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Seismic Response of RC Irregular Buildings as per IS1893:2016

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Abstract: Many buildings in the present scenario have irregular configurations both in plan and elevation and these in future may be subjected to devastating earthquakes. The irregularities introduced has variations in performance against seismic loads which acts on the structure in lateral direction. The aim of this study is to investigate the response of the vertically irregular structures subjected to different earthquakes. For this four R.C. frame models (G+9) are considered out of which one is regular and three are irregulars. All four models are designed with the help of IS1893:2002. The response of the structure in terms of storey drift with respect to time is studied. The study providing with the results regarding comparison of storey drift calculated in x-direction and in y-direction for respective time histories. The study resulted in the conclusion that the storey drift has larger value in upper stories of irregular building than in lower stories.

I. INTRODUCTION

Earthquake resistant design of reinforced concrete buildings is a continuing area of research since the earthquake engineering has started not only in India but in other developed countries also. The buildings still damage due to some or the other reason during earthquakes. In spite of all the weaknesses in the structure, either code imperfections or error in analysis and design, the structural configuration system has played a vital role in catastrophe. The IS 1893 (Part 1): 2016 has recommended building configuration system in Section 7 for the better performance of RC buildings during earthquakes. The building configuration has been described as regular or irregular in terms of size and shape of the building, arrangement of structural elements and mass.

Regular building configurations are almost symmetrical (in plan and elevation) about the axis and have uniform distribution of the lateral force-resisting structure such that, it provides a continuous load path for both gravity and lateral loads. A building that lacks symmetry and has discontinuity in geometry, mass, or load resisting element is called “Irregular”. These irregularities may cause interruption of force flow and stress concentrations. Asymmetrical arrangements of mass and stiffness of elements may cause a large torsional force (where the center of mass does not coincide with the center of rigidity). The Section 7 of IS 1893 (Part 1): 2016 enlists the irregularity in building configuration system. These irregularities are categorized in two types:

1. Vertical irregularities referring to sudden change of strength, stiffness, geometry, and mass results in irregular distribution of forces and/or deformation over the height of the building and
2. Horizontal irregularities which refer to asymmetrical plan shapes (e.g. L, T, U, F) or discontinuities in the horizontal resisting elements (diaphragms) such as cut-outs, large openings, re-entrant corners, and other abrupt changes resulting in torsion, diaphragm deformations and stress concentrations.

Many buildings in the present scenario have irregular configurations both in plan and elevation and these in future may be subjected to devastating earthquakes. It is necessary to identify the performance of such irregular structures against disaster for both the new and existing ones. Structures experience lateral deflections under earthquake loads. Magnitude of these lateral deflections is related to many variables such as structural system, mass of the structure and mechanical properties of the structural materials. Reinforced concrete multi-storied buildings are very complex to model as structural systems for analysis. The current version of the IS 1893 (Part 1):2016 requires that practically all multistoried buildings be analyzed as three-2 dimensional systems. This is due to the irregularities in plan or elevation or in both. Structural irregularities are important factors which decrease the seismic performance of the structures. The study as a whole makes an effort to evaluate the effect of vertical irregularity on RC buildings. The behavior of a building during an earthquake depends on several factors such as, stiffness, adequate lateral strength, and ductility, simple and regular configurations. The buildings with regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much less damage compared to irregular configurations. But nowadays need and demand of the latest generation and growing population has made the architects or engineers inevitable towards planning of irregular configurations. Hence earthquake engineering has developed the key issues in understanding the role of building configurations.

