Seismic study and performance of 30 storey high rise building with beam slab, flat slab and alternate flat-beam slab systems in Zone-V

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Abstract - The use of flat slab building provides many advantages over conventional RC Frame building in Terms of architectural flexibility, use of space, easier formwork and shorter construction time. The structural efficiency of the flat-slab construction is hindered by its poor performance under earthquake loading. Whereas the conventional beam slab buildings perform better in seismic regions. The main objective of this research is to study and compare the seismic performance of reinforced concrete buildings with conventional beam slabs, flat slabs and alternate flat – beam slab that are analysed as per India Standard IS 1893(2002). Response spectrum analysis (ETABS) was used as the tool to generate the necessary responses to allow for an in-depth comparison. When comparing the time period at 90 % mass participation in both x and y directions the time period of beam slab structure is more when compared with flat slab structure and alternate flat – beam slab structure. The response spectrum accelerations of the flat slab structure is found to be more when compared with beam slab building and alternate flat slab – beam slab building. Base shear of beam slab building is more when compared with both flat slab building and alternate flat slab – beam slab building. For all the cases considered drift values follow a parabolic path along storey height with maximum value lying somewhere near the middle storey. Story drift in buildings with flat slab construction is significantly more as compared to beam slab building. The drift values of alternate flat slab – beam slab buildings lies in between the two structures but somewhat nearer to the beam slab building. (due to rigidity of the beam slab structure). As a result of high drift ratios in flat slab building, additional moments are developed and columns of such buildings should be designed by considering additional moment caused by the drift.

Key Words*: *Flat Slabs, Beam Slabs, Alternate Flat and Beam Slab, Shear, Story Shears, Story Displacements, Story Drifts, Model Participation Mass Ratios, Time Periods, Column Forces.

1. INTRODUCTION

Need for High-rise buildings in Indian context need not be emphasised. Such buildings call for meticulous planning and design, if the large investments made in them are to give the maximum benefits in functional utility, comfort and safety. The art of designing high rise buildings in seismic area is to bestow them with enough strength to resist forces generated by earthquakes and enough stiffness or energy dissipation so that people working on upper floors are not disturbed by the buildings' periodic swaying. Stiffness and ductility considerations rather than strength would govern the design. The intent in seismic design then is to limit building movements, not so much to reduce perception of motion but to maintain the building's stability and prevent danger to pedestrians due to breakage and falling down of non-structural elements. Conventional RC Frame buildings are commonly used for the construction. The use of flat slab building provides many advantages over conventional RC Frame building in terms of architectural flexibility, use of space, easier formwork and shorter construction time. In this system, resistance to horizontal loading is provided by a combination of shear walls and rigid frames. The shear walls are often placed around elevator and service cores while the frames with relatively deep spandrels occur at the building perimeter. When a wall–frame structure is loaded laterally, the distinctly different deflected forms of the walls and the frames can be quite effective in reducing the lateral deflections to the extent that buildings of up to 50 stories or more are economical. The potential advantages of a wall–frame structure depend on the intensity of horizontal interaction, which is governed by the relative stiffness of the walls and frames, and the height of the structure. The taller the building and the stiffer the frames, the greater the interaction. Without a question, this system is one of the most—if not the most—popular system for resisting lateral loads in medium- to high-rise buildings. The system has a broad range of application and has been used for buildings as low as 10 stories to as high as 50 stories or even taller. The linear sway of the moment frame, combined with the parabolic sway of the shear wall, results in enhanced stiffness of the system because the wall is restrained by the frame at the upper levels while at the lower levels, the shear wall restrains the frame. Even for buildings in the 10- to 15-story range, unreasonably thick shear walls may be required if the walls are placed only around the building's service core. For such buildings, using a combination of rigid frames with shear walls might be a better option. Although relatively deep girders are required for a substantial frame action, rigid frames are often architecturally preferred because they are least objectionable from the interior space planning considerations. If the deflection modes of shear walls and moment frames were similar, the lateral loads would be distributed between the two systems more or less, according to their relative stiffness. However, in general, the two systems deform with their own characteristic shapes. The interaction between the two, particularly at the upper levels of the buildings, results in quite a different lateral load distribution. The lateral deflections of a shear wall may be considered as similar to those of a cantilever column near the bottom, the shear wall is relatively stiff, and therefore, the floor-to-floor deflections will be less than half the values near the top. At top floors, the deflections increase rather rapidly, mainly from the cumulative effect of wall rotation. Moment frames, on the other hand, deform predominantly in a shear mode. The relative story deflections depend on magnitude of shear applied at each story level. Although the deflections are larger near the bottom and smaller near the top as compared to the shear walls, the floor-to-floor deflections can be considered more nearly uniform throughout the height. When the two systems—the shear walls and moment frames—are connected by rigid floor diaphragms, a non-uniform shear force develops between the two. The resulting interaction typically results in a more economical structural system. The structural efficiency of the flat-slab construction is hindered by its poor performance under earthquake loading. Whereas the conventional beam slab buildings perform better in seismic regions. In the present work another model with alternate flat slab and beam slab arrangement is considered and all the three structures are compared.

