

Seismic Behaviour of Flat Slab Building Strengthened With Perimeter Beams, Shear Walls and Beam Slab in Alternate Storeys

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ABSTRACT: The common practice of design and construction of buildings is beam-column construction in which slab is supported by beam and beams by column. Nowadays slabs are directly put on the column for increasing the room height, aesthetic beauty; such slabs are called as Flat slabs. In the present study a C shaped building of Flat slab was compared with conventional RCC building at G+3, G+6, and G+ 9 by varying storey heights. Flat slab buildings were strengthened with perimeter beams, shear walls and beam slab at alternate stories. Analysis was done by Linear Static and Response Spectrum analysis in zone V using ETABS software. The parameters such as storey displacement, storey shears, storey drift, storey stiffness were checked after the analysis. Flat slab buildings were also analysed at 20 and 30 storeys to understand at which storey height they are admissible in seismic areas. Based on the study conducted, Flat slab buildings with shear walls were preferred because there is a considerable reduction in storey displacement and storey drift in zone V. Even though Flat slab with drop in place of beam slab arrangements increases maximum displacement values, these all were well within permissible limits up to 20 storeys.

KEYWORDS: conventional RCC, flat slab, beam slab, alternate beam slab, shear wall, perimeter beams structures.

I. INTRODUCTION

The infrastructure facilities of India has increased, thank to its urbanization but it has put pressure on the limited land space. This has lead to the development of medium to sky rise buildings. Architectural beauty is a matter of concern to all at present. This has led to the formation of irregular plans like L, T, C, H shapes. They are preferred because the rest of the open spaces can be used for parking area.

Buildings are subjected to two types of loads vertical load and lateral loads. The building consists of (i) Horizontal framing system consists of slab and beams (ii) Vertical framing system, consisting of beams and columns Murthy et al. [1]. In the absence of elements for the formation of conventional frames, the horizontal load-bearing strength is deficient compared to that of other structures. In the case of multi-storey structures, concern about the global stability is greater in the case of beamless floor slabs. In order to overcome this limitation, rigid cores can be provided. Nowadays beam free structures called Flat slabs are gaining importance hence it is important to check the performance of these structures in the earthquake prone areas. Earthquake resistant buildings have gained prominence across the globe due to the great destruction that has occurred during the past years due to poorly designed construction practices.

1.1 Flat slab

In 1906 flat slabs were originally invented in USA and many slabs were load tested between the years 1910-20 which leads to the start of this type of construction Patil et al. [2]. The common practice of design and construction is beam-column construction that is supporting the slab by beam and beams by column. Nowadays slabs are directly put on the column for aesthetic point of view and the loads are directly transferred to the columns, such slabs are called as Flat slabs. Flat slab building structures are significantly flexible than traditional frame structures as shown in Fig 1, thus becoming more vulnerable to seismic loading condition. Flat slab reduces dead weight and enhances the floor area,

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reduces the available net clear ceiling height by 10-15%. Flat slab constructions are mainly used in offices, warehouses foundations, although they can also be used in the construction of roadways and paths.

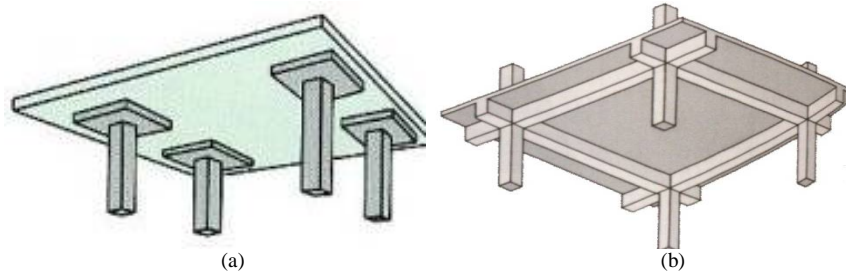


Fig 1 Comparison between one-way and Two-way slab (a) Flat slab (b) Two way slab

1.2 Lateral load resisting systems for multi-storeyed buildings

Flat slabs are subjected to both vertical loads and lateral loads. Wind and earthquake loads govern the design rather than the vertical loads [3] indicate the need to analyse their global stability; hence there is a need of proper lateral load resisting to build a safe structure. The lateral load resisting systems used for study are perimeter beams and shear walls.

