Comparative Study on Static and Dynamic Analysis of RC Buildings of Different Heights in Different Seismic Zones

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1 Introduction

An earthquake is a random and unpredictable event. It can cause significant damage to structure as well as human life which makes it one of the most destructive natural calamities. With the increase in total world population the number of high-rise building is increasing exponentially in the modern time. In a country like India which has been hit by several high magnitude earthquakes many times in the past, the seismic analysis and earthquake resistant design of structures have become prime challenges for all the civil engineers. Seismic analysis is mainly concerned with the behaviour of a structure under the action of earthquake loads. Two types of methods are used for analysis of earthquake loads, namely, static analysis method and dynamic analysis method. Static method, which includes Equivalent Static Method, does not take the dynamic behaviour of the loads into consideration and assumes that during an earthquake the building responds in its fundamental mode. On the contrary, dynamic analysis method, which includes Response Spectrum Method, considers multiple mode of response and takes the dynamic aspect of the loads acting on a building into consideration.

In this study, buildings of different heights located in different seismic zones are analysed using both static and dynamic analysis methods in STAAD-Pro software and the responses of various members of the buildings are compared for both the methods.

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S. Kolathayar and S. C. Chian (eds.), *Recent Advances in Earthquake Engineering*, Lecture Notes in Civil Engineering 175,
https://doi.org/10.1007/978-981-16-4617-1_13

2 Literature Review

Gottala and Yajdhani [1] carried out static and dynamic analysis of G + 9 building in STAAD-Pro as per the IS 1893(Part-1): 2002. Comparing the values of the responses obtained from both the methods, the authors found that the moments obtained from dynamic analysis are 35–45% higher than those obtained from static analysis. It was also observed that nodal displacements values are 50% higher for dynamic analysis than those for static analysis.

Sharma and Maru [2] performed static and dynamic analysis for regular G + 30 buildings situated in zone-II and zone-III. The structure had a plan area of 25 m × 45 m with a storey height of 3.6 m each. The authors concluded that the values of moments and displacements obtained from dynamic analysis were 10–15% and 17–28% higher, respectively, than those obtained from static analysis.

3 Objective

The IS 1893(Part 1): 2016 recommends the use of Equivalent Static Method only for regular buildings of height less than 15 m situated in Seismic Zone II and Response Spectrum Method for all the buildings other than regular building of height less than 15 m located in Zone II [3]. However, in common practice it is observed that the Equivalent Static Method is also used for analysis of buildings other than those suggested by the code. The use of inappropriate method may significantly affect the performance of the building during an earthquake.

The objective of this study is to make a comparative analysis between responses obtained from Equivalent Static Method and Response Spectrum Method. For this purpose, G + 3, G + 5 and G + 8 buildings situated in Seismic Zone II and Seismic Zone V are modelled in STAAD-Pro software. The analyses of these buildings are carried out in the software by both the methods as per Indian Standard code and the responses like axial force, shear force, bending moment and nodal displacement are compared.

4 Methods of Seismic Analysis

4.1 Equivalent Static Method (ESM)

The dynamic nature of the loads acting on the building must be taken into account for earthquake resistant design of buildings. However, in this simplified technique, the effect of earthquake force is substituted by a static force that is distributed laterally on a structure by using formulas given in the code [4]. The basic principle behind this method is the approximation of a MDOF system to a SDOF system that responds in its fundamental mode. In most of the codes of practice, this method is permitted for regular, low-to-medium rise buildings in lower seismic zones.

4.2 Response Spectrum Method (RSM)

Response spectra curves represent the maximum response of an idealized SDOF system subjected to a particular earthquake ground motion corresponding to its natural time period. A building possesses multiple modes of vibration during earthquake shaking. All the modes of responses are taken into account in response spectrum method. Depending on the modal frequency and modal mass, a response is obtained from the design spectrum corresponding to each mode. In the end, an estimate of the total response of the structure is found out by combining all the modes [4]. In most of the codes of practice, this method is permitted for irregular, high-rise buildings in higher seismic zones.

5 Building Configuration

In our study, we have considered three models of G + 3, G + 5 and G + 8 buildings of equal plan area in both seismic zones II and V. Some general specifications related to building models and soil data are listed below [5].

