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Earthquake Assessment and Retrofitting of RC Flat Plate Structure

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Abstract

Flat-plate system has become one of the most popular practices now-a-days, primarily for Architectural flexibility, use of space, easier formwork and shorter construction time. However, the structural efficiency of the flat-plate is hindered by its poor performance under earthquake loading. Post-earthquake observations and experimental testing have shown that lateral movements induced by earthquake can make the connections between slabs and columns susceptible to punching shear failures. Though Reinforced Concrete Frame (RCF) is widely used in India, flat-plate constructions are also becoming popular. ACI has suggested that flat-plate frames can be designed either by Direct Design or Equivalent Frame Method.

The present study deals with the Seismic evaluation of existing Flat plate structure using Linear Dynamic Analysis i.e., Response Spectrum Analysis done in CSI SAP2000. The frame was analysed to calculate the Displacements and Stresses. Here the design spectra recommended by Indian Standard Code IS 1893-2000 is considered. Many existing flat plate buildings in India may not have been designed for seismic forces. Hence, it is important to study their response under seismic conditions and to evaluate seismic retrofit schemes. Based on the Seismic evaluation results, 4 different Models have been created to improve the seismic performance of an existing Nine-storied flat plate building which was considered as a model representative of all flat plate buildings in India.

Keywords: Earthquake, flat plate, response spectrum analysis, retrofitting, linear dynamic analysis, reinforced concrete.

INTRODUCTION

A Flat plate slab is a one-way or two-way system usually supported directly on columns or load bearing walls. The principal feature of the flat plate floor is a uniform or near-uniform thickness with a flat soffit which requires only simple formwork and is easy to construct. The floor allows great flexibility for locating horizontal services above a suspended ceiling or in a bulkhead. The economical span of a flat plate for low to medium loads is usually limited by the need to control long-term deflection and may need to be sensibly pre-cambered (not overdone) or pre-stressed.

With increasing demand for flexibility in interior layout, the use of flat plate for landed houses is gaining much popularity amongst architects. The main and unique feature of this system is that it provides a way for the architect to achieve the concept of high and completely flat ceiling with no beam protrusion. Flat plate does not have any column head or drop panel.

Shear wall is a structural member used to resist lateral forces i.e. parallel to the plane of the wall. For slender walls where the bending deformation is more, Shear wall resists the loads due to Cantilever Action. In other words, Shear walls are vertical elements of the horizontal force resisting system.

A braced frame is a structural system which is designed primarily to resist wind and earthquake forces. Members in a braced frame are designed to work in tension and compression, similar to a truss. Braced frames are almost always composed of steel members. Most braced frames are concentric. This means that, where members intersect at a node, the centroid of each member passes through the same point.

LITERATURE REVIEW

1) **Ashwini Bidari (2014)** has done the analysis and design of high-rise steel building frame with and without braces under effect of earthquake and wind. The software used for analysis was Sap2000. Dynamic analysis was carried out by using Equivalent Static method and Response spectrum method for earthquake zone V as per Indian code. The Natural period, Design Base shear, lateral Displacements are compared for the different soil supporting models. The braced system gives economical results as compared to un-braced system in terms of frequency and displacement.

2) **Baldev D. Prajapati (2013)** has studied the analysis & design procedure adopted for the calculation of symmetric high rise multi-storey building (G+30) under effect of Earthquake and Wind forces. The R.C.C., Steel, & Composite building with shear wall is considered to resist lateral forces effectively.

3) **Wakchaure M.R (2012)** has investigated the effect of masonry walls on high rise building. Linear dynamic analysis is done on high rise building with different arrangements. Analysis is done on G+9 R.C.C. framed building. Earthquake time history is applied to the models. Equivalent static method is used to calculate the width of strut. Various cases of analysis are taken. Analysis is carried out by software ETABS. Base shear, storey displacement, story drift is calculated and all models are compared.

