Performance of Lead Rubber Bearing as a Base Isolator

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Abstract

One of the most dangerous natural hazard is earthquake. The damages caused by earthquakes are uncountable. The occurrence of earthquake causes loss of lives and damages to manmade structures. One of the most widely accepted solution for reducing the damages caused by earthquake on Civil Engineering structures is Base isolation. Among the wide variety of base isolation systems, Lead rubber bearing plays an important role. The performance of lead rubber bearing during earthquake is evaluated by the finite element modelling and non-linear analysis in ANSYS workbench 17.0 in this study. The behaviour of lead rubber bearing is compared with that of laminated rubber bearing.

Keywords: ANSYS Workbench 17.0, Base Isolation, Hysteresis Curve, Lead Rubber Bearing, Non-Linear Analysis

I. INTRODUCTION

Base isolation is a new technique used in preventing the damages caused by earthquake on buildings, bridges and other man-made structures. The technique doesn’t require any additional energy source for working, so it is called a passive system of seismic control. Base isolation system prevents the superstructure from damaging during earthquake by decoupling the fixity between the superstructure and substructure. This is achieved by the increase in lateral flexibility of the structure by the provision of a flexible layer between the foundation and superstructure. The base isolator increases the time period of vibration of the structure which in turn shift the frequency of structure out of the range of frequency of the seismic waves and ground motion. The isolating pad is formed by alternate layers of rubber and steel vulcanized together to form a laminated rubber bearing. Extra damping is provided by the insertion of a lead cylinder core into the center of laminated rubber bearing, which is termed as a Lead rubber bearing base isolator. The study is intended to evaluate the performance of circular lead rubber bearing by the finite element modelling and analysis in the finite element package of ANSYS Workbench 17.0 incorporating all the non-linearity’s. The study in this paper is extended by a comparison between circular laminated rubber bearing and lead rubber bearing base isolators.

II. NON-LINEAR STATIC ANALYSIS OF BEARINGS IN ANSYS 17.0

A. Geometry of the Bearings

The geometry of the rubber bearings are fixed for a vertical load carrying capacity of 450 kN and maximum horizontal displacement of 150mm. The dimensions of the bearing are adopted from the Isolator Engineering properties provided by Dynamic Isolation systems [2]. For the laminated rubber bearing, total diameter of the bearing was taken as 305mm, with 8-13mm thick rubber layers and 7-3mm thick steel shims making up a total height of 175mm including two steel mounting plates of thickness 25 mm at top and bottom of the bearing. For the lead rubber bearing, a central lead cylinder of diameter 70mm is incorporated to the above mentioned bearing. The overall geometry of the two bearings are shown in Fig. 1.
B. Finite Element Modelling

The bearings are modelled as three dimensional structural solids in ANSYS 17.0 by considering a half plane symmetry for reducing the computation time.

![Finite element semi model of lead rubber bearing](image1)
Fig. 2(a): Finite element semi model of lead rubber bearing

![Finite element semi model of laminated rubber bearing](image2)
Fig. 2(b): Finite element semi model of laminated rubber bearing

C. Material models used

The material properties considering the non-linearity of rubber, steel and lead for the finite element analysis are as follows.
- Lead: Bilinear isotropic algorithm with initial yield strength 10 MPa, Elastic modulus 17500 MPa, Poisson’s ratio 0.44.
- Rubber: Neo Hookean model with Initial shear modulus 0.4 MPa, Bulk modulus 2000 MPa.
- Steel: Non-linear structural steel with yield stress 250 MPa, Poisson’s ratio 0.3, Tangent modulus 1450 MPa and Young’s modulus 2x10^5 MPa.

D. Boundary conditions and loading

All the nodes at the bottom surface were fixed against rotations and translations. The load was given as strain controlled by applying 50% strain of bearing as a constant amplitude cyclic loading with 52mm as the maximum displacement on the top surface nodes in X-direction for a duration of 4 seconds.

![Cyclic displacement applied in mm](image3)
Fig. 3: Cyclic displacement applied in mm

III. RESULTS OF NON-LINEAR STATIC ANALYSIS AND DISCUSSIONS

The two models of lead rubber bearing and laminated rubber bearing are analyzed by considering geometric and material non-linearity’s in static structural platform and the obtained results are given below.

A. Lateral displacement of bearings

![Lateral displacement of lead rubber bearing](image4a)
Fig. 4(a): Lateral displacement of lead rubber bearing

![Lateral displacement of laminated rubber bearing](image4b)
Fig. 4(b): Lateral displacement of laminated rubber bearing
Both the bearings could take the lateral displacement of 52 mm without failure. The lateral displacement for both the bearings were found to be in the range of 52 mm. The rubber layers shows a lateral bulging under loading in both the bearings, but it is minimised by the steel shims.

B. Force-deformation curves of bearings

The figure 5 shows the force-displacement curves of both laminated and lead rubber bearings. It is very much visible that the energy dissipation capacity of lead rubber bearing is enormously greater than that of laminated rubber bearing. The force-lateral displacement curve of lead rubber bearing forms a hysteresis loop producing an energy dissipation of 1887 kNm taken as the area of hysteresis loop. This increase in energy dissipation of lead rubber bearing is due to the damping produced by plastic deformation of the additional lead core present in lead rubber bearing. The slopes of force-deformation curves show the stiffness of bearing. In the figure 5(a), the dashed line shows the yielding point beyond which the bearing deforms plastically. The slope of the curve after yield point is termed as yielded stiffness or post-yield stiffness.

From the force-deformation curve of laminated bearing, no visible hysteresis was observed and shows nearly linear shear stress-strain behavior under this small displacement as damping in elastomeric bearing is not hysteretic in nature. But it produces a lateral displacement equivalent to lead rubber bearing which makes it suitable in base isolation by increasing the natural period of vibration of superstructure from the lateral flexibility of rubber layers.

The slope of force-deformation curve before yield point is termed as pre-yield stiffness. From figure 5(a), the post-yield stiffness and pre-yield stiffness are calculated for lead rubber bearing. The ratio between pre-post yield stiffnesses for a lead rubber bearing is nearly 10 [9]. The value of pre-yield stiffness was found to be 1.153 kN/mm and that of post-yield stiffness was 0.124 kN/mm. Thus the ratio between pre-yield and post-yield stiffnesses was calculated to be 9.3 from this study which matches with the theoretical ones. This verifies the accuracy of finite element model of the bearing.

C. Equivalent Stress in Steel Shims and Rubber Layers

The stress in steel shim and rubber layer of lead rubber bearing is larger than that of laminated rubber bearing (figure 6&7) and the maximum stress occurs at the interface between lead and rubber-steel layers due to the confinement of lead core (figure 6(a) and 7(a)).
IV. CONCLUSIONS

The non-linear static analysis of laminated and lead rubber bearings done in ANSYS Finite Element package shows that the performance of lead rubber bearing is better than the conventional laminated rubber bearing. The higher energy dissipation capability of lead rubber bearing is due to the plastic deformation of lead core which deforms even under small shear stress which makes it suitable in strong earthquake regions. The lead readily transform to the plastic state because of the very small yield stress about 10 MPa. The laminated rubber bearing showed a linear shear force-displacement curve without much hysteresis. It also undergone a lateral displacement equivalent to lead rubber bearing which makes it suitable near low-moderate earthquake regions. The ratio between the elastic and post yield stiffness of lead rubber bearing in this numerical analysis goes well with the theoretical value which shows that the presented finite element simulation could accurately capture the behaviour of bearings.

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