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INFLUENCE OF FLOOR DIAPHRAGM BUILDING WHILE CONSIDERING SEISMIC FORCES

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ABSTRACT

In this work, seismic analysis of multi storey RC building frames have been carried out considering different types of floor diaphragm. Floor diaphragm are very efficient in resisting lateral forces. STAAD.Pro software has been used for analysis purpose. Analyses of multi storey RC building frames are carried out in 3 parts I) Building frame without floor diaphragm, II) Building frames with semi rigid floor diaphragm III) Building frames with rigid floor diaphragm. Results are collected in terms of maximum moments in beams, axial force, shear force, maximum displacement and storey displacement which are critically analysed to quantify the effects of various parameters. This approach focuses various floor diaphram in a structure and their effectiveness in reducing the lateral displacement ultimately to achieve economy in construction with similar structural frames.

KEYWORDS: Seismic ;Floor diaphragm; Maximum moment; Shear Force; Storey displacement; Peak storey displacement.

INTRODUCTION

Floor diaphragm means, the interaction of the lateral load with lateral-force-resisting vertical elements is achieved by the use of floor systems that generally possess large in-plane stiffness. Thus, the vertical load resisting elements will contribute to the total lateral load resistance in proportion to their own stiffness. Floors can act as diaphragm because of its large in-plane stiffness. The main function of the floor diaphragm is to transmit the inertial forces generated by the ground motion of the floor mass at a given level to the lateral-force-resisting vertical elements generated by the ground motion. At lower storey, significant lateral load need to be transferred from one element to another element causing significant shear forces and bending moments in the diaphragm.

Some of the prominent literature on the topic are as follows -

D. R. Gardineret al. (2008) research investigates the magnitude and trends of forces in concrete floor diaphragms, with an emphasis on transfer forces, under seismic loading. This research considers the following items: inertial forces which develop from the acceleration of the floor mass; transfer forces which develop from the interaction of lateral force resisting elements with different deformation patterns, such as wall and frame elements; and variation of transfer forces due to different strengths and stiffness of the structural elements. The magnitude and trends of forces in the floor diaphragms have been determined using 2-dimensional inelastic time history analysis. **Ho Jung et al. (2007)** discussed 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. **Joel M. Barron and Mary Beth D. Hueste (2004)** analysed under seismic loading, floor and roof systems in reinforced concrete (RC) buildings act as diaphragms to transfer lateral earthquake loads to the vertical lateral force-resisting system (LFRS). In current practice, horizontal diaphragms are typically assumed to be rigid, thus neglecting the effect of their in-plane movement relative to the vertical LFRS. The objective of this study is to evaluate the impact on in-plane diaphragm deformation on the structural response of typical RC rectangular buildings using a performance-based approach. Three-story and five-storey RC buildings with end shear walls and two aspect rations (approximately 2:1 and 3:1) were developed and designed according to current code procedures assuming rigid diaphragm behaviour. The performance-based design criteria outlined in the FEMA 273-NEHRP Guidelines for Seismic Rehabilitation of

Buildings were used to assess the adequacy of the four case study buildings when diaphragm flexibility was included in the structural response. **D. K. Bull (2003)** investigates the variety of layouts of lateral force resisting elements in structures, subjected to inelastic behaviour, make the design of diaphragms [4] significantly more complex than the traditional "simple beam" approach typically employed. Traditionally held views that diaphragms are inherently robustness and hence do not requires significant engineering input have been shown to be inappropriate by recent major earthquakes and recent laboratory studies. The simple beam method, at times, fails to recognise that the traditional load paths assumed are compromised by localised damage in the floor (diaphragms) due to incompatibility of deformation between the floors and the supporting structures (walls, beam and columns). "Strut and tie" methods are suggested as a means of tying these diaphragms into the lateral force resisting structures and as a way of dealing irregular floor plates and penetrations (stairs, lifts, atriums) through the floors. The focus of research in determining the seismic lateral forces into and through floor diaphragms has been on the magnitude of the floor inertias. However, it has been shown that primary structural elements interacting through the diaphragm, can cause stresses in the floors many more times than those of the inertia effects. These two sources of forces and stresses are interrelated. **M.M. El-Hawary (1994)** investigates the importance of including the effects of the flexibility of the horizontal diaphragmswhen using the P-delta method of analysis, especially when considering the loads applied to intermediateframes on trusses that are not part of the lateral force resisting system. Analyses were conducted forstructural systems with a variable number of stories, number of bays and diaphragm stiffnesses andsupported by rigid jointed plane frames or vertical trusses. **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. **Sashi K. Kunnath (1991)** emphasized the in-plane flexibility of floor-slab systems has been observed to influence the seismic response of many types of reinforced concrete buildings. The assumption of rigid floor diaphragms is often used to simplify engineering analyses without significant loss in the accuracy of seismic response prediction for most buildings. However, for certain classes of structures, such as long and narrow buildings (especially with dual-braced lateral load-resisting systems), and buildings with horizontal (T or L-shaped) or vertical (setbacks or cross-walls) offsets, the effect of diaphragm flexibility cannot be disregarded. This paper presents an simplified macro-modelling scheme to incorporate the effect of inelastic floor flexibility in the seismic response analysis of RC buildings. The slab model includes effects of both in-plane flexure and shear. The inelastic behaviour of diaphragms is emphasized through a study of narrow rectangular buildings with end walls. The study shows that the in-plane deflections of floor slabs impose a larger demand on strength and ductility of flexible frames than predicted values using the assumption of rigid or elastic slabs. These demands may in turn lead to a failure of the gravity load supporting system. A quantitative estimate of this effect is presented in terms of the floor aspect ratios