4) **Kasliwal Sagar et a., (2010)** has investigated two multi storey buildings both are of sixteen stories and modelled using software package ETABS and SAP2000 for earthquake zone V in India. The paper also deals with the Dynamic linear Response spectra method and static non-linear pushover method. The analysis is carried on multi storey shear wall building with variation in number and position of shear wall. The author has concluded that the shear walls are one of the most effective building elements which resist the lateral forces during earthquake. The shear wall in proper position can minimize effect and damages due to earthquake and winds.

5) **Mayuri D. Bhagwat (2014)** conducted dynamic analysis of G+12 multi-storied RCC building considering for Koyna and Bhuj earthquake. The time history analysis and response spectrum analysis and seismic responses of such buildings are comparatively studied. The model with the help of ETABS software is made. Two time histories (i.e. Koyna and Bhuj) have been used to develop different acceptable criteria (base shear, storey displacement, storey drifts).

6) **Mohammad Hossain, Tahsin Hossain (2014**) worked on FEM approach to Perform Parametric Study on Slender Columns for Flat Plate Structures. They evaluated the effect of column on flat slab structure. With the help of ETAB software, work is done to know the different aspects of flat plate structures. The different parameters used by them were Height of column, cross section of column with various panel sizes for different loads. From their result it has been seen that column was more sensitive for slenderness effect in flat plate structure. Slenderness effect is observed in corner as well as edge column as compared to inner columns.

METHODOLOGY

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 and retrofit in regions where earthquakes are prevalent.

Response-spectrum analysis (RSA) is a linear-dynamic statistical analysis method which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. Response-spectrum analysis provides insight into dynamic behavior by measuring pseudo-spectral acceleration, velocity, or displacement as a function of structural period for a given time history and level of damping. It is practical to envelope response spectra such that a smooth curve represents the peak response for each realization of structural period.

Response-spectrum analysis is useful for design decision-making because it relates structural type-selection to dynamic performance. Structures of shorter period experience greater acceleration, whereas those of longer period experience greater displacement. Structural performance objectives should be taken into account during preliminary design and response-spectrum analysis. The flat plate frame which is in Zone-IV and 5% Damping ratio has been taken for analysis.

Case study

The Layout of plan having 5 X 5 bays of equal length of 6 m is considered. The building considered is 9 storey i.e. G+8. Five different models have been designed. All these buildings have been analysed by Response Spectrum Analysis method. Building is analysed by taking Zone IV and 5% damping ratio. The storey height is kept uniform of 3.2 m for all building models.

The preliminary data assumed for the analysis of frames are shown below in Table 1

Table 1: Preliminary Data of Building

S.no	Variable	Data
1	Type of structure	RCC Flat Plate structure, Commercial
2	Type of frame	Ordinary RC Moment Resisting Frame
3	Bays	5 X 5
4	No of Storeys	G+8
5	Storey Height	3.2 m
6	Building Height	28.8 m
7	Dead load	1.0 kN/m^2
8	Live Load	4.0 kN/m^2
9	Super Dead Load	1.5 kN/m^2
10	Specific weight of RCC	25 kN/m^3
11	Zone	IV
12	Importance Factor	1
13	Response Reduction Factor	3
14	Type of soil	Medium, Type II
15	Wind speed	45 m/s
16	Terrain category	2
17	Structure class	B
18	Risk coefficient	1
19	Topography (k3)	1
20	Thickness of RCC Slab	175 mm
21	RCC Columns: Bottom 2 storeys	650 X 650 mm
22	Middle 4 Storeys	600 X 600 mm
23	Top 3 Storeys	550 X 550 mm
24	Grade of concrete: RCC Slab (Thin shell)	M25
25	Columns	M30
26	Grade of Steel	HYSD415

The plan and isometric view of five building models considered are presented in Fig. 1-6

