Seismic Analysis of High-Rise Building by Response Spectrum Method

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Abstract
This paper describes seismic analysis of high-rise building using program in STAADPro. with various conditions of lateral stiffness system. Some models are prepared that is bare frame, brace frame and shear wall frame. Analysis is done with response spectrum method. This analysis will produce the effect of higher modes of vibration & actual distribution of forces in elastic range in a better way. Test results including base shear, story drift and story deflections are presented and get effective lateral load resisting system.

Keywords: High-rise building, response spectrum method, seismic analysis, story deflection, time period, lateral load resisting system, storey drift

I. Introduction
A large portion of India is susceptible to damaging levels of seismic hazards. Hence, it is necessary to take in to account the seismic load for the design of high-rise structure. The different lateral load resisting systems used in high-rise building are: 1.Bare frame 2.Brace frame 3.Shear wall frame. In tall building the lateral loads due to earthquake are a matter of concern. These lateral forces can produce critical stresses in the structure, induce undesirable stresses in the structure, induce undesirable vibrations or cause excessive lateral sway of the structure.

Sway or drift is the magnitude of the lateral displacement at the top of the building relative to its base.Traditionally, seismic design approaches are stated, as the structure should be able to ensure the minor and frequent shaking intensity without sustaining any damage, thus leaving the structure serviceable after the event. The structure should withstand moderate level of earthquake ground motion without structural damage, but possibly with some structural as well as non-structural damage. This limit state may correspond to earthquake intensity equal to the strongest either experienced or forecast at the site.In present study the effect of bare frame, brace frame and shear wall frame is studied under the earthquake loading. The results are studied for response spectrum method. The main parameters considered in this study to compare the seismic performance of different models are storey drift, base shear, story deflection and time period.

2. Objective Of Studies
[1] To analyze the building as per code IS 1893-2002 part I criteria for earthquake resistant structure.
[2] Dynamic analysis of the building using response spectrum method
[3] Building with different lateral stiffness systems
[4] To get economical and efficient lateral stiffness system

2.1 Response Spectrum Method
The response spectrum represents an envelope of upper bound responses, based on several different ground motion records. For the purpose of seismic analysis, the design spectrum given in figure 1 of IS: 1893 (Part 1): 2002 is used. This spectrum is based on strong motion records of eight Indian earthquakes.This method is an elastic dynamic analysis approach that relies on the assumption that dynamic response of the structure may be found by considering the independent response of each natural mode of vibration and then combining the response of each in same way. This is advantageous in the fact that generally only few of the lowest modes of vibration have significance while calculating moments, shear and deflections at different levels of the building.
Following procedure is generally used for the spectrum analysis:

[1] Select the design spectrum.
[2] Determine the mode shapes and periods of vibration to be included in the analysis.
[3] Read the level of response from the spectrum for the period of each of the modes considered.

[4] Calculate participation of each mode corresponding to the single-degree-of-freedom response read from the curve.
[5] Add the effect of modes to obtain combined maximum response.
[6] Convert the combined maximum response into shears and moments for use in design of the structure. Analyze the building for the resulting moments and shears in the same manner as the static loads.In this method, natural frequencies and mode shapes are to be obtained by a free vibration analysis. The design lateral force at each floor level in each mode of vibration is given by the equation. The peak shear force acting in storey i in mode k is given by the equation.

$$Q_i = A_k \theta_{ik} P_k W_i$$

$$P_k = \frac{\sum_{i=1}^{n} W_i \theta_{ik}}{\sum_{i=1}^{n} W_i (\theta_{ik})^2}$$

The peak storey shear force in storey i due to all modes considered is obtained by combining those due to each mode in accordance with using SRSS combination given by equation. So the lateral force at each storey due to all modes considered is calculated by the equation

$F_{roof} = V_{roof}$

$F_i = V_i – V_{i+1}$

In response spectrum method the peak response of the structure is calculated from model combination, where the following two methods can be used.

a) Square Root of Sum of Square (SRSS) Method

$$\lambda = \sqrt{\sum_{k=1}^{r} (\lambda_k)^2}$$

where, λ_k = Absolute value of quantity in mode k

r = Number of modes being considered.

