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A Study of the Various Structural Framing Systems Subjected to Seismic Loads

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Abstract:
The objective of this study is to investigate the seismic behavior of the structure having various structural configurations like OMRCF (Ordinary Moment Resisting Concrete Frames), SMRCF (Special Moment Resisting Frames) and BSF (Braced Steel Frames). A comparative study of all the types of frames will shed light on the best suited frame to be adopted for seismic loads in Indian scenario. For this purpose, a G+4 building was designed for OMRCF, SMRCF and BSF framing configurations in Seismic Zone V according to Indian codes. Tests were carried out to evaluate their structural efficiencies in terms of storey drifts, Base shear, amount of reinforcement etc. Moment frames have been widely used for seismic resisting systems due to their superior deformation and energy dissipation capacities. A moment frame consists of beams and columns, which are rigidly connected. The components of a moment frame should resist both gravity and lateral load. Lateral forces are distributed according to the flexural rigidity of each component.

Keyword: OMRF, SMRF, BSF, Seismic behavior, Seismic Design, Earthquake, STAAD.Pro

Introduction:

The selection of a particular type of framing system depends upon two important parameters i.e. Seismic risk of the zone and the budget. The lateral forces acting on any structure are distributed according to the flexural rigidity of individual components. Indian Codes divide the entire country into four seismic zones (II, III, IV & V) depending on the seismic risks. OMRCF is probably the most commonly adopted type of frame in lower seismic zones. However with increase in the seismic risks, it becomes insufficient and SMRCF or Steel Brace frames need to be adopted.

A rigid frame in structural engineering is the load-resisting skeleton constructed with straight or curved members interconnected by mostly rigid connections which resist movements induced at the joints of members. Its members can take bending moment, shear, and axial loads. They are of two types: Rigid-framed Structures & Braced-frames Structures The two common assumptions as to the behavior of a building frame are that its beams are free to rotate at their connections and that its members are so connected that the angles they make with each other do not change under load.

Moment-resisting frames are rectilinear assemblages of beams and columns, with the beams rigidly connected to the columns. Resistance to lateral forces is provided primarily by rigid frame action-that is, by the development of bending moment and shear force in the frame members and joints. Frames may be designed using concept of strong column-weak girder proportions. There are two types of MRF: OMRF and SMRF. Ordinary Moment Resisting Frame (OMRF) is a moment-resisting frame not meeting special detailing requirements for ductile behavior. Special Moment Resisting Frame (SMRF) is a moment-resisting frame specially detailed to provide ductile behavior and comply with the requirements given in IS-4326 or IS-13920 or SP6.

