SEISMIC BEHAVIOUR OF TYPICAL MASS ECCENTRIC BUILDINGS

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Abstract: Buildings, which are symmetric in mass and stiffness also display torsional coupling due to the asymmetric distribution of mass over the floor slabs, are called mass eccentric systems. When the otherwise translation only modes are coupled with torsional effects, it can result in unpredictable deformations and the failure of the entire structure during a seismic event. Mass eccentricity mainly occurs due to the presence of concentrated mass elements such as water tanks, machineries etc. in certain floor levels. Failures of mass eccentric buildings reported in past earthquakes indicate the inadequacy of the existing codal procedures. As a first step of investigation, the present study focusses on the behavior of typical mass eccentric buildings with regard to free vibration and time history responses. It is observed that natural period of the structure steadily increases with eccentricity of the mass. Also the shear forces in the columns adjacent to the center of mass are found to undergo increasing trend but those located far away undergo a decreasing trend. When eccentricity is provided in opposite directions in adjacent storeys of a two storey building, the shear forces are found to be reduced.

Keywords: RC buildings, Mass Eccentricity, Free Vibration, Equivalent Static, Time History, Torsional Response

I. INTRODUCTION

Seismic loads are the most unwanted of all types of loads when setting out to design a building structure. This is because of the hazardous nature in which they can affect the structure and the fact that they cannot be predicted or prevented by any means. The only remedy a structural engineer can provide is to minimize the response the building shall undergo when it is laterally loaded with seismic excitation. This way, it can be ensured that the structure will have to show the minimal effects under light and moderate loadings and that it doesn’t collapse under heavy loading (Murty et al, 2012).

Seismic response of a structure can be highly random in nature, resulting out of a number of reasons such as building geometry, material properties, loading pattern, mass distribution etc. One such element of concern is the lateral-torsional coupling due to eccentricity between Centre of Mass (CM) and Centre of Rigidity (CR). This issue is generally found in asymmetric buildings, as the mass concentration and stiffness concentration could be found at distinct points because of the asymmetry the structure shows in its plan. As a result of this eccentricity, torsional vibration is additionally found in the response where otherwise purely translational vibration occurs. This is due to the non-concurrent lines of action of inertia force and the resistive force, as the former acts through the Centre of Mass while the latter acts through the Centre of Rigidity; causing a time varying twisting moment.

Mass eccentricity is when there is an asymmetric distribution of masses over the floor slabs, even while the structure is symmetric with respect to stiffness and strength. This can happen due to the presence of concentrated mass elements in certain floors such as machineries, water tanks etc… As a result, there is an asymmetric distribution of lateral forces in resisting elements so that they present different lateral strength capabilities (Steffano and Pintucchi, 2003)

Mass eccentric buildings and its torsional behaviour have been focus of research for the several decades. Borzouie and Moghadam (2012) proposed the use of friction dampers to control torsion in steel buildings. Tabatabaei (2011) discovered that the coupling effect is maximum when the translation frequency of the system equals the uncoupled torsional frequency, for a given eccentricity. Wu and Li (2003) studied the effect of translational and torsional response of idealized models coupled with rubber bearing isolators and observed that the responses were significantly reduced. Stefano and Pintucchi (2004) developed a one-storey plan asymmetric building which will consider vertical forces from ground motion and gravity both along with the effects of inelastic interaction between axial force and bi-directional horizontal forces. Stefano and Pintucchi (2003) proposed the difference in ductility demand between flexible and rigid sides. Stathopoulos and Anagnostopoulos (2003) conducted various studies on the torsional behaviour of buildings. For a torsionally stiff building, the effect of natural eccentricity on ductility demands appear to be negligible over the whole period range, while for a torsionally flexible buildings, stiffer edges demand more ductility with eccentricity while flexible edges demand lesser. But further studies (Stathopoulos and Anagnostopoulos, 2005) showed that the response is actually the reverse when a frame-type multi-storey building is used for analysis instead of the simplified, one-storey shear beam model.