1.2.1 Perimeter beams

Due to the flexibility of Flat slab buildings, they must be combined with a stiffer lateral force resisting system in high seismic regions to reduce the lateral loads on structure. Perimeter beams are provided for resisting the lateral loads.

1.2.2 Shear walls

A shear wall is a structural system composed of shear panels to counter the effects of lateral load acting on a structure. These walls generally start at foundation level and are continuous throughout the building height.

1.3 Analysis methods

1.3.1 Equivalent Static Analysis: Seismic analysis is carried out on the assumption that the lateral (horizontal) force is equivalent to the actual (dynamic) loading [4]. This is permitted in most codes of practice for regular, low- to medium-rise buildings without significant coupled lateral-torsional modes, in which only the first mode is of significance.

1.3.2 Response Spectrum Analysis: This method is applicable to those structures where modes other than the fundamental one significantly affect the response of the structure. Generally, the method is applicable to analysis of the dynamic response of structures, which are asymmetrical or have areas of discontinuity or irregularity.

II. OBJECTIVES

The following are the main objectives of the study:

- To check the vulnerability and strength of a C shaped building of Flat slab in Zone V.
- To find out the deficiency of lateral load resistance of Flat slab buildings compared to Conventional RCC building at G+3, G+6, G+9 stories.
- To find the effectiveness of the Flat slab building at G+3, G+6, G+9 storeys by strengthening Flat slab building with perimeter beams, shear walls and beam slab at alternate stories.
- Flat slab buildings are also analyzed at 20 and 30 storeys to understand at which storey height they are admissible in seismic areas.
- Linear Static and Response Spectrum analysis should be performed using ETABS 15.2.0 software on the models using various parameters such as storey drift, storey displacement, storey shears, and storey stiffness.

III. METHODOLOGY

The multi storied RC frame and Flat slab buildings at 4, 7, 10, 20 and 30 storeys in seismic zone V are modelled in ETABS 15.2.0 software. The Flat slab buildings are strengthened with perimeter beams, shear walls and beam slab buildings at alternate stories. A total of thirty eight models as shown in Table 1 are created by defining the material and structural properties according to the code recommendations to the buildings. All buildings modelled subjected to

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gravity and dynamic loads are analysed by Equivalent Static and Response Spectrum analysis. The modelled buildings analysed and the results are extracted. The results are exported to the Microsoft excel and respective graphs are plotted.

Table 1 Building description

Storey	Model designation	Building description
G+3 G+6 G+9	BS4, BS7, BS10	Beam slab building in four, seven, ten storey respectively
	FS4, FS7, FS10	Flat slab building in four ,seven, ten storey respectively
	FSP4,FSP7, FSP10	Flat slab building with perimeter beams in four, seven, ten storey respectively
	FB4, FB7, FB10	Flat slab building having beam slab in alternate stories in four, seven, ten storey respectively
	FPB4,FPB7,FPB10	Flat slab building with perimeter beam and beam slab in alternate stories in four, seven, ten storey respectively
	FSS4,FSS7, FSS10	Flat slab building having shear walls in four, seven, ten storey respectively

IV. BUILDING MODELS

Modelled plans of the buildings such as (i) FS (ii) FSP (iii) BS (iv) FSS using ETABS software are shown in Fig (a), Fig (b), Fig (c), Fig (d).

