4 Aim of the Work

- To find the response time of decoupled bridges and Non-Isolated bridges for same material, structural properties, and study the performance of isolator in prolonging the response time subjected to seismic loads.
- To find the displacement of bridge deck of Isolated and non- isolated bridges in both directions.

2 Methodology

In the present study, two railway bridges, one with base isolation and one without base isolation having 39 m in length and 12.16 m width are designed by LIMIT STATE OF DESIGN method. SAP2000 V14 is a standout amongst the most refined and easy to understand programming. Both models are analyzed by RESPONSE SPECTRUM METHOD in SAP2000. High damping rubber isolator for isolated bridge is designed as per AASTHO code. Dynamic responses of models are compared and studied.

Slab to support ballastless broad gauge of track width 1.676 m is analyzed and designed by considering live load 80.9 kN/m on both the rails as per IRS Standards. SAFE is the ultimate tool for designing RCC floor and foundation systems. In this present study, structural and geometrical design of slab on which rails are resting has been done by SAFE.

2.1 Response Spectrum Method

Earthquake analysis and the design of a structure to be built at a specific location require real-time history records of earthquakes. However, it is not possible to have such records everywhere. Furthermore, seismic analysis of structures cannot be done only on the basis of the maximum value of the earth acceleration because the response of the structure depends on the frequency of the earth motion and its dynamic properties. To overcome the above difficulties, the most popular tool in seismic analysis of structures used is seismic response spectrum. This method calculates only the maximum values of displacement and member forces in each vibration mode.

2.2 Governing Factors

- Energy dissipation
- Epi-central distance
- Soil condition
- Richter magnitude
- Damping
- Time period.

2.3 Description of Model

Dynamic live load on rail tracks is converted into static load and applied on both the rails. As per IRS standards, live load on each track of broad gauge of width 1.6765 m is 80.9 kN/m. Along with live load on track, self-weight of track is also considered as per IRS standards, i.e., 0.58 kN/m. In this study, ballast less slab of width 6.08 m is analyzed and designed for above mentioned load configuration in SAFE software. As a result, intensity and nature of various stresses that have been generated in slab model is studied and designed for the maximum stresses.

In this study, 2-span elevated RC-Bridge of each span length 19.5 m is considered. Typical circular piers of height 10 and 1 m in cross section are supporting pier cap of size 0.4 m $\times$ 0.9 m, over which longitudinal girders of size 1.3 m $\times$ 0.8 m are resting. And also, to enhance lateral stability of super structure, cross girder of size 0.65 m $\times$ 0.4 m is introduced at center of each span of bridge. Center-to-center distance between piers in lateral direction is 4.955 m. And total thickness of slab designed and considered is 0.35 m.

High damping rubber bearing is introduced at the top of pier cap, i.e., between pier cap and longitudinal girders. Load on each HDRB is calculated and designed as per AASTHO shown in Table 4. Here, HDRB is used to decouple the superstructure and substructure to avoid the transfer of hazardous seismic ground motions to superstructure by means of energy dissipation. When structure gets excited at certain frequency during earthquake, kinetic energy is transferred to the super structure through sub structure. When isolators are introduced in between superstructure and substructure, kinetic energy will get dissipated by converting into heat energy. And also, these isolators have got good restoring capacity because of their own material properties to regain its original position.

2.4 Description of Bridge

The Super structure model of bridge structure chosen for analysis is modelled in SAFE is shown in Fig. 1. The bridge was modelled in SAP 2000 and the model is shown in Fig. 2. The geometrical properties of the slab, unit weight of the material are presented in Table 1, bridge components data in Table 2, and selected criteria for the analysis in Table 3 and the properties of High damp rubber bearing are given in Table 4.

Model has been analyzed for severe earthquake conditions.

Designed Properties of High Damping Rubber Bearing (As per AASTHO).

3 Results and Discussions

The results of non-isolated bridge model, i.e., time period and frequency, static–dynamic percentage, and displacement are shown in Tables 5, 6, and 7, respectively, and Fig. 3 represents the response spectrum curve of non-isolated bridge.

