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Parametric Seismic Analysis of Tall Buildings with Different Geometry and Constant Plan Area

ASHISH MOHAN SHIVHARE[1], K.K. PATHAK[2,*], S.K. DUBEY[1]

[1]Department of Civil Engineering, MANIT, Bhopal (MP) 462003, India

[2]Department of Civil and Environmental Engineering, NITTTR, Bhopal (MP) 462002, India

***Email: kkpathak1@rediffmail.com**

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Abstract: In this study, seismic analysis of high rise building frames have been carried out considering four buildings of different geometrical plan but same area , three diaphragms and four seismic zones. In this way total 48 frames were analysed for 27 load combinations. STADD-Pro software has been used for analysis purpose. Structural analyses results are collected in terms of maximum moments in columns and beams, storey displacement, peak storey displacement which are critically analysed to quantify the effects of various parameters.

Keywords: Seismic; Maximum moment; Base shear; Storey displacement; Peak storey displacement; Diaphragm

INTRODUCTION

Tall buildings are a special class of structures with their own peculiar characteristics and requirements (Chopra 1995). Tall buildings are often occupied by a large number of people. Therefore, their damage, loss of functionality, or collapse can have very severe and adverse consequences on the life and on the economy of the affected regions. Each tall building represents a significant investment and as such tall building analysis is generally performed using more sophisticated techniques and methodologies. Therefore, understanding modern approaches to seismic analysis of tall buildings can be very valuable to structural engineers and researchers. Behaviour of tall structures to seismic forces has to be critically examined considering various geometrical and seismic parameters. Some of the prominent literature on the topic are as follows

Kai Hu, et al. (2012) concluded that, the conventional software can no longer meet the needs of calculation and analysis. In this study, response spectrum,

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time history and linking slab in-plan stresses analysis were executed. Lucia Tirca and Liang Chen (2012) investigated the inelastic behaviour of the 4, 8 and 12 storey elastic zipper braced frame (E-ZBF) buildings located in a high risk seismic zone (Victoria, BC) under crustal, subduction, and near-field ground motion ensembles. Rana Roy and Sekhar Chandra Dutta (2010) recognized that inelastic response for short period systems is very sensitive to reduction factors (R) and may be phenomenally amplified even for small R due to soil–structure interaction implying restrictive applicability of dual-design philosophy. Limited study on the plan-asymmetric low-rise buildings depicts that inelastic response of the asymmetric structure relative to its symmetric counterpart is not appreciably influenced due to soil–structure interaction (SSI). The study also confirms that equivalent single story model characterized by the lowest period rather than the fundamental one of the real system tends to yield conservative estimation of inelastic demand at least for the short-period systems. Hong Fan et al. (2009) conducted a shaking table test to determine the constitutive relationships for the concrete filled steel tube (CFT) columns and steel members for establishing the finite element (FE) model of the tall building. Then, the seismic responses of the super-tall building were numerically investigated. Guoxin Wang et al. (2009) proposed an optimal assessment method for the design of accelerograph arrays to monitor the seismic response of high-rise buildings. This method used a finite element model of the structure based on a simplified multi-degree-of-freedom system model defined using the parameter identification method. Ho Jung et al. (2007) explained a simple method to more accurately estimate peak interstorey drifts that accounts for higher mode effects described for low-rise perimeter shear wall structures having flexible diaphragms or even for stiff diaphragms. Wilkinson and Hiley (2006) analysed a materially non-linear plane-frame model subjected to earthquake forces. The model represents each storey of the building by an assembly of vertical and horizontal beam elements The model introduced yield hinges with ideal plastic properties in a regular plane frame. The displacements were described by the translation (sway) of each floor and the rotation of all beam–column intersections. The mass was only associated with the translations, and thus the analysis could be carried out as a static condensation of the rotations, combined with integration of the dynamic equations for the translations. Dong-Guen et al. (2002) analysed box system structures, composed of only reinforced concrete walls and slabs. In this study, an efficient method was proposed to analyze high-rise box system structures considering the effects of floor slabs. Zeynep Sindel et al. (1996) emphasized that, the aseismic safety of a tall building as well as its susceptibility to nonstructural damage are primarily indexed to its ability to restrict the relative storey displacements, in addition to its adequate strength, ductility and toughness. A moment resisting frame building satisfying all requirements of strength and ductility may still be subjected to severe nonstructural damage, if the interstorey drifts are not restricted properly by means of shear walls. Several stringent deflection criteria as well as a damage control index are introduced to be conscientiously determined and checked during the design calculations for the purpose of controlling damage especially to nonstructural elements. Seong-Kwon Moon and Dong-Guen Lee (1994) adopted the rigid floor diaphragm assumption for the analysis of multistorey building structures because of the simplicity in the analysis procedure.