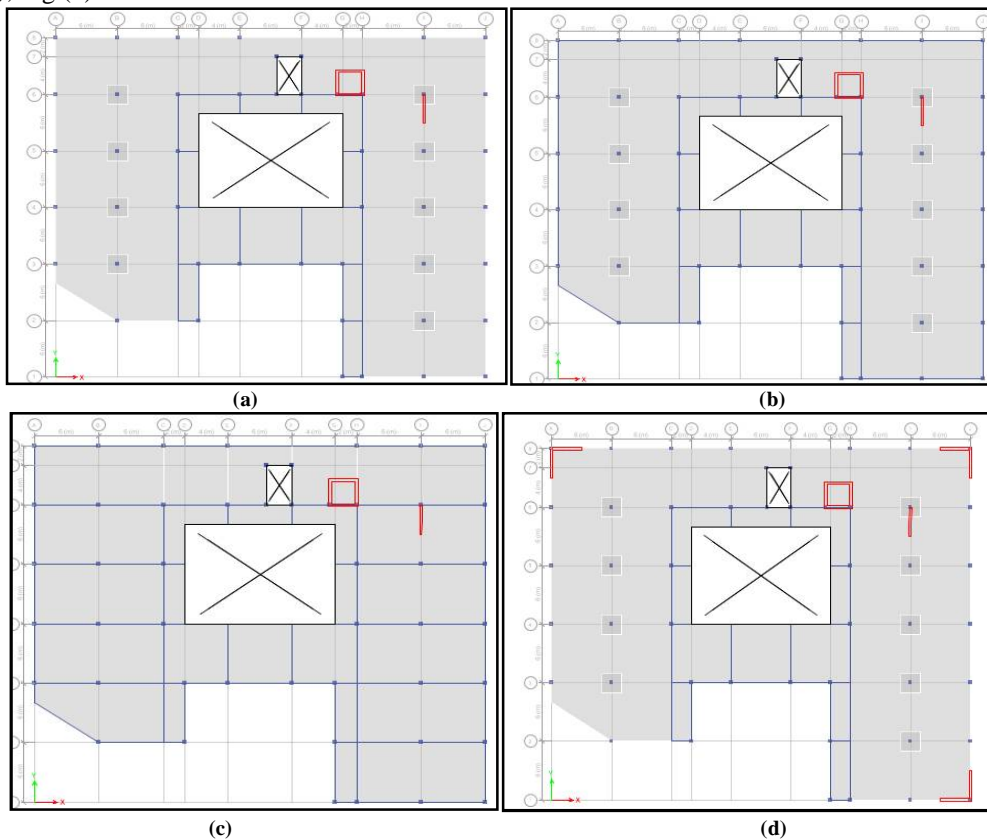


Fig. 2. Building plans (a) FS (b) FSP (c) BS(d) FSS

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The structural details of the modelled buildings are shown in the Table 2. The buildings are modelled according to the Indian Code recommendations.

