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Study on the Effect of LRB Isolators on Different Asymmetric Plans of RC Structure

Rasna.P.[1], Shinu Shajee [2]
[1](*P.G Student, Civil Engineering, A.W.H Engineering College, Kuttikkattur, Kerala, India)*
[2](*Assistant Professor, Civil Engineering, A.W.H Engineering College, Kuttikkattur, Kerala, India)*
Corresponding Author: Rasna.P.

Abstract: *Symmetric buildings are those which must have its centre of mass coincident with centre of rigidity at each of the floor level. But practically, the condition is not met and most of the buildings are asymmetrical to varying degree mainly due asymmetry in the plan, elevation, mass distribution etc. In this research, asymmetric structures with plan irregularity are compared. For creating the asymmetry in the structures, eccentricity from 0% to 30% is provided in centre of mass of the structure. To assess the effect of LRB isolators on the response of structures, for the present study 4 types of structures having same outer perimeter area are considered. Both fixed base and base isolated models are created and analyzed in ETABS-2016 software. Comparison based on eccentricity is also carried out by varying the height of the structure from low-rise to high rise building.*
Keywords– *Base Isolation, Centre of Rigidity, Eccentricity, LRB Isolators, Mass Asymmetry.*

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I. INTRODUCTION

For seismic design of building structures, the traditional method, *i.e*., strengthening with respect to the stiffness, strength, and ductility of the structures, has been in common use for a long time. Therefore, the dimensions of structural members and the consumption of material are expected to be increased, which leads to higher cost of the buildings as well as larger seismic responses due to larger stiffness of the structures. Thus, the efficiency of the traditional method is constrained. To overcome these disadvantages associated with the traditional method, many vibration-control measures called structural control have been studied and remarkable advances in this respect have been made over recent years. Structural control is a diverse field of study. In terms of different vibration absorption methods, structural control can be classified into active control, passive control, hybrid control, semi-active control and so on. The passive control is more studied and applied to the existing buildings than the others. Nowadays, the advantages of seismic isolation compared to conventional strengthening methods are universally recognized. These methods generally include adding new structural elements and enlarging the existing members. The addition of shear walls and bracings is the most popular strengthening method due to its effectiveness and lower overall project cost compared to the column and beam jacketing. However, the typical effect of these conventional strengthening methods is the increase in both the stiffness and the lateral load capacity of the structure. As stiffness increases so does the strength. Furthermore, due to the increased stiffness, which translates into a decreased fundamental period, the seismic demand on the structure is also increased. In fact, the period shortening of the structure generally increases the seismic demand except in the case of low-rise buildings that fail in the constant-acceleration region of the response spectrum. Thus, the capacity increase is partly alleviated by the increase in seismic demand, and the overall performance of the structure is improved slightly. As an alternative, seismic isolation and supplemental energy dissipation are recognized as the two main effective methods in reducing the dynamic responses of structures when subjected to earthquakes without increasing their global stiffness.

1.1 Base Isolation

Base isolation lengthens the natural period of the structure away from the predominant frequency of the ground motions. Base isolation is a passive vibration control system that does not require any external power source for its operation and utilizes the motion of the structure to develop the control forces. It reduces the effect of ground motion and thus leads to nullify the effect of earthquake on the structure. Base isolation has become popular in last couple of decades in its implementations in buildings and bridges. Basic principle of base isolation is to differentiate the building from its foundation, so during the seismic action, building is stays unaffected from the ground motion. In other words, even though ground moves aggressively, the building will tend to move ideally as a rigid body rather than collapsing. This reduces the floor hastening and storey gliding and so the building components are left less harmed. In the model, separation is total but practically, there is some co relation between the ground and the building which provides flexibility to the structure. Any stiff structure will have short period. During the ground movement, amount of acceleration entrusted in the structure is the same of ground acceleration that results in zero displacement between the structure and the ground. In other words, ground and structure will move with equal amount. Flexible structure will have longer life span.

1.2 Different Types of Base Isolators

The most commonly used base isolator in building are, laminated rubber (elastomeric) bearing, which includes natural and synthetic rubber bearing (low damping) and natural rubber bearing (high damping), lead rubber bearing (LRB) and friction pendulum (FPS) system bearing.