The objective of the present study is to investigate the effectiveness of building frame, considering different geometrical plans with constant area under various seismic parameters. This is achieved by doing comparative analysis of the building frames with rigid diaphragm, semi-rigid diaphragm and without diaphragm building frames. Analyses results are critically studied to reach to some concrete conclusions.

METHODOLOGY

This study includes comparative study of behaviour of high rise building frames considering different geometrical plan but constant area configurations and diaphragm constraints under earthquake forces. A comparison of results in terms of moments, displacements has been made. Following steps are adopted in this study:

Step-1 Selection of building geometry, bays and story (4 geometry)

Step-2 Selection of diaphragm models - without diaphragm, semi rigid diaphragm and rigid diaphragm (3 types)

Step-3 Selection of 4 seismic zones (II, III, IV, V)

Step-4 Formation of load combination (27 load combinations)

Step-5 Modelling of building frames using STADD.Pro software

Step-6 Analyses considering different diaphragm models, seismic zones and each load combinations (48 cases)

Step-7 Comparative study of results in terms of maximum moments in columns and beams, story displacement, peak story displacement.

STRUCTURAL MODELLING AND ANALYSIS

(a) Modelling of building frames

Building frame with the following four geometrical configurations are considered for analysis-

CASE-1: Square in plan area is 225 sq. m and 13 storey height.
CASE-2: Rectangle in plan area is 225 sq. m and 13 storey height.
CASE-3: Trapezoidal in plan area is 225 sq. m and 13 storey height.
CASE-4: L-Shape in plan area is 225 sq. m and 13 storey height.

Structural models for the four cases are shown in Fig. (1-4). No. of beams and columns for these cases are given in Table 1. Modeling of the building frames are carried out using the GUI of STAAD.Pro software (Ref.11) .

