SEISMIC BEHAVIOUR OF PRESTRESSED FLAT SLAB BUILDINGS

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ABSTRACT-India is a fast developing country as well as India have got second place in the world population. So that now a days the demand of area of construction is going on increasing everywhere. To overcome this problem one of the best method is vertical development among many solutions. Vertical development will leads to the construction of high raised buildings. These high raised buildings should resist seismic load and wind loads which are more critical in these structures. Prestressed flat slab buildings are now a days becoming more common due to its many advantages compared to the conventional buildings. So it's very important to know seismic behavior of the prestressed flat slab buildings.

This study aims at analysis of Flat plate and Flat slab with drop buildings under the seismic forces using the software ETABS version 16.2.0. The structural conditions for 8 storey and 12 storey buildings are analysed by ESA and RSA methods. Structure with cracked and un-cracked conditions analysis are performed. For the seismic analysis IS 1893 Part 1:2016 codal provisions are used. This paper also deals with a comparative study of parameters like Storey drifts and Storey shear for every model.

KEYWORDS- **Prestressed Flat slab, Cracked section, Un-cracked section, Storey drift, Storey shear, ETABS v16.2.0**

1 INTRODUCTION

Flat slab can be simply defined as the floor without beam is directly supported by wall or column. Flat slab buildings have many advantages that it can maintain the storey height uniform throughout the floor. In flat slab buildings loads on the foundation will be comparatively lesser since the storey height is less. Flat slabs are mainly subjected to gravity loads and lateral loads. Gravity load analysis of flat slabs can be done by Equivalent frame method or Direct design method. From the comparative studies it is proven that Prestressed flat slab are more economical and safe compared to RCC flat slab buildings , if the span length is more. There are many advantages for the prestressed flat slab buildings. Among those advantages some of them are listed below.

- Size of the structural members will be reduced ,so that we can increase the clearance of the floors.
- For heavy load case also we can use large spans with shallow members.
- Self weight of the building will be reduced because of the smaller dimensions of the structural members.
- In prestressed concrete we can reduce the tension on concrete, so that we can get crack free members of structure.
- There are many other general advantages for prestressing concrete like, low maintenance costs, elegance, adaptability, high corrosion-resistance, excellent fire resistance.

2 Methods of Seismic Analysis

Seismic analysis is the method of structural analysis used for calculating the responses of a building or a non-building structure towards the earthquake forces. Different types of earthquake analysis methods used are shown in the Fig 2.1 given below.

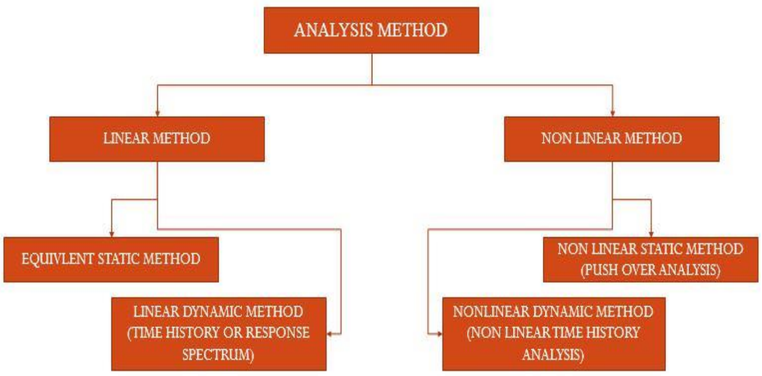


Fig.2.1 Types of seismic analysis

For the current study I have used two methods equivalent static analysis and Response spectrum analysis method

2.1 EQUIVALENT STATIC ANALYSIS

Equivalent static analysis is an elastic design Method. Equivalent static analysis procedure mainly consists of the following steps.

i. First of all estimate the first mode response time period of the building from design response spectra.
ii. Use this specific design response spectra to determine base shear of whole building.
iii. Finally distribute this base shear between various lumped mass levels based on the inverted triangular shear distribution of 90% of the base shear which has calculated.

This method shows the effect of earthquake when series of forces are applied on a building, through a seismic design response spectrum. Static analysis is linear type of analysis. To consider the effects due to yielding of structure, modification factors are applied by many codes that reduce the design forces. In this method, the lateral force that is equivalent to the design basis earthquake is applied statically. These equivalent lateral forces are applied at the design center of mass at each floor.