1.2.1 Laminated Rubber (Elastomeric) Bearing

A. Low damping rubber bearing: - it is made of alternate layers of natural rubber that provide flexibility and steel reinforcing plates that leads to vertical load-carrying capacity. At the top and bottom of these layers are steel laminated plates which distribute the vertical loads and transfer the shear force to the internal layer of rubber. This system of elastomeric bearing is variedly used in residential buildings, hospitals and halls constructed on the subway or railroads.

B. High damping rubber bearing:- it is similar to elastomeric bearings where the elastomeric used (either natural or synthetic rubber) provides a significant amount of damping the damping in the bearing is increased by adding extra-fine carbon block, oils or resins and other proprietary fillers.

1.2.2 Lead Rubber Bearing

The LRB was first used in New Zealand in1975 and was from then onwards used on large scale in New Zealand, Japan and United States. It is a slightly modified form of elastomeric bearing with a solid lead "plug" in the middle to absorb energy and adds damping these are same laminated as low-damping rubber bearings. One or more than one lead plugs are installed in the bearings which support the structure and provides along the ground flexibility to the structure.

1.3 Plan Asymmetry

Plan asymmetric structures are those in which seismic response is not only translational but also torsional, and is due to stiffness and/ or mass eccentricity in the structure. A regular structure may actually be asymmetric if the structure has masonry infill walls or stiffer lateral resisting systems on one side of the structure that has not been considered in the analysis. Asymmetry may in fact exist in a nominally symmetric structure because of uncertainity in the evaluation of centre of mass and centre of stiffness. Researchers on plan irregularities mainly focused on variation of positions of centre of mass or centre of stiffness with respect to each other to create eccentricity. To create eccentricity, the position of centre of superstructure or centre of rigidity is varied keeping position of centre of mass constant. It is called stiffness eccentricity. Producing eccentricity by varying position of centre of mass and keeping centre of superstructure constant is called mass eccentricity. Also creating a difference in strength of resisting elements to vary position of centre of strength with respect to centre of mass is termed as strength eccentricity.

Irregular distribution of strength and stiffness are one of the major causes of failure during earthquake. Both of these irregularities are interdependent. Irregular structures in this thesis are a rectangular structure, L shape structure and a C shape structure. In these structures irregularity is introduced by creating eccentricity in plan, i.e., plan asymmetry in structures.

II. Related Works

Many research investigations have been carried out considering the comparison of fixed base and base isolated structures and so many efficient methods have been put forward in buildings intended for reducing the vibrations due to earthquake to the superstructure. Massimiliano ferraioli and alberto mandara [1] deals with the analysis and design of an existing multiple building structure seismic retrofitted by a base isolation system incorporating rubber bearing and sliding devices. Preliminary investigations, in situ measurements and laboratory tests, and seismic assessment of existing fixed base structure were done. The earthquake response analysis of the hospital building was performed chiefly with reference to the horizontal displacements of the isolation plane and the relative displacements of three buildings in elevation. The maximum value of lateral displacement on the flexible side of the isolation plane was found greater than 35% compared to that in centre of mass. Design project, construction process and details of isolation interventions were presented. The possibility of pounding between the adjacent structures in elevation during strong earthquake was thoroughly investigated. For this study, the maximum relative displacement in the direction where pounding can occur was compared to the minimum separation gap required to prevent pounding. They observed that seismic isolation reduced seismic force demand on the superstructure and gave protection without extensive strengthening.

Muhammed asim khan et al [2] had made study on a total of 9 models, with l shape for analysis to cover a broader spectrum of low, medium and high rise buildings for seismic control using pushover analysis. Different techniques adopted in the study include lead rubber bearing and masonry infill wall and analysis were carried out using sap 2000 software. The study gave conclusion that the presence of isolators increases time period and thus flexibility. Also a five storey asymmetric rc framed building with lead rubber bearing isolator show better performance and maximum reduction of torsional moment.

S etedali et al., [3] compared the torsional behavior of asymmetric structures with fixed base and isolated base. Studied structures are three-dimensional, three and eight story steel structures whose nonlinear time history analysis was conducted based on the records of El Centro earthquake (1940), Tabas earthquake (1978), and Bam earthquake (2003). Results show the efficiency of seismic isolations to reduce the rotation of asymmetric structure stories. However, increasing the eccentricity reduces the effect of isolations on decreasing torsion. By increasing the eccentricity and the period of the isolation system, displacements of isolations located on the flexible edge will also rise. Practical solutions to strengthen torsion of the base-isolated asymmetric structures have been proposed. To strengthen the torsion of higher base-isolated asymmetric structures, simultaneous increase in flexible edge stiffness of the superstructure system and isolation system is suggested. In these structures, increasing the flexible edge stiffness of superstructure stories, conditional on approximate the center of stiffness of the base story (isolation system) to the center of mass, leads to torsional strengthening and reduces the torsion of stories.