2. LITERATURE REVIEW

This literature review focuses on research concerned with computer-automated analysis of buildings with conventional slabs and flat slab structural entities. It is important to note that this area of research i.e., construction of alternate flat slab-beam slab buildings is not yet well investigated. and, therefore, that there are not many related documents directly available concerning alternate flat slab-beam slab high-rise buildings. Furthermore, it is necessary to mention that the researches discussed in the following do not cover all the aspects involved in the present process but do try to address the problem from several important viewpoints.

Sathawane [1] determined the most economical slab between flat slab with drop, Flat slab without drop and grid slab. Apostolska [2] states that, flat-slab building structures possesses major advantages over traditional slab-beam-column structures because of the free design of space, shorter construction time, architectural –functional and economical aspects. Sable, Ghodechor and Kandekar [3] investigated the effect of seismic forces on three types of buildings with different height using STAAD Pro2007 software. Eebrik [4] discussed about Flat-slab RC buildings exhibit several advantages over conventional moment resisting frames. Eebrik [5] focuses on the study of earthquake records compatible with the design spectrum selected to represent the variability in ground motion. Inelastic response-history analysis was used to analyse the random sample of structures subjected to the suite of records scaled in terms of displacement spectral ordinates, whilst monitoring four performance limit states. Mohamed [6] Introduced the lateral analysis for tall buildings due to the seismic performance for different reinforced concrete slab systems. It study three systems, flat slab, ribbed slab, and panelled beam slab. Navyashree and Sahana [7] presented a work on six number of conventional RC frame and Flat Slab buildings of G+3, G+8, and G+12 storey building models are considered. Sumit Pahwa, Vivek Tiwari, Madhavi Prajapati [8] compared behavior of flat slab with old traditional two way slab. Gupta [9] studied about flat slab building structures which are more significantly flexible than traditional concrete frame/wall or frame structures, thus becoming more vulnerable to seismic loading. Siva Bhanu Sai Kumar, Rama Rao and Markandeya Raju [10] analysed the Seismic Fragility of Regular and Setback RCC Frames. Markandeya Raju [11] studied the Effect of Column Spacing on Economy of G+ 5 RC Moment Resisting Frame using STAAD.Pro.

3. SCOPE

The main objective of this research is to study and compare the seismic performance of reinforced concrete buildings with conventional beam slabs, flat slabs and alternate flat – beam slab that are analysed as per India Standard IS 1893(2002). Response spectrum analysis was used as the tool to generate the necessary responses to allow for an in-depth comparison. The primary deliverables of this study are: An evaluation of the seismic performance of three structures, which are geometrically identical excluding the slabs, Examine the Performance of Alternate Flat slab-beam slab building structure and check the feasibility of the structure, Comparison of the performance of the three buildings under Seismic loads. In the current study three major tasks were performed. Modelling and analysis three structures viz., beam slab structure, Flat slab structure and Alternate flat slab-beam slab structure. It is assumed that the structures are situated in a high seismic region as per Indian standards. The structural system consists of moment-resting frames with shear walls. The commercial analysis and design software ETABS Version 13.1.5 (2013) was used for this purpose. The paper provides introduction for high rise buildings and its seismic performance along with review of related literature. After describing the methodology and final member sizes and details, the overall performance as well as the responses of the three structures, as established by Response spectrum analyses, is compared and discussed. Conclusions of the work and future research are presented at the end.