After extensive literature study it is observed that in various papers authors have emphasized on study of seismic demands of regular and irregular structures (Chintanapakdee and Chopra 2004), some studied two-dimensional regular and irregular plane frames with the same peak ground acceleration (PGA) and material characteristics (Athanassiadou 2007), whereas combined experimental and analytical study about the response to strong base motions of reinforced concrete structures having irregular vertical configurations (Yachawad and Bhakre 2018). (Bhosale and Davis 2017) checks the adequacy of fundamental mode properties for the quantification of vertical irregularity which further check the correlation between existing vertical irregularity indicators and the seismic risk. (Cheung and Tso 1987) have analyzed the building for the lateral loadings and have presented the method to obtain the load distribution on the resisting elements of symmetric and eccentric setback which subjected to lateral loadings. (Kalibhat et al. 2014) examined about the method of pushover analysis which will be used to conduct the seismic analysis by considering the mass irregularities in structure. (Soni and Mistry 2006) discussed various criteria defining the vertical irregularity as per the current building codes and review of various studies on the seismic behavior of vertically irregular structures along with their findings has also been presented. (Sarkar 2010) There is a paper which proposes a new method of quantifying irregularity in stepped building frames, accounting for dynamic characteristics (mass and stiffness). (Kumar and Gupta 2012) studied the Response of Structurally Irregular Building Frames to Seismic Excitations in which Response of a plane frame to lateral loads is studied for mass and stiffness irregularities in the elevation. (Moehle and Alarcon 1986) studied about the methods which we can use for the seismic evaluation of the reinforced concrete building with vertical irregular profile.

II. STRUCTURE ANALYZED

Four models of ten storey buildings are considered for analysis. First building is considered as regular frame with uniform distribution of mass, strength and stiffness along the height and width of the structure. This regular building is modified for irregular frames by introducing some setbacks without any change in design details. The setbacks are introduced by reducing the lateral dimensions of the structure along the height at different storey in different models so that the A/L ratio is different for all three models. These models are analyzed against earthquake loadings by using both IS 1893 (Part 1):2002. These frames are subjected to specified ground motions and the response of the structure is analyzed with time history method. Computer software SAP2000 was used for carrying out nonlinear time-history analysis.

III. PROBLEM STATEMENT

The objective of this study is to analyze the behavior of regular and irregular structure under seismic conditions. In this paper the irregular structures are referred as structures with setbacks. One irregular and three setback structures are considered. The geometric and material data are given in Table 1.

Table 1
Geometric and Material Data

Parameter	Values
Type of structure	RC special moment resisting frame
Number of storey	G+9
Storey height	3.5 m
Plan dimension	28 m x12 m
Spacing of frames along X direction	4 m
Spacing of frames along Y direction	3 m
Size of column	C1- 400 mm x 500 mm
	C2- 450 mm x 550 mm
	C3- 500 mm x 600 mm
Size of beam	B1- 230 mm x 350 mm
	B2- 300 mm x 450 mm
Depth of slab	125 mm
Comp. Strength, fck	25 N/mm^2
Reinforcement yield strength, fy	415 N/mm^2

Plan of the model considered is as shown in Fig. 1

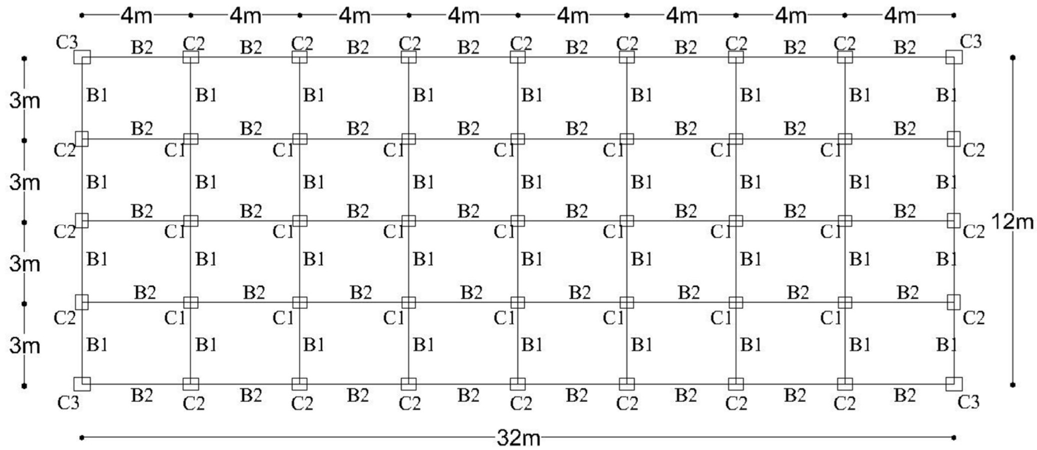

Fig. 1 Plan for regular and irregular models.