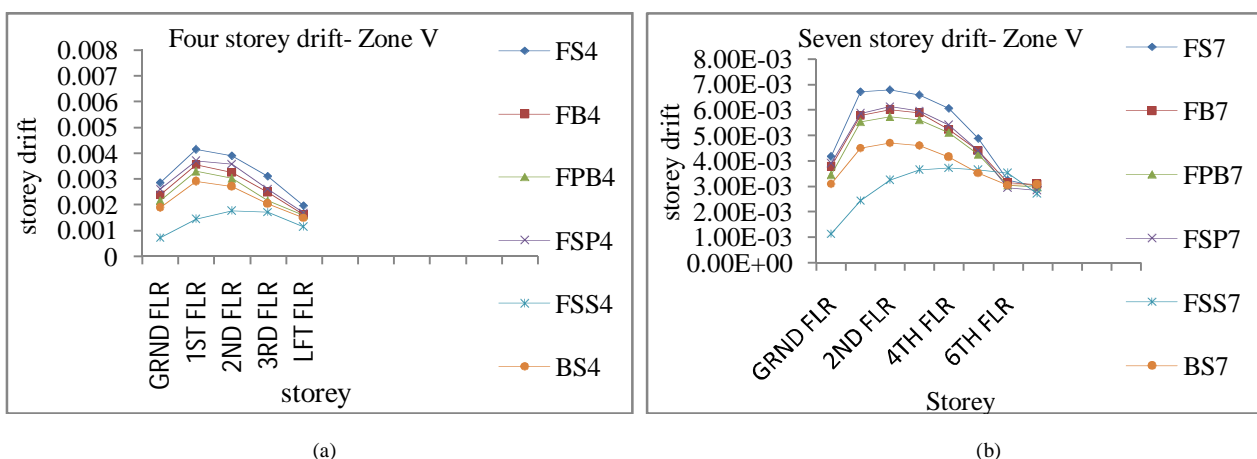
Table 2 Structure details

Details of structure			
1. Grade of concrete for RCC column	=M25	17. Grade of concrete for beam and slab	=M25
2. Number of storey	=G+3, G+6, G+9	18. Grade of steel	=Fe 415
3. Storey height	=3m	19. Size of perimeter beam	=0.3m x 0.5m
4. Type of building	=Commercial building, OMRF	20. Partition wall thickness	=200mm
5. Column	=0.4m x 0.4 m	21. Zone	=V
6. Floor finishes	=1.5kN/m ²	22. Zone factor, Z	=0.36
7. Roof	=1.5kN/m ²	23. Importance factor, I	=1.00
8. Floor	=4.0kN/m ²	24. Response reduction factor, R	=3
9. Thickness of Flat slab	=250mm	25. Damping ratio	=5%
10. Thickness of drop	=160 mm	26. Soil	=Type II
11. Sizes of drop	=2m x 2m	27. Restraints	=Fixed support
12. Thickness of normal slab	=120 mm	28. Floor diaphragm rigidity	=Rigid
13. Thickness of roof slab	=120 mm	29. Density of RC	=25 kN/m ³
14. Shear wall thickness	=250 mm	16. Ec	=25000kN/m ³

V. RESULTS AND DISCUSSIONS

5.1 Linear Static Analysis Results

Total of eighteen models such as (i) FS (ii) FSP (iii) FB (iv) FPB (v) FSS (vi) BS were modelled in zone V by ETABS software by Linear Static Analysis at G+3, G+6, G+9 storey and results were extracted for the parameters such as storey drift, storey displacement, storey shear, storey stiffness and respective graphs were plotted.



After analyzing drift values reaches maximum values and then decreases following a non linear path. Storey drift of FS7 is 65% greater than FS4; FS10 is 11.2 % greater than FS7 as shown in Fig 3. BS7 is 69% greater than BS4; BS10 is 10.2% greater than BS7. FSS7 is 0.87 times greater than FSS4; FSS10 is 11.92% greater than FSS7. So it is clear that storey drift increases as height increases. In storey ten it is observed that storey drift of FSP10 is 17.71% lesser than that of FS10, FB10 is 6.39% lesser than FSP10, BS10 is 31.3% lesser than FS10, FSS10 is 24.33% lesser than BS10. FS and FSP has got the maximum displacement and FSS has got the least in G+3, G+6, and G+ 9 storeys

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and as the storey height increases displacement increases .Displacement of FS7 is 1.5 times FS4, FS10 is 45.2% greater than FS7. BS7 is 1.46 times BS4; BS10 is 41% greater than BS7. FSS7 is 1.5 times greater than FSS4 and FSS10 is 39.36% greater than FSS7. Storey displacement of FSP10 is 7.22% lesser than FS10, FB10 is 9.4% lesser than FSP10, BS10 is 33.74% lesser than FS10 and FSS10 is 50.35% lesser than BS10 as shown in Fig 3 (f).