4. DESIGN

4.1. Design Considerations

The conceptual design deals with the identification of different concepts and the selection of overall best subsystems and their configurations. The preliminary design stage involves the initial development of one or a few conceptual models. The detailed design stage defines a complete solution for al1 subsystems, and results in final drawings for architectural, structural, electrical and mechanical systems. Design and construction features important to seismic performance: Stable foundations, Continuous load paths, adequate stiffness and strength, Regularity, Redundancy, Ductility and toughness and Ruggedness.

4.2. Seismic analysis procedure as per the code

The basic intent of design theory for earthquake resistant structures is that

i. Buildings should be able to resist minor earthquakes without damage,
ii. Resist moderate earthquakes without structural damage but with some non-structural damage,
iii. Resist major earthquakes without collapse but with some structural and non-structural damage.
iv. To avoid collapse during a major earthquake, members must be ductile enough to absorb and dissipate energy by post-elastic deformation.
v. Redundancy in the structural system permits redistribution of internal forces in the event of the failure of key elements.
vi. When the primary element or system yields or fails, the lateral force can be redistributed to a secondary system to prevent progressive failure.

4.3. Response spectrum method

The response spectrum of an earthquake is considered as a very useful input for the seismic analysis of structures which is favoured by earthquake engineers for a number of reasons.

i. Firstly, the method provides a technique for performing an equivalent static lateral load analysis of structures for earthquake forces.
ii. Secondly, it allows a clear understanding of the contributions of different modes of vibration to the overall seismic response of structures.
iii. Thirdly, it offers a simplified method for finding the design forces for the members of structures for earthquake forces.
iv. Finally, it is also useful in the approximate evaluation of the reliability and safety of structures under earthquake forces.

4.4. Methodology

Three different structures are considered by keeping column properties same with flat slabs, beam slabs and alternate flat and beam slab. The structures are modelled in 3D in the commercial structural analysis and design software ETABS 2013 (Version 13.1.5 Build 1102). X and Y axis are the global horizontal axis and Z is the global vertical axis. The buildings are analysed as space frames. The buildings are compared for base shear, story shears, story displacements, story drifts, model participation mass ratios, time periods, Column forces. Number of Stories – 30, Height of the Story - 3.2m, Building lateral dimensions - 42mx42m,

Table -1: Beam sizes considered

Structure	Beam 300 x 600	Beam 350 x 450
Beam slab structure	All beams	Lift core and stair case
Flat slab structure	Plinth and peripheral beams	Lift core and stair case
Alternate structure	Plinth and peripheral beams	Lift core and stair case

Table -2: Internal Column sizes considered

Size	Storey level
900x900	Base -8th storey
750x750	8th storey – 16th storey
600x600	17th storey- 24th storey
450x450	25th storey-30th storey

Table -3: Peripheral Column sizes considered

Size	Storey level
600x600	Base -15th storey
450x450	16th storey - 30th storey

Table -4: Details of buildings

Flat slabs	180mm
Drop thickness	120mm
Size of Drop	3m x 3m
Normal slab	150mm
Roof slab	150mm
Thickness of shear wall	250mm
Density of concrete	25 KN/m^3
Grade of concrete	Columns, shear walls M40 Beams and slabs M30
Grade of Steel	Fe415
Live load	Typical 5 kN/m^2, Roof level 3 kN/m^2
Super imposed load (SDL) (including furnishings)	Typical 4 kN/m^2, Roof level 2 kN/m^2
Live load contribution	50%
Zone factor	0.36
Type of soil	Type II, Medium, 5% Damping
Importance factor	1.5
Response reduction factor	5

Table -5: Load combinations considered

Collapse	Serviceability
1.5(DL+LL)	(DL+LL)
1.5(DL ± EQX)	(DL ± EQX)
1.5(DL ± EQY)	(DL ± EQY)
1.2(DL + LL ± EQX)	(DL+ 0.8 LL ± 0.8 EQX)
1.2(DL + LL ± EQY)	(DL+ 0.8 LL ± 0.8 EQY)