The live loads considered for the analysis of RC building are as referred in IS 875-part 2 and are given in Table 2.

Table 2
Geometric and Material Data

Parameter	Magnitude
Live Load	2 kN/m^2
Roof Live Load	1.5 kN/m^2
Floor Finish	1 kN/m^2

To define earthquake loadings it is essential to know the zone factor of the region. And to consider the other factors regarding seismic zone IS 1893-2002 has been referred. The details for the same are as mentioned in the Table 3.

Table 3
Seismic data required for analysis

Parameter	Values as per IS 1893 (part 1):2002	Clause
Type of structure	RC Special moment resisting frame	Table 7, Clause 6.4.2
Seismic zone	V	Table 2, Clause 6.4.2
Zone factor (Z)	0.36	Table 2, Clause 6.4.2
Type of soil	Medium soil	Clause 6.4.5
Damping	5 %	Figure 2, Clause 6.4.5
Response reduction factor (R)	5	Table 6, Clause 6.4.2
Importance factor (I)	1	Table 7, Clause 6.4.2
Time period	0.075 x $h^{0.75}$	Clause 7.6.1

For the analysis one structure with constant geometric dimensions along the height is considered as the regular model while the same structure with following setbacks are considered as vertically irregular models. When the A/L ratio is less than one but greater than 0.25 it is considered as irregular model. Where L is horizontal dimension of building in x-direction and A is reduced lateral dimension of building in x-direction only. Type of irregularities are as mentioned in Table 4 where 'L' is the dimension of building in x-direction and 'A' is the reduced lateral dimension of the building.

Table 4
Type of irregularities

Model	Irregularity Table 5 IS 1893 (part 1) :2002	Type of irregularity
R	L1=L2	Regular
S1	A/L = 24/28 = 0.85 > 0.25	Setback
S2	A/L = 20/28= .714> 0.25	Setback
S3	A/L = 16/28= 0.57 > 0.25	Setback

Elevations of regular model is as shown in Fig. 2 and that of irregular models are shown in Figs 3, 4 and 5.

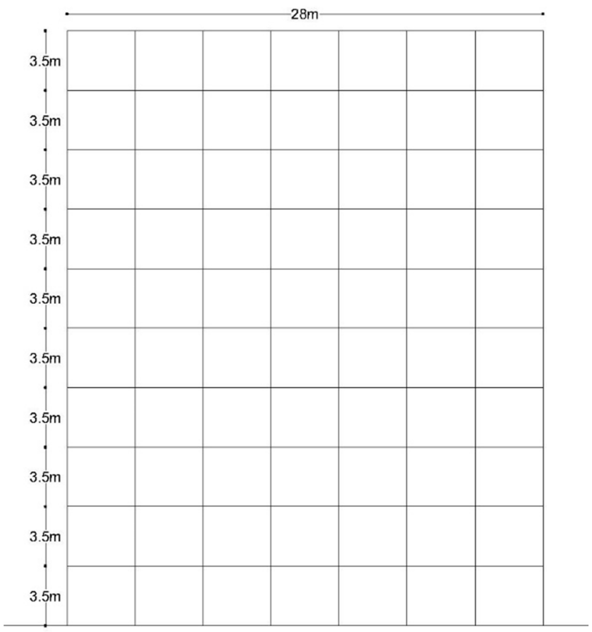

Fig. 2 Elevation for regular model.