O. V. Mkrtychev et al [4] studied the efficiency of seismic isolation system in the form of lead rubber bearings with different height buildings at multicomponent seismic impact. Here five, nine and sixteen storey buildings are considered. Calculations are performed considering the nonlinear nature of lead rubber bearings. The analysis of the effectiveness of buildings with and without seismic isolation was performed. The analysis shows the effectiveness of the seismic isolation in the form of lead rubber bearings. When performing numerical studies there is a reduction of seismic loads on the building depending on its height. They concluded that generalization of result is difficult considering all types of buildings. High intensity seismic impacts induce the development of plastic strains in structural elements and soil base, which require accounting for the nonlinear character of buildings and structures.

In this paper asymmetric structures with plan irregularity are compared. In order to make this true, four different types of plan which includes a rectangular shape, a c shape, an l shape and a t shape structures with different mass eccentricity and different heights are compared with two base conditions. The base conditions are fixed base and base isolated structures. The mass eccentricity ranges from 0% to 30%. The height variations include four storey, ten storey, fifteen storey and twenty storey. A study on various responses like storey rotation, storey acceleration, storey displacement, storey drift and time period is included.

III. Seismic Analysis Of Structure

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment in regions where earthquakes are prevalent.

3.1 Equivalent Static Analysis

Linear static analysis or equivalent static analysis can only be used for regular structure with limited height. All design against seismic loads must consider the dynamic nature of the load. However, for simple regular structures, analysis by equivalent linear static methods is often sufficient. This is permitted in most codes of practice for regular, low- to medium-rise buildings. It begins with an estimation of base shear load and its distribution on each story calculated by using formulas given in the code. The base shear is the total horizontal force on the structure which is calculated on the basis of structure mass and fundamental period of vibration and corresponding mode shape.

3.2 Non-Linear Dynamic Analysis

A non-linear dynamic analysis or inelastic time history analysis describes the actual behaviour of the structure during an earthquake. The method is based on the direct numerical integration of the motion differential equations by considering the elasto-plastic deformation of the structure element. This method captures the effect of amplification due to resonance, the variation of displacements at diverse levels of a frame, an increase of motion duration and a tendency of regularization of movements result as far as the level increases from bottom to top.

IV. Description Of Models

4.1 Details of Structures

Storey height =3.0 meters, bay width along x-direction = 3.5 meters, bay width along y-direction = 4.5 meters, beam-1 250x350mm, column- 250x450mm, slab- 150mm.

Table 1 Seismic details of the structure in general

Types Of Structures	Multistorey Structures	
Materials	Concrete	M20, M25
	Reinforcing Bar	Fe 415
Zonal Considerations	Zone	IV
	Zone Factor	0.24
	Soil Type	II
	Importance Factor	1
	Reduction Factor	5
Live Load	$3kN/m^2$	

4.2 Details of LRB Isolators (Designed as per UBC-97)

Effective Stiffness: 1064.43kn/m
Horizontal Stiffness: 350kn/m
Vertical Stiffness: 180MN/m
Yield Force: 20kn, Stiffness Ratio: 0.1, Damping: 0.05.