b) Complete Quadratic Combination Method:

$$\lambda = \sum_{i-1}^{r} \sum_{j-1}^{r} \lambda_1 P_1 \lambda_j$$

where, λ_i = Response quantity in mode

P_{ij} = Cross modal coefficient

λj = Response quantity in mode j

P_j = Cross-modal coefficient

$$\frac{8}{(1-\beta^2)^2 + 4}$$

where, ξ = Modal damping ratio in fraction

β = Frequency ratio = $\omega j/\omega i$

ωi = Circular Frequency in i^{th} mode

ωj = Circular frequency in j^{th} mode

2.2 Response Spectrum Method by using StaadPro

This is accurate method of analysis. The design lateral force at each floor in each mode is computed by STAADPro in accordance with IS: 1893 (Part 1)-2002. The software provides result for design values, modal masses and storey wise base shear. Response Spectrum data specification is shown in figure 1.

Methodology: The design lateral shear force at each floor in each mode is computed by STAAD in accordance with the IS: 1893 (Part 1) -2002 following equation.

$\mathbf{Q_{ik} = A_k * f_{ik} * P_k * W_k}$ **and** $\mathbf{V_{ik} = Q_{ik}}$

STAAD utilizes the following procedure to generate the lateral seismic loads.

[1] User provides the value for $\frac{Z}{2} \times \frac{I}{R}$ as factors for input spectrum.
[2] Program calculates time periods for first six modes or as specified by the user.

[3] Program calculates Sa/g for each mode utilizing time period and damping for each mode.
[4] The program calculates design horizontal acceleration spectrum A_k for different modes.
[5] The program then calculates mode participation factor for different modes.
[6] The peak lateral seismic force at each floor in each mode is calculated.
[7] All response quantities for each mode are calculated.
[8] The peak response quantities are then combined as per method (CQC or SRSS or ABS or TEN or CSM) as defined by the user to get the final results.

3. Analysis of Building With Response Spectrum Method

Seismic Analysis of high-rise building having following data is analyzed for different models of lateral load resisting systems. Typical plan is shown in figure 2. Analysis is

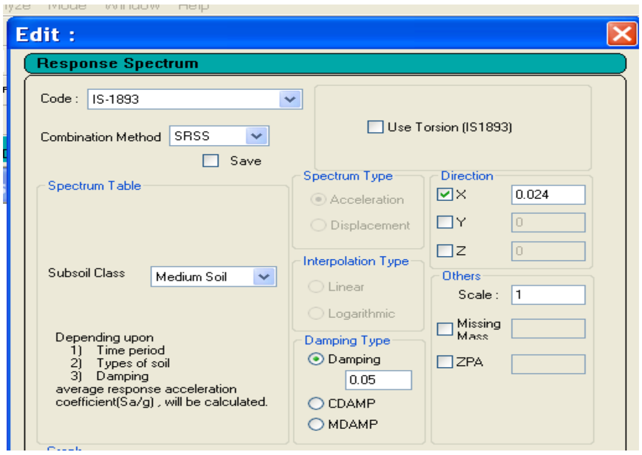

Figure:1 Response Spectrum data specification

done by taking into account the data form STAADpro. Space frame model is prepared. Member Properties are column size up to 6th storey 0.45 X 0.60m, column size above 6th storey 0.30 X 0.45m, beam size 0.23 X 0.30m, shear wall 0.2m, concrete bracing 0.23 X 0.23m, thickness of slab 0.1m. Loads considered are floor load, wall load, live load and earthquake load. The grade of concrete is M_{20} & steel used is Fe_{415}.
The parametric study for following mentioned models is carried.

[1] Bare frame
[2] Brace frame

Case 1 Bracing at location A in plan- Bracing is centrally located at exterior frame of Z direction through out height.
Case 2 Bracing at location B in plan- Bracing is centrally located at exterior frame of X direction through out height.
Case 3 Bracing at location A and B in plan- Bracing is centrally located at exterior frame of both X and Z direction through out height.
Case 4 Bracing at location C in plan- Bracing is located at exterior frame end corners of both X and Z direction through out height.

3.1 Shear wall frame

Case 1 Shear wall at location A in plan- Shear wall is centrally located at exterior frame of Z direction through out height.
Case 2 Shear wall at location B in plan- Shear wall is centrally located at exterior frame of X direction through out height.
Case 3 Shear wall at location A and B in plan- Shear wall is centrally located at exterior frame of both X and Z direction through out height.
Case 4 Shear wall at location C in plan- Shear wall is located at exterior frame end corners of both X and Z direction through out height.