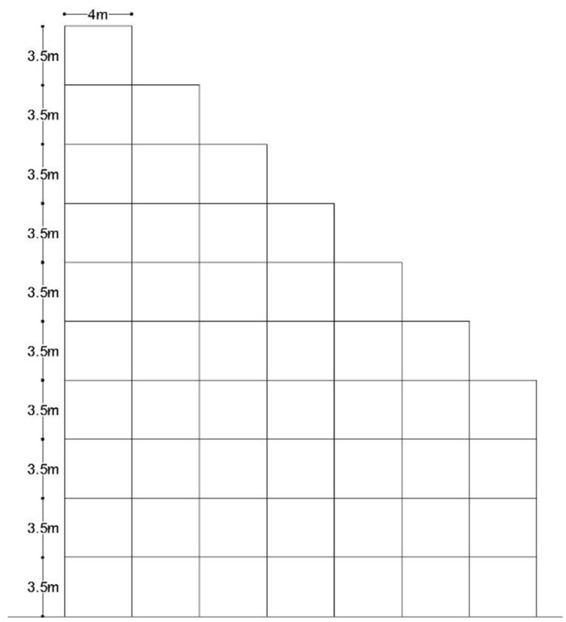

Fig. 3 Elevation for setback-1 model.

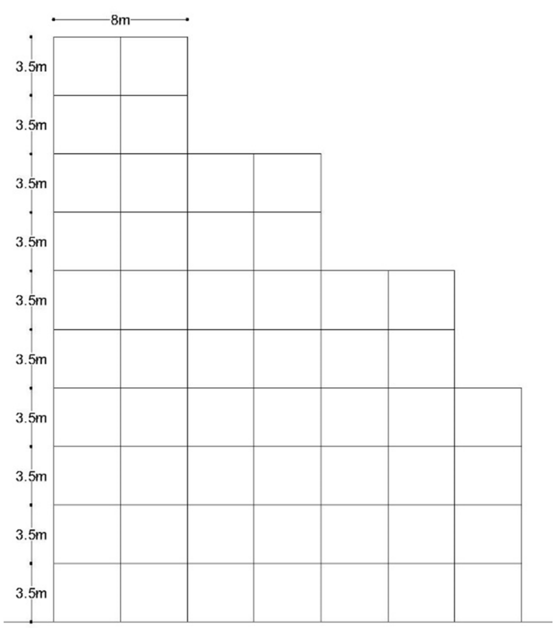

Fig. 4 Elevation for setback-2 model.

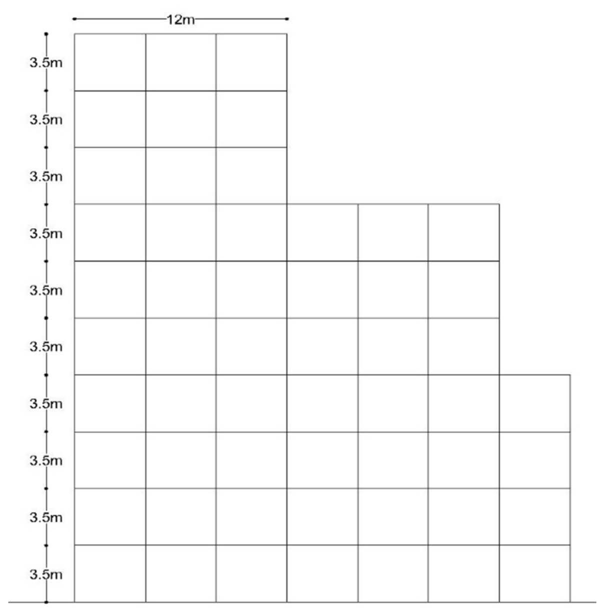

Fig. 5 Elevation for setback-3 model.

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IV. RESULTS AND DISCUSSIONS

Time history analysis is a step-by-step analysis of the dynamic response (in time domain) of a structure subjected to a specified ground motion. The dynamic input has been given as a ground acceleration time-history which was applied uniformly at all the points of the base of the structure; only one horizontal component of the ground motion has been considered. Four natural ground acceleration time histories were employed for the dynamic analysis of the study.