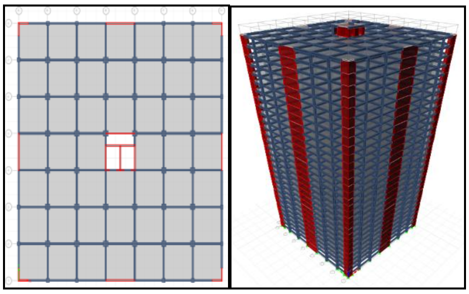

Fig -2: Plan and 3D view of Beam slab structure

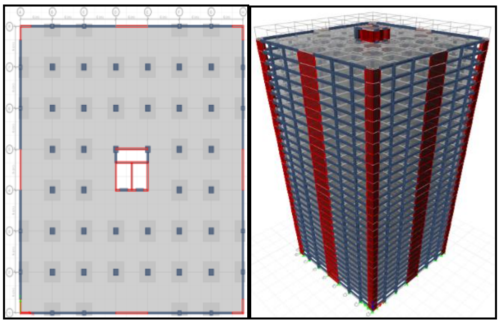

Fig -3: Plan and 3D view of Flat slab structure

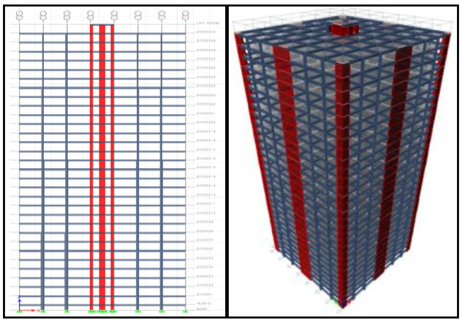

Fig -4: Elevation at Grid and 3D View of alternate flat slab and beam slab building structure.

5. RESULTS AND DISCUSSION

As use of flat slabs makes the structure flexible under seismic loading, therefore, in present work a third type of model was generated with alternate arrangement of flat slab and beam slab and behaviour of these three buildings are studied and compared. To study the effectiveness of all these models,

- Modal mass participation ratios
- Base shear
- Time period and spectral accelerations
- the storey drift,
- column forces of structure are drawn from the analysis.

These results obtained from the analysis have been discussed in detail.

5.1. Parameter studied on modal mass participation ratios

For the response spectrum analysis, the current code IS1893:2002 (7.8.4.2) states that "at least 90 percent of the participating mass of the structure must be included in the calculation of response of each principle direction. For trial 15 modes have been considered for all the three structures. After analysis results had shown that beam slab building is achieving 90% mass participation at 9th mode with a time period of 0.547sec in both X and Y Directions. For flat slab building 90% mass participation is achieved at 11th mode with a time period of 0.356 sec in both X and Y Directions. Whereas for alternate flat slab and beam slab structure 90% mass participation is achieved at 11th mode with a time period of 0.355 sec in both X and Y Directions.

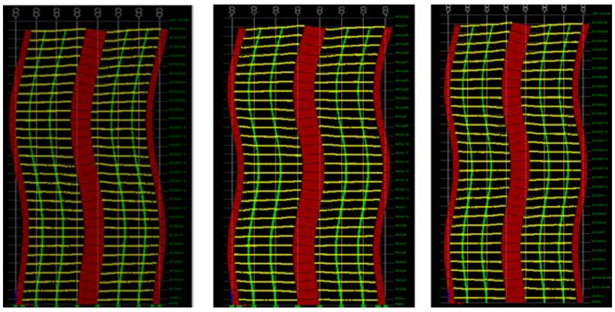

Fig -5: Mode shapes at 90% mass participation for Beam slab, Flat slab and alternate Flat-Beam slab structures

5.2. Parameters studied on Base shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. It can be observed from the graph and tables that the beam slab building is having higher base shear when compared with flat slab and alternate flat slab and beam slab buildings. Comparing the three models the beam slab building is having about 11.5 to 12% higher base shear when compared with flat slab building and 7 to 8% high when compared with alternate flat slab – beam slab building in X and Y Directions.