Aim for this study is to understand the effect of seismic in multi storey structure and the remedial measures to control these effects. To do this, models are generated and analysed with the help of STAAD.Pro software, and the effect of with and without floor diaphragm including core and outer pattern to resist the seismic forces are critically analysed.

METHODOLOGY

Following steps have been adopted in this study-

Step-1 selection of building geometry, bays and story
Step-2 Selection of floor diaphragm (with out floor diaphragm, semi rigid floor diaphragm and rigid floor diaphragm)
Step-3 selection of 4 seismic zones (II,III,IV and V)
Step-4 Formation of load combination (13 load combinations)

Load case no.	Load cases details
1.	E.Q. IN X DIR.
2.	E.Q. 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)

Step-5 Modelling of building frames
Step-6 Analysis considering different bracing system, seismic zones and each load combinations
Step-7 Comparative study of results in terms of maximum moments in columns and beams, base shear, story displacement, peak story displacement.

STRUCTURAL MODELLING AND ANALYSIS

CASE-1: Bare frame without bracing of G+7 storey height.
CASE-2: Semi rigid diagram of G+7 storey height.
CASE-3: Rigid floor diaphragm of G+7 storey height.
STAAD.Pro is used in modelling of building frames. STAAD.Pro is Structural Analysis and Design Program is a general purpose program for performing the analysis and design of a wide variety of structures. The basic three activities which are to be carried out to achieve this goal are -
a. Model generation
b. Calculations to obtain the analytical results
c. Result verification- These are allfacilitated by tools contained in the program's graphical environment.

Structural Models

Structural models for different cases are shown in Fig. 1 to 4.

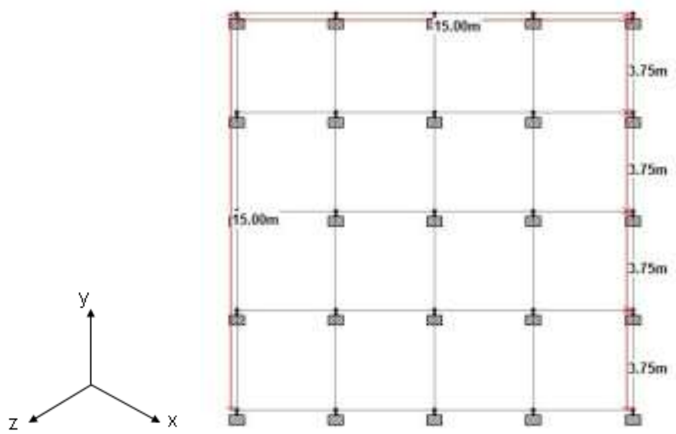


Figure 1: Plan of Bare frame

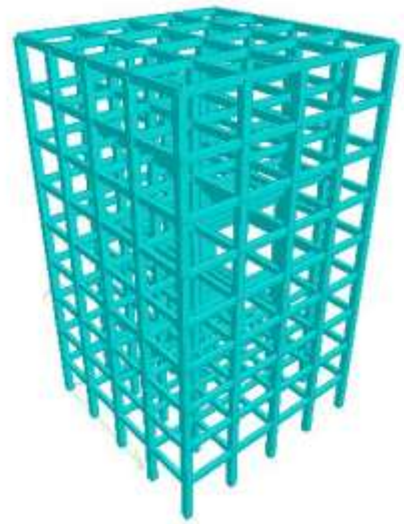
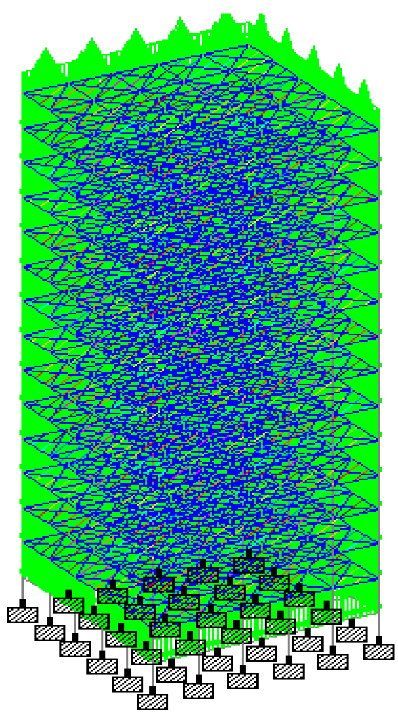