Four natural ground acceleration time histories have been used for the dynamic analysis of the structural models. All these acceleration data were collected from Strong Motion Database available in the website of Center for Engineering Strong Motion Data, USA (http://www.strongmotioncenter.org/) and were scaled to have various peak ground accelerations ranging from 0.18g and 0.36g. The compatible time histories has been compiled in one graph and shown in Fig. 6, 7, 8, and 9 shows the time histories of Imperial Valley, Kern County, Loma Prieta, Oakland Outer Harbor Wharf respectively.

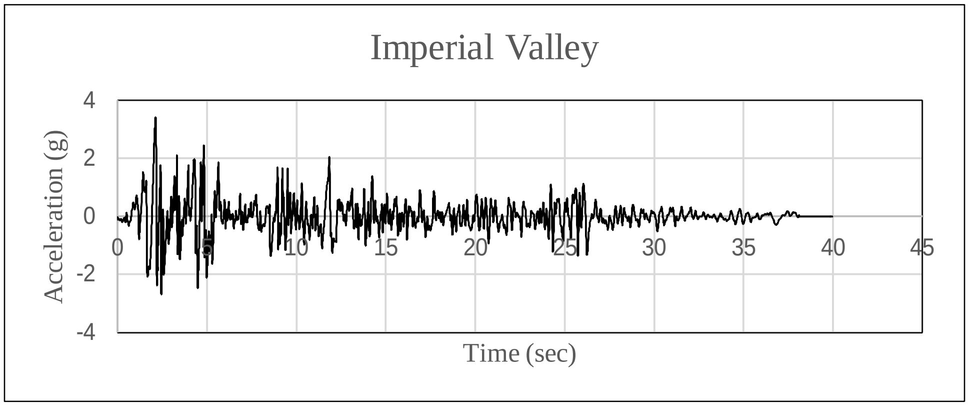

Fig. 6 Time History of Imperial Valley

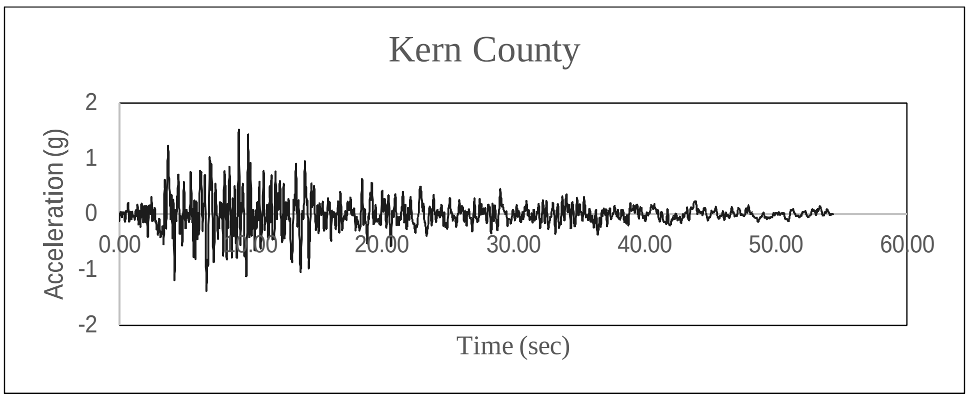

Fig. 7 Time History of Kern County

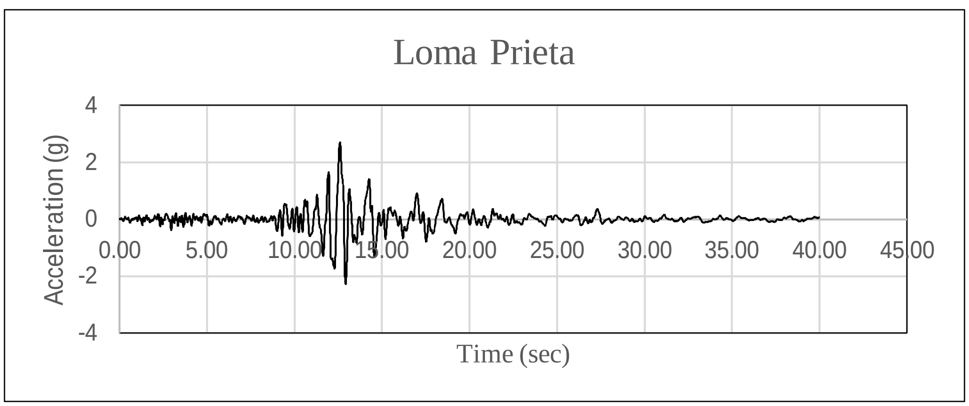

Fig. 8 Time History of Loma Prieta

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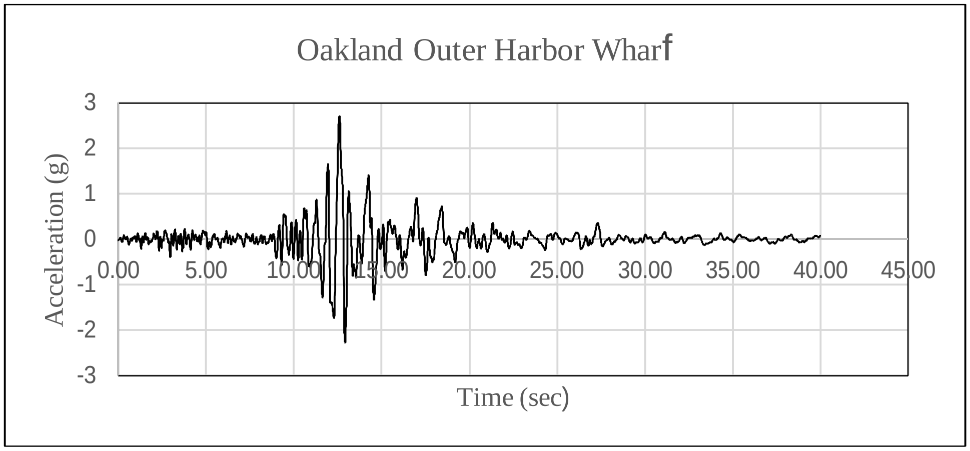

Fig. 9 Time History of Oakland Outer Harbor Wharf

The responses of regular model and different setback models after subjected to above four earthquakes are as shown in Fig. 10, 11, 12 and 13 resp.