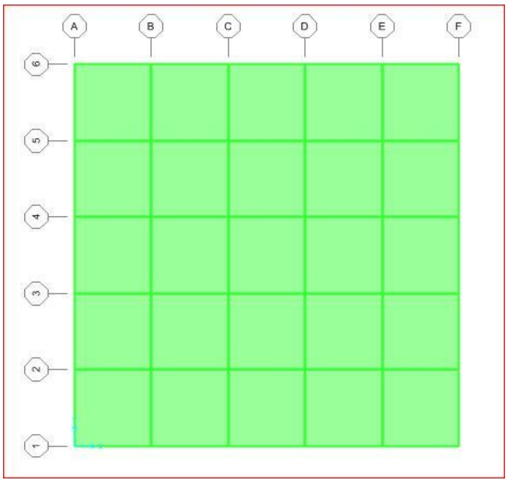

Figure 1: Plan view of all 5 Models

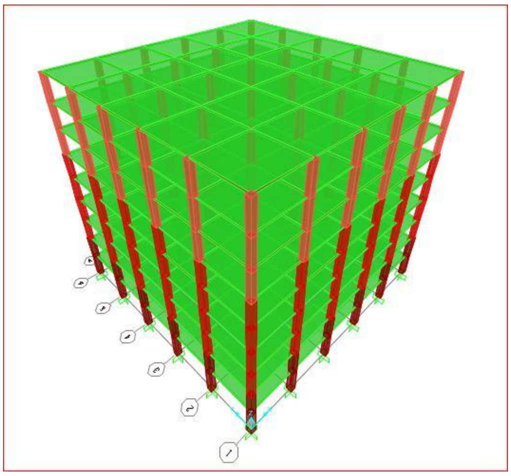

Figure 2: Isometric view of Model 1

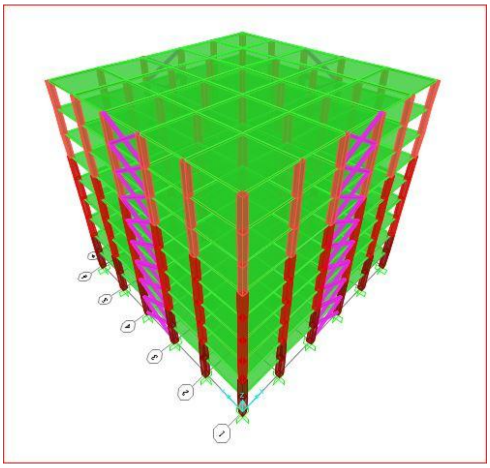

Figure 3: Isometric view of Model 2

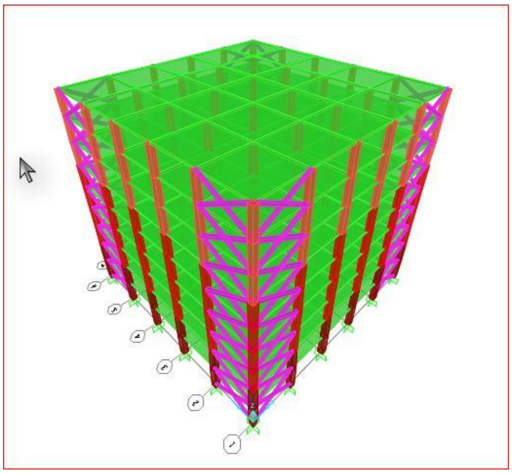

Figure 4: Isometric view of Model 3

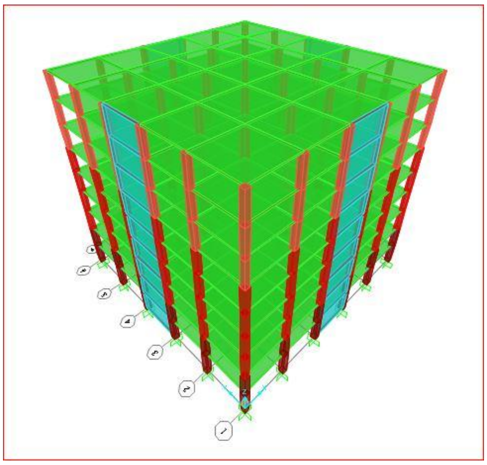

Figure 5: Isometric view of Model 4

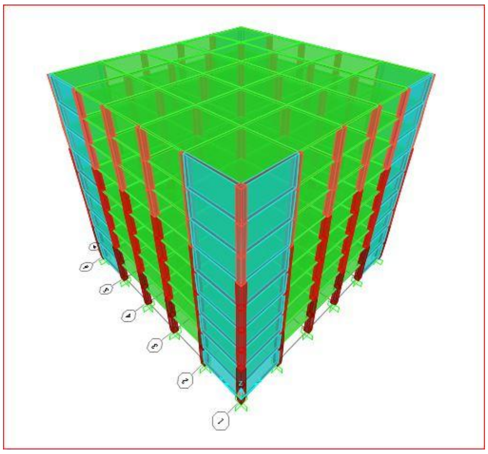

Figure 6: Isometric view of Model 5

RESULTS AND DISCUSSION

Maximum horizontal displacements:

The maximum horizontal displacements obtained from the analysis are presented in Table 2 and Fig. 7

Table 2: Maximum Displacements of All Models

S.NO	MODELS	MAXIMUM DISPLACEMENT (mm)
1	MODEL-1	157.1
2	MODEL-2	114.86
3	MODEL-3	93.82