2.2 RESPONSE SPECTRUM ANALYSIS

Response Spectrum Analysis is a linear dynamic statistical analysis method. In this method, the multiple modes of response of a building are to be taken. It measures the contribution of each natural mode of vibration to show the maximum seismic response of an elastic structure. The response of a structure can be defined as a combination of different modes. To determine these different modes for a structure, software analysis can be used and can be done by ETABS software. In accordance to modal mass and the modal frequency, for each mode, a response can be found from the design spectrum. By this, the total magnitude of forces in each direction is evaluated and its effects on building are observed. The types of combination methods include.

- Square Root of the Sum of the Squares (SRSS)
- ❖ The peak response quantities can be combined by this method if building does not have closely spaced modes.
- Complete Quadratic Combination (CQC)
- ❖ A method that is an improvement over SRSS for closely spaced modes.
- Absolute
  - Peak values are added together.

Structural Modelling of Prestressed Flat plate and Flat slab with Drop Using ETABS and the Analysis Results.

3 PROBLEM FORMULATION

The problem considered for the study is Prestressed Flat Slab buildings.The buildings for the analysis have been modelled in ETABS 16.2.0 Software. These buildings have been analyzed using Equivalent Static Method and Response Spectrum Method of IS: 1893-2016(Part 1)

3.1 LOAD COMBINATION

A load combination results when more than one load type acts on the structure. Design codes usually specify a variety of load combinations together with load factors (weightings) for each load type in order to ensure the safety of the structure under different maximum expected loading scenarios. In the limit state design of this RC building model the following load combinations are considered as per codal provisions provided in Clause 6.3.1., IS: 1893-2016 (Part 1)

a) 1.5(DL + IL)
b) 1.2(DL + IL ± EL)
c) 1.5(DL ± EL)
d) 0.9DL ± 1.5EL

3.2 STRUCTURAL ELEMENT MODELLING

Details of the buildings considered in the present study are given in Table 3.1. Following are the main modelling assumption used in the study:-

Rigid Slab:-It is assumed that all the frames in the buildings are connected by floor diaphragms that are rigid in their own plane. Therefore every floor has only two translational

Table 3.1 Structural Details of Buildings

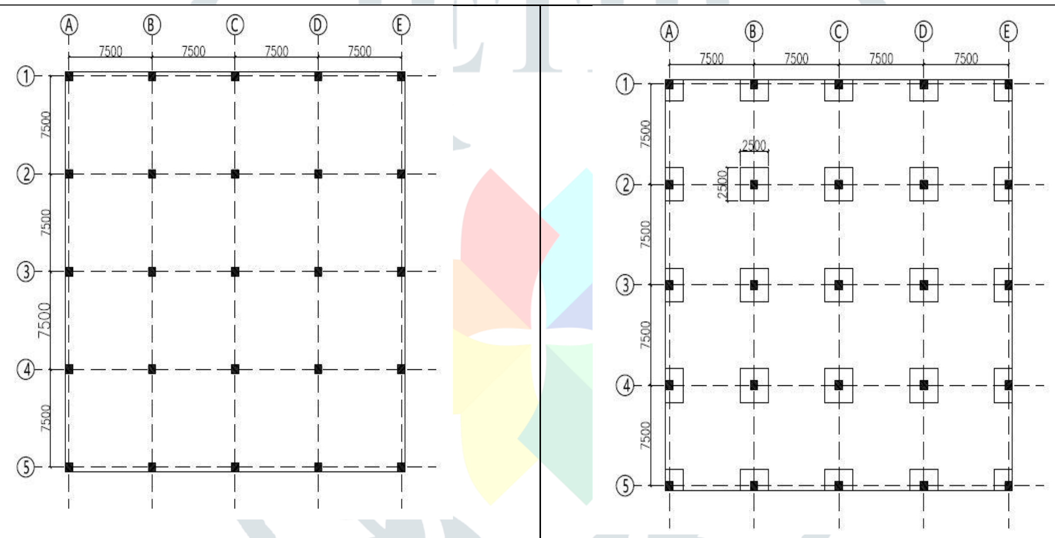
Specification	8 Storey Building	12 Storey Building
Span in X direction (m)	7.5	7.5
Span in Y direction (m)	7.5	7.5
Height of each floor (m)	3	3
Live Load Floor(kN/m^2)	4	4
Dead load Floor (kN/m^2)	3	3
Live Load Roof (kN/m^2)	1.5	1.5

Dead load Roof (kN/m^2)	2	2
Earthquake Zone	III	III
Damping Ratio	5%	5%
Importance factor-	1.2	1.2
Type of Soil	Medium	Medium
Type of structure	SMRF	SMRF
Response reduction Factor-	3	3
Grade of concrete for Column	M30	M30
Grade of concrete for Slab	M50	M50
Grade of steel	Fe415	Fe415

Fixed Base:-The frames of building are assumed to be fixed at their base on an infinitely rigid foundation. No soil-structure interaction effect is considered in this study.