For present work response spectrum method as per IS:1893-2002 is carried out for reinforced concrete moment resisting frame having (G+14) storey situated in zone IV. The floor to floor height of the building is 3m. The total height of building is 45m.
Load combinations considered in this analysis are

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1) 1.5(DL+LL)
2) 1.2(DL+LL+EQX)
3) 1.2(DL+LL-EQX)
4) 1.2(DL+LL+EQZ)
5) 1.2(DL+LL-EQZ)
6) DL+1.5EQX
7) DL-1.5EQX
8) DL+1.5EQZ
9) DL-1.5EQZ

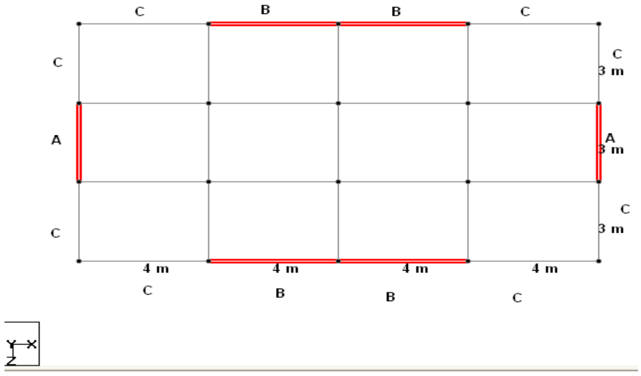

Figure 2 Plan of building showing location of braced frame & shear wall frame

Design Parameters: The design spectrum used is of medium soil as per IS 1893 Part I (2002). A response spectrum is shown in figure 3.

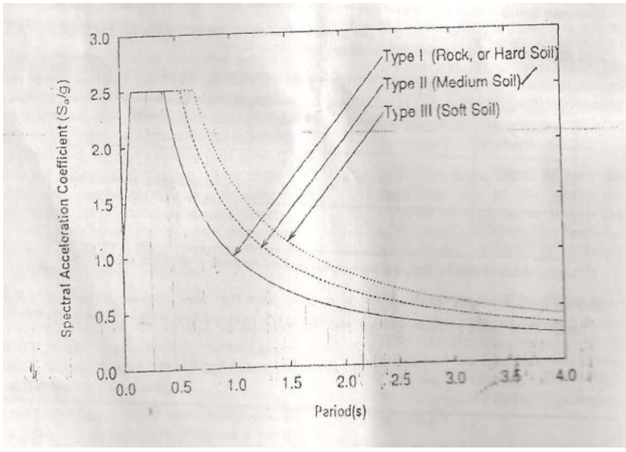

Figure 3 Response spectrum for soil as per IS 1893 Part I (2002)

4. Result and Discussion

The variation of storey drift, base shear, story deflection and time period is evaluated for all these models and compared with response spectrum method.

4.1 Variation of base shear, story deflection, storey drift and time period

The parametric study to know base shear, story deflection, storey drift & time period in case of all models is performed here. The results are shown in table I to IV & in graph 1 to 4 which are listed below. From Table I and graph 1, it is observed that base shear minimum for case 2 and 3 in both brace frame and shear wall frame. From Table II and graph 2, time period is also less for case 2 and 3 in both brace frame and shear wall frame. As base shear increases time period of models decreases and vise versa. Building with short time period tends to suffer higher accelerations but smaller displacement. Therefore, from table III & IV, graph 3 & 4 story deflections is also minimum for case 2 and 3 in both brace frame and shear wall frame. Story drift i.e. top story displacement is also reduced for case 2 and 3 in both brace frame and shear wall frame.

