iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** III **Month of publication:** March 2019

DOI: http://doi.org/10.22214/ijraset.2019.3256

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue III, Mar 2019- Available at www.ijraset.com

Experimental and Analytical Investigation on Fiber Reinforced Elastomeric Isolator: Review

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Abstract: In the past two decade many research has been done in the field of Base Isolation System, mainly in replacing conventional isolators with low-cost multi layer elastomeric isolators. This paper presents an overview of fiber-reinforced elastomeric isolators. The overcome made by going through papers are; FREI is an alternative of steel-reinforced elastomeric isolators (SREI). FREI is low cost, effective in dissipating the seismic forces and easy to construct as compared to conventional isolators. The experiment and analysis on FREI shows that it consists of higher vertical stiffness and lower horizontal stiffness. The effective damping of FREI is superior to conventional isolators. The cost of FREI is around thousands of rupees whereas conventional isolators come in lakh. Hence, FREI is more convenient to those developing countries which often have inadequate seismic protection in earthquake prone-zones because they are cheaper when compared to conventional isolators and also lightweight installation.
Keyword: Fiber-Reinforced elastomeric Isolators (FREI), Steel Reinforced Elastomeric Isolators (SREI), vertical stiffness, horizontal stiffness, damping.

I. INTRODUCTION

In passive earthquake protection system, base isolation plays an important role. It is an efficient method to reduce the vulnerability of structures in high seismic risk zones. The basic concept of base isolation is to minimize the effect of earthquake motion by reducing the stiffness, increasing the natural period, and to increase energy dissipation in the system. The isolators used in structures are heavy and expensive, which make it rare in developing country like India. To make the isolation a viable method it is necessary to reduce the cost of isolators.

II. STEEL-REINFORCED ELASTOMERIC ISOLATORS (SREI)

Conventionally, Steel plates are used as reinforcing material. Steel plates are placed between rubber layers and heating them under pressure for several hours bonded them as one. This type of isolator is called Steel-reinforced elastomeric bearings (SREI). Further, while placing thick end plates of steel on both ends of isolator makes it heavy, expensive and complicated process. All these make conventional isolators unsuitable for use in low rise buildings, particularly in developing countries. This problem can be overcome when steel is being replaced by fiber materials.

III. FIBER-REINFORCED ELASTOMERIC ISOLATORS (FREI)

When fiber material is vulcanized by rubber layers, fiber-reinforced Elastomers are formed. Such elastomer, when used as bearing is called Fiber-Reinforced Elastomeric Isolators (FREI). They are light in weight, easy to manufacture, low skilled labour are required and cheaper than SREI. The reinforcement has been provided to impart vertical stiffness to the elastomer. Another advantage of fiber reinforcement is that it would then be possible to build isolators in long rectangular strips, whereby individual isolators could be cut into required size. They are completely flexible in bending, therefore when a fiber-reinforced isolator is loaded in shear, a plane cross section becomes curved. When bearing is displaced in shear, the tension in fiber bundle produces a frictional damping that is due to individual strands in the fiber bundle slipping against each other. This energy dissipation in the reinforcement leads to additional damping.

IV. LITERATURE REVIEWS

An Experimental and Analytical works have been presented on Fiber-reinforced Elastomeric Isolators. In this review paper some literature in brief is presented by different Scholars and researchers.

Kelly [1986] summarized the bibliography of all literature on theoretical aspects of seismic isolation as published from 1900 to 1984.the first use of un- reinforced rubber block as earthquake protection was in an elementary school in Skokie, Yugoslavia. The base isolated building underwent rigid body motion during the first mode of vibration with all the deformation mainly at the isolator level. For higher node, seismic load was treated as an equivalent lateral load which was proportional to the rigid body mode. Thus working principle of base isolation system is to deflect energy rather than to absorb energy.