Design Spectrum:-Design spectra are not uneven curves since they are intended to be the average of many earthquakes. An idealized design spectrum of earthquake ground motions is applied at the base of the buildings as per IS 1893:2016. Due to the fixed base assumption, all supports are assumed to move in phase. No vertical ground motion components are applied to the buildings.

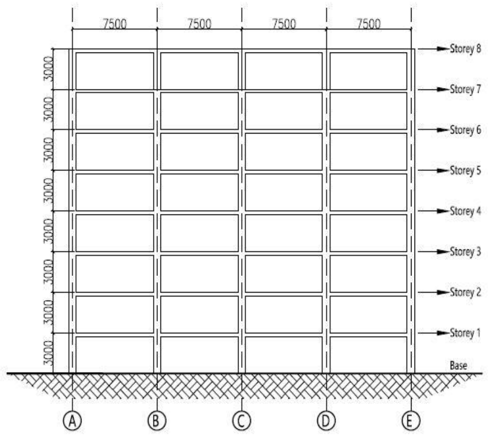
Plan and elevation of 8 storey and 12 storey buildings are given in Figs 3.1- 3.3 respectively.



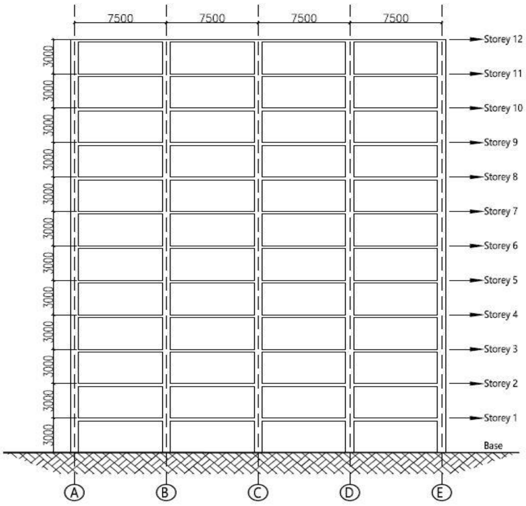
a. Floor plan without drop

b. Floor plan with drop
Drop size-2500x2500

Fig 3.1 Typical floor plan for Eight and Twelve storey buildings
(all dimensions are in mm)

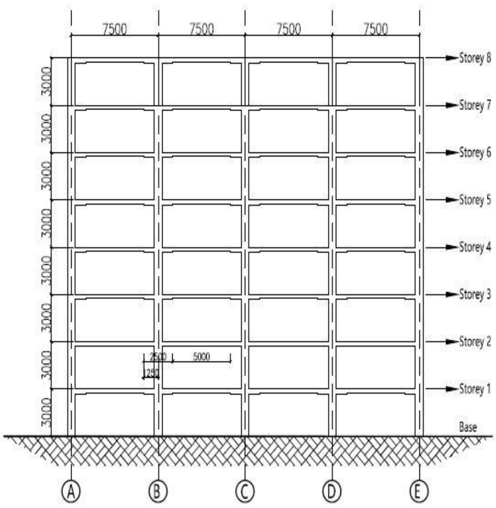


a. Eight Storey building without drop
Slab = 280 : column =750x750

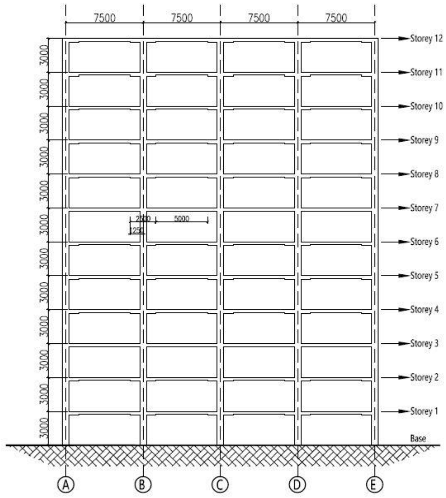


b. Twelve storey building without drop
Slab =300 : column= 850x850

Fig 3.2 Elevation (all dimensions are in mm)