4	MODEL-4	78.95
5	MODEL-5	44.75

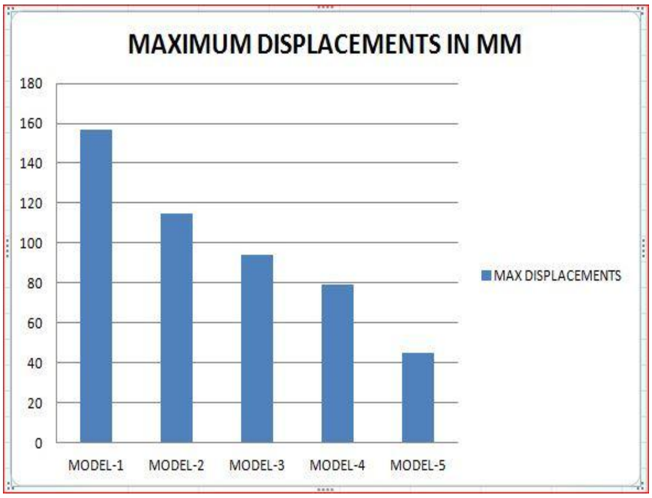

Figure 7: Maximum Displacements graph of All Models

The maximum value can be seen in Model-1 which is 157.1 mm, since no retrofitting techniques have been applied for this model. The least value can be seen in Model-5 that is 44.75 mm. The displacements of Model-2, Model-3, Model-4 and Model-5 are less than 26.89% , 40.28%, 49.75% and 71.51% from Model-1 respectively.

Model-2, Model-3 have bracing walls therefore displacements are lesser in these models, whereas Model-4, Model-5 have shear walls therefore these models have least values of displacements.

Maximum storey drifts:

The maximum storey drifts obtained from the analysis are presented in Table 3 and Fig. 8