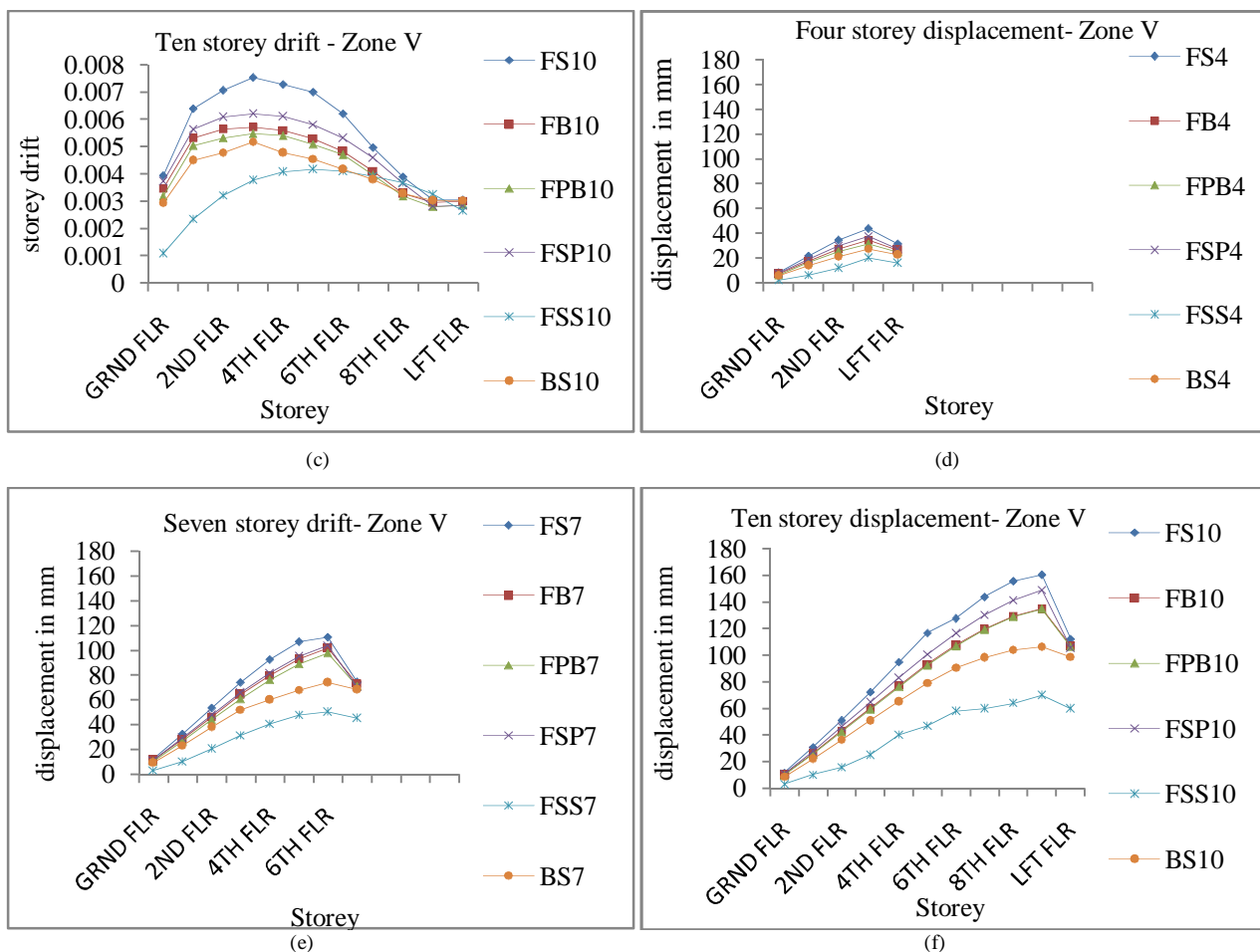


Fig. 3. Storey drift and displacement (a) Four storey drift-Zone V (b) Seven storey drift-Zone V (c) Ten storey drift-Zone V (d) Four storey displacement-Zone V (e) Seven storey displacement -Zone V (f) Ten storey displacement-Zone V