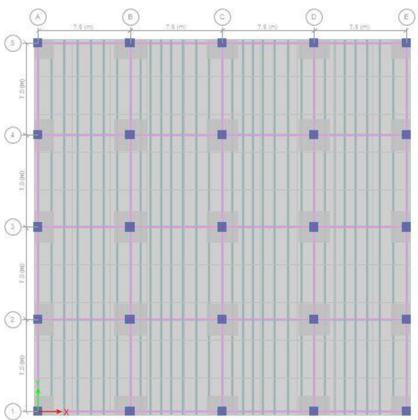
a. Eight Storey building with drop
slab = 280 : column =750x750



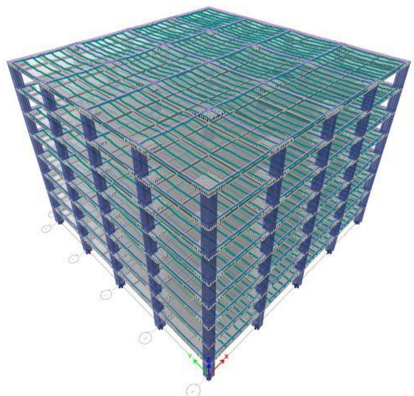
b. Twelve storey building with drop
slab =280 , drop:350 , column= 850x850

Fig 3.3 Elevation (all dimensions are in mm)

Models are analyzed using ETABS and analysis results are evaluated and compared with different cases and the analysis results are listed below. Plan and 3D view of 8 storey building with drop in ETABS are shown in Fig 3.4.



a. PLAN



b. 3D-view

Fig 3.4 Model of 8 storey flat slab building with drop in ETABS

3.3 STOREY SHEAR COMPARISON

Story shear is an important parameter in seismic analysis. The magnitude of the lateral force depends on the mass of the building at each floor level, the distribution of stiffness over height and the storey displacement in a given mode. Storey base shear of all building models by static and dynamic analysis are compared and presented in the form of tables and graphs. Abbreviations used for the graphs and tables are :-

- FPUC - Flat plate un-cracked
- FPC - Flat plate cracked
- FSDUC- Flat slab with drop un-cracked
- FSDC -flat slab with drop -cracked

3.3.1 Storey Shear Comparison for Eight Storey buildings by ESA as per IS 1893: 2016

Storey shear comparison of 8 storey buildings by ESA as per IS 1893: 2016 have been shown in Table 3.2. Maximum value observed for drop Un-cracked building model is Storey shear comparison of 8 storey buildings by ESA as per IS 1893: 2016 has been 2978.9936 kN. Obtained results are shown in Fig.3.5.

Table 3.2 Storey shear for Eight storey buildings by ESA as per IS 1893: 2016

Storey No.	FPUC (kN)	FPC (kN)	FSDUC (kN)	FSDC (kN)
0	2485.95	2379.61	2978.99	2858.23
1	2485.95	2379.61	2978.99	2858.23
2	2472.63	2366.86	2963.05	2842.93
3	2419.35	2315.86	2899.29	2781.76
4	2299.46	2201.10	2755.84	2644.13
5	2086.33	1997.09	2500.81	2399.44
6	1753.32	1678.32	2102.34	2017.11
7	1273.78	1219.29	1528.53	1466.57
8	621.06	594.50	747.51	717.21

3.3.2 Storey Shear Comparison for Eight Storey buildings by RSA as per IS 1893: 2016

Storey shear comparison of 8 storey buildings by RSA as per IS 1893: 2016 have been shown in Table 3.3. Maximum value observed for drop Un-cracked building model is 2935.3599 kN. The obtained results are shown in Fig.3.6

Table 3.3 Storey shear for Eight storey buildings by RSA as per IS 1893: 2016

Storey No.	FPUC (kN)	FPC (kN)	FSDUC (kN)	FSDC (kN)
0	2487.09	2373.70	2935.36	2855.72
1	2487.09	2373.70	2935.36	2855.72
2	2367.06	2254.24	2817.27	2735.11
3	2140.77	2034.94	2584.52	2503.93
4	1908.34	1816.14	2317.88	2245.02
5	1699.29	1624.04	2039.61	1979.26
6	1487.59	1425.72	1728.20	1679.47
7	1181.64	1130.15	1313.55	1274.58
8	674.23	637.56	709.12	680.57