Figure 2: Structural model of Bare frame



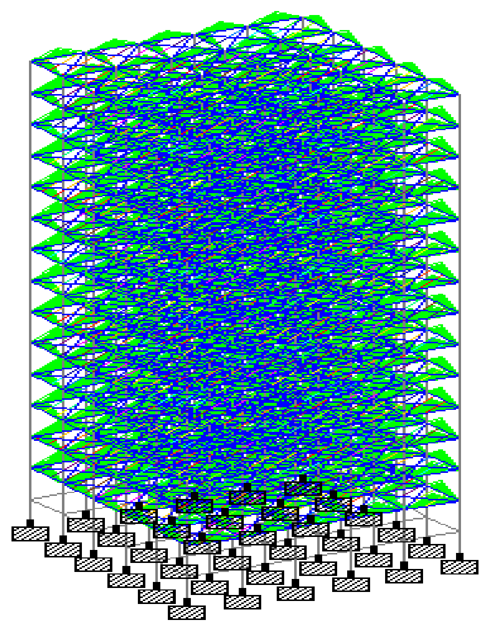


Figure 3:Dead load diagram Figure 4: Live load diagram

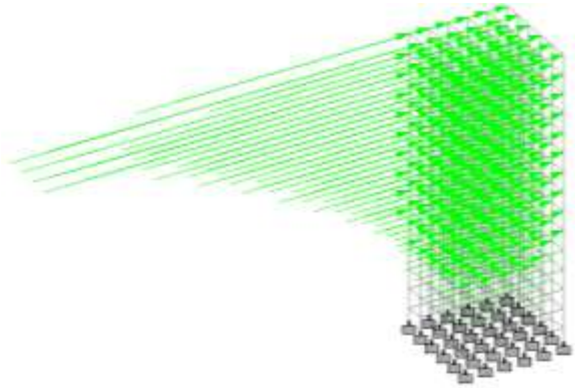


Figure 5:Earthquake load in X direction

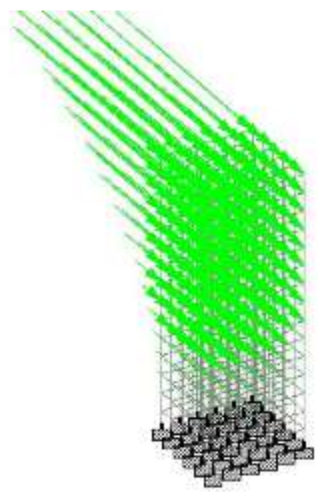


Figure 6:Earthquake load in Z direction

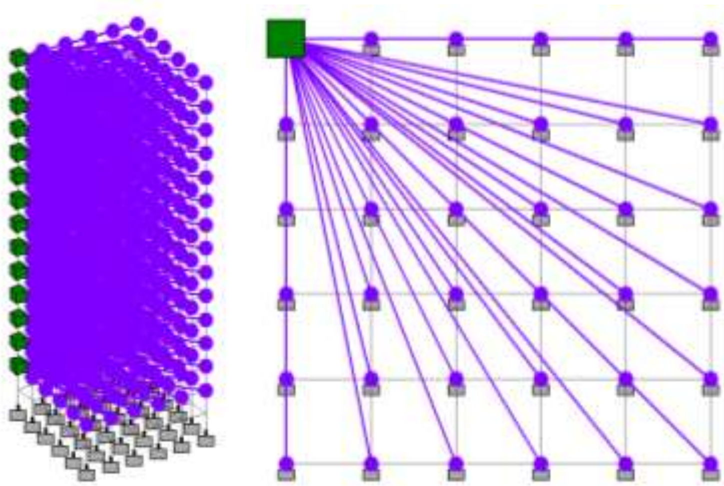


Figure 7: A typical isomeric diagram for diaphragm and Figure 4.9:A typical plan diagram for diaphragm
The column size is of 450MM x 450MM, and the beam size is 230MM x 450MM.

MATERIAL AND GEOMERICAL PROPERTIES

Following material properties have been considered in the modelling -
Density of RCC: 25 kN/m^3
Density of Masonry: 20 kN/m^3 (Assumed)
Young's modulus of concrete: $5000\sqrt{fck}$
Poisson'sratio: 0.17
The foundation depth is considered at 2.0m below ground level and the typical storey height is 3.0 m.