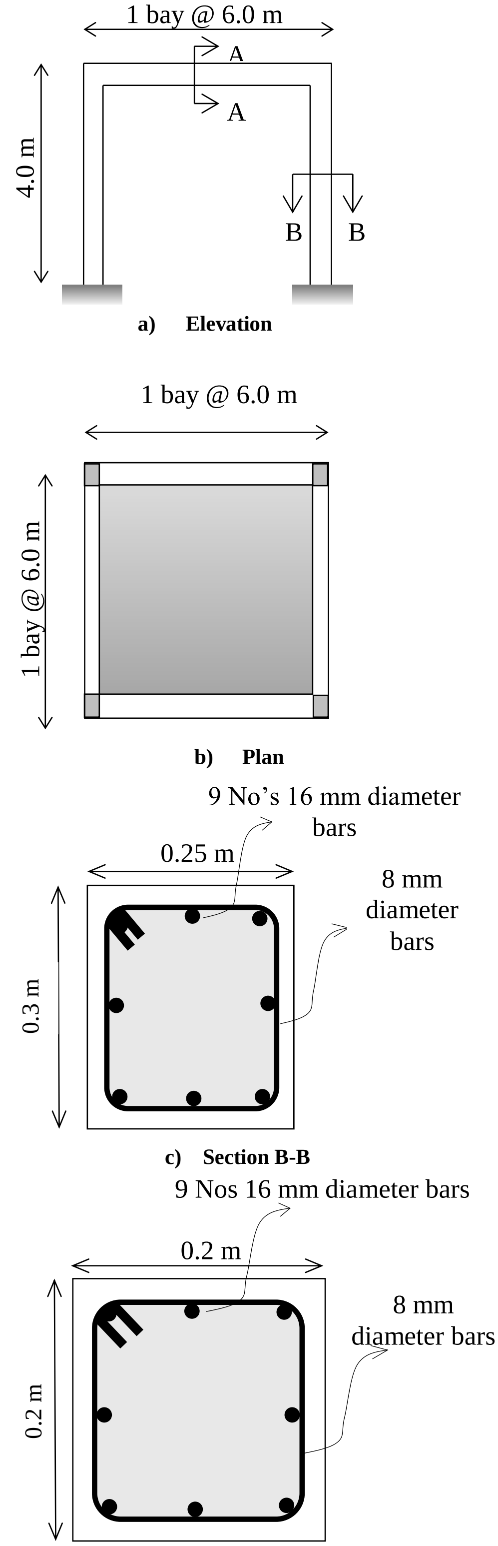
Most of the previous studies deals with deformation, vertical loads and ductility behaviour of plan asymmetric or setback buildings. The research work on the behavior of mass eccentric buildings in terms of column shear force and period of vibration is very limited. It is important to address issues related to variation of static eccentricity in various floors and its implication in the estimation of design forces in mass eccentric buildings. Hence the first part of the present study focusses on free vibration behaviour. Variation of shear force in the columns are considered in the second part of this study.

II. DESCRIPTION OF THE STRUCTURE

In the current study, two symmetric buildings having one and two number of storeys have been considered; the plan, elevation and section details of which are as shown in Figs. 1 and 2 respectively. The selected framed buildings are assumed to have a single bay with a bay width of 6 m and a uniform storey height of 4 m. The characteristic strength of concrete and reinforcement steel are taken as 25 and 415 MPa respectively. The size (breadth and depth) of columns and beams are taken as 250 x 300 mm and 200 x 200 mm respectively.