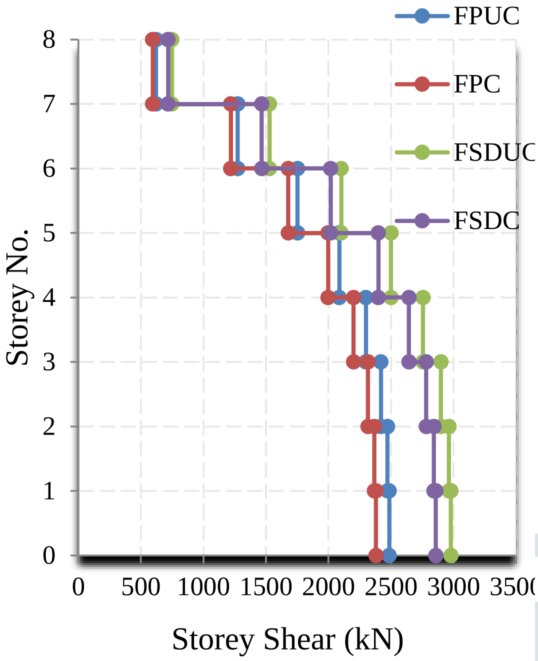


Fig. 3.5 Storey shear for Eight storey buildings by ESA as per IS 1893: 2016

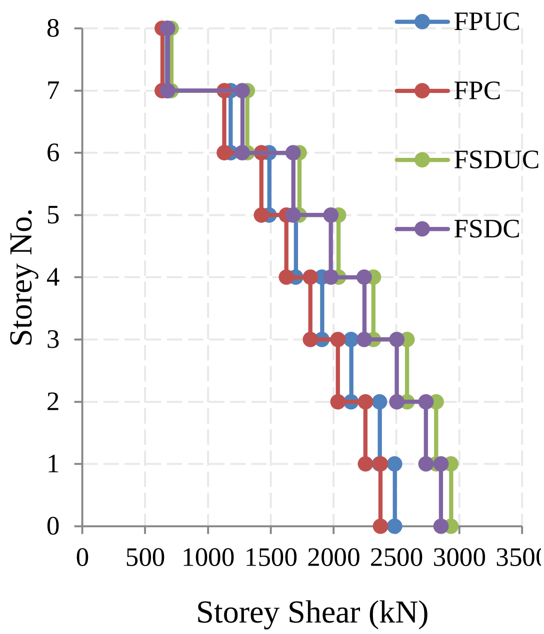


Fig. 3.6 Storey shear for Eight storey buildings by RSA as per IS 1893: 2016

3.3.3 Storey Shear Comparison for twelve Storey buildings by ESA as per IS 1893: 2016

The distribution of shear along the height of the 12 storey building due to the equivalent static analysis is compared and tabulated as shown in Table 3.4. Storey shear of un-cracked buildings are more compared to cracked buildings. Storey shear of 12 storey buildings by ESA as per IS 1893: 2016 are represented in Fig.3.7.

Table 3.4 Storey shear for Twelve storey buildings by ESA as per IS 1893: 2016

Storey No.	FPUC (kN)	FPC (kN)	FSDUC (kN)	FSDC (kN)
0	2887.07	2792.67	3032.19	2936.15
1	2887.07	2792.67	3032.19	2936.15
2	2882.35	2788.11	3027.22	2931.34
3	2863.47	2769.84	3007.36	2912.11
4	2820.98	2728.74	2962.68	2868.84
5	2745.45	2655.68	2883.24	2791.92
6	2627.42	2541.51	2759.12	2671.73
7	2457.47	2377.12	2580.39	2498.66
8	2226.15	2153.36	2337.11	2263.09
9	1924.01	1861.10	2019.37	1955.40
10	1541.62	1491.21	1617.21	1565.99
11	1069.53	1034.55	1120.73	1085.24
12	498.30	482.00	519.99	503.52

3.3.4 Storey Shear Comparison for Twelve Storey buildings by RSA as per IS 1893:2016

The distribution of shear along the height of the 12 storey building due to the response spectrum analysis is compared and tabulated as shown in Table 3.5. Storey shear of Un-cracked buildings are more compared to cracked buildings. Storey shear of 12 storey buildings by RSA as per IS 1893: 2016 are represented in Fig 3.8.