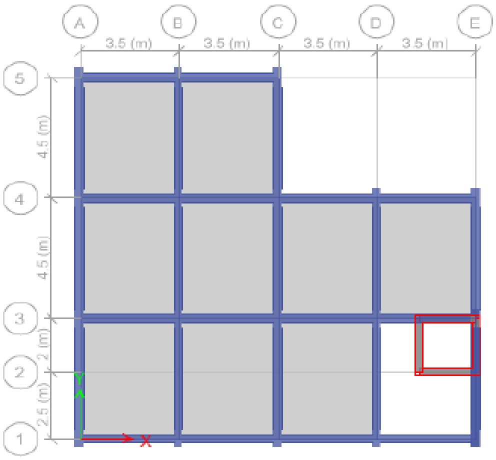

Fig 1 Plan of asymmetric L shape model

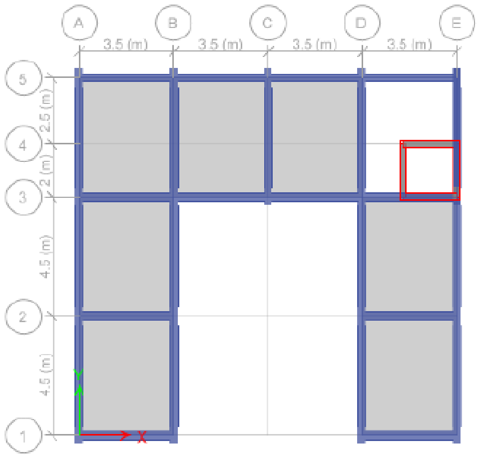

Fig 2: Plan of asymmetric C shape model

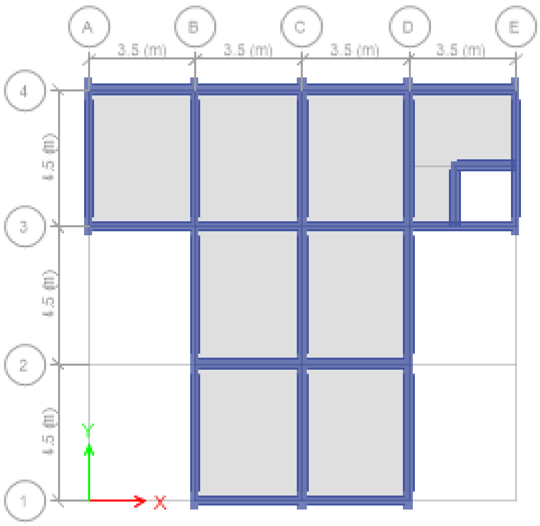

Fig. 3 Plan of asymmetric T Shape Structure

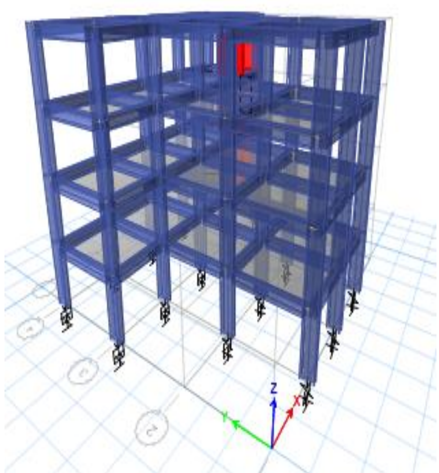

Fig. 4. 3D Model of a G+3 T shape plan structure

V. RESULTS AND DISCUSSION

The linear static and nonlinear time history analysis for the models have been carried out using etabs 2016 software [7]. The seismic details were incorporated in accordance to the IS code 1893:2002[5] and UBC-97[7]. The results of parametric study by varying the eccentricity of centre of mass for different plan shapes are included. The time period, storey rotation, storey acceleration, storey displacement and storey drift values are noted and comparison graphs are plotted for four models in both fixed base and base isolated structures.

5.1 Storey Rotation

Storey rotation of C shape, L shape and T shape RC structure by considering mass eccentricity from 0 to 30% with varying height from four storey to twenty storey were depicted from fig 5 to fig 7.

Fig 5 shows the variation of storey rotation of C shape plan structure with storey height. We can notice that on increasing the mass eccentricity, storey rotation of both fixed base and base isolated structure is increasing. Though while comparing the base of the structure, base isolated structure has the least value of rotation and the percentage reduction is 77%, 55% 54% and 37% for 4, 10, 15 and 20 storey structures respectively.