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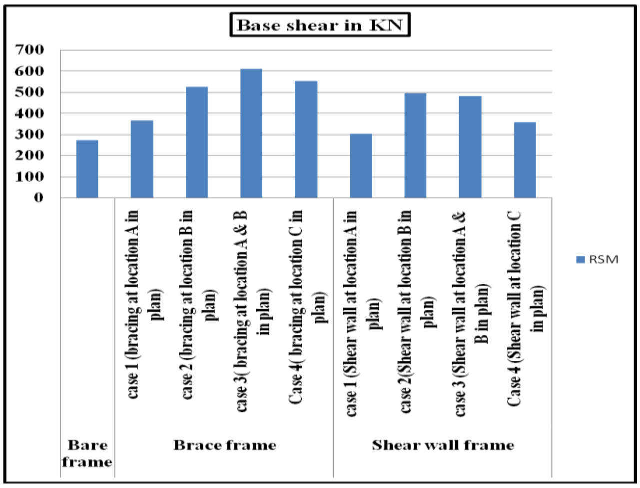
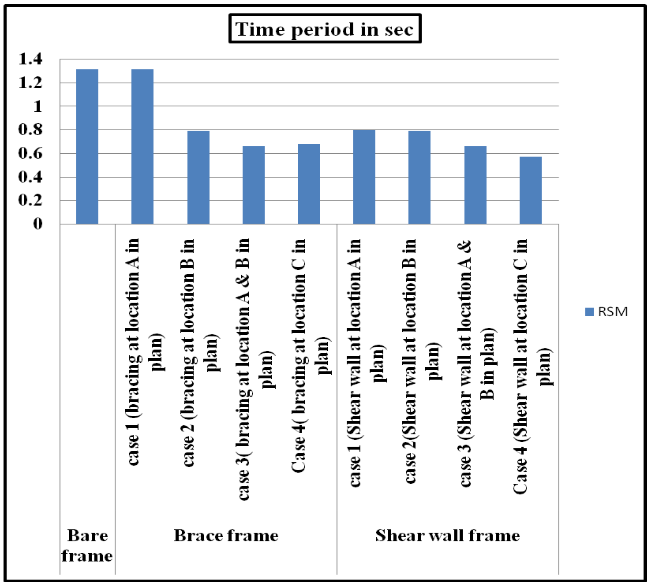
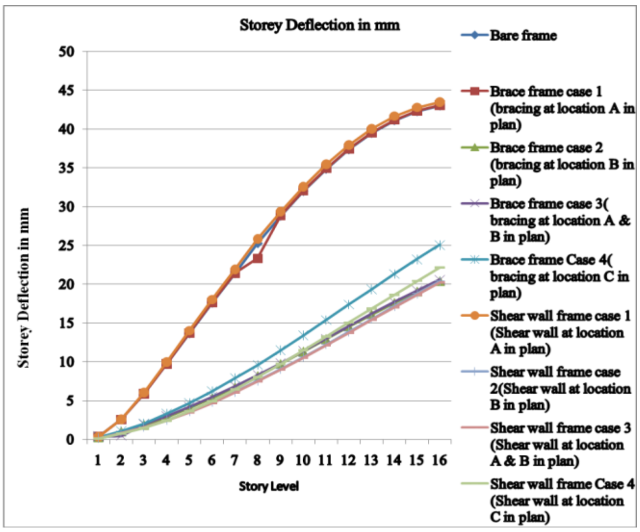


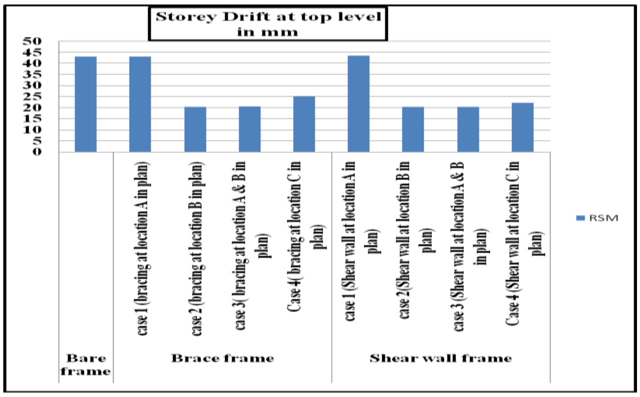
Graph 1 Design Base Shear in KN



Graph 2 Time period in sec



Graph 3 Storey deflection in mm



Graph 4 Storey drift in mm

Method	Bare frame	Brace frame				Shear wall frame			
		case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
RSM	272.5	366.92	527.2	612.9	553.9	304.05	495.4	482.9	358