3.4 INTER-STOREY DRIFT COMPARISON

Storey drift is the drift of one level of a multi-storey building relative to the level below. Inter-story drift is the difference between the roof and floor displacements of any given storey as the building sways during the earthquake, normalized by the storey height. Drift is defined as the lateral displacement. Storey drift is directly related to the stiffness of the structure. The higher the stiffness lowers the drift and higher the lateral loads on structure.

3.4.1 Inter- Storey Drift Comparison for Eight Storey buildings by ESA as per IS 1893: 2016

The inter-storey drifts for all the 8 storey buildings calculated by ESA are presented in below Table 3.6. Fig.3.9 shows a plot of storey drift ratios for all storey obtained by ETABS. IS 1893 (Part-1):2016 specifies that storey drift should not be greater than 0.004 for all storey other than the roof, for roof it is 0.001.

Table 3.5 Storey shear for twelve storey buildings by RSA as per IS 1893: 2016

Storey No.	FPUC (kN)	FPC (kN)	FSDUC (kN)	FSDC (kN)
0	2880.86	2783.67	3029.51	2937.52
1	2880.86	2783.67	3029.51	2937.52
2	2821.15	2714.83	2960.57	2868.90
3	2652.39	2553.44	2791.24	2705.55
4	2463.44	2379.36	2595.38	2522.36
5	2294.74	2225.11	2414.44	2353.89
6	2134.77	2072.65	2243.85	2189.98
7	1988.32	1925.30	2090.00	2035.34
8	1843.77	1773.97	1937.65	1876.52
9	1664.38	1589.72	1746.08	1679.81
10	1437.13	1365.48	1496.91	1432.20
11	1117.07	1055.61	1145.77	1088.99
12	590.99	552.29	592.52	556.12

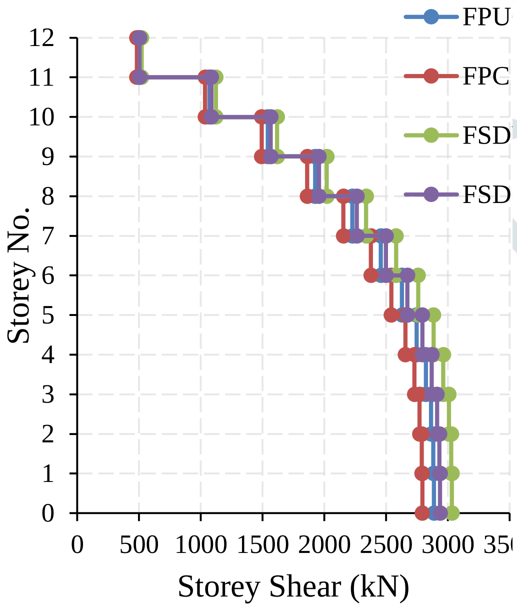


Fig 3.7 Storey shear for Twelve storey buildings by ESA as per IS 1893: 2016

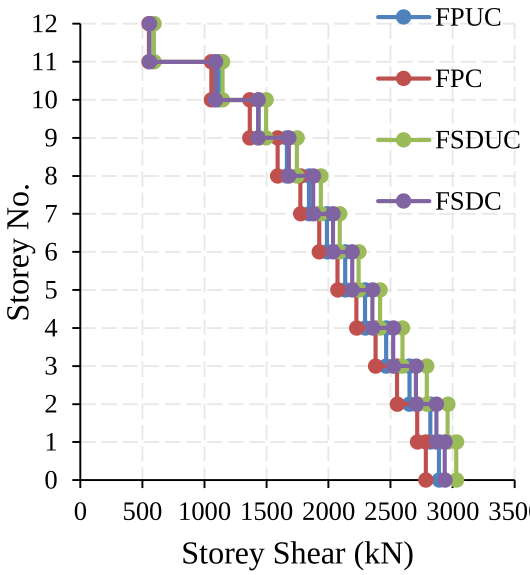


Fig 3.8 Storey shear for Twelve storey buildings by RSA as per IS 1893: 2016

Table 3.6 Inter-storey drift for Eight storey buildings by ESA as per IS 1893: 2016

Storey No.	FPUC	FPC	FSDUC	FSDC
0	0	0	0	0
1	0.000788	0.000888	0.000743	0.000834
2	0.001743	0.00189	0.001554	0.001669
3	0.002146	0.002257	0.001838	0.001914
4	0.002226	0.002293	0.001858	0.001901
5	0.002096	0.002126	0.001718	0.001739
6	0.001818	0.001812	0.001459	0.001462
7	0.001448	0.001398	0.001118	0.001094
8	0.001096	0.000996	0.000785	0.000723

3.4.2 Inter- Storey Drift Comparison for Eight Storey buildings by RSA as per IS 1893: 2016

The inter-storey drifts for all the 8 storey buildings calculated by RSA are presented in below Table 3.7. Fig.3.10 shows storey drift ratios obtained by ETABS. From the storey drift plot it can be observed that for all storey, storey drifts are within the permissible limits. From the graph it is visible that storey drift values are more in ESA than RSA method of analysis.