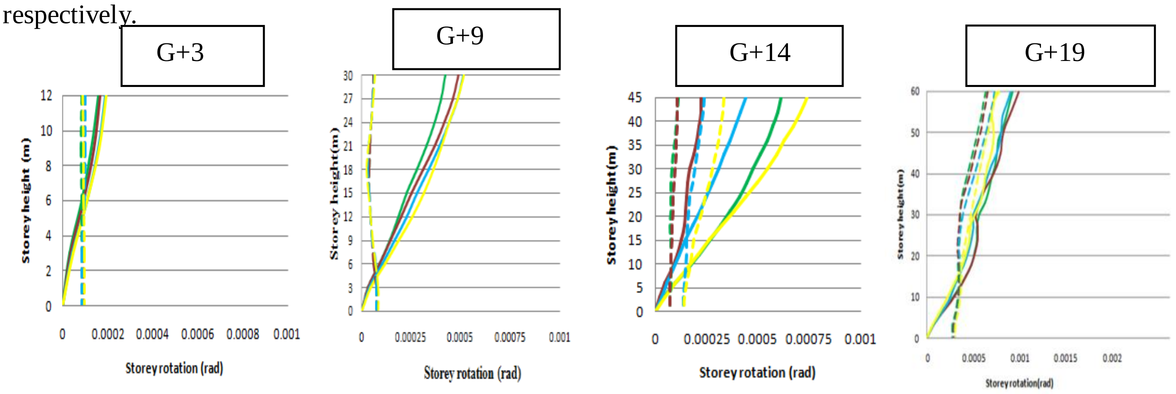

Fig.5 Maximum Storey rotation of C Shape plan shaped structure with varying heights

Fig6 shows storey rotation Vs storey height graph of L shape plan structure. When comparing the fixed base and base isolated structures, percentage reduction of storey rotation for base isolated structures are 83%, 71%, 65% and 31% for 4, 10, 15 and 20 storey structures.

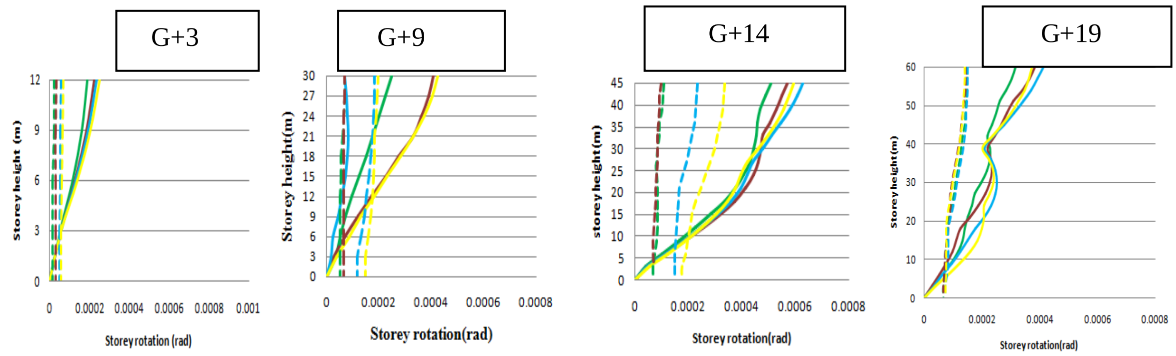

Fig 6 Maximum storey rotation of L shape plan building with varying heights

Fig 7 shows storey rotation of T shape plan structure. The percentage reductions of storey rotation for base isolated structure are 76%, 67%, 43% and 28% for 4, 10, 15 and 20 storey structures.

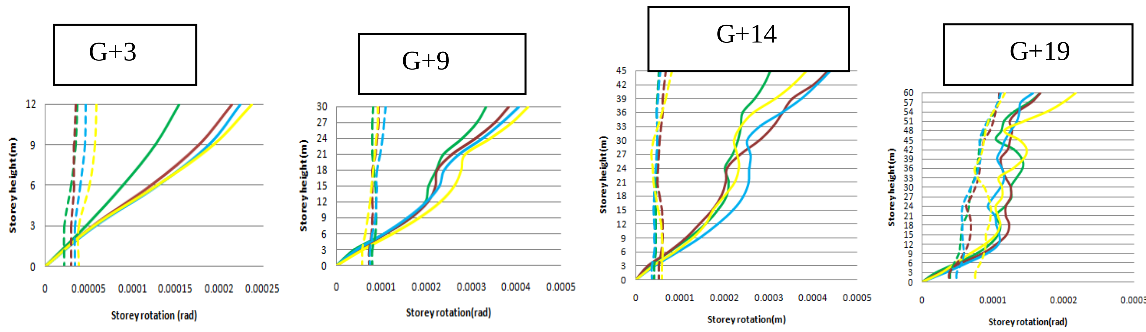

Fig 7 Maximum storey rotation of T shape plan building with varying heights

5.2 Storey Acceleration

Storey acceleration of C shape, L shape And T shape RC structure by considering mass eccentricity from 0 to 30% with varying height from four storey to twenty storey were depicted from Fig 8 to Fig 10. Fig 8 shows storey acceleration of C shape plan structure. The percentage reductions of storey acceleration for base isolated structure are 72%, 61%, 57% and 54% for 4, 10, 15 and 20 storey structures.