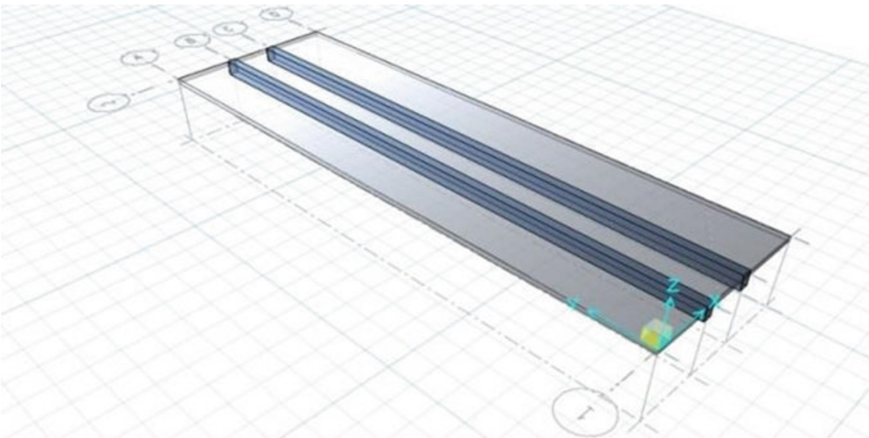


Fig. 1 Slab model in SAFE

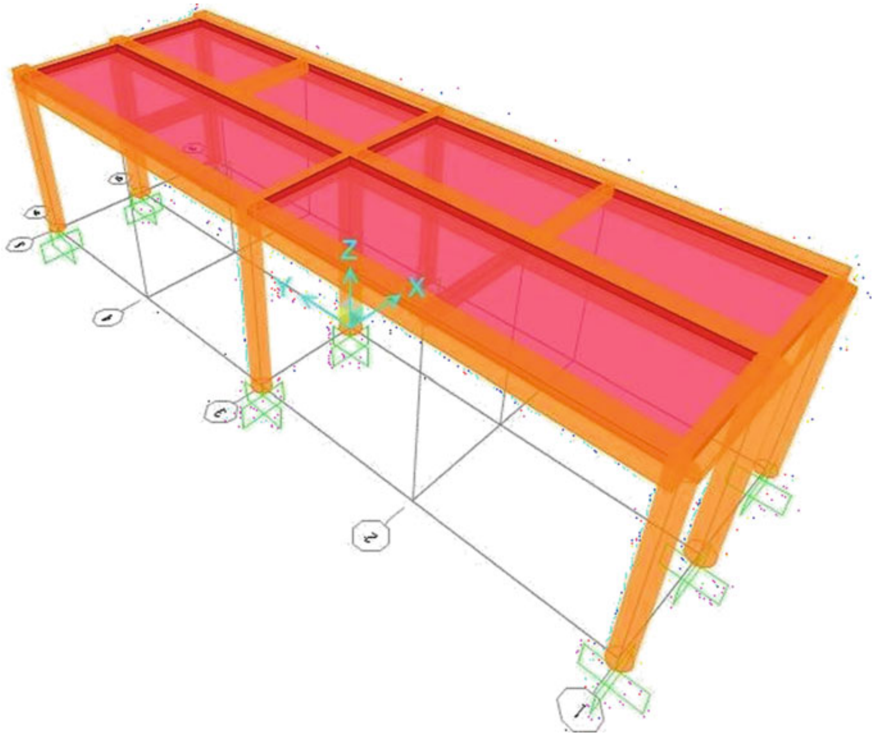


Fig. 2 Model in SAP

Table 1 Geometrical properties of slab

Length	19.5 m
Width	6.08 m
Thickness	0.20 m
Load on each track	80.9 kN/m
Weight of rail	0.58 kN/m

Table 2 Bridge data

Total length	39 m
Width	12.16 m
Pier height	10.0 m
Dimensions of pier	1.0 m in diameter
Dimensions of pier cap	0.4 m * 0.9 m
Clear span length	19.5 m
Cross section of longitudinal girder	1.3 m * 0.8 m
Cross section of cross girder	0.65 m * 0.4 m
Thickness of slab	0.350 m
Distance between piers	4.955 m

Table 3 Criteria's

Zone	V
Importance factor-I	1.5
Response reduction factor-R	3
Soil type	II (Medium)
Damping of structure	5%

3.1 Non-isolated Bridge model

The results of isolated bridge model, i.e., time period and frequency, static–dynamic percentage, and displacement are shown in Tables 8, 9, and 10, respectively, and Fig. 4 represents the response of Isolated Bridge.