III. METHODOLOGY

Analysis of the selected frames are performed by modelling the mass and stiffness of the selected frames appropriately. The seismic weights of each floors are lumped at the center of masses as per the provisions given by IS 1893 (2002). In order to compare the responses of the building for various values of eccentricity, the building with zero eccentricity is considered as reference. Variations in natural periods and shear forces are recorded and normalized with respect to that of reference frame to display the variation graphically.



d) Section A-A

Figure 1: Geometry and design details – one storey building

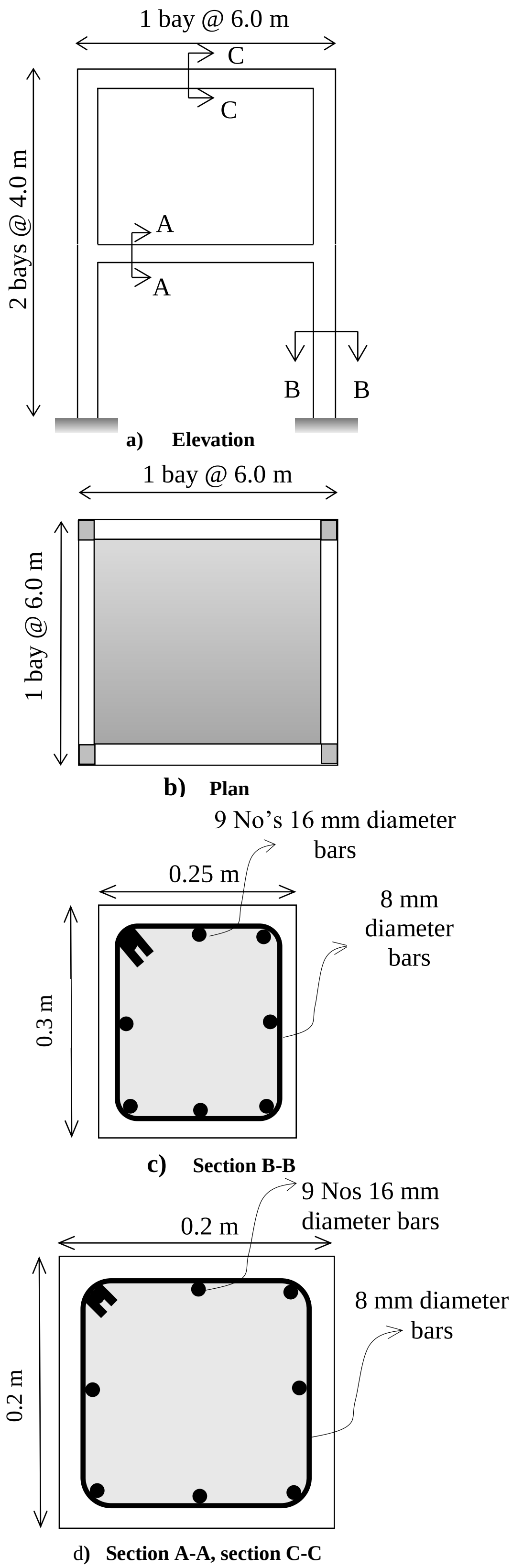


Figure 2: Geometry and design details – two storey building

The shear forces in the columns at near side of center of mass (CM) and far side of CM are considered to study its variation with the eccentricity. Static and time history analysis of the selected buildings subjected to design lateral forces is carried out. The shear forces in the columns are monitored for different values of eccentricities. The same procedure is repeated in the case of two storey buildings except in the application of design lateral force in each floors. Three cases, varying the eccentricity in each floors have been considered in the case of two storey building.

IV. DISCUSSION OF RESULTS

i) FREE VIBRATION ANALYSIS

To study the variation of natural period and mass participation factors with respect to eccentricity, free vibration analysis of the 1-storey building done. The graphs depicting the same are as shown in Figs 3 and 4 respectively. It is seen that the natural period (Fig. 3) shows an increasing trend with increase in eccentricity whereas mass participation factor (translational degree of freedom, UX and UY) shows a decreasing trend (Fig. 4a and 4b) towards the direction to which it is asymmetric and corresponding increase in the mass participation in the direction of rotation (RZ). This is due to the presence of torsional coupling to the otherwise translational only modes when the CM is displaced from its reference position.