Kelly [1999] presented method of evaluation of the mechanical characteristics of fiber reinforced elastomeric isolator in which steel plant of conventional elastomeric isolators were replaced by fiber reinforced. Fiber fabric has high stiffness in extension, but lacks flexural rigidity. The influence of fibre flexibility on the mechanical properties of FREI, such as vertical and horizontal stiffness was studied. Some specific advantages of FREI as light weight and ease of manufacturing were also presented in this study.

Kelly and Takhirov [2001] carried out theoretical and experimental analyses for the evaluation of mechanical characteristics of FERIs. Compression stiffness of isolator with flexible reinforcement was derived. Four 305 mm diameter isolators were tested in shear in pairs under a vertical load equivalent to a pressure of 6.90 MPa. Isolators were tested in cyclic shear, with three fully reversed cycles at three maximum strain levels of 50%, 100% AND 150%. The test result showed that it was possible to use un-bounded isolators for seismic isolation of structures. Although a considerable amount of edge uplift occurs, the force displacement curve always had positive stiffness, indicating that the bearing was still stable at 150% shear deformation even though it appears to be undergoing roll over deformation.

Moon et al. [2002] designed and manufactured some specimens of fiber-reinforced multilayer elastomeric isolators using different kinds of fiber such as carbon, glass, nylon and polyester. Experiments were carried out to evaluate and compare the performances of fiber reinforcement with performance of steel reinforcement, and the differences in performance among different kinds of fiber reinforcement. Experiments showed that performance of the carbon FREI was even superior to that of SREI in view of vertical stiffness and effective damping. Vertical stiffness of carbon fiber reinforcement was higher than that of glass fiber reinforcement. Vertical stiffness of the carbon FREI was three times higher than that of SREI. Further, the bulging of carbon FREI was lesser than that of SREI.

Experimental study of strip isolator was carried out by Kelly and Takhirov [2002]. Using long strips of rectangular isolators had many advantages over conventional isolators, especially in case of buildings where walls provide lateral resistance. Generally, at base level of base isolated buildings, wall beams are provided between isolators to carry the load of walls. The base level wall beams can be avoided by using long strip isolators on continuous wall footing of the building. The test result showed that the concept of a strip isolator reinforced with carbon fiber was viable. The isolator could be made in long rectangular strip and cut to the required width for use as a strip below wall of the building. Manufacturing cost of large size rectangular strip isolator will be less as compared to the manufacturing of individual circular or rectangular isolator.

Tsai and Kelly [2002b] presented a theoretical approach to analyze the bending stiffness dominant. The stiffness formula was derived. The influences of fiber flexibility on the mechanical properties of the FREI subjected to pure bending moment were studied, mechanical properties such as the pressure in elastomer, the stress in reinforcement and the bonding shear stress between elastomer and reinforcement affected by the bending were presented.

Moon, Kang, Kelly et al. [2003] in this paper, a strip-type fiber-reinforced elastomeric isolator is proposed. To provide the variable characteristic of the isolator, theoretical analysis and experimental tests were carried out. From the horizontal test, the horizontal stiffness of the fiber-reinforced isolator in certain directions is higher than that of the conventional isolator. Also, it is shown that for a specified period the isolator satisfies the current UBC code for seismic isolation formulation. From the vertical test at average pressure, an adequate vertical vibration frequency is obtained, which is important for any isolation application with an effective compression modulus.

Tsai et al. [2004] in this paper the compression stiffness of the laminated elastomeric bearings of infinite-strip shape with flexible reinforcements are derived. Three types of the elastic layers bonded to flexible reinforcements are studied. The first type simulates the interior elastic layers of the bearings with shear-free ends. The second type simulates the exterior elastic layers of the free-end bearings. The third type simulates the elastic layers in the bearings which ends are bonded to rigid plates. The theoretical solutions to the compression stiffness of the bearings are extremely close to the results obtained by the finite element method, which proves that the displacement assumptions utilized in the theoretical derivation are reasonable.