Table 3: Maximum Storey Drift of All Models

S.NO	MODELS	MAXIMUM STORY DRIFT (MM)
1	MODEL-1	24.83
2	MODEL-2	15.1
3	MODEL-3	12.06
4	MODEL-4	11.29
5	MODEL-5	6.31

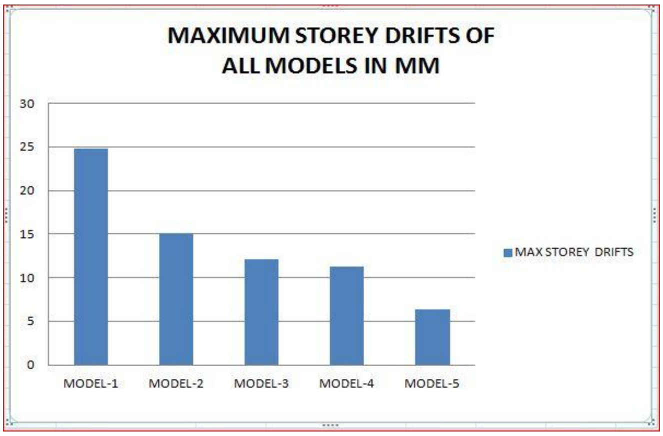

Figure 8: Maximum Storey drift graph of All Models

The maximum value of storey drift can be seen in Model-1 which is 24.83 mm since for this model no protection is applied against earthquake or wind forces. Other models have fewer values since they have bracing walls and shear walls.

The least value can be seen in Model-5 that is 6.31 mm. The storey drifts of Model-2, Model-3, Model-4 and Model-5 are less than 39.19% , 51.43%, 54.53% and 74.59% compared to that of Model-1.

Maximum column bending moments :

The maximum column bending moments obtained from the analysis are presented in Table 4 and Fig. 9

Table 4: Maximum Column bending Moments of All Models

S.NO	MODELS	MAXIMUM BENDING MOMENT (KNM)
1	MODEL-1	1090.03
2	MODEL-2	828.97
3	MODEL-3	717.84
4	MODEL-4	260.62
5	MODEL-5	170.29

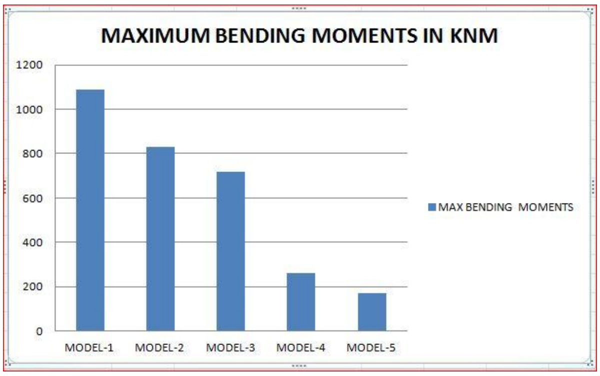

Figure 9: Maximum Column bending Moments graph of All Models

The maximum value of column bending moment can be seen in Model-1 which is 1090.03 kN-m, since it is normal conventional RCC frame moment totally resisted by column only whereas in other models moment is resisted by both column and vertical walls. The least value can be seen in Model-5 that is 170.29 kN-m. The bending moments of Model-2, Model-3, Model-4 and Model-5 are less than 23.95%, 34.14 %, 76.09% and 84.38% compared to Model-1.

Maximum column axial forces :

The maximum column axial forces obtained from the analysis are presented in Table 5 and Fig. 10

Table 5: Maximum Column Axial forces of All Models

S.NO	MODELS	MAXIMUM COLUMN AXIAL FORCE (KN)
1	MODEL-1	1005.01
2	MODEL-2	729.06
3	MODEL-3	637.24
4	MODEL-4	124.54
5	MODEL-5	324.35