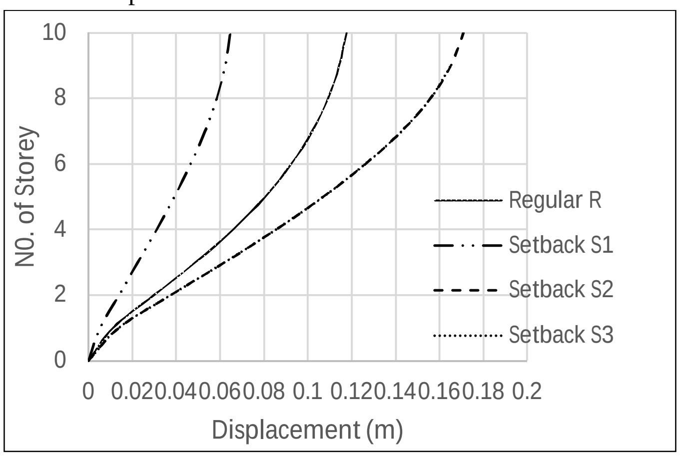

Fig. 10 Time History response on Regular model

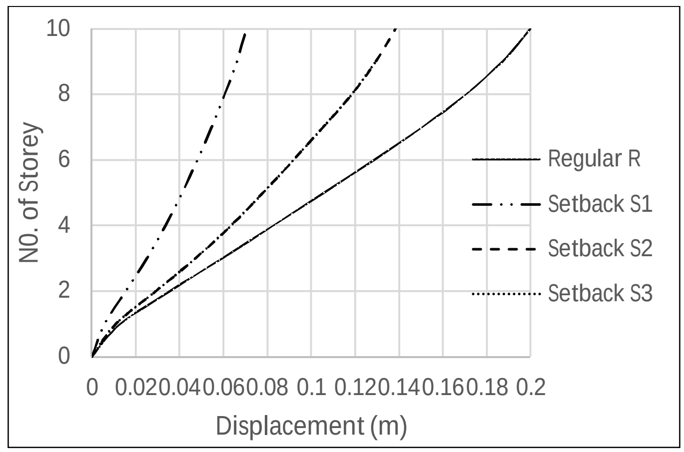

Fig. 11 Time History response on Setback-1

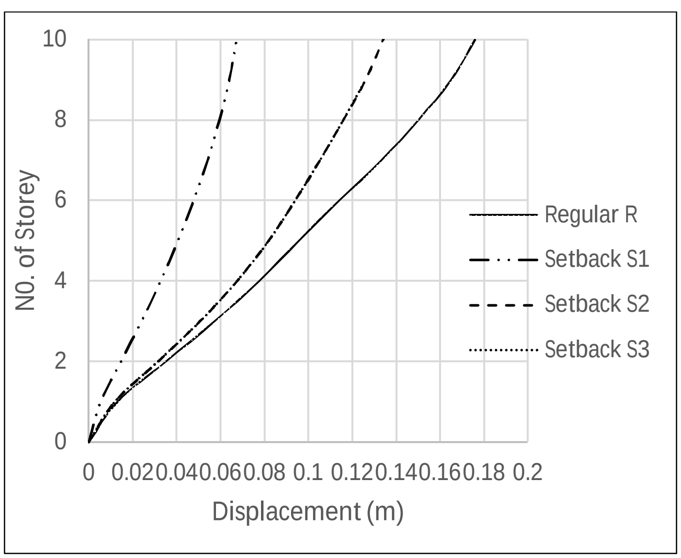

Fig. 12 Time History response on Setback-2

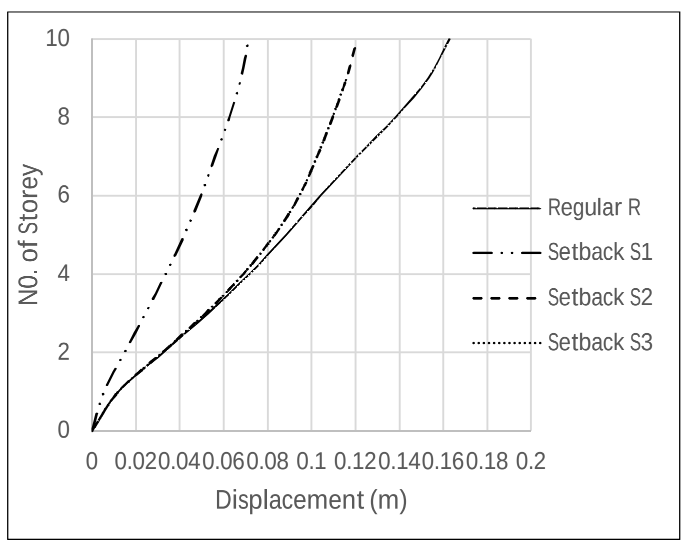

Fig. 13 Time History response on Setback-3

V. CONCLUSION

The observations according to the response of the building are as follows.

For models regular R, irregular with setback S1, irregular with setback S2 and irregular with setback S3, the storey drift in x direction for PGA of 0.18g, Imperial Valley and Kern County have values within a permissible limits given by the specification mentioned in IS1893 (part 1): 2002.

For models irregular with setback S1, irregular with setback S2 and irregular with setback S3, the storey drift in x direction for PGA of 0.18g, Imperial Valley have values within a permissible limits given by the specification mentioned in IS1893(part 1): 2016.

For models irregular with setback S1, irregular with setback S2 and irregular with setback S3, the storey drift in x direction for PGA of 0.18g, Kern County have values within a permissible limits given by the specification mentioned in IS1893(part 1): 2016.

For model irregular with setback S3 the storey drift in x direction for PGA of 0.18g, Loma Prieta have values within a permissible limits given by the specification mentioned in IS1893 (part 1): 2016.