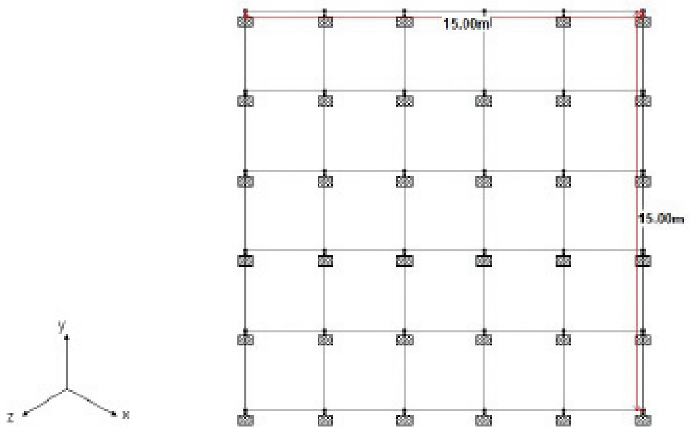

Figure 1: Structural model of CASE-1

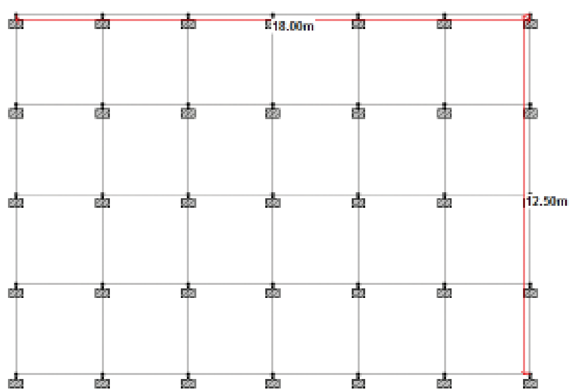

Figure 2: Structural model of CASE-2

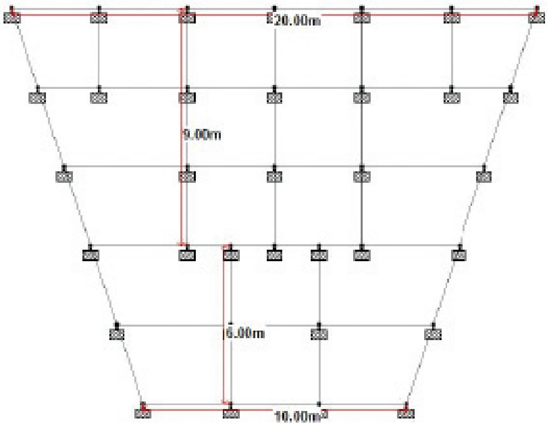

Figure 3: Structural model of CASE-3

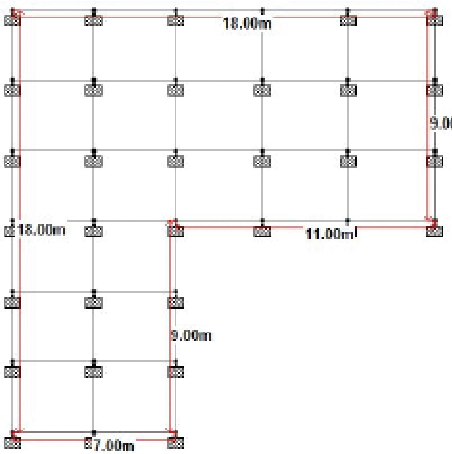

Figure 4 : Structural model of CASE-4

(b) Types of diaphragms

The following three types of diaphragm conditions have been considered for analysis-

Type-A : Model without Diaphragm constraint.

Type-B : Model with Semi rigid Diaphragm constraint in the plane of slab (XZ Plane).

Type-C : Model with rigid Diaphragm constraint.

Table 1: No. of beams and columns in different cases

CASE MEMBER	CASE-1	CASE-2	CASE-3	CASE-4
Columns	540	525	510	495
Beams	900	870	795	795

(c) Material and geometrical properties

Following material properties have been considered in the modelling -

Density of RCC: 25 kN/m^3

Density of Masonry: 20 kN/m^3

Young's modulus of concrete : $2x10^4$ N/mm^2

Poisson ratio : 0.17

The foundation depth is considered at 2.0m below ground level and the typical storey height is 3.0 m. The column size is 450mm x 450mm, and the beam size is 230mm x 450mm.

(d) Loading conditions

Following loading are conducted for analysis -

1) Dead Loads:
   a. Self wt. of slab considering 150mm thick slab = 0.15*25 = 3.75 kN/m^2
   b. Floor finish load = 1 kN/m^2
   c. Water proofing load on roof = 2.5 kN/m^2
   d. Masonry wall load = 0.25 x 2.55 x 20 = 12.75 kN/m
2_ Live Loads:
   a. Live load on typical floors = 2 kN/m^2
   b. Live load on roof = 1.5 kN/m^2
3) Earthquake Loads:

   All the building frames are analyzed for 4 seismic zones

   The earthquake loads are derived for following seismic parameters as per IS: 1893(2002)

   a. Earth Quake Zone-II,III,IV,V
   b. Response Reduction Factor : 5
   c. Importance Factor : 1
   d. Damping : 5%
   e. Soil Type: Medium Soil

(e) Structural Analysis

Structural analyses of the building frames are carried out using STAAD.Pro software (Ref.11) . All the columns are rigidly supported at ground and 27 load combinations, given in Table 2, are considered for the analysis purposes. Application of boundary and loading conditions are done through the GUI mode of software.

Table 2: Load Combinations.

Load case no.	Load case detail
1.	EQ IN X DIR.
2.	EQ IN Z DIR.
3.	DEAD LOAD
4.	LIVE LOAD
5.	1.5 (DL + LL)
6.	1.5 (DL + EQX)
7.	1.5 (DL - EQX)
8.	1.5 (DL + EQZ)
9.	1.5 (DL - EQZ)
10.	1.2 (DL + LL + EQX)
11.	1.2 (DL + LL - EQX)
12.	1.2 (DL + LL + EQZ)
13.	1.2 (DL + LL - EQZ)
14.	0.9DL + 1.5EQX
15.	0.9DL - 1.5EQX
16.	0.9DL + 1.5EQZ
17.	0.9DL - 1.5EQZ
18.	1.0 (DL + LL)
19.	1.0 (DL + EQX)
20.	1.0 (DL - EQX)
21.	1.0 (DL + EQZ)
22.	1.0 (DL - EQZ)
23.	0.8 (DL + LL + EQX)
24.	0.8 (DL + LL - EQX)
25.	0.8 (DL + LL + EQZ)
26.	0.8 (DL + LL - EQZ)
27.	LOAD FOR CHECK