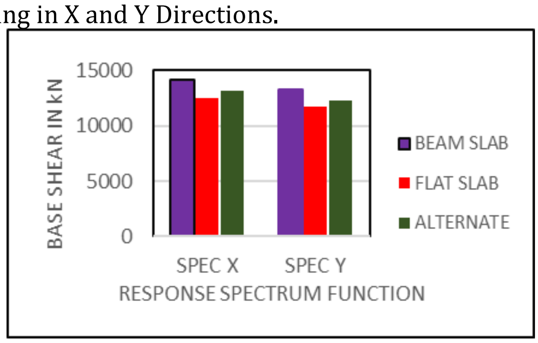

Chart -1: Comparison of base shear

5.3. Parameters studied on Storey shear

It can be observed that the storey shear is maximum at plinth level for all the three structures. After plinth level the base shear decreases as the height of the buildings increases. It can be observed from the figures that the storey shear of beam slab building is more when compared with flat slab building and alternate flat and beam slab buildings. The difference between the beam slab and flat slab building varies from 12 to 14 % for different load combinations. While the difference between the beam slab and alternate flat - beam slab building varies from 7 to 9 % for different load combinations.

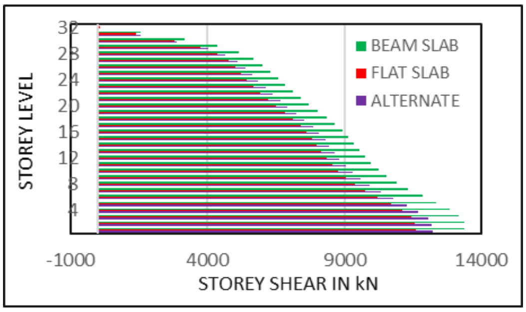

Chart -2: Storey shear for spec X

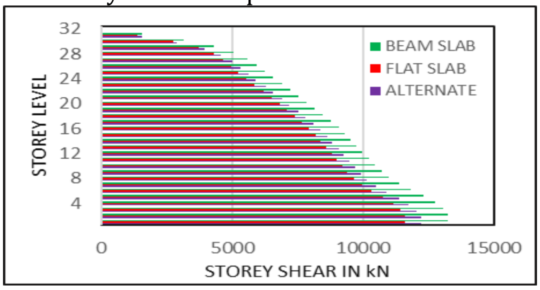

Chart -3: Storey shear for spec Y

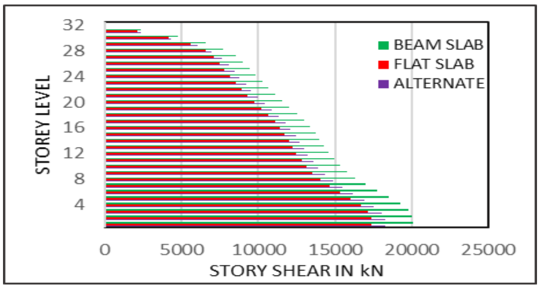

Chart -4: Storey shear for 1.5(DL+EQX)

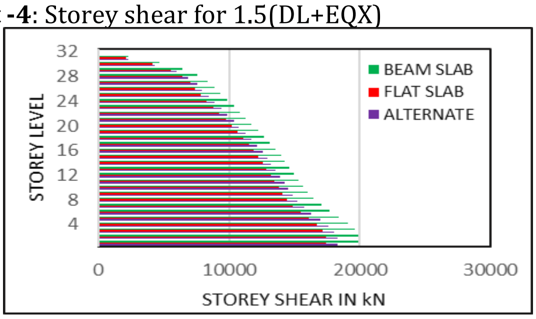

Chart -5: Storey shear for 1.5(DL+EQY)

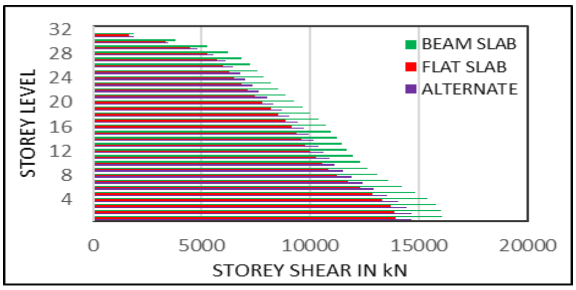

Chart -6: Storey shear for 1.2(DL+LL+EQX)

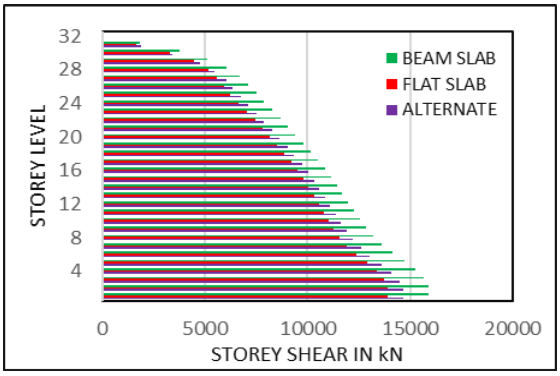

Chart -7: Storey shear for 1.2(DL+LL+EQY)

5.4. Parameters studied on Time period

It can be observed that the time period is maximum at initial modes and goes on decreasing with increase of the number of modes. Due to the symmetric of the building the time period will be same in both directions.