Storey shear of FB10 is 5.08% greater than FSP10, BS10 is 37.76% greater than FS10 and FPB10 is 4.64% greater than that of FB10. Storey shear of FB10 is 20.72% greater than FS10 and FPB10 is 8.895% greater than BS10. Storey shear of FSP4 is 10.47% greater than FS4, FSS4 is 34.3% greater than FS4, BS4 is 3.6% greater than FPB4, FS7 is 29.49% greater than FS4, FS10 is 5.36% greater than FS7. Storey shear of BS7 is 25.18% greater than that of BS4, and BS10 is 11.14% greater than BS7. Storey shear of FSS7 is 25.23% greater than FSS4 and FSS10 is 10.69% greater than FSS7. FSS and BS have got the maximum shear and FS has the least as shown in Fig 4 (a), (b), (c).

Storey stiffness of FS7 is 23.12% lesser than that of FS4, FS10 is 7.42% lesser than FS7, BS7 is 23.54% lesser than BS4 and BS10 is 7.46% lesser than BS7. Stiffness of FSS7 is 23.35% lesser than FSS4, FSS10 is 12.71% lesser than FSS7, as the storey height increases stiffness decreases as shown in Fig 4 (d), (e), (f). Storey stiffness of FSP4 is 10.07% greater than FS4, BS4 is 6% greater than FPB4 and BS4 is 31.207% greater than FS4. FSP7 is 13.47% greater than FS7, and BS7 is 30.50% greater than FS7, FSP10 is 13% greater than FS10, and BS10 is 30.464% greater than

FS10. FB10 is 3% greater than FSP10, and storey stiffness of FPB10 is 45% greater than FS10. Storey stiffness increases after strengthening with perimeter beams and shear walls with the increase in storey height.