RESULT AND DISCUSSION

Results of structural analyses can be described under following heads -

a. Moments in columns and beams

Minimum and maximum moments in columns for different cases are shown in Fig. 5 and 6. The minimum moment in column are observed in TYPE-C, CASE-1 and ZONE-II and the maximum moments are observed in TYPE-B, CASE-3 and ZONE-V. It is also found that the moments in columns are less than moments in beam TYPE-A and TYPE-B but in TYPE-C it is inverse means moment in beam in TYPE-C is less than column moment in TYPE-C. Moment in columns decreases from TYPE-A to TYPE-C and it is also observed from graphs that in CASE-3 moments are maximum in both beam and column.

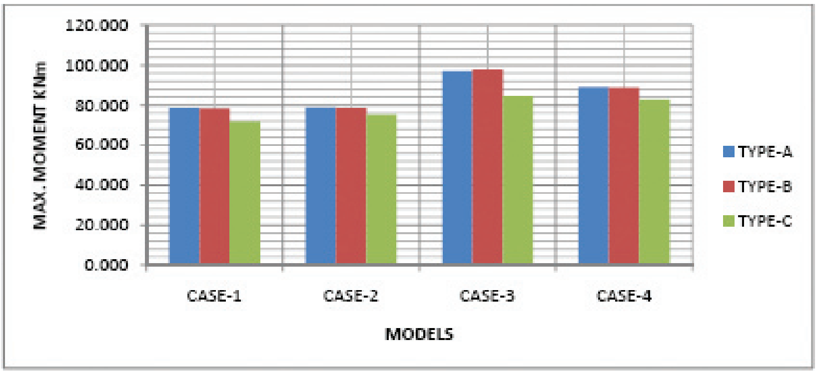

Figure 5 : Graph of min. moment in column TYPE-C, CASE-1 and ZONE-II

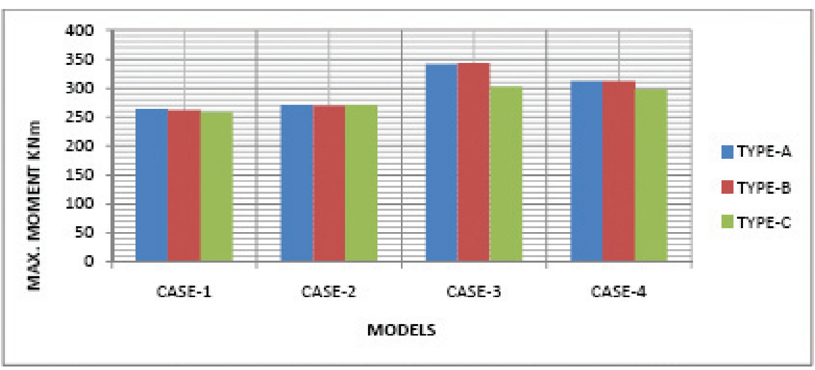

Figure 6: Graph of max. moment in column TYPE-B, CASE-3 and ZONE-V

Minimum and maximum moments in beams for different cases are shown in Fig. 7 and 8. The minimum moment in beam are observed in TYPE-C, CASE-1 and ZONE-II and the maximum moments are observed in TYPE-A, CASE-3 and ZONE-V. Moment in beam decreases from TYPE-A to TYPE-C. It can be observed that variation in moments with respect to types is maximum in beam than column irrespective of cases. Hence beam moments can be drastically reduced using rigid diaphragm model.