The time period is on an average more for flat slab building by 8% and for alternate flat slab - beam slab building by 4.5% compared to conventional beam slab building. At 90% mass participation, the time period of beam slab structure is higher than flat slab structure and alternate flat slab - beam slab structure by 19%.

The Response Spectral acceleration coefficient is on an average more flat slab building by 5% and for alternate flat slab and beam slab building it is less by 2% compared to conventional beam slab building. At 90% mass participation, the Spectral acceleration flat slab structure and flat slab and beam slab structures are more when compared to beam slab structure by 24% and 15% respectively. At 11th mode for which the flat slab building and alternate flat slab - beam slab are having 90% mass participation, these two structures are having same time period but the spectral acceleration is high for flat slab building.

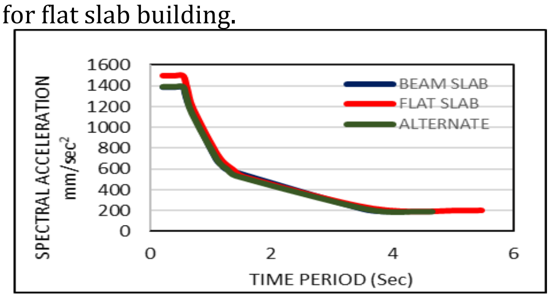

Chart -8: Response spectral acceleration for spec X

5.5. Parameters studied on Storey Drifts:

The storey drift in any storey due to minimum specified design lateral force with partial safety factor of unity shall not exceed 0.004 times the storey height. From the results it was observed that the storey drifts both in X and Y Directions are maximum at mid stories for all the three structures considered. The Story Drift is on an average more flat slab building by 60 – 80 % and for alternate flat slab and beam slab building by 20 – 30 % when compared to conventional beam slab building for load combinations

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 02 | Feb -2017 www.irjet.net p-ISSN: 2395-0072

considered. As Storey drifts in buildings with flat slab structure and alternate flat – beam slab structure is more when compared to conventional R.C.C building.

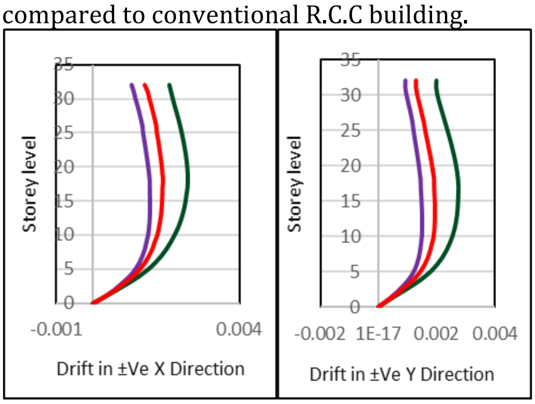

Chart -9: Drift for (DL ± EQX) and (DL ± EQY) respectively

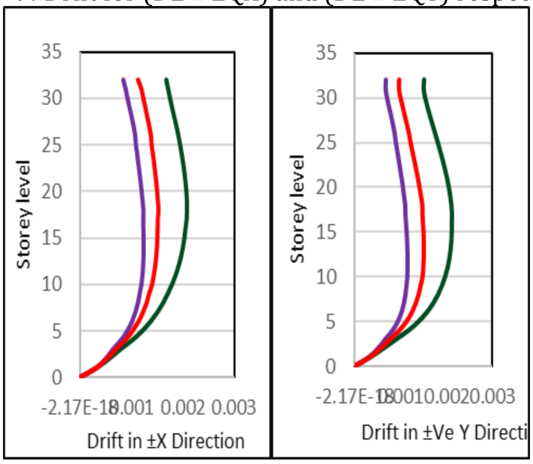

Chart -10: Drift for (DL + LL ± EQX) and (DL + LL ± EQY) respectively

5.6. Parameters studied on column forces:

For the study of column forces two columns i.e., one external column and one internal column are selected from the 15th storey and the following results have been found. Axial load is on an average less for flat slab building by 17 - 19 % and for alternate flat slab and beam slab building it is 6 - 8% less when compared to conventional beam slab building for different load combinations. Shear forces are on an average more for flat slab building by 68-95 % and for alternate flat slab and beam slab building it is 38 - 70 % less when compared to conventional beam slab building for different load combinations. Moments are on an average more for flat slab building by 14 - 35 % and for alternate flat slab and beam slab building it is 10 - 16 % more when compared to conventional beam slab building for different load combinations.