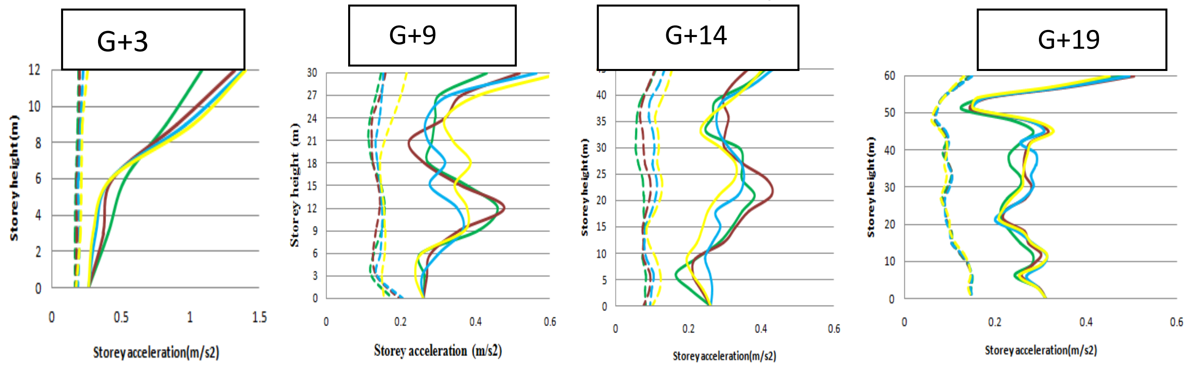

Fig 8 Maximum storey acceleration of C shape plan building with varying heights

Fig 9 shows storey acceleration of L shape plan structure. The percentage reductions of storey acceleration for base isolated structure are 67%, 64%, 60% and 59% for 4, 10, 15 and 20 storey structures.

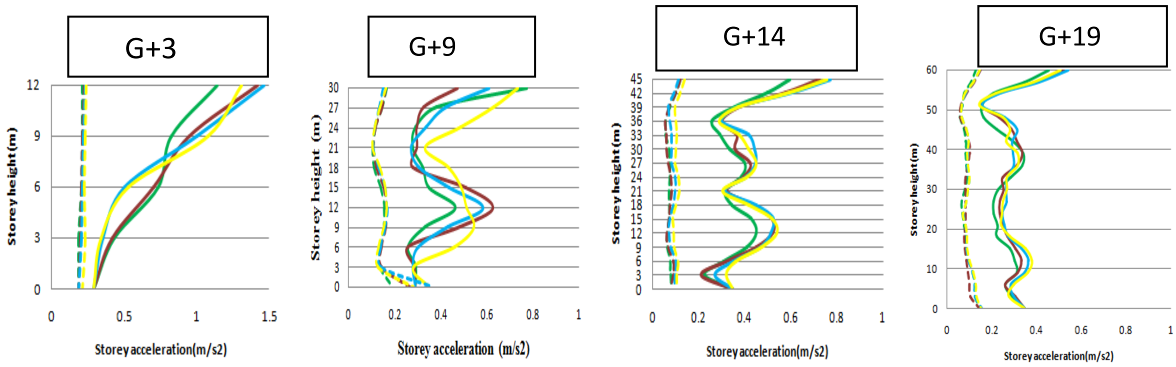

Fig 9 Maximum storey acceleration of L shape plan building with varying heights

Fig 10 shows storey acceleration of T shape plan structure. The percentage reductions of storey acceleration for base isolated structure are 64%, 61%, 55% and 54% for 4, 10, 15 and 20 storey structures.