Tsai et al. [2006] this paper describes about the compression stiffness of a circular bearing that consists of laminated elastic layers interleaving with flexible reinforcements is derived in closed form. The stiffness of the bearing with monotonic deformation was derived first. Then, the bearings with both ends being free from shear force and the bearings with both ends being bonded to rigid plates were studied. The theoretical solutions to the compression stiffness of the bearings are extremely close to the results obtained by the finite element method, which proves that the displacement assumptions utilized in the theoretical derivation are reasonable.

Alfred strauss et al. [2008] this paper consist of high damping rubber bearings strengthened with glass fiber fabrics. A numerical investigation through finite element analysis is carried out in order to develop and verify analytical models for these new isolation devices. Therefore, FEA of the liquid storage tank was performed in both isolated and unisolated configuration which result in expected acceleration reduction and period shift were and the validity of the design choices was documented and verified by modal analysis as well as displacement and stress checking.

Pinarbasi, Mengi et al. [2008] in this study, a new formulation is presented for the analysis of elastic layers bonded to flexible reinforcements under uniform compression, pure bending and pure warping. The displacement boundary conditions are included in the formulation, there is no need to start the formulation with some assumptions. Thus, the solutions derived from this formulation are valid not only for thin layers of strictly or nearly incompressible materials but also for thick layers and compressible materials. Its applications are demonstrated by solving the governing equations for bonded layers of infinite-strip shape using zeroth and first order theory. For each deformation mode, closed-form expressions are obtained for displacement/stress distributions and effective layer modulus. The effects of three key parameters: shape factor of the layer, Poisson's ratio of the layer material and extensibility of the reinforcing sheets, on the layer behavior are also studied.

Nezhad, Tait et al. [2009] in this seismic response of an ordinary low-rise base isolated (BI) structure, employing stable unbounded-fiber reinforced elastomeric isolator (SU-FREI) bearings, is predicted by using two different simplified analytical models. Subsequently, the accuracy of the two models is evaluated by using measured test results from a shake table study. The accuracies of two different analytical techniques used to model the lateral load–displacement hysteresis loops of SU-FREI bearings subjected to different input earthquakes were investigated in this paper. Both of these models were constructed based on lateral load–displacement hysteresis loops of the prototype SU-FREI bearings obtained from lateral cyclic testing. In model 1, the lateral response of the bearings was simulated based on the amplitude and rate of lateral displacements but it was not able to capture completely the influence of rate and amplitude of lateral displacements on effective stiffness and damping of the bearings. Whereas, model 2 response prediction was in better agreement as compared with model 1.

Nezhad, Tait et al. [2011] this paper presents a finite element (FE) model for the analysis of strip fiber reinforced elastomeric isolators (FREIs) that are subjected to any given combination of static vertical and lateral loads. The model is able to simulate both bonded and un-bonded boundary conditions at the top and bottom contact surfaces of the isolator. Compared to bonded (B)-FREIs, the FE-analysis of stable un-bonded (SU)-FREIs presents additional analysis challenges. SU-FREI refers to un-bonded FREIs that exhibit stable rollover deformation under lateral loads. Additional analysis challenges are attributed to changes in the boundary conditions of SU-FREI as a result of rollover type deformation. To address these challenges, the utilized FE-mesh is updated during analysis consistent with the deformed geometry of the isolator. Using the proposed FE model, the lateral responses of a B-FREI and a SU-FREI were evaluated. Both isolators had the same material and geometrical properties and were subjected to identical constant vertical loading. Comparing the lateral responses, it was found that the SU-FREI was considerably more efficient than the B-FREI as a seismic isolator. In addition, the in-service stress demands on the SU-FREI were found to be significantly lower than the B-FREI.

Das, Dutta, SK Deb et al. [2012] carried out the mechanical characterization of multilayer fiber reinforced plastic by finite element simulation using ANSYS. Thus, circular and rectangular isolator models were attempted for the analysis. The stable rollover deformation was shown by un-bounded isolator at higher displacement. Further, while horizontal stiffness values are comparable to conventional isolators, higher damping makes FREI's as even better option.