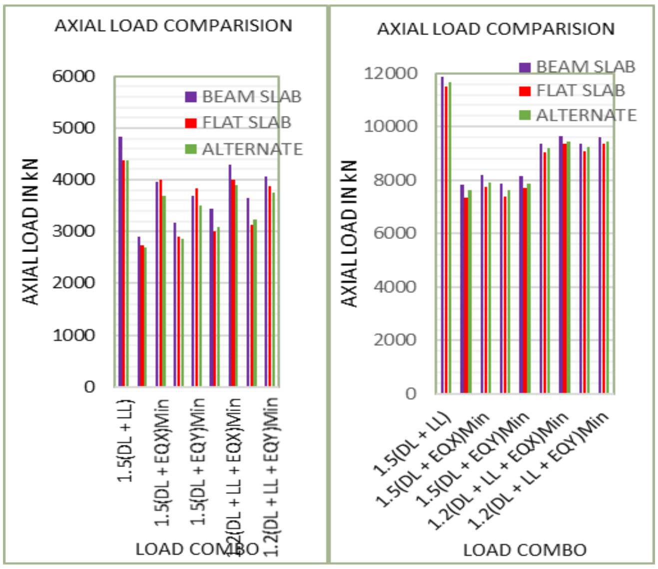

Chart -11: Variation of Axial Force for End Column A7 and Internal Column F6 at Story 15

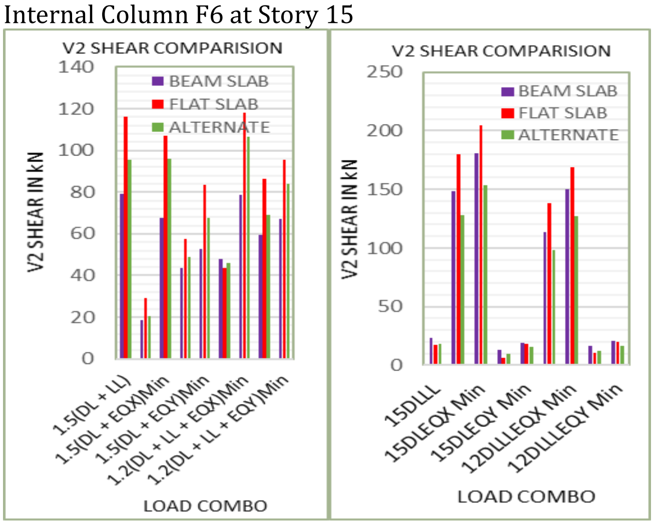

Chart -12: Variation of V2 Shear Force for End Column A7 and Internal Column F6 at Story 15

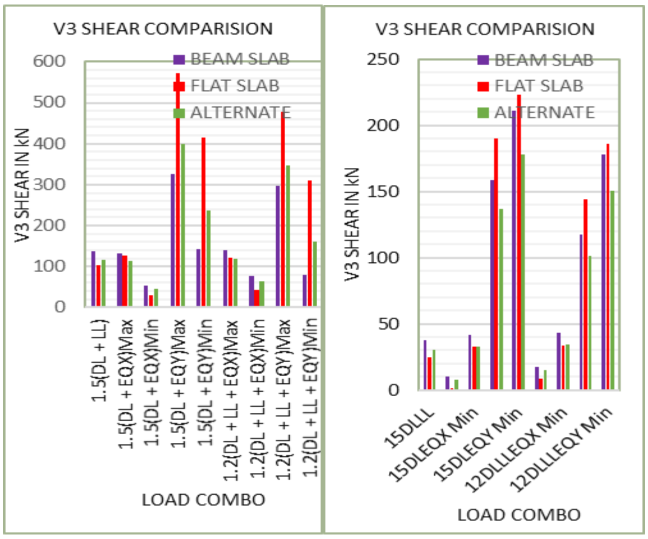

Chart -13: Variation of V3 Shear Force for End Column A7 and Internal Column F6 at Story 15