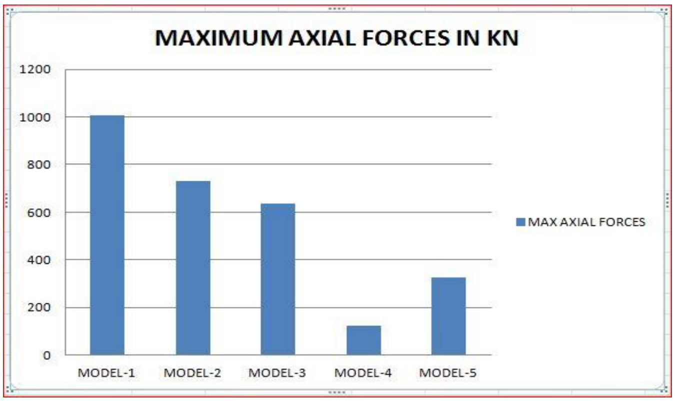

Figure 10: Maximum Column Axial forces graph of All Models

The maximum value can be seen in Model-1 which is 1005.01 kN, as total axial force is transferring through column only. The least value can be seen in Model-4 that is 124.54 kN. The axial forces of Model-2, Model-3, Model-4 and Model-5 are less than 27.46% , 36.59 %, 87.61 % and 67.73% from Model-1.

Maximum column shear forces :

The maximum column shear forces obtained from the analysis are presented in Table 6 and Fig. 11

Table 6: Maximum Column Shear forces of All Models

S.NO	MODELS	MAXIMUM COLUMN SHEAR FORCE (KN)
1	MODEL-1	270.72
2	MODEL-2	244.98
3	MODEL-3	225.18
4	MODEL-4	114.35
5	MODEL-5	45.73

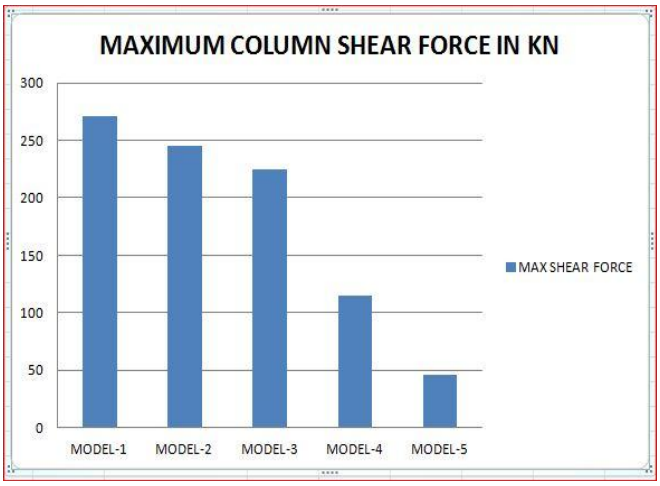

Figure 11: Maximum Column Shear forces graph of All Models

The maximum value of column shear is noted for Model-1 which is 270.72 kN. Since Model-1 has no retrofitting techniques only columns are resisting the shear forces, whereas in other models shear forces are resisted by both columns and vertical walls.

The least value can be seen in Model-5 that is 45.73 kN. The shear forces of Model-2, Model-3, Model-4 and Model-5 are less than 9.51% , 16.8%, 57.76% and 83.11% from that of Model-1.

CONCLUSION

- After the analysis of the Flat plate RC building, the comparison of the frames is carried out on the basis of displacements, storey drifts, bending moments and shear forces obtained
- High rise Flat plate buildings which are vulnerable to lateral loads and hence need shear walls to reduce lateral deflection and storey drift.
- From the results it is concluded that the Model-1 frame is inadequate to resist the seismic load and storey drifts values are very much higher than the values specified by the IS code 1893-2000 (Part 1).
- It is best to provide Shear wall as in Model-4 and Model-5 as it can be seen that more than 50% lesser Displacements, Storey drifts values are obtained when compared to Normal Building model.
- Shear wall is very effective to resist horizontal forces coming from earthquake and wind forces etc. in multi storey structure. If it is properly oriented it will reduce the shear forces in columns.
- The purely flat plate RC structural system is considerably more flexible for horizontal loads than the traditional RC frame structures, which contributes to the increase of its vulnerability to seismic effects. To increase the bearing capacity of the flat plate structure under horizontal loads, particularly in seismically prone areas, modifications of the system by adding structural elements is necessary.
- Retrofitting techniques like Bracing system and Shear wall helps in prevention of the Building from damage and collapse, increases the strength of the building. They also decrease the displacement and storey drift of the building.

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