For model irregular with setback S2 and irregular with setback S3 the storey drift in x direction for PGA of 0.18g, Oakland Outer Harbor Wharf have values within a permissible limits given by the specification mentioned in IS1893 (part 1): 2016.

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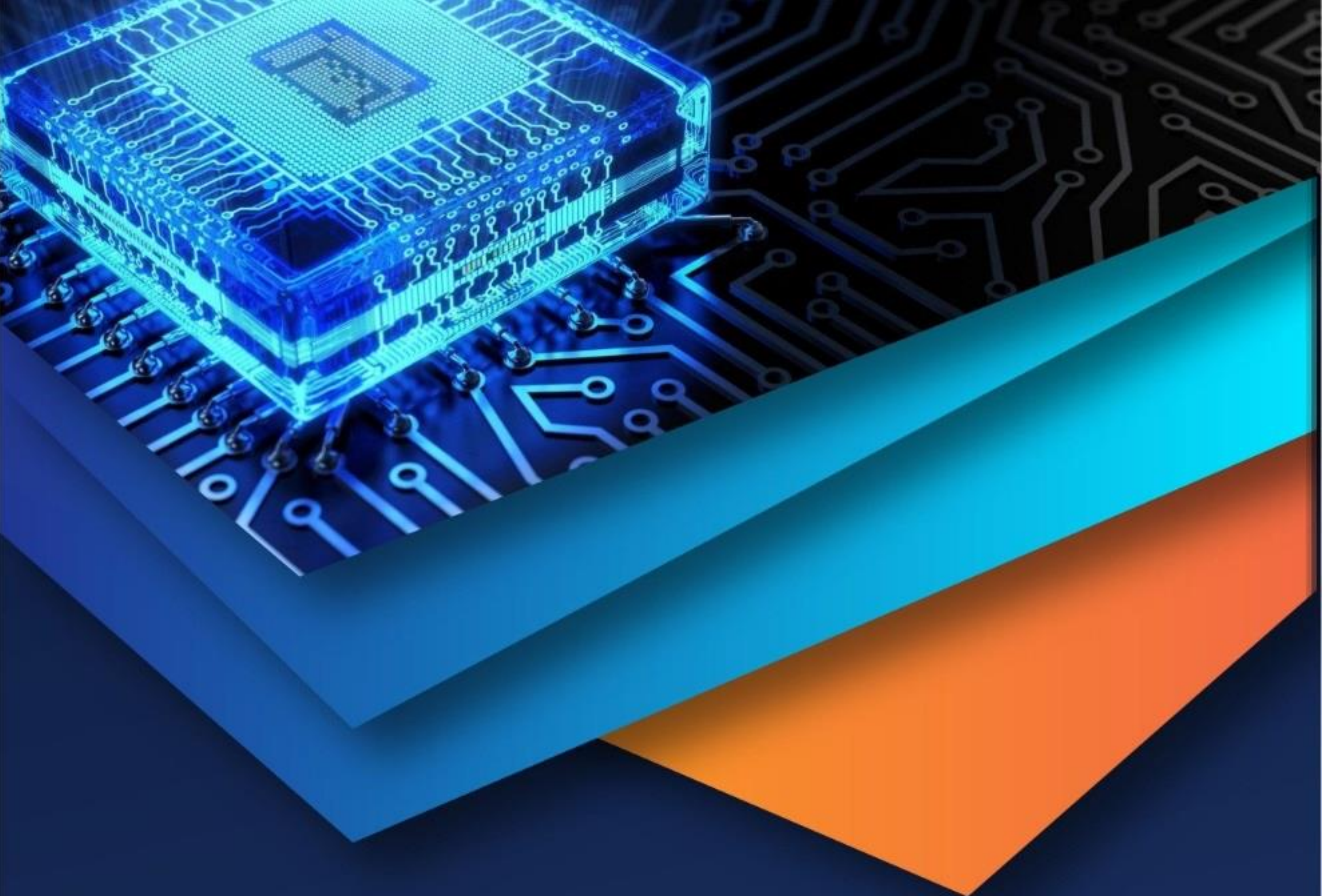

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