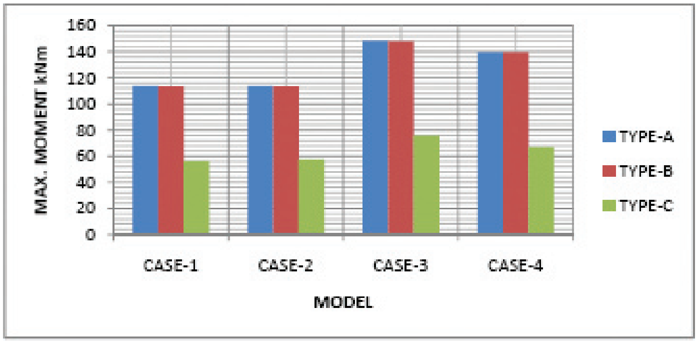

Figure 7 : Graph of min. moment in beam TYPE-C, CASE-1 and ZONE-II

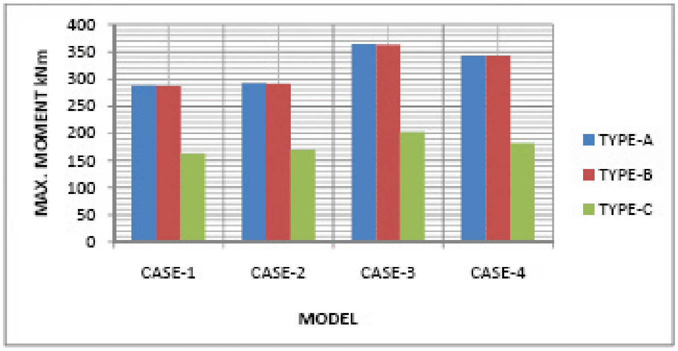

Figure 8 : Graph of max. moment in beam in TYPE-A, CASE-3 and ZONE-V

b. Storey displacement

Minimum and maximum storey displacement are shown in Fig. 9 and 10. The minimum storey displacement is in TYPE-C, CASE-2, ZONE-II in Z direction and the maximum storey displacement in TYPE-B, CASE-4, ZONE-V in X direction. The storey displacement increases from ZONE-II to ZONE-V for all

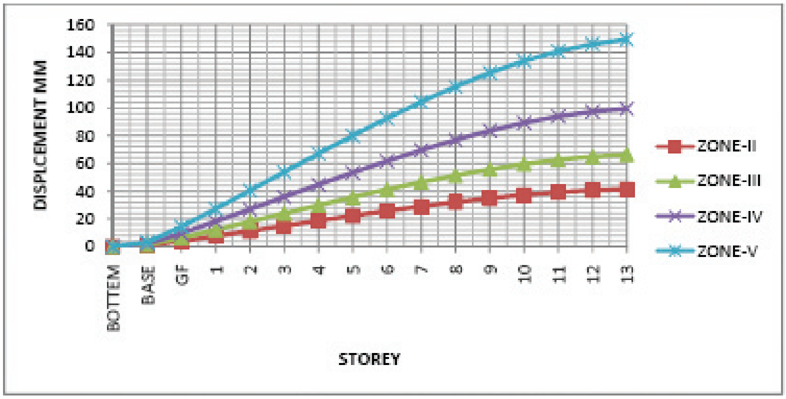

Figure 9 : Graph of min. storey displacement in TYPE-C ZONE-II (CASE-2), Z-direction

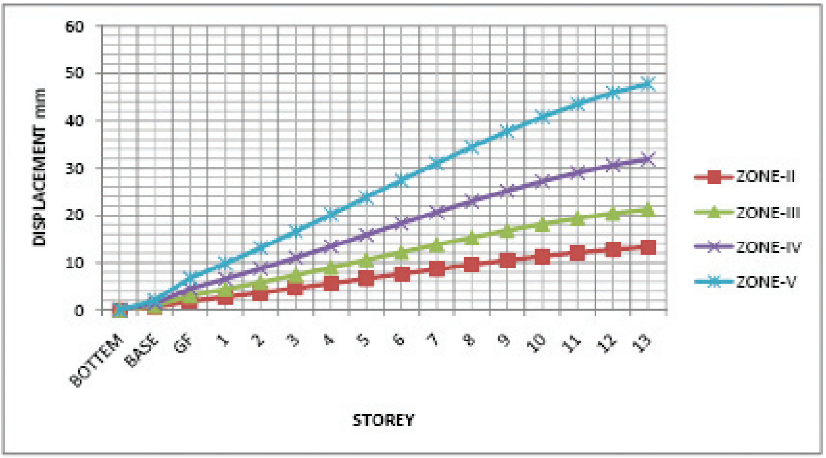

Figure 10 : Graph of max. storey displacement in TYPE-B, ZONE-V (CASE-4), X-direction

the cases. It is observed from graph that nature of storey displacement is same in all zones and cases. Storey displacement increases with increase in storey height. Maximum storey displacement is seen in top floor of every cases. TYPE-A and TYPE-B shows almost same result but in TYPE-C is less than half of TYPE-A and TYPE-B.