No. of bays	5 in both x and y-direction
Bay length	3 m in both x and y-direction
Storey height	3 m
Plan dimension	15 m × 15 m
Size of beam	300 mm × 450 mm
Size of column:	
For 12 m high (G + 3) building	300 mm × 300 mm
For 18 m high (G + 5) building	350 mm × 400 mm
For 27 m high (G + 8) building	450 mm × 400 mm
Wall thickness	150 mm
Thickness of slab	100 mm
Type of soil	Type-II, medium soil as per IS 1893 (Part 1): 2016
Grade of concrete	M25
Grade of reinforcement	Fe415
Specific weight of concrete	25 kNm^{-3}
Specific weight of infill	20 kNm^{-3}

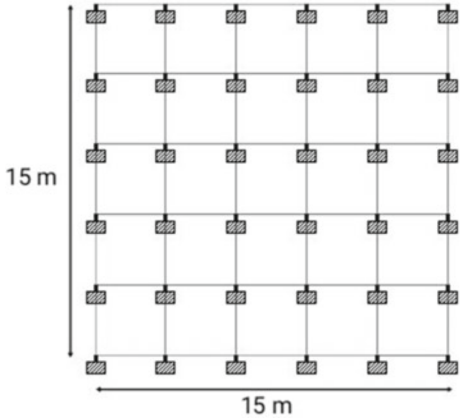


Fig. 1 Plan view of building models

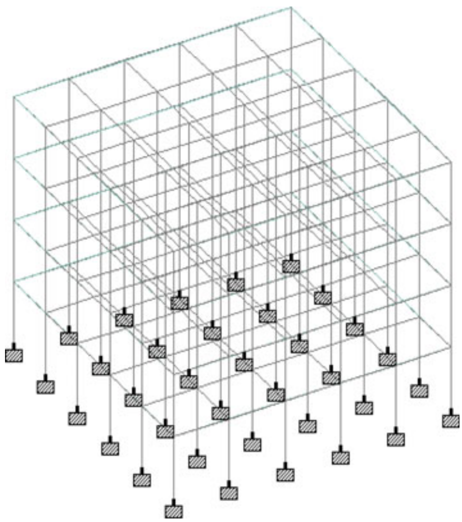


Fig. 2 3D view of 12 m high building

6 Results and Observations

Analyses of the buildings of various heights situated in seismic zone II and V were carried out and the responses were compared.

Fig. 3 3D view of 18 m high building

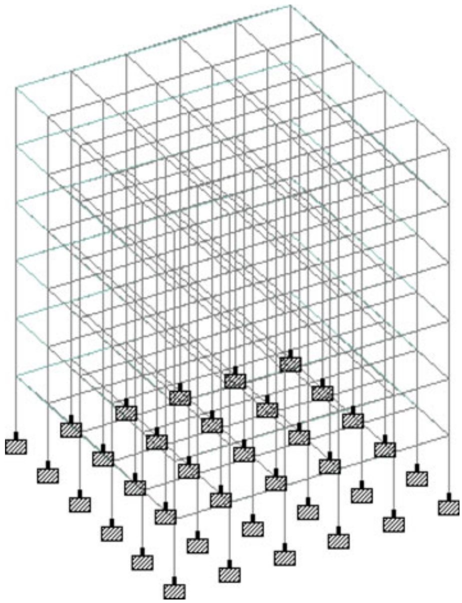
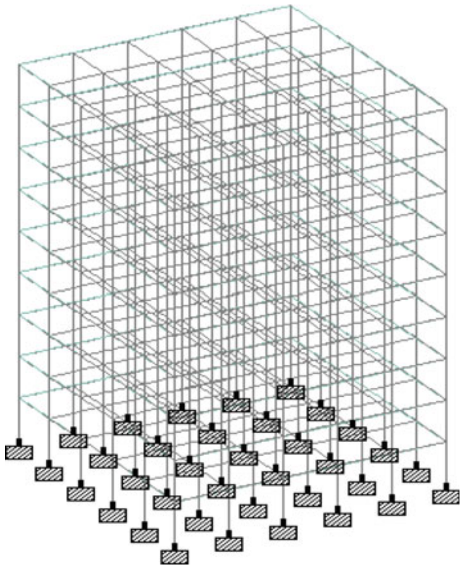


Fig. 4 3D view of 27 m high building



6.1 12 m High Building in Zone II

Responses for columns

Both ESM and RSM gives same values of axial forces. Values of bending moments are 7–35% higher for RSM than the values obtained from ESM (Table 1).