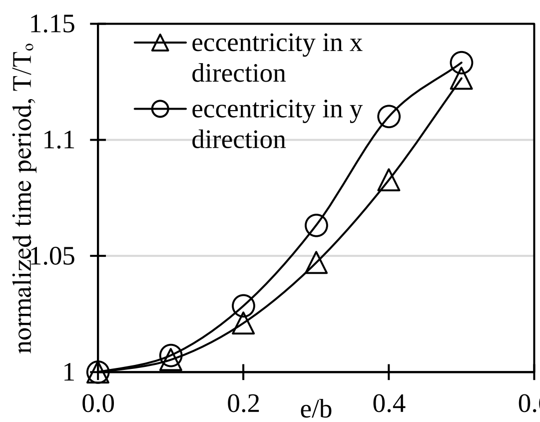


Figure 3: Variaton of natural period with eccentricity

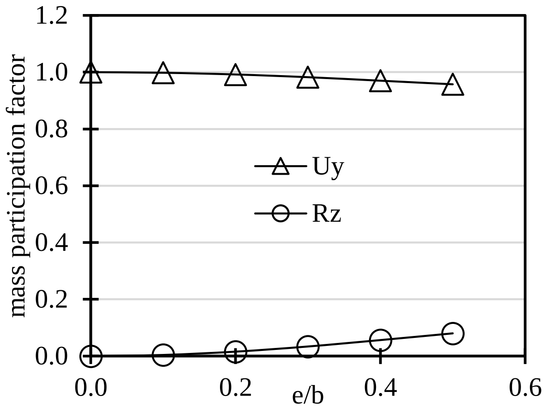


Figure 4a: Variation of mass participation factor – eccentricity in x direction

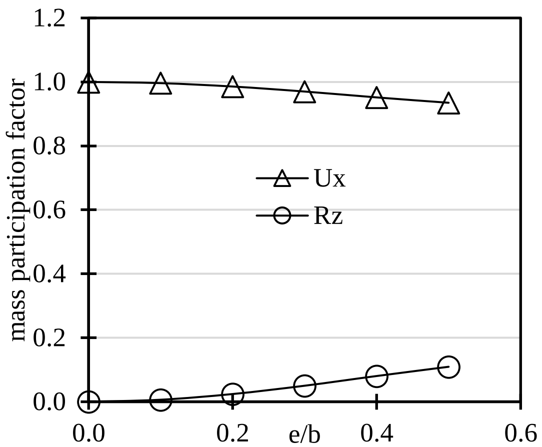


Figure 4b: Variation of mass participation factor – eccentricity in y direction

ii) EQUIVALENT STATIC ANALYSIS

Equivalent static analysis was carried out by providing a constant force (story weights) to the CM in a direction opposite to that of eccentricity. In the case of 1-storey building, as shown in Fig. 5a and 5b, the columns nearer to CM, shows an increasing value of shear force (SF) while the columns farther to the CM is affected with a decrease in value of SF when the building is eccentric.

But for a 2-storey building, shear force displays a very interesting variation phenomena. When eccentricity in both floors are towards the same side, there is a significant increase in shear force in the ground storey columns near to CM (as expected from the trend for one single storied building). But when the ground floor eccentricity is fixed at the geometric center, keeping top floor eccentricity dynamic, the increase in SF is found to be of a lesser degree. Even lesser increase rate is observed when both the floor eccentricities are in the opposite sides (Fig 6a) of centroid. The normalized graph almost reaches a constant value of unity in this case. Same result is observed in the flexible side, only difference being that it is a decreasing graph. (Fig 6b).

The trend of variation of SF with eccentricity for the 3 cases is similar for the first storey columns as well. But it should be noted here that there is no (Fig 7a and 7b) significant variation between the normalized values for the three cases considered.