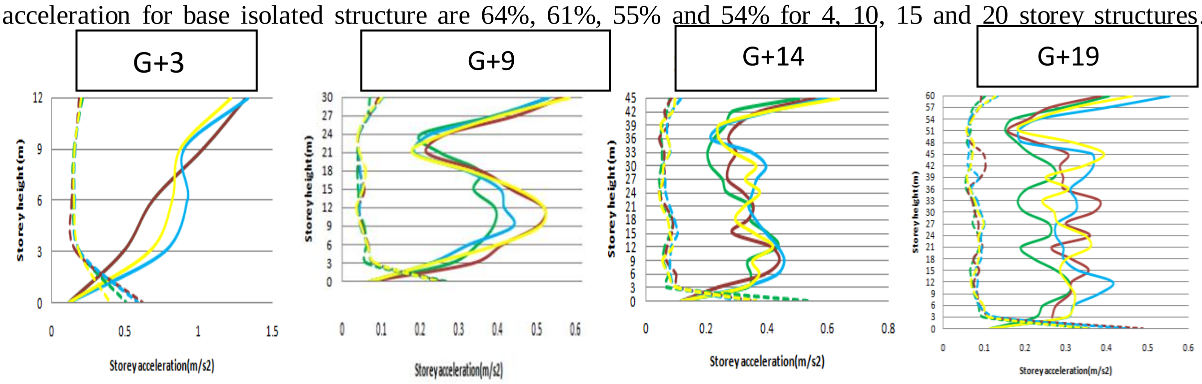

Fig 10 Maximum storey acceleration of T shape plan building with varying heights

5.3 Storey Displacement

Graph as depicted from Fig 11 to Fig 13 indicates the variation of storey displacement with storey height. It is clear that the displacements are increased with the storey height which is due to increase in time period. The percentage increase of storey displacement for base isolated structure are 122%, 98%, 35% and 34% for 4, 10, 15 and 20 storey structures.

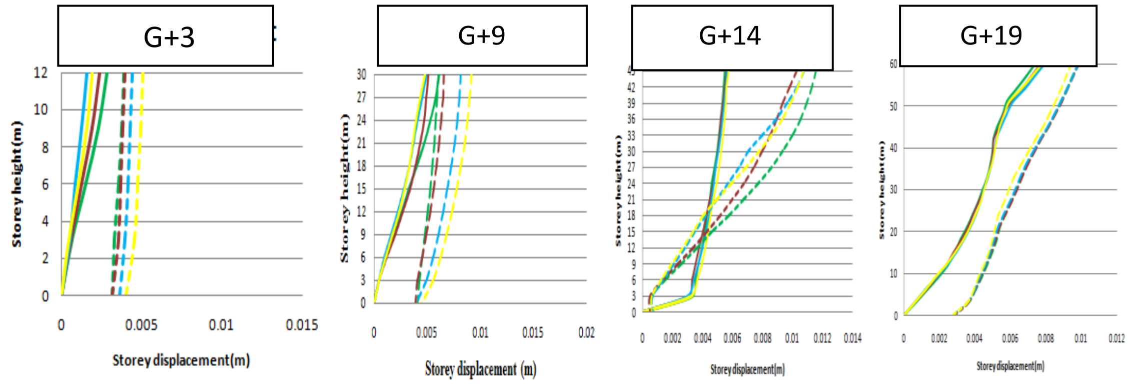

Fig 11 Maximum storey displacement of C shape plan building with varying heights

Fig 12 shows storey acceleration of L shape plan structure. The percentage reductions of storey acceleration for base isolated structure are 154%, 98%, 31% and 19% for 4, 10, 15 and 20 storey structures.

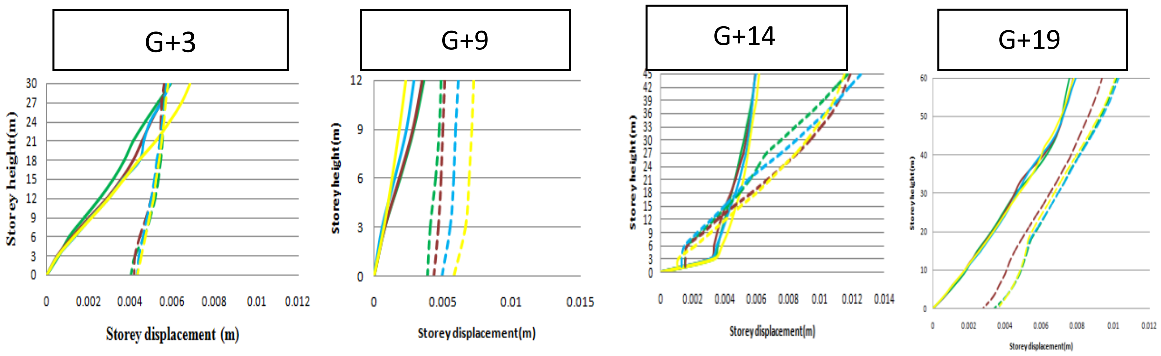

Fig 12 Maximum storey displacement of L shape plan building with varying heights

Fig 13 shows storey acceleration of T shape plan structure. The percentage reductions of storey acceleration for base isolated structure are 64%, 37%, 36% and 34% for 4, 10, 15 and 20 storey structures.