Responses for beams

Values of shear forces are 4–14% higher for RSM than those obtained from ESM. Again, values of bending moments are 9–26% higher for RSM than those obtained from ESM (Table 2).

Nodal displacements

Nodal displacements are 20–32% higher for RSM than those obtained from ESM (Table 3).

Table. 1 Responses in column for 12 m high building in zone II

Column No.	Location	Axial Force (kN)		Bending Moment (kNm)	
		ESM	RSM	ESM	RSM
199	Ground level	702.3	702.3	−23.3	−35.5
205	1st floor	518.9	518.9	22.7	31.5
211	2nd floor	338.7	338.7	20.3	24.4
217	3rd floor	160.4	160.4	13.2	14.1

Table. 2 Responses in beam for 12 m high building in zone II

Beam No.	Location	Shear Force (kN)		Bending Moment (kNm)	
		ESM	RSM	ESM	RSM
177	1st floor	53.9	62.7	42.8	58.1
182	2nd floor	50.4	55.9	42.2	51.6
187	3rd floor	44.7	46.7	35.5	39.1
192	4th floor	38.7	38.6	−19.7	−19.9

Table. 3 Nodal displacements for 12 m high building in zone II

Node No.	Location	Nodal displacement (mm)	
		ESM	RSM
127	1st floor	2.75	4.07
133	2nd floor	5.89	8.28
139	3rd floor	8.66	11.431
145	4th floor	10.45	13.16

6.2 12 m High Building in Zone V

Responses for columns

Both ESM and RSM gives the same values of axial forces. Values of bending moments are 9–35% higher for RSM than those obtained from ESM (Table 4).

Responses for beams

Shear forces are 16–24% higher for RSM than the values obtained from ESM. Again, bending moments are 20–30% higher for RSM than those obtained from ESM (Table 5).

Nodal displacements

Nodal displacements are 20–32% higher for RSM than those obtained from ESM (Table 6).

Table. 4 Responses in column for 12 m high building in zone V

Column No.	Location	Axial Force (kN)		Bending Moment (kNm)	
		ESM	RSM	ESM	RSM
199	Ground level	702.3	702.3	82.8	−127.9
205	1st floor	518.9	518.9	−80.6	−113.0
211	2nd floor	338.7	338.7	70.1	87.4
217	3rd floor	160.4	160.4	45.8	50.3

Table. 5 Responses in beam for 12 m high building in zone V

Beam No.	Location	Shear Force (kN)		Bending Moment (kNm)	
		ESM	RSM	ESM	RSM
177	1st floor	102.5	134.4	126.7	181.6
182	2nd floor	83.1	105.8	94.34	−129.4
187	3rd floor	94.2	113.9	117.5	151.4
192	4th floor	82.4	98.1	−92.3	−116.1

Table. 6 Nodal displacements for 12 m high building in zone V

Node No.	Location	Nodal displacement (mm)	
		ESM	RSM
127	1st floor	10	14.64
133	2nd floor	21.22	29.8
139	3rd floor	31.16	41.16
145	4th floor	37.61	47.32

6.3 18 m High Building in Zone II

Responses for columns

Both ESM and RSM gives the same values of axial forces. Again, values of bending moments are 4–12% higher for ESM than those obtained from RSM (Table 7).

Responses for beams

Values of shear forces are 10–14% higher in case of ESM than those obtained from RSM. Again, values of bending moments are 10–24% higher in case of ESM than those obtained from RSM (Table 8).

Nodal displacements

Nodal displacements are 20–32% higher for ESM than those obtained from RSM (Table 9).

Table. 7 Responses in column for 18 m high building in zone II

Column No.	Location	Axial force (kN)		Bending moment (kNm)	
		ESM	RSM	ESM	RSM
295	Ground level	872.6	870.4	−43.7	33.9
301	1st floor	736.1	736.1	−47.2	−40.0
307	2nd floor	594.1	594.1	−49.8	−40.4
313	3rd floor	446.5	446.5	−49.4	−38.6
319	4th floor	294.9	294.9	−44.5	−34.3
325	5th floor	140.2	140.2	−39.8	−32.1

Table. 8 Responses in beam for 18 m high building in zone II

Beam No.	Location	Shear force (kN)		Bending moment (kNm)	
		ESM	RSM	ESM	RSM
265	1st floor	61.5	55.6	−54.2	48.3
270	2nd floor	59.8	52.7	59.8	48.1
275	3rd floor	57.7	50.0	56.6	43.8
280	4th floor	52.6	46.9	49.9	38.0
285	5th floor	47.5	46.8	39.1	31.7
290	6th floor	39.2	39.2	21.6	18.3