Loading Conditions

Following loadings are considered for analysis -
(a) Dead Loads: as per IS: 875 (part-1) 1987
Self wt. of slab considering 150 mm thick. Slab = 0.15 x 25 = 3.75 kN/m^2 (slab thick. 150 mm assumed)
Floor Finish load = 1 kN/m^2
Water Proofing Load on Roof = 2.5 kN/m^2
Masonry Wall Load = 0.25 x 2.55 x 20 = 12.75 kN/m
(b) Live Loads: as per IS: 875 (part-2) 1987
Live Load on typical floors = 2 kN/m^2
Live Load on Roof = 1.5 kN/m^2
(c) Earth Quake Loads:
All the building frames are analyzed for 4 seismic zones
The earth quake loads are derived for following seismic parameters as per IS: 1893 (2002) [21]
a. Earth Quake Zone-II,III,IV,V (Table - 2)
b. Importance Factor: 1 (Table - 6)
c. Response Reduction Factor: 5 (Table - 7)
d. Damping: 5% (Table - 3)
e. Soil Type: Medium Soil (Assumed)
f. Period in X direction (PX): $\frac{0.09*h}{\sqrt{dx}}$ seconds Clause 7.6.2 [21]
g. Period in Z direction (PZ): $\frac{0.09*h}{\sqrt{dz}}$ seconds Clause 7.6.2 [21]
Where h = height of the building
dx= length of building in x direction
dz= length of building in z direction

RESULTS AND DISCUSSION

Analysis of building frame for various seismic zones in different floor diaphragm model

Results can be described under following heads -

- **Max. Displacement**

The maximum displacement in X direction for different earthquake zones are shown in Table 5.1 and Fig. 5.1

Table 5.1: Maximum displacement (mm) in X direction

Structure type	In X Direction			
	Zone II	Zone III	Zone IV	Zone V
Bare Frame	38.465	61.488	92.186	138.232
Rigid Diaphragm	11.074	17.718	26.577	39.865
Semi Rigid Diaphragm	37.434	59.894	89.842	134.762

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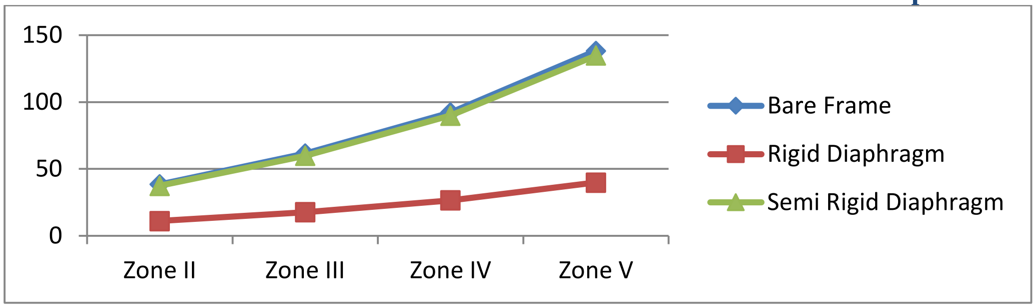

Fig. 5.1: Maximum displacement in X direction

Maximum displacement is observed in bare frame and minimum in rigid diaphragm means rigid diaphragm provide better stability

The maximum displacement in Z direction for different earthquake zones are shown in Table 5.2 and Fig. 5.2

Table 5.2: Maximum displacement (mm) in Z direction

Structure type	In Z Direction			
	Zone II	Zone III	Zone IV	Zone V
Bare Frame	38.465	61.488	92.186	138.232
Rigid Diaphragm	11.074	17.718	26.577	39.865
Semi Rigid Diaphragm	37.434	59.894	89.842	134.762

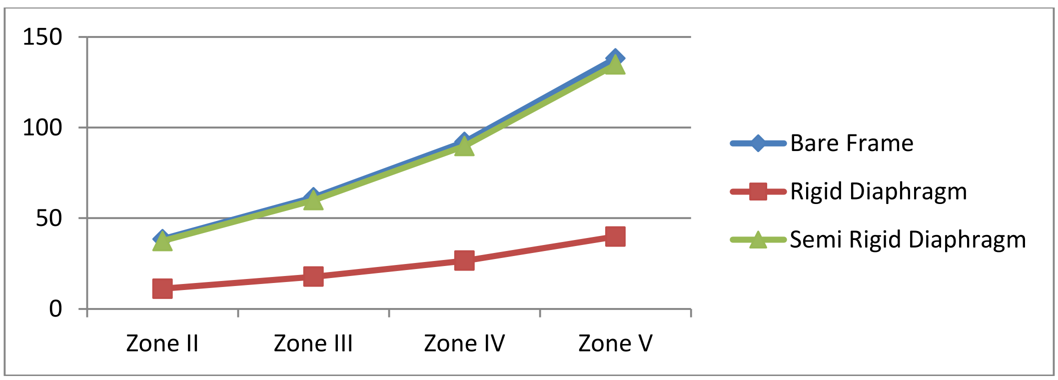

Fig. 5.2: Maximum displacement in Z direction

Maximum displacement is observed in bare frame and minimum in rigid diaphragm means rigid diaphragm provide better stability

- **Maximum bending moment**

The maximum bending moment for different earthquake zones are shown in Table 5.3 and Fig. 5.3

Table 5.3: Maximum bending moment (kNm) for different floor diaphragm

Structure type	Max Bending Moment			
	Zone II	Zone III	Zone IV	Zone V
Bare Frame	137.728	187.212	253.191	366.537
Rigid Diaphragm	65.779	105.246	157.869	236.803
Semi rigid Diaphragm	135.768	184.114	248.575	358.501