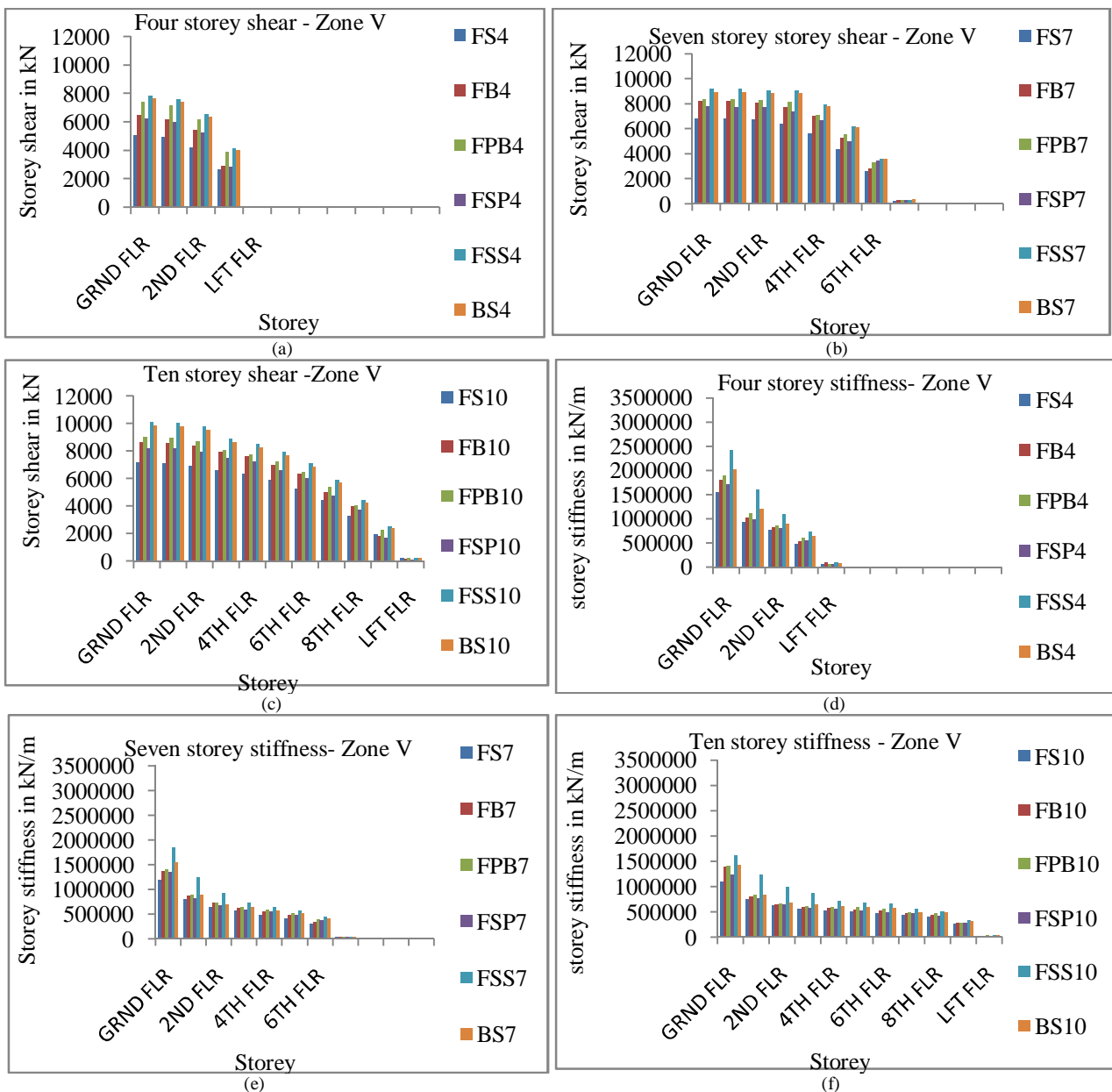


Fig. 4. Storey shear and stiffness (a) Four storey shear-Zone V (b) Seven storey shear-Zone V (c) Ten storey shear-Zone V (d) Four storey stiffness-Zone V (e) Seven storey stiffness-Zone V (f) Ten storey stiffness-Zone V

5.2 Response Spectrum Analysis Results

After the Linear Static analysis, Response Spectrum analyses were done to all the models. In reference to IS 1893- 2002, Dynamic analysis shall be performed for all irregular framed buildings higher than 12m in zones IV and V. For irregular buildings, lesser than 40 m in height in zones II and III, even though not mandatory, is recommended.

After zone V analysis , storey drift of FSS4 is 0.632 times lesser than that of FS4 and FSP4 is 17.3% lesser than that of FS4, FSP7 is 8.53% lesser than that of FS7, FSS7 is 0.6 times lesser than that of FS7 BS10 is 38% lesser than that of FS10, FPB10 is 2.27% lesser than FB10, FSP10 is 11.37% lesser than FS10.Storey displacement of FSP4 is 14.75% lesser than FS4 FSS4 is 0.5 times lesser than FS4, FSP7 is 7.17% lesser than that of FS7, FSS7 is 0.55 times lesser than that of FS7 BS10 is 39% lesser than FS10, FPB10 is 2.38% lesser than FB10, FSP10 is 8.41% lesser than FS10.Storey shear of FSP4 is 10.47% greater than FS4,FSS4 is 34.3% greater than FS4, FSP7 is 13.89% greater than that of FS7, FSS7 is 35.26% greater than that of FS7, BS10 is 37% greater than FS10,FSS10 is 41.92% greater than FS10,FPB10 is 4.64% greater than FB10,FSP10 is 15.13% greater than FS10 and storey shear is maximum at the ground floor. Storey stiffness of BS4 is 14.2% greater than FPB4, FSP4 is 26% greater than FS4, FSS4 is 1.17 times greater than FS4 BS4 is 39.88% greater than FS4, of FSP7 is 7.93% greater than that of FS7, FSS7 is 0.93 times greater than that of FS7, BS10 is 41% greater than FS10, FSS10 is 0.95 times stiffer than FS10, FPB10 is 5.41% greater than FS10, and FSP10 is 12.6% greater than FS10.