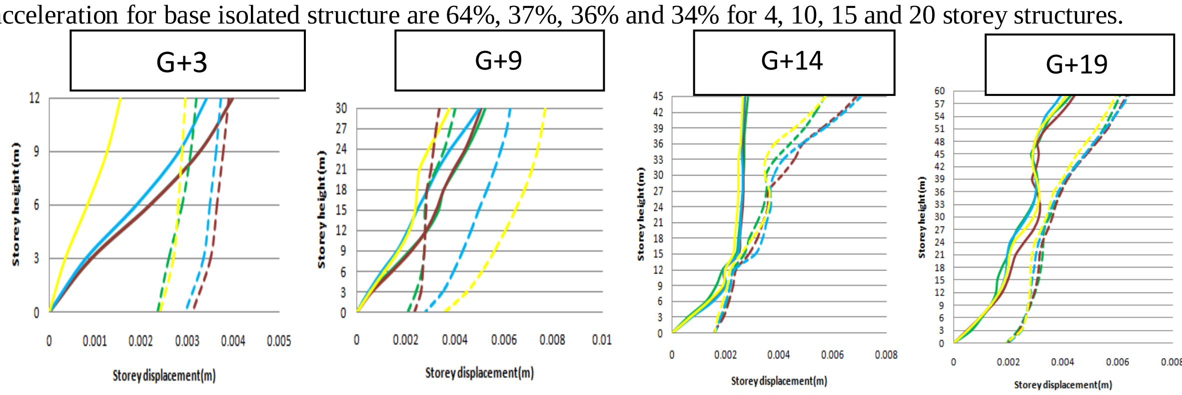

Fig 13 Maximum storey displacement of T shape plan building with varying heights

5.4 Time Period

In Fig 14 maximum time period with respect to storey height is plotted. In this case the maximum time period for top storey of each asymmetrical plan is noted and corresponding graph is plotted. It can see that time period is high for base isolated buildings which indicate that structures are highly flexible. Also on increasing storey height, the time period is also increasing.

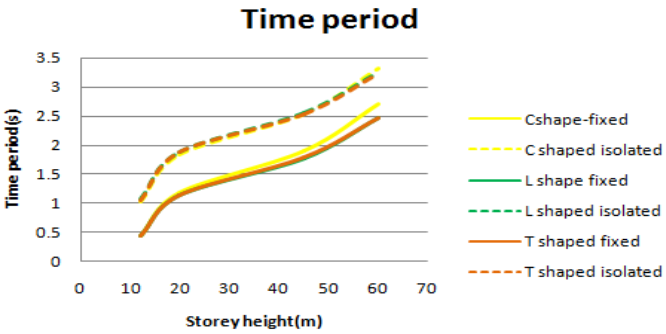

Fig 14 Maximum Time period

5.5 Storey Drift

Graph is depicted as in Fig 15 which indicates the variation of storey height with storey drift. It is clear that the drift of all the plans are very less as compared with fixed base building. Minimum drift value is for T shaped structure.

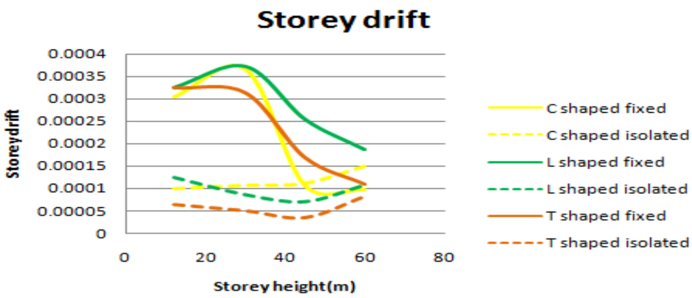

Fig 15 Maximum Storey drift

VI. Conclusion

- From the analysed models, the behaviour of fixed base and base isolated C shaped, L shaped and T shaped structures are investigated by applying 0% to 30% eccentricities.
- Analysis results show the efficiency of seismic isolation to reduce storey rotation. Also by increasing the eccentricity, the efficiency of isolation in diminishing rotation is slightly reducing.
- Storey acceleration is less and varying uniformly on increasing height in case of base isolated structures. But in fixed base structures, value of storey acceleration is high on increasing the height of the structure.
- Considering storey displacement of base isolated structures, there is a small displacement at the base and as storey height increases, the displacement is increasing at a constant rate.
- The storey drift is considerably reduced in base isolated structures on increasing height when compared to fixed base buildings.

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