Table 3.7 Inter-storey drift for Eight storey buildings by RSA as per IS 1893: 2016

Storey No.	FPUC	FPC	FSDUC	FSDC
0	0	0	0	0
1	0.000652	0.000741	0.000625	0.000717
2	0.001382	0.001508	0.00126	0.00138
3	0.001618	0.001704	0.00142	0.001501
4	0.001609	0.001653	0.001373	0.001422
5	0.001484	0.001503	0.001232	0.001263
6	0.001297	0.001298	0.001039	0.001057
7	0.001065	0.001042	0.000805	0.000804
8	0.000827	0.000767	0.000575	0.000543

3.4.3 Inter- Storey Drift Comparison for Eight Storey buildings by ESA as per IS 1893: 2016

The inter-storey drift profiles of the various 12 storey building models by ESA as per IS 1893: 2016 are shown in Table 3.8 and the results are plotted and shown in Fig 3.11 Maximum storey drift ratio is observed in 5th storey for FP Cracked building with a value of 0.002139. It is less than the permissible limit specified by IS codes.

3.4.4 Inter- Storey Drift Comparison for Eight Storey buildings by RSA as per IS 1893: 2016

The inter-storey drift profiles of the various 12 storey building models by RSA as per IS 1893: 2016 are shown in Table 3.9 and the results are plotted and shown in Fig 3.12 Maximum storey drift ratio is observed in 4th storey for FP Cracked building with a value of 0.001599. It is less than the permissible limit specified by IS codes. For 12 storey also values obtained by RSA give less value compared to ESA method.

Table 3.8 Inter-storey drift for Eight storey buildings by ESA as per IS 1893: 2016

Storey No.	FPUC	FPC	FSDUC	FSDC
0	0	0	0	0
1	0.000635	0.000718	0.000614	0.000693
2	0.001452	0.001582	0.001381	0.001499
3	0.001866	0.001971	0.001751	0.001842
4	0.002051	0.00212	0.001908	0.001966
5	0.002098	0.002139	0.001941	0.001974
6	0.002053	0.002075	0.001892	0.00191
7	0.001937	0.001947	0.001781	0.00179
8	0.001763	0.001763	0.001617	0.001619
9	0.001537	0.001527	0.001406	0.001399
10	0.001274	0.001247	0.001158	0.001138
11	0.000998	0.000946	0.000894	0.000853
12	0.000771	0.000689	0.000674	0.000606

Table 3.9 Inter-storey drift for Eight storey buildings by RSA as per IS 1893: 2016

Storey No.	FPUC	FPC	FSDUC	FSDC
0	0	0	0	0
1	0.000535	0.00061	0.000523	0.000598
2	0.001182	0.0013	0.001139	0.001254
3	0.001458	0.001553	0.001386	0.001478
4	0.001535	0.001599	0.001446	0.001508
5	0.001514	0.001555	0.001417	0.001457
6	0.001444	0.00147	0.001346	0.001373
7	0.00135	0.001365	0.001255	0.001274
8	0.001238	0.001244	0.001149	0.001161
9	0.001107	0.001102	0.001024	0.001027
10	0.000953	0.000936	0.000875	0.000867
11	0.00078	0.000746	0.000703	0.000678
12	0.000616	0.000558	0.000542	0.000494

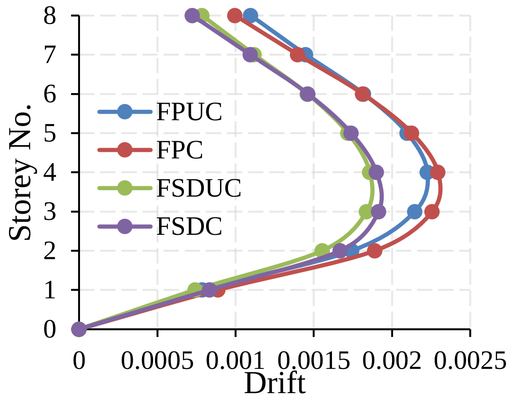


Fig.3.9 Inter-storey drift for Eight storey buildings by ESA as per IS 1893: 2016