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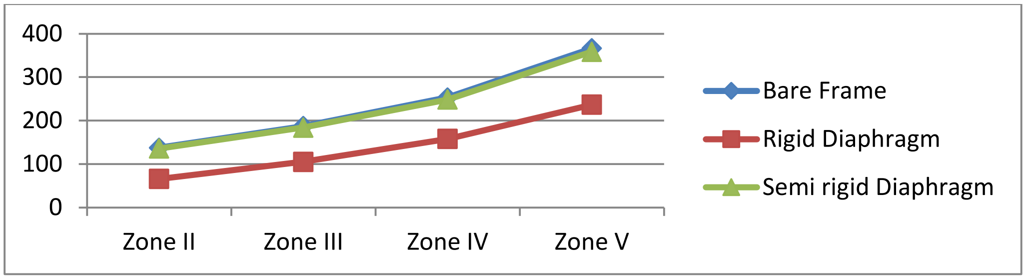

Fig. 5.3: Maximum bending moment (kNm) for different floor diaphragm

Maximum bending moment is observed in bare frame and minimum in rigid diaphragm

- **Maximum shear force**

The maximum shear force for different earthquake zones are shown in Table 5.4 and Fig. 5.4

Table 5.4: Maximum shear force (kN) for different floor diaphragm

Structure type	Max Shear force			
	Zone II	Zone III	Zone IV	Zone V
Bare Frame	115.938	141.473	175.52	226.59
Rigid Diaphragm	83.587	83.587	104.454	156.682
Semi rigid Diaphragm	114.929	139.875	173.137	223.031

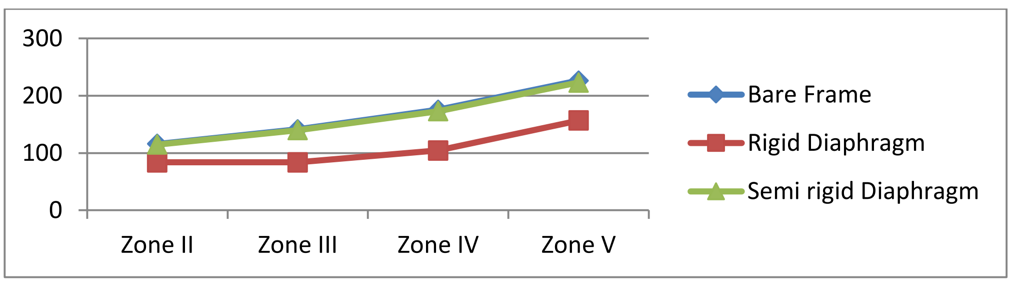

Fig. 5.4: Maximum shear force (kN) for different floor diaphragm

Maximum shear force is observed in bare frame and minimum in rigid diaphragm

- **Maximum storey displacement**

The maximum storey displacement X direction for different floor diaphragm are shown in Table 5.5 and Fig. 5.5

Table 5.5: Max. storey displacement X direction for different floor diaphragm in Zone-II

Max. storey displacement for different floor diaphragm zone-II			
Floor	In X Direction		
	Bare Frame	Rigid Diaphragm	Semi rigid Diaphragm
Base	0	0	0
Ground Floor	2.088	0.954	2.13
1st Floor	5.565	1.941	5.667
2nd Floor	9.239	2.944	9.418
3rd floor	12.828	3.937	13.096
4th floor	16.184	4.888	16.546

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5th floor	19.162	5.758	19.619
6th floor	21.608	6.5	22.144
7th floor	23.362	7.061	23.945
8th floor	24.378	7.382	24.956

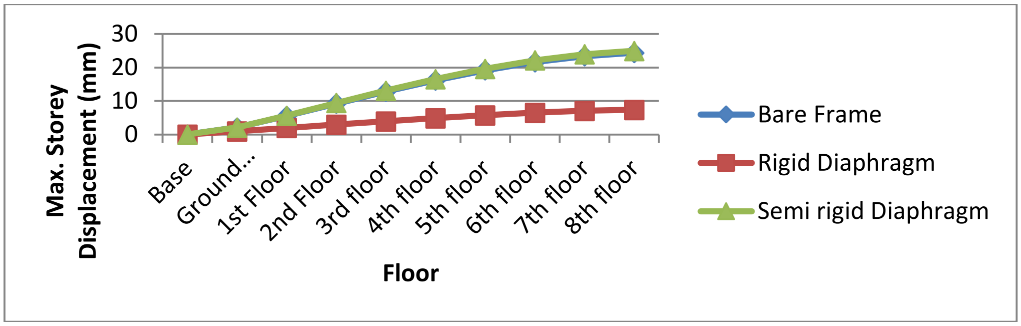

Fig. 5.5: Max. storey displacement X direction for different floor diaphragm in Zone-II
Maximum storey displacement is observed in bare frame and minimum in rigid diaphragm

The maximum storey displacement for Z direction different floor diaphragm are shown in Table 5.6 and Fig. 5.6