5.3 Comparison of 10, 20, 30 storey drift in zone V after Response Spectrum analysis

Drift values at 10, 20, 30 storeys of Flat slab building are compared to know up to which storey height it is admissible.

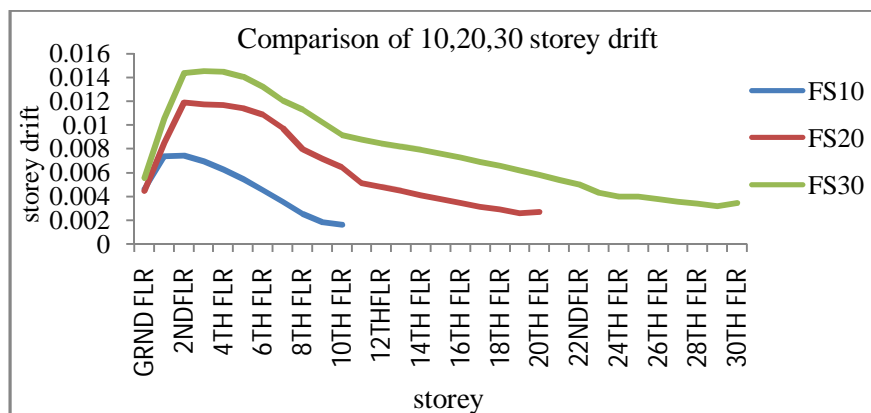


Fig 5 Comparison of 10, 20, 30 storey drifts

Storey drift of 10, 20, 30 storey of Flat slab building is 0.007417 m, 0.01188m, 0.014539 m respectively as shown in Fig 5. As per IS: 1893 2002 [5] Clause 7.11.1 Storey Drift limitation shall not exceed 0.004 times storey height, $0.004 \times 3000 = 12\text{mm}$. storey drift of 20 storey is almost equal to 12mm and drift value exceeds its limit in 30 storey.

VI. CONCLUSION

A C shaped building of Flat slab was compared with conventional RCC building by varying storey heights. Flat slab buildings were strengthened with shear walls and perimeter beams. Analysis was done by Linear Static and Response Spectrum analysis in zone V using ETABS software. The following conclusions were made after the study:-

- As the storey height increases drift value also increases following a nonlinear path. Storey drift of FS>FSP>FB>FPB>BS>FSS.
- Storey displacement of FS>FSP>FB>FPB>BS>FSS in zone V. Displacement value also increases as height of the storey increases. Storey displacement of BS10 is 33-45% lesser than FS10
- Storey shear of FSS>BS>FPB>FB>FSP>FS. Storey shear due to Response Spectrum is comparatively lower than Equivalent Static method. Storey shear of BS10 is 38% greater than FS10.

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- As the storey height increases stiffness of the building decreases. Storey stiffness of FSS>BS>FPB>FB>FSP>FS. Storey stiffness in storey 4 > storey 7 > storey 10. Storey stiffness of BS10 is 30-41% greater than FS10.
- The drift and displacement values of FPB lie in between the two structures but somewhat nearer to the beam slab building. As the storey height increases the drift value of FPB is becoming closer to the drift value of FB.
- Based on the study conducted, Flat slab buildings with shear walls are preferred because there is a considerable reduction in storey displacement and storey drift in zone V.
- The strengthening of the Flat slab is done at varying storeys because drift value of Flat slab building is 38% greater when compared to beam slab building and to check to what extent the performance of Flat slab building when strengthened will improve compared to conventional RCC structure. It is observed that Flat slab building when combined with shear wall, drift value is 24.33% lesser than beam slab building.
- Even though Flat slab with drop in place of beam slab arrangements increases maximum displacement values, these all are well within permissible limits up to 20 storeys but exceeds in case of 30 storey.

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