Table I Design Base Shear in KN

Method	Bare frame	Brace frame				Shear wall frame			
		case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at locatio n C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
RSM	1.315	1.319	0.794	0.66	0.68	0.8	0.79	0.66	0.57

Table II Time Period in sec

Story Level	Bare frame	Brace frame				Shear wall frame			
		case 1 (bracing at location A in plan)	**case 2 (bracing at location B in plan)**	**case 3(bracing at location A & B in plan)**	**Case 4(bracing at location C in plan)**	**case 1 (Shear wall at location A in plan)**	**case 2(Shear wall at location B in plan)**	**case 3 (Shear wall at location A & B in plan)**	**Case 4 (Shear wall at location C in plan)**
1	0.34	0.34	0.23	0.39	0.3	0.35	0.14	0.14	0.09
2	2.55	2.56	1	0.48	1.06	2.63	0.87	0.87	0.7
3	5.88	5.9	1.85	1.98	2.05	6.06	1.58	1.57	1.44
4	9.69	9.73	2.87	3.03	3.32	9.99	2.48	2.45	2.42
5	13.65	13.71	4.04	4.21	4.71	14.05	3.55	3.51	3.6
6	17.58	17.64	5.32	5.49	6.24	18.05	4.77	4.72	4.95
7	21.38	21.46	6.68	6.85	7.86	21.92	6.11	6.05	6.44

8	25.26	23.35	8.16	8.3	9.61	25.85	7.55	7.48	8.05
9	28.79	28.89	9.71	9.82	11.47	29.4	9.07	8.99	9.74
10	31.98	32.09	11.31	11.4	13.4	32.61	10.64	10.55	11.49
11	34.84	34.96	12.92	13	15.39	35.48	12.25	12.15	13.28
12	37.34	37.47	14.52	14.6	17.38	37.98	13.88	13.76	15.08
13	39.45	39.58	16.09	16.18	19.37	40.06	15.51	15.39	16.88
14	41.09	41.23	17.58	17.71	21.33	41.69	17.15	17.02	18.68
15	42.25	42.39	19.04	19.2	23.23	42.82	18.78	18.64	20.46
16	42.99	43.12	**20.38**	**20.6**	25.09	43.51	**20.38**	20.23	**22.19**

Table III Storey deflection in mm

Method	**Bare frame**	**Brace frame**				**Shear wall frame**			
		case 1 (bracing at location A in plan)	case 2 (bracing at location B in plan)	case 3(bracing at location A & B in plan)	Case 4(bracing at location C in plan)	case 1 (Shear wall at location A in plan)	case 2(Shear wall at location B in plan)	case 3 (Shear wall at location A & B in plan)	Case 4 (Shear wall at location C in plan)
RSM	42.99	43.12	20.38	**20.6**	25.09	43.51	**20.38**	20.23	22.19

Table IV Storey drift (Top storey displacement) in mm

5. Conclusions

- A significant amount of decrease in story drift has been observed in case 2 and 3 i.e. lateral stiffness system is centrally located at exterior frame of X direction through out height and lateral stiffness system is centrally located at exterior frame of X & Z direction through out height in both brace frame and shear wall frame compared to other models. Also shear wall models in case 3 gives less storey deflection and storey drift than bare frame and brace frame.
- A significant amount of decrease in time period of model in case 2 and 3 i.e. lateral stiffness system is centrally located at exterior frame of X direction through out height and lateral stiffness system is centrally located at exterior frame of X & Z direction through out height in both brace frame and shear wall frame compared to other models, therefore displacements in the structure are minimized.
- Building with short time period tends to suffer higher accelerations but smaller displacement.
- Comparing the top storey drift in the longitudinal direction, it can be seen that it decrease by 52.59%, 52.08% & 41.63% in case 2, 3 and 4 of brace frame as compared to bare frame and it decreases by 52.59%, 52.94 & 48.38% in case 2, 3 and 4 of shear wall frame as compared to bare frame. The models with shear wall located at exterior frame of X & Z direction through out height is found most effective in resisting lateral loads because it shows least deflection as compare with other models.
- A significant amount of increase in the lateral stiffness has been observed in all models of brace frame and shear wall frame as compared to bare frame.
- More accurate values of response may be obtained for buildings by the modal analysis method, using modified design response spectra for inelastic analysis.

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