Table 5.6: Max. storey displacement Z direction for different floor diaphragm in Zone II

Max. storey displacement for different floor diaphragm zone-II			
Floor	In Z Direction		
	Bare Frame	Rigid Diaphragm	Semi rigid Diaphragm
Base	0	0	0
Ground Floor	2.088	0.954	2.13
1st Floor	5.565	1.941	5.667
2nd Floor	9.239	2.944	9.418
3rd floor	12.828	3.937	13.096
4th floor	16.184	4.888	16.546
5th floor	19.162	5.758	19.619
6th floor	21.608	6.5	22.144
7th floor	23.362	7.061	23.945
8th floor	24.378	7.382	24.956

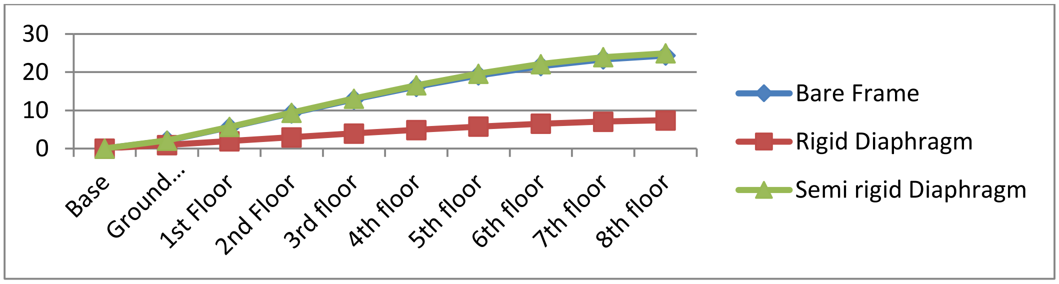

Fig. 5.6: Max. storey displacement Z direction for different floor diaphragm in Zone-II
Maximum storey displacement is observed in bare frame and minimum in rigid diaphragm

The maximum storey displacement X direction for different floor diaphragm are shown in Table 5.7 and Fig. 5.7

Table 5.7: Max. storey displacement X direction for different floor diaphragm in Zone-III

Max. storey displacement for different floor diaphragm zone-III			
Floor	In X Direction		
	Bare Frame	Rigid Diaphragm	Semi rigid Diaphragm
Base	0	0	0
Ground Floor	3.341	1.527	3.408
1st Floor	8.903	3.106	9.067
2nd Floor	14.782	4.71	15.07
3rd floor	20.525	6.299	20.953
4th floor	25.894	7.821	26.474
5th floor	30.66	9.213	31.391
6th floor	34.572	10.4	35.43
7th floor	37.379	11.298	38.311
8th floor	39.004	11.812	39.93

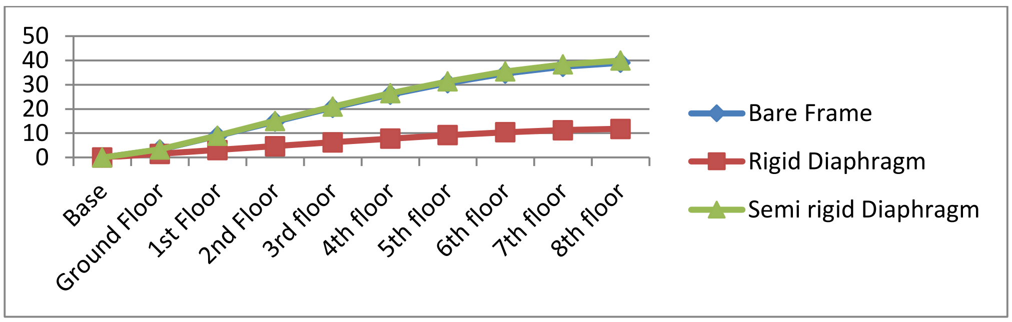

Fig. 5.7: Max. storey displacement X direction for different floor diaphragm in Zone-III

Maximum storey displacement is observed in bare frame and minimum in rigid diaphragm
The maximum storey displacement Z direction for different floor diaphragm are shown in Table 5.8 and Fig. 5.8

Table 5.8: Max. storey displacement Z direction for different floor diaphragm in Zone-III

Max. storey displacement for different floor diaphragm zone-III			
Floor	In Z Direction		
	Bare Frame	Rigid Diaphragm	Semi rigid Diaphragm
Base	0	0	0
Ground Floor	3.341	1.527	3.408
1st Floor	8.903	3.106	9.067
2nd Floor	14.782	4.71	15.07
3rd floor	20.525	6.299	20.953
4th floor	25.894	7.821	26.474
5th floor	30.66	9.213	31.391
6th floor	34.572	10.4	35.43
7th floor	37.379	11.298	38.311
8th floor	39.004	11.812	39.93