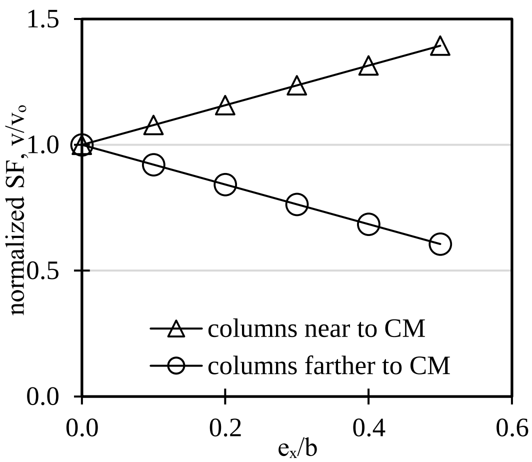


Figure 5a: Variation of shear force with eccentricity in 1-storey building- eccentricity in x direction

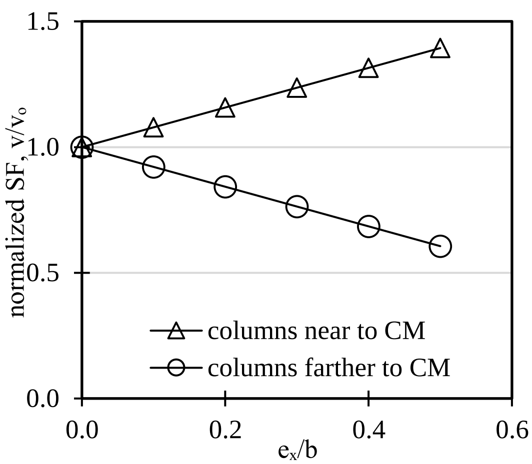
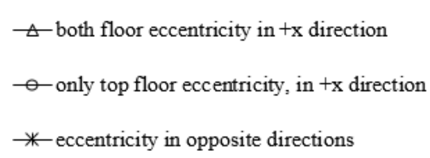


Figure 5b: Variation of shear force with eccentricity in 1-storey building – eccentricity in y direction



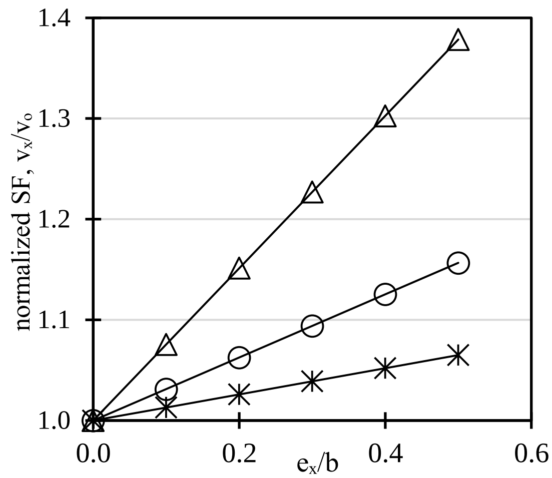


Figure 6a: Variation of shear force in ground storey columns in 2-storey frame – columns near to CM

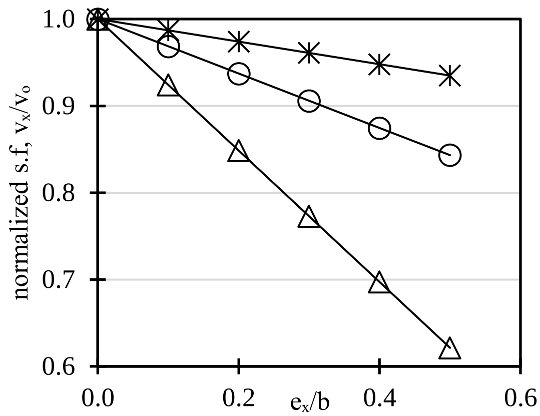


Figure 6b: Variation of shear force in ground storey columns in 2-storey frame – columns farther to CM

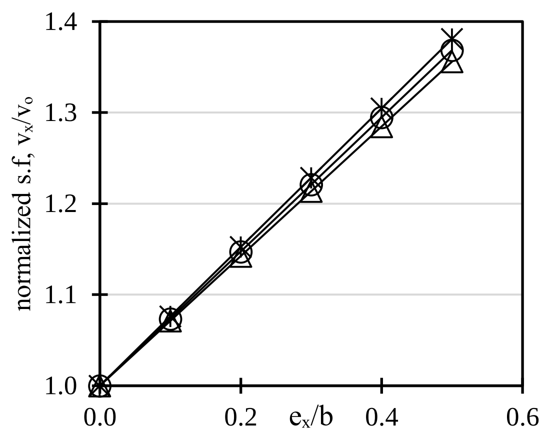


Figure 7a: Variation of shear force in top storey columns in 2-storey frame – columns near to CM