4 Observations and Conclusions

By the observation of the RESPONSE SPECTRUM curves of both isolated and non-isolated bridges, the time periods or response time of isolated bridges is observed to get postponed from 0.40288 to 0.4742 s because of the use of HDRB rubber bearing for isolation for same seismic, material, and structural parameters.

Model participation ratios for both non-isolated and isolated bridges are 99.99%. Displacement of bridge deck or superstructure for non-isolated bridge is 26.2 mm in X-direction and 73.5 mm in Y-direction. Whereas for the isolated bridge, it is 26.3 mm in the X-direction and 0.8 mm in Y-direction. The reduction in the displacement is not observed in X-direction because of higher stiffness of the bridge in that particular direction.

The reduction in displacement in Y-direction is observed significantly and a reduction of 91.87% is observed.

The study of 12 mode shapes of dynamic response show the lateral displacement of bridge in both the directions, i.e., X and Y for the first two mode shapes, respectively. Most importantly, the torsion is observed in the bridge model at 3 mode shape of the response.

Table 4 Properties of HDRB

	HDBR for (6089.91 kN)	HDBRfor (11593.96 kN)	HDBR for (12119.04 kN)	HDBR for (23066.36 kN)
Diameter of Rubber (d) (m)	0.9944947	1.372	1.4029	1.93547
No. of layer (N)	8.0	6.0	6.0	4.0
Steel Plate thickness (ts) (m)	0.0023678	0.0032671	0.0033403	0.0046083
Height of bearing (m)	0.1486072	0.148607	0.148607	0.1486072
Base shear Vb (kN)	4384.7352	8347.6512	8725.7088	16607.779

Table 5 Period and frequency

Period (s)	Frequency (Cyc/s)
0.40288	2.4821106
0.40233	2.4855317
0.33778	2.9604959
0.19966	5.0085891
0.1649	6.0643451
0.16261	6.1495877
0.15978	6.258487
0.12185	8.2066327
0.10948	9.1343455
0.06248	16.006078
0.03127	25.980709
0.03002	27.020723

Table 6 Static and dynamic percentage for non-isolated bridge

	Item	Static percent	Dynamic percent
Acceleration	X-direction	100	99.998
	Y Direction	100	99.999

Table 7 Displacements for non-isolated bridge

X-direction	Y-direction
6.2 mm	73.5 mm

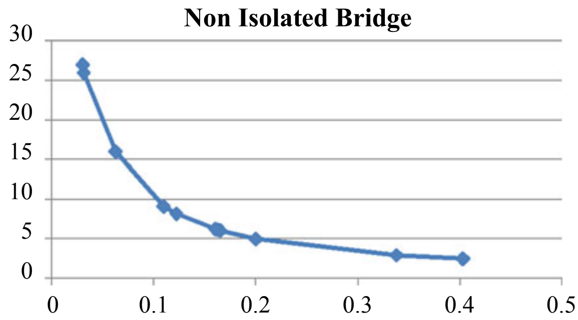


Fig. 3 Response curve for non-isolated bridge (time period v/s frequency)

Table 8 Time period and frequencies

Period (s)	Frequency (Cyc/s)
0.4742	2.4821106
0.47131	2.4855317
0.37473	2.9604959
0.20067	5.0085891
0.17528	6.0643451
0.16517	6.1495877
0.16016	6.258487
0.13399	8.2066327
0.12227	9.1343455
0.09272	16.006078
0.06989	25.980709
0.05947	27.020723

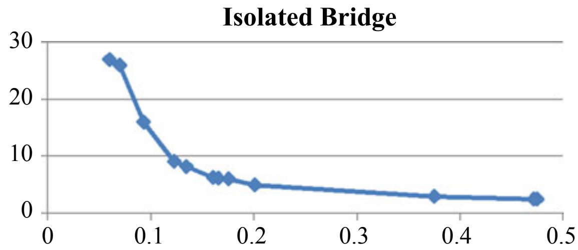
Table 9 Static and dynamic percentage for isolated bridge

	Item	Static percent	Dynamic percent
Acceleration	X-direction	100	99.9999
	Y-direction	100	99.9999

Table 10 Displacements for isolated bridge

X-direction	Y-direction
26.3 mm	0.8 mm

Fig. 4 Response curve for isolated bridge (time period v/s frequency)



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