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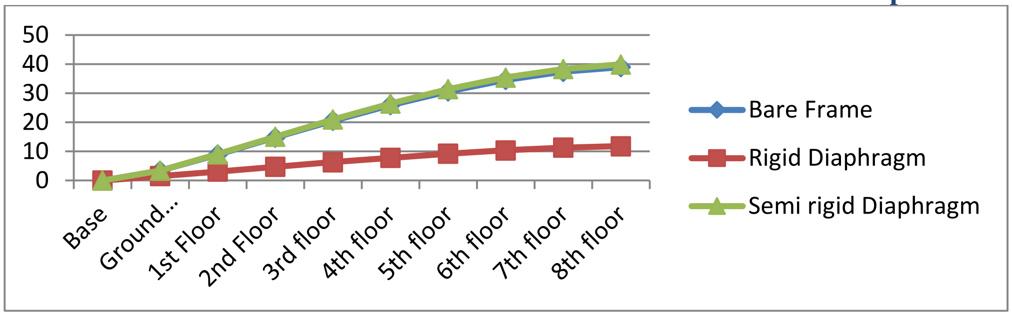

Fig. 5.8: Max. storey displacement X direction for different floor diaphragm in Zone-III

Maximum storey displacement is observed in bare frame and minimum in rigid diaphragm

The maximum storey displacement X direction for different floor diaphragm are shown in Table 5.9 and Fig. 5.9

Table 5.9: Max. storey displacement X direction for different floor diaphragm in Zone-IV

Max storey displacement for different floor diaphragm zone-IV			
Floor	In X Direction		
	Bare Frame	Rigid Diaphragm	Semi rigid Diaphragm
Base	0	0	0
Ground Floor	5.012	2.29	5.112
1st Floor	13.355	4.659	13.601
2nd Floor	22.174	7.066	22.604
3rd floor	30.788	9.449	31.43
4th floor	38.841	11.732	39.711
5th floor	45.99	13.819	47.086
6th floor	51.858	15.6	53.146
7th floor	56.069	16.947	57.467
8th floor	58.508	17.718	59.894

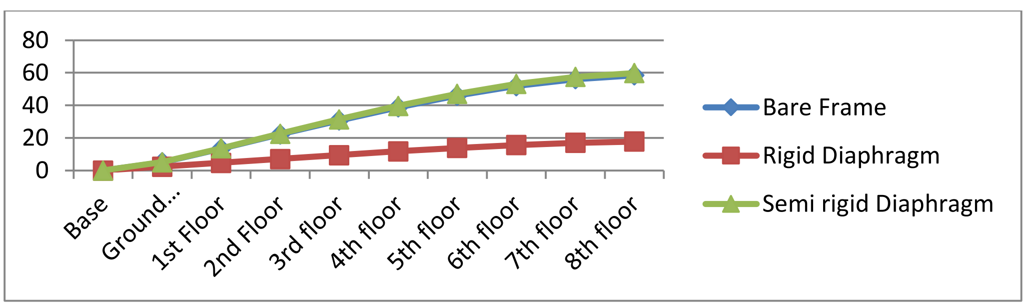

Fig. 5.9: Max. storey displacement X direction for different floor diaphragm in Zone-IV
Maximum storey displacement is observed in bare frame and minimum in rigid diaphragm

The maximum storey displacement Z direction for different floor diaphragm are shown in Table 5.10 and Fig. 5.10

Table 5.10: Max. storey displacement Z direction for different floor diaphragm in Zone-IV

Max storey displacement for different floor diaphragm zone-IV			
Floor	In Z Direction		
	Bare Frame	Rigid Diaphragm	Semi rigid Diaphragm
Base	0	0	0
Ground Floor	5.012	2.29	5.112
1st Floor	13.355	4.659	13.601
2nd Floor	22.174	7.066	22.604
3rd floor	30.788	9.449	31.43
4th floor	38.841	11.732	39.711
5th floor	45.99	13.819	47.086
6th floor	51.858	15.6	53.146
7th floor	56.069	16.947	57.467
8th floor	58.508	17.718	59.894

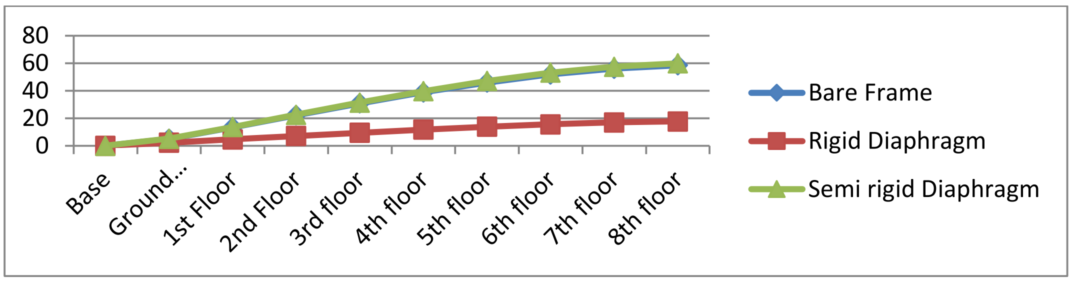

Fig. 5.10: Max. storey displacement Z direction for different floor diaphragm in Zone-IV

Maximum storey displacement is observed in bare frame and minimum in rigid diaphragm