Engelen, D. Konstantinidis, Tait et al. [2012] here the utilization of Stable Unbounded Fiber Reinforced Elastomeric Isolators was investigated. The load-displacement behaviour of the SU-FREIs was analyzed using a bilinear model with the experimental test data for two different designs. One of the isolators considered has holes in the loaded surface, which serve as a means to modify the horizontal and vertical properties of the isolator. Two historical earthquake time histories are used to investigate the performance of these base isolated structures in comparison to a fixed base structure. The peak acceleration, inter story drift, and base shear were investigated in comparison to a fixed base structure as important performance indicator. It was found that the response of base isolated structures ranged between approx 20% and 30% of the fixed base structure response. And isolators with holes found to have lower effective horizontal stiffness.

Russo, Pauletta et al. [2013] this paper describes an experimental study on elastomeric isolators reinforced by bi-directional carbon fiber fabrics performed to investigate the static friction at contact surfaces. The isolators were placed in contact with concrete surfaces and subjected to compressive stress and shear strains. Friction behavior was analyzed in terms of isolator sliding with respect to the concrete sub- and super-structure. Influence on friction behavior of different parameters, such as level of compressive stress, rubber typology, concrete roughness, aging and loading rate, was investigated. The tests showed that, in relation to the value of the applied compressive stress, uncontrolled sliding of the isolator can occur by increasing the shear force.

Naghshineh, Caner et al. [2013] this research has been carried out by using fiber mesh instead of fiber sheet as reinforcement. Four pairs of both fiber mesh elastomeric bearings and conventional bearings were subjected to various levels of compression stresses and cyclic shear strain with strain levels of 25%, 50%, 100% of the total rubber thickness under constant vertical pressure. It was found during the test that fiber-reinforced elastomeric bearings can develop a considerable low horizontal stiffness compared with conventional isolators.

Das et al. [2014] carried out studies to evaluate performance of square FREI subjected to a constant vertical load and cyclic lateral displacement by 3D finite element analysis using ANSYS, a general purpose finite element software. Ogden (three-term) material model and Lagrange multiplier-based u-p element was used to simulate deformation of fully incompressible hyper-elastic materials. These bearings were made by vulcanization of sheets of elastomer to bi-directional carbon fiber fabric. Analysis of all bearings was carried out for both bonded and un-bonded boundary conditions and two lateral loading directions, namely, 0/90 and 45 degrees. Numerical results showed that the lateral stiffness of U-FREI was lesser than B-FERI at higher lateral displacement, and hence efficacy for seismic isolation would be higher than that in 0 degree loading direction. An experimental validation of numerical results was carried out and very good agreement was observed in terms of mechanical properties and deformed configuration of U-FREIs.

Dezfuli, Alam et al. [2014] the paper main aim is to show how efficient the carbon FREIs in bonded applications can operate under different loading conditions. Experimental results show that under cyclic displacements, although a partial de-lamination occurs between rubber layer and steel supporting plate because of the rollover deformation at shear strains greater than 50%, the rubber bearings perform properly up to 100% shear strain. The vertical stiffness increases with increasing the fiber-reinforced layers' thickness and with decreasing the elastomers' thickness. The flexibility in the horizontal direction increases by increasing the total thickness of rubber layers, while the energy dissipation capacity enhances with increasing the thickness of both fiber-reinforced and elastomeric layers.

Konstantinidis, Kelly et al. [2014] this paper presents an overview of the latest advances in seismic isolation using rubber for applications. The discussion focuses on two types of multi-layer elastomeric isolation bearings where the reinforcing elements, normally thick and inflexible steel plates, are replaced by thin flexible reinforcement. In the first type, the reinforcement is provided by carbon fiber; while in the second type, it is provided by thin flexible steel shims. A theoretical analysis of these bearings suggests, and test results confirm, that it is possible to produce a strip isolator that matches the behavior of a conventional steel-reinforced isolator. Also the tested un-bonded bearings with flexible reinforcement survived very large shear strains, comparable to those expected of conventional seismic isolators under seismic loading.