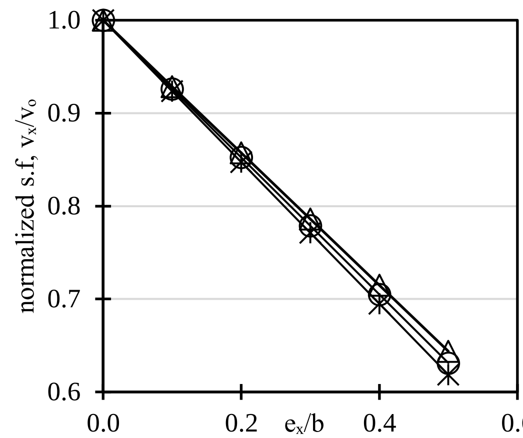


Figure 7b: Variation of shear force in top storey columns in 2-storey frame – columns farther to CM

iii) TIME HISTORY ANALYSIS

To determine the response of the structure under seismic loads and to validate the static analysis of the structure, time history analysis of the building is done. The El-Centro earthquake record is used as ground motion input data. For ease in procedures, only linear analysis is carried out. The mass and stiffness proportional damping factors are chosen based on the first two modes of the structure so that the equivalent viscous damping ratio is equal to 5%. The peak ground acceleration (PGA) of this data is known to be 0.2141g. The maximum shear forces in the columns of one storey (Fig. 8) and two storey buildings (Fig. 9 and 10) are obtained from the time history analysis.

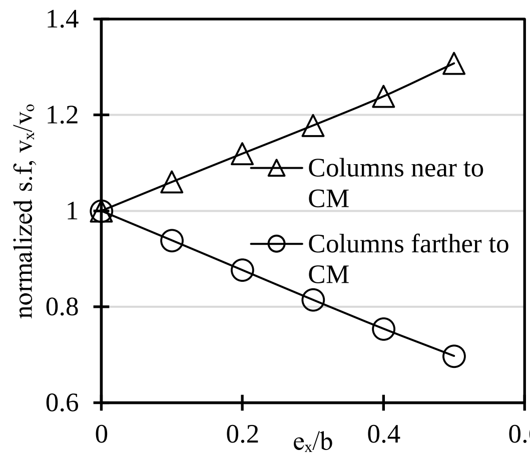


Figure 8: Variation of shear force with eccentricity in 1-storey building- eccentricity in x direction

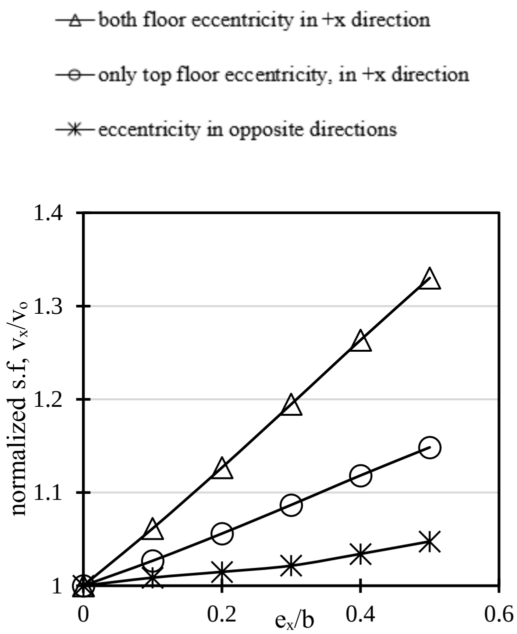


Figure 9a: Variation of shear force in ground storey columns in 2-storey frame – columns near to CM