The maximum storey displacement for different floor diaphragm are shown in Table 5.11 and Fig. 5.11

Table 5.11: Max. storey displacement for different floor diaphragm in Zone-V

Max storey displacement for different floor diaphragm zone-V			
Floor	In X Direction		
	Bare Frame	Rigid Diaphragm	Semi rigid Diaphragm
Base	0	0	0
Ground Floor	7.517	3.435	7.669
1st Floor	20.033	6.989	20.402
2nd Floor	33.26	10.598	33.907
3rd floor	46.182	14.173	47.144
4th floor	58.262	17.597	59.567
5th floor	68.985	20.729	70.63
6th floor	77.787	23.4	79.718
7th floor	84.103	25.42	86.201
8th floor	87.759	26.577	89.842

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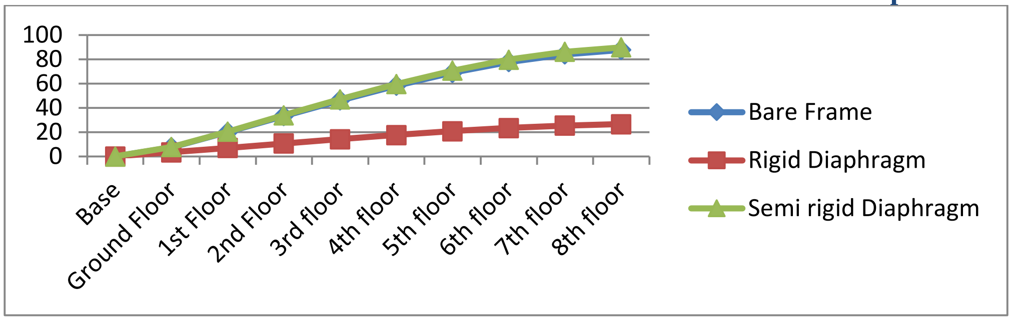

Fig. 5.11: Max. storey displacement X direction for different floor diaphragm in Zone-V
Maximum storey displacement is observed in bare frame and minimum in rigid diaphragm

The maximum storey displacement Z direction for different floor diaphragm are shown in Table 5.12 and Fig. 5.12

Table 5.12: Max. storey displacement Z direction for different floor diaphragm in Zone-V

Max storey displacement for different floor diaphragm zone-V			
Floor	In Z Direction		
	Bare Frame	Rigid Diaphragm	Semi rigid Diaphragm
Base	0	0	0
Ground Floor	7.517	3.435	7.669
1st Floor	20.033	6.989	20.402
2nd Floor	33.26	10.598	33.907
3rd floor	46.182	14.173	47.144
4th floor	58.262	17.597	59.567
5th floor	68.985	20.729	70.63
6th floor	77.787	23.4	79.718
7th floor	84.103	25.42	86.201
8th floor	87.759	26.577	89.842

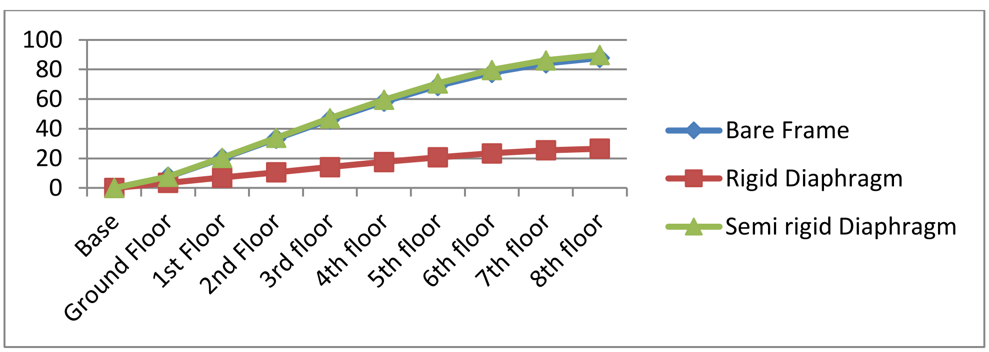

Fig. 5.12: Max. storey displacement Z direction for different floor diaphragm in Zone-V

Maximum storey displacement is observed in bare frame and minimum in rigid diaphragm

CONCLUSION

Following are the salient conclusions of this study-

From the present study it is seen that rigid diaphragm is much efficient in compared to other diaphragms system in reducing moment, storey displacement, peak displacement. The analysis done in the present study clearly shows that semi-rigid diaphragm and without diaphragm models shows almost same results means we can say nature of without diaphragm structures is same of semi rigid diaphragm structure. And semi rigid diaphragm and without diaphragm produces more displacement, shear force and moments than the rigid diaphragm models. And rigid diaphragm reduces displacement thrice, moment twice and shear force almost one and half means it helps in reducing frame section and area of steel. So, It has been observed from the analysis of various building the rigid diaphragm is more effective. It is concluded that the building with rigid diaphragms will be structurally economic resulting into a great deal of saving in reinforcement steel.

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