Nezhad [2014] proposed two simplified analytical models to evaluate horizontal stiffness of U-FREI. These two models were derived based on the geometry. The net contact area and free area of the bearing and horizontal displacement were used to derive the horizontal stiffness of bearing. Results of analytical solution for horizontal stiffness of bearing. Results of analytical solution for horizontal stiffness showed a close agreement with FE analysis results with maximum error up to 13%. These formulae can be used for preliminary design of FREI. However, 3D effects were neglected and influence of vertical load and stress-softening of elastomer were not addressed in the developed simplified model. Limitation of these models was identified by the author.

Osgooei et al. [2014b] carried out three-dimensional FE analysis to investigate the lateral response of square FREIs having different aspect ratios and loaded in different horizontal directions. The FE analysis results were validated using experimental test results. The result showed that effective horizontal stiffness of the bearing increased as the loading direction changes from 0 to 45 degree. Further, as the aspect ratio was decreased, the sensitivity of the lateral response to the loading directions also increased.

Spizziuoco, Serino et al. [2014] carried out an experimental study on unbounded square carbon Recycled Rubber–Fiber Reinforced Bearings (RR-FRBs) was conducted to investigate their lateral and vertical behavior, under seismic loading. In this work, the seismic performance of the proposed bearings was investigated by means of both experimental tests and Finite Element Analyses (FEAs). The study provides useful information on both horizontal and vertical stiffness, and on the damping properties of the isolators. Moreover, a description of the instability of the bearings is discussed. The sensitivity of RR-FRBs to lateral displacement history and vertical pressure applied on the bearings is pointed out.

Strauss, Apostolidi, Zimmermann, Gerhaher, Dritsos et al. [2014] In this present article, a literature review on the mechanical characteristics of fiber reinforced elastomeric bearings is presented and the shortcomings of the current European standards concerning statically and dynamically loaded elastomeric bearings are discussed. An experimental procedure conducted on elastomeric bearings with various reinforcing materials and under various loading and support conditions is described for comparison purposes. The experimental procedure includes cyclic loading tests with the application of vertical stress for three bearing types of different dimensional and material properties. The influence of parameters such as vertical stress, horizontal deflection, bearing height, number of elastomer and reinforcement layers, reinforcement material, and type of bearing support on the effective shear modulus and damping coefficient are examined. Moreover, comparisons between experimental and analytical results obtained by respective analytical formulations are further discussed.

Habieb, Milani et al. [2017] in this research we go through the detailed 3D finite element analysis to predict the behavior of the low cost rubber isolator undergoing moderate deformations. The Yeoh Hyper elasticity model is assumed for rubber pads. An isolation system is implemented to structure of two story masonry house prototype, identifying the 3D model with a damped nonlinear spring model. For masonry, concrete damage plasticity (CDP) model available in the commercial FE code Abaqus is adopted. A nonlinear static-pushover analysis is conducted to assess the performance of the isolated building. To simulate a realistic condition under a seismic event, ground motion data is applied to observe the dynamic behavior of the building by monitoring the damage level of masonry. The results reveal that the isolation system proposed can improve the seismic performance of the masonry building effectively, with an excellent applicability of the low-cost rubber isolator.

V. CONCLUSION

These presented reviews of fiber-reinforced elastomeric bearing gives an idea, how the different materials can be used with rubber instead of steel-rubber composition for making it cheaper, light in weight and easy to install. It has also been shown that the vertical stiffness of FREI is higher than conventional isolators such as SREI. It consists of low horizontal stiffness which makes it more efficient. Damping of FREI is comparable to SREI. After all these studies, the device can help to control the responses of medium rise building such as displacement drift and PSa and PSv. There is some more scope which must be analyzed. As whole research work is limited to prototype investigation. Therefore, medium rise building of actual plan should be installed with FREI. And its response spectrum analysis should be done using Indian earthquake parameters. As in developing country like India, FREI will be the better option because its cost efficiency.

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