Table. 9 Nodal displacements for 18 m high building in zone II

Node No.	Location	Nodal displacement (mm)	
		ESM	RSM
175	1st floor	2.31	1.84
181	2nd floor	5.31	4.1
187	3rd floor	8.23	6.13
193	4th floor	10.84	7.80
199	5th floor	12.90	9
205	6th floor	14.15	9.67

6.4 18 m High Building in Zone V

Responses for columns

Values of axial forces are 4–12% higher in case of ESM than those obtained from RSM. Again, values of bending moments are 15–32% higher for ESM than those obtained from RSM (Table 10).

Responses for beams

Table. 10 Responses in column for 18 m high building in zone V

Column No.	Location	Axial force (kN)		Bending moment (kNm)	
		ESM	RSM	ESM	RSM
295	Ground level	1174.8	1041.3	−151.9	−128.6
301	1st floor	961.6	852.7	−148.8	−120.7
307	2nd floor	742.3	662.2	−146.6	−112.5
313	3rd floor	527.1	477.1	−137.7	−98.8
319	4th floor	324.8	301.8	−116.1	−79.2
325	5th floor	145.6	140.7	−84.3	−57.5

Table. 11 Responses in beam for 18 m high building in zone V

Beam No.	Location	Shear force (kN)		Bending moment (kNm)	
		ESM	RSM	ESM	RSM
265	1st floor	132.2	111.0	169.8	139.9
270	2nd floor	129.9	104.3	174.9	126.5
275	3rd floor	120.9	92.9	160.9	114.7
280	4th floor	104.8	78.9	128.1	92.0
285	5th floor	76.2	61.3	93.8	63.2
290	6th floor	48.8	41.9	42.8	30.0

Table. 12 Nodal displacements for 18 m high building in zone V

Node No.	Location	Nodal displacement (mm)	
		ESM	RSM
176	1st floor	8.35	6.63
182	2nd floor	19.13	14.77
188	3rd floor	29.61	22.07
194	4th floor	39.01	28.04
200	5th floor	46.42	32.36
206	6th floor	50.87	34.75

Values of shear forces are found to be 14–25% higher for ESM than those obtained from RSM. Again, values of bending moments are 18–32% higher for ESM than those obtained from RSM (Table 11).

Nodal displacements

Nodal displacements are 20–32% higher for ESM than those obtained from RSM (Table 12).

6.5 27 m High Building in Zone II

Responses for column

Compared to RSM, the ESM gives 15–20% and 25–35% higher values of axial forces and bending moment, respectively (Table 13).

Responses for beams

Table. 13 Responses in column for 27 m high building in zone II

Column No.	Location	Axial force (kN)		Bending moment (kNm)	
		ESM	RSM	ESM	RSM
145	Ground level	1742.4	1403.4	59	41.6
151	1st floor	1556.5	1264.3	61	44.1
157	2nd floor	1369.8	1117.6	63	46.8
163	3rd floor	1182.6	964.9	67	45.7
169	4th floor	990.8	807.6	59	47.6
175	5th floor	795.5	646.8	63	46.9
181	6th floor	597.2	483.4	61	44.9
187	7th floor	397.9	318.2	53	40.3
193	8th floor	185.7	151.0	51	42.4

Table. 14 Responses in beam for 27 m high building in zone II

Beam No.	Location	Shear force (kN)		Bending moment (kNm)	
		ESM	RSM	ESM	RSM
101	1st floor	63	54.1	62	−49.45
106	2nd floor	67	56.4	67	−52.67
111	3rd floor	67	55.4	67	−51.10
116	4th floor	66	53.8	67	−48.56
121	5th floor	64	51.8	63	−45.55
126	6th floor	60	49.4	58	−41.87
131	7th floor	55	46.2	44	−37.06
136	8th floor	50	42.4	41	−31.39
141	9th floor	39	38.6	28	−24.16

Table. 15 Nodal displacements for 27 m high building in zone II

Node No.	Location	Nodal displacement (mm)	
		ESM	RSM
68	1st floor	1.8	1.35
74	2nd floor	4.69	3.30
80	3rd floor	7.59	5.23
86	4th floor	10.46	7.00
92	5th floor	13.18	8.59
98	6th floor	15.66	9.96
104	7th floor	17.78	11.08
110	8th floor	19.40	11.90
116	9th floor	20.43	12.40

The values of shear forces and bending moments obtained by ESM were 3–20% and 3–30% higher, respectively (Table 14).