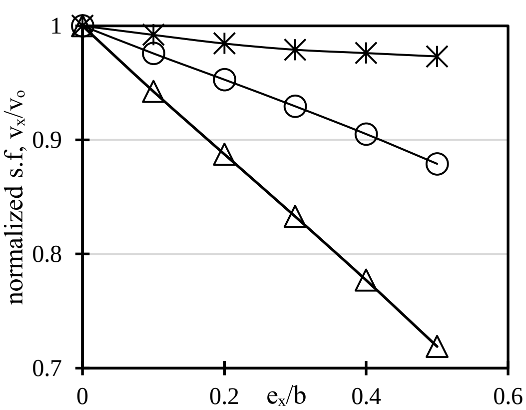


Figure 9b: Variation of shear force in ground storey columns in 2-storey frame – columns farther to CM

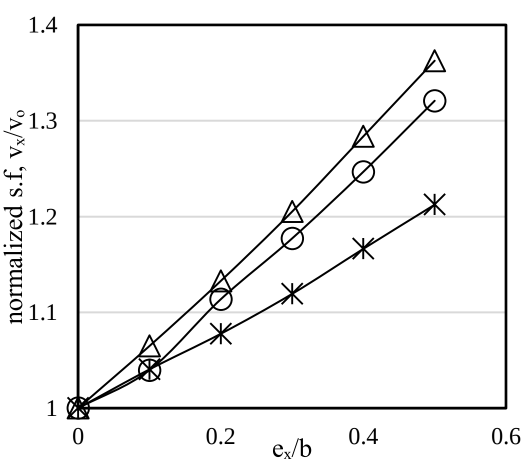


Figure 10a: Variation of shear force in top storey columns in 2-storey frame – columns near to CM

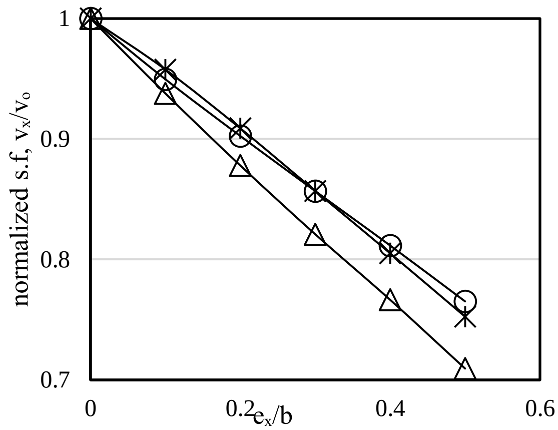


Figure 10b: Variation of shear force in top storey columns in 2-storey frame – columns farther to CM

The responses obtained from the dynamic time history analysis follows almost the same trend as that of the static analysis. While the nearer columns to CM shows an increasing trend is SF, the columns towards the far end has a decreasing value of SF (Fig 8).

For a 2-storey building, it has been observed that, under time dependent seismic loading, the least value of SF in ground storey columns is obtained in the case where both the floor eccentricity is towards opposite directions (Fig 9a and 9b). While the top-storey columns also show a similar trend, the deviation is more pronounced unlike that of the static analysis which showed an almost collinear trend.

V. CONCLUSIONS

A generalized conclusion that can be drawn from this study is the trend of variation of natural period and shear force with uniaxial eccentricity. No matter the geometric or material configuration or the direction of eccentricity, period of vibration is seen to be increasing in the mode in which it is asymmetric. Also shear force in columns tend to increase in the columns located in the stiffer side. The flexible columns undergo rather decreasing rate of shear force values. This result is validated with the help of both static and time history analyses. Implication of the results show that in unavoidable cases where extra mass needs to add in a building, it can be provided in opposite sides of center of building to reduce the shear force demand in the columns.

VI. SCOPE FOR FURTHER STUDY

By far only structures with linear configuration and uniaxial asymmetry was considered for the study with free vibration, static and dynamic analyses. It can be further extended to non-linear structures and having biaxial eccentricity, which may lead to the generation of complex structures and complex analysis procedures. Other dynamic analysis methods are also suggested so as to obtain a proper response under seismic loads thereby studying the possible methods to resist them.

VII. REFERENCES

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