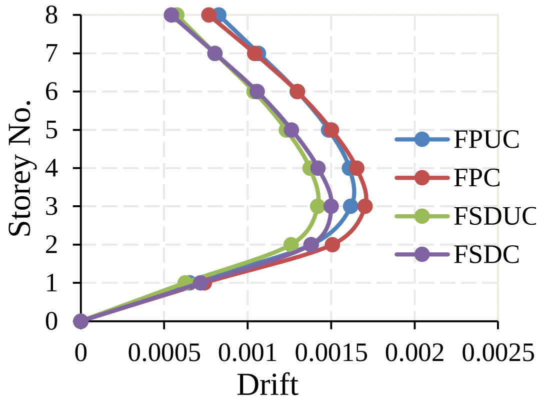


Fig. 3.10 Inter-storey drift for Eight storey buildings by RSA as per IS 1893: 2016

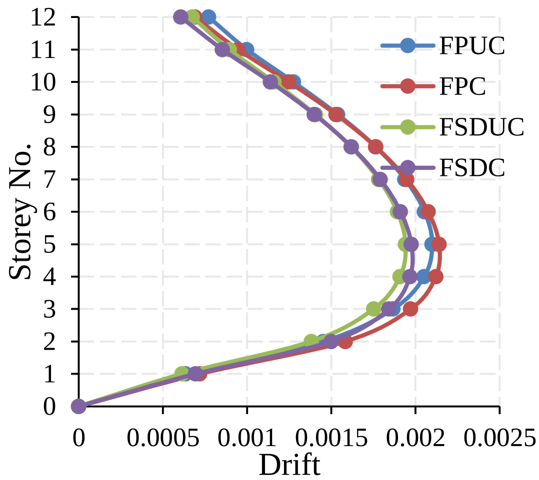


Fig. 3.11 Inter-storey drift for Twelve storey buildings by ESA as per IS 1893: 2016

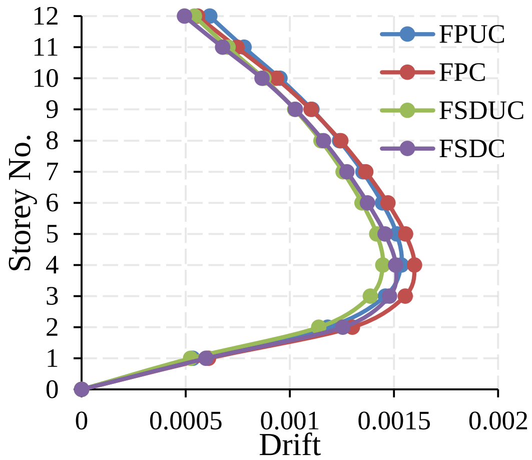


Fig 3.12 Inter-storey drift for Twelve storey buildings by RSA as per IS 1893: 2016

CONCLUSION

- Storey shear is more for prestressed flat slab building compared to prestressed flat plat building.
- storey shear is more for un-cracked section compared to cracked section.

- Storey shear values obtained from the ESA method are little higher than the RSA method.
- On going from 4 storey to 12 storey building for higher storey buildings at higher storeys shear values are much closer for flat slab and flat plate building.
- Storey displacements are more for flat plate buildings compared to flat slab buildings .compared to un-cracked sections cracked sections has more storey displacement.
- The drift envelope of all building models has similar shapes that bulge out at the middle ,this is representative of the behaviour of a frame structure
- Drift is almost similar at the bottom storeys for both cracked and un-cracked sections but its more for cracked sections at middle of the storeys, again it is almost similar at the top storeys.
- The calculated drifts were in well within the 25- 60% the code specified limit of 0.004 times story height .
- . Prestressed flat slabs will give better performance during seismic loads compared to the normal rcc flat slab building.
- Deflection also can be controlled for prestressed flat slab buildings.
- Rapid and economic constructions are possible in this field .

Based on the studies, it can be conclude that prestressed flat slab buildings are more safe and economical if span is high. Prestressed flat slabs will give better durability and performance during seismic loads compared to the normal RC flat slab building.

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