Nodal displacements

The nodal displacement values were found to be 25–39% higher in case of ESM (Table 15).

6.6 *27 m High Building in Zone V*

Responses for columns

The values of axial forces and bending moments obtained by ESM were 3–24% and 22–39% higher, respectively, than those obtained from RSM (Table 16).

Table. 16 Responses in column for 27 m high building in zone V

Column No.	Location	Axial force (kN)		Bending moment (kNm)	
		ESM	RSM	ESM	RSM
145	Ground level	2248.2	1692.2	185.7	143.9
151	1st floor	1551.6	1495.1	187.8	135.1
157	2nd floor	1520.8	1289.3	190.7	131.2
163	3rd floor	1457.2	1084.8	195.4	124.7
169	4th floor	1121.4	883.5	180.2	116.8
175	5th floor	795.8	687.0	176.1	107.8
181	6th floor	597.7	497.4	155.2	95.8
187	7th floor	399.2	318.5	124.5	77.7
193	8th floor	190.1	151.2	91.7	62.7

Table. 17 Responses in beam for 27 m high building in zone V

Beam No.	Location	Shear force (kN)		Bending moment (kNm)	
		ESM	RSM	ESM	RSM
101	1st floor	140.5	109.0	172	−132.1
106	2nd floor	155.4	115.6	200	−142.8
111	3rd floor	155.9	112.6	200	−136.6
116	4th floor	151.7	106.4	194	−126.9
121	5th floor	143.7	99.0	182	−115.7
126	6th floor	130.5	90.0	162	−102.1
131	7th floor	111.9	78.3	134	−84.6
136	8th floor	88.6	64.4	99	−63.5
141	9th floor	60.4	48.2	52	39.9

Responses for beams

In case of beam, the values of shear force and bending moments obtained by ESM were 20–31% and 23–37% higher, respectively (Table 17).

Nodal displacements

The nodal displacement values obtained by ESM were 28–40% higher than those obtained by RSM (Table 18).

Table. 18 Nodal displacements for 27 m high building in zone V

Node No.	Location	Nodal displacement (mm)	
		ESM	RSM
68	1st floor	6.79	4.85
74	2nd floor	16.88	11.89
80	3rd floor	27.35	18.82
86	4th floor	37.65	25.23
92	5th floor	47.46	30.94
98	6th floor	56.39	35.87
104	7th floor	64.02	39.89
110	8th floor	69.86	42.85
116	9th floor	73.52	44.68

6.7 Observations from Manual Calculations

We considered a G + 4 building situated in seismic zone V and applied ESM and RSM to it separately. In the comparative analysis of member responses of a critical frame, the following results were observed:

1. The values of axial forces in columns are 5–12% higher, and bending moments are 15–30% higher for ESM than those obtained from RSM.
2. The shear forces in beams are 6–12% higher and bending moments are 18–25% higher in case of ESM than those obtained from RSM.
3. Nodal displacements are found to be 20–30% higher in case of ESM than those obtained from RSM.

7 Conclusion

- For 12 m high building, in Seismic Zone II and V, both ESM and RSM give almost the same values of axial forces in columns. However, RSM gives higher values of bending moments in columns than ESM in both the zones. Similarly, shear forces and bending moments in beams and nodal displacements are found to be higher in case of RSM in both the zones.
- For 18 m high building, in Seismic Zone II, no change is observed in the values of axial forces for columns obtained from both the methods. But, in Seismic Zone V, the axial forces in columns are found to be marginally higher in case of ESM than those obtained from RSM. Moreover, bending moments in columns and beams, shear forces in beams and nodal displacements are found to be higher from ESM than those obtained from RSM in both the Seismic Zones.
- For 27 m high building, all the responses of beams and columns and nodal displacements are found to be higher in case ESM in both the Seismic Zones.

- From our comparative analysis it can be concluded that RSM gives higher values of responses for low rise buildings, while ESM gives higher value of responses for high rise buildings.
- Hence, ESM is more economical in case of low-rise buildings and for high rise buildings RSM is found to be more cost effective.

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