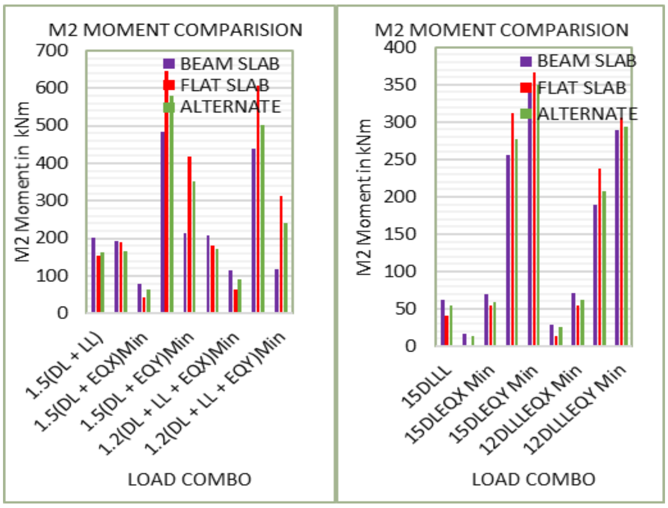

Chart -14: Variation of M2 Moment for End Column A7 and Internal Column F6 at Story 15

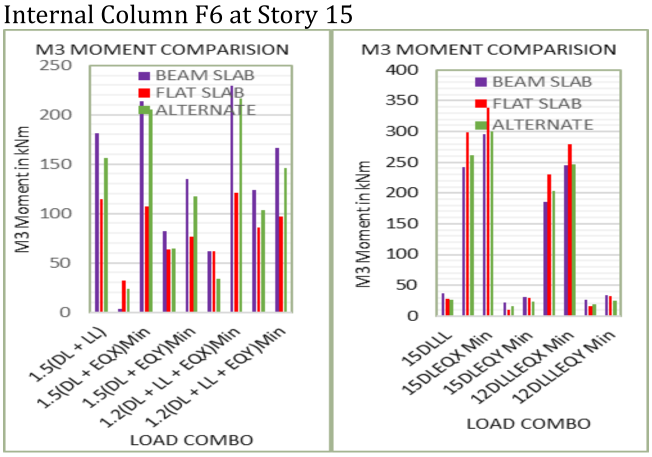

Chart -15: Variation of M3 Moment for End Column A7 and Internal Column F6 at Story 15

6. CONCLUSIONS

Based on the observations and the results obtained during the course of this study, the following conclusions can be stated:

i. When comparing the time period at 90 % mass participation in both x and y directions the time period of beam slab structure is more when compared with flat slab structure and alternate flat – beam slab structure.

ii. Whereas the time period of flat slab structure and alternate flat slab – beam slab structure was found to be almost same at 90% mass participation.

iii. The response spectrum accelerations of the flat slab structure is found to be more when compared with beam slab building and alternate flat slab – beam slab building.

iv. Whereas the spectral accelerations of beam slab building and alternate flat slab – beam slab building are found to be almost same.

v. Base shear of beam slab building is more when compared with both flat slab building and alternate flat slab – beam slab building.

vi. For all the cases considered drift values follow a parabolic path along storey height with maximum value lying somewhere near the middle storey.

vii. Story drift in buildings with flat slab construction is significantly more as compared to beam slab building. The drift values of alternate flat slab – beam slab buildings lies in between the two structures but somewhat nearer to the beam slab building. This is due to rigidity of the beam slab structure.

viii. As a result of high drift ratios in flat slab building, additional moments are developed. Therefore, the columns of such buildings should be designed by considering additional moment caused by the drift.

7. SCOPE OF FURTHER STUDY

The performance of the buildings with plan and elevation irregularities needs to be accessed and compared. Column forces of alternate flat slab – beam slab structure needs further investigation. The Study can be extended to the structure by altering the position of flat slabs and beam slabs at different floors. The performance of structures to wind loads should be studied and compared. This work can be extended to unsymmetrical buildings considering the torsional provisions.

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