c. Peak storey displacement

Minimum and maximum peak storey displacement are shown in Fig. 11 and 12. The minimum peak storey displacement is in TYPE-C, CASE-2 and ZONE-II in X direction and the maximum peak storey displacement is in TYPE-A, CASE-4 and ZONE-V in X direction. The peak storey displacement in TYPE-C is less than half of TYPE-A and TYPE-B. It mean that TYPE-C stiffness is twice that of TYPE-A and TYPE-B. As per nature of graph, it is seen that CASE-2 has less peak displacement and CASE-4 has maximum peak displacement.

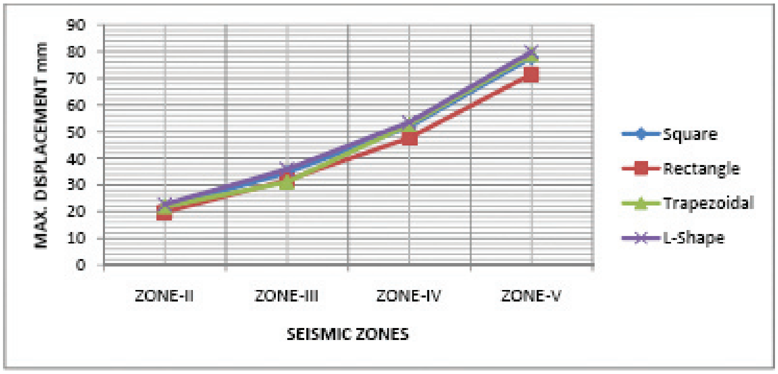

Figure 11 : Graph of min. peak storey displacement in TYPE-C, ZONE-II (CASE-2), X-direction

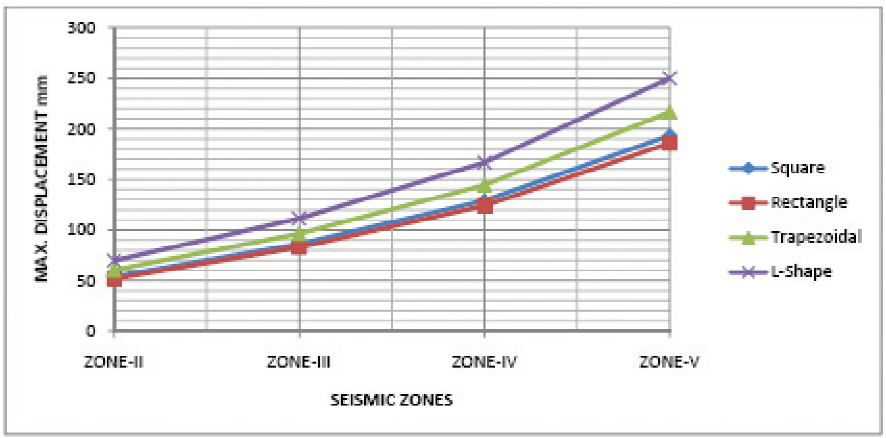

Figure 12 : Graph of max. peak storey displacement in TYPE-A, ZONE-V (CASE-4), X-direction

CONCLUSIONS

In this study, performance of building frames are studied considering various geometrical and seismic parameters. For this 48 frame cases are analysed considering 27 load combinations. Result of this parametric study shows that diaphragm modelling has major influence on moment and displacement. Moments in beams are more sensitive to diaphragm models than that of columns. It has been found from the analysis of various building with different geometry plans but same area that the Rigid diaphragm is more effective in case of a building of nearly rectangle in plan. The analysis done in the present study clearly shows that semi-rigid diaphragm models produce more frame displacement and moments than the rigid diaphragm models. Although, no building in real sense, can be provided with a perfect rigid diaphragm, it can be concluded that the structural economy of the building shall be proportional to the degree of rigidity of the diaphragm.

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