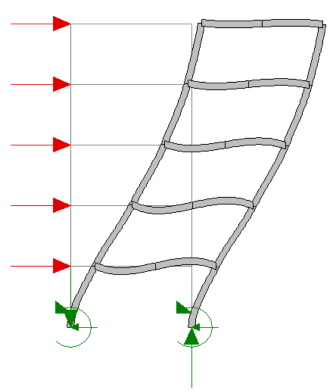


Fig. 1 – Deformation of Moment Resisting Frames

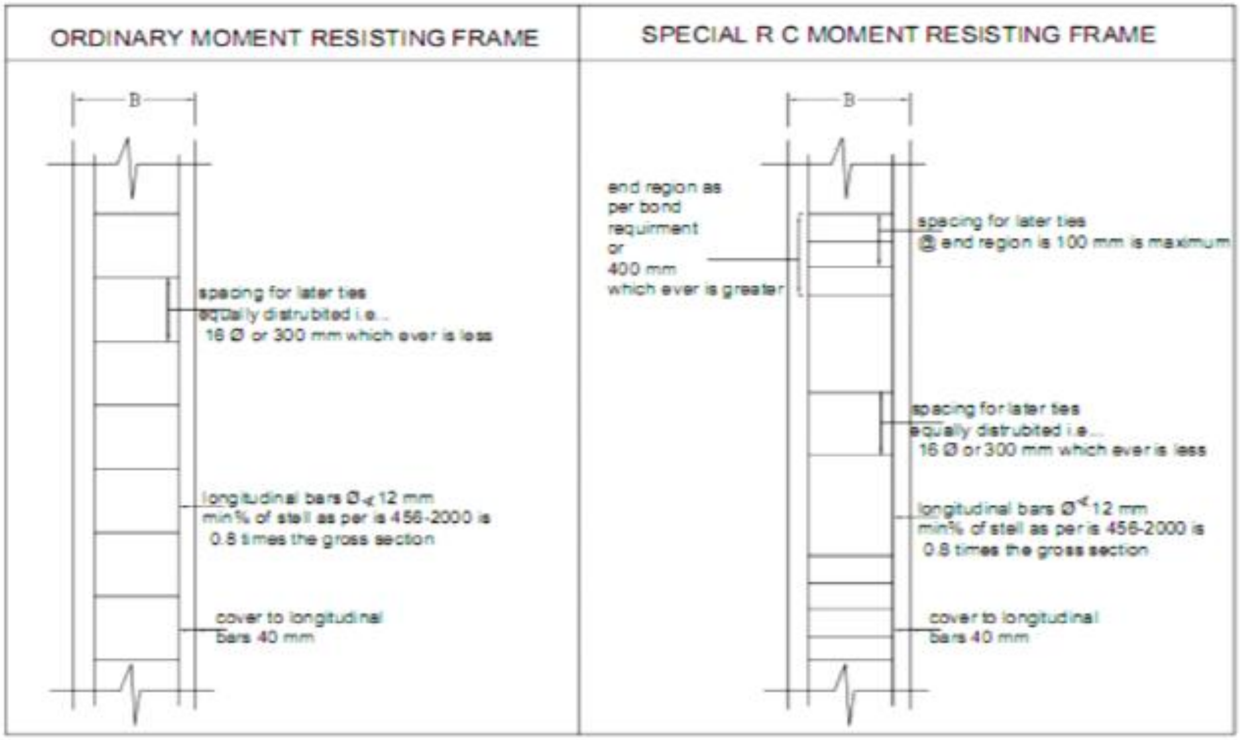


Fig. 2 – Minimum column reinforcement according to IS-456:2000 in OMRCF & SMRCF

The main aims of the present study are as follows:

- ❖ To model 3 structures for analyzing multistoried frames having OMRCF, SMRCF & BSF configurations.
- ❖ To carry out the analysis and design of the selected buildings in Seismic zone V.
- ❖ To make a comparative study of the storey drifts and Base shear for these frames.
- ❖ To provide structural engineers with a guideline on the economy aspect that could be obtained using Base Isolation.

Codes used for design are:

- o RCC Design - IS 456:2000
- o Steel Design - IS 800:2007
- o Loads for Steel Design - IS:875 (Part 1&2)
- o Seismic Design - IS 1893:2000 (Part 1)
- o Wind Loads – ASCE 7

The building frames are modeled in STAAD.Pro and the average displacement, beam stresses, slab stresses, storey drift and base shear are analyzed to give a comparative result in between the different framing systems.

Seismic Map of India:

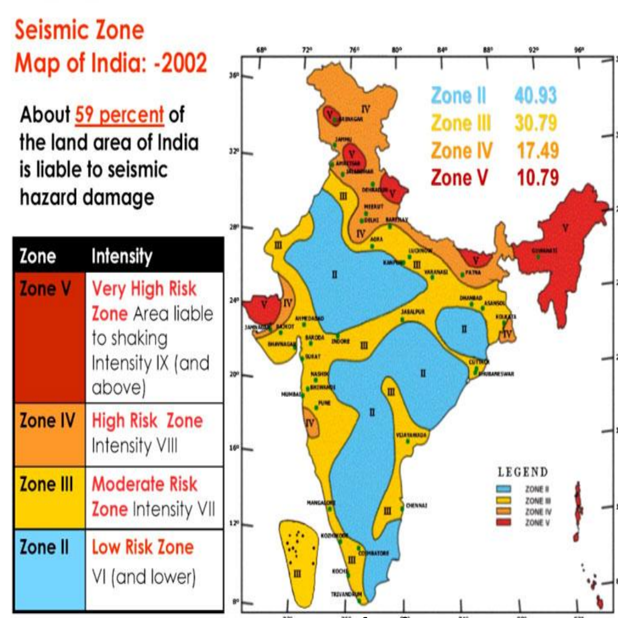


Fig.3 – Seismic Zones of India

Based on the levels of intensities sustained during past earthquakes, the zone map divided India into 5 zones in 1970 which was later revised in 2002 to 4 zones i.e. Zones II, III, IV & V. The areas under seismic zone I of the 1970 version of the zone map were merged with the areas of zone II.

Earthquake Design Philosophy:

The severity of ground shaking at any particular location during the event of an earthquake can be categorized as *minor, moderate and major*. The aim of the designers is to construct a structure that may resist even the major earthquake shaking. It is very rare and may occur only about once in 500 or 1000 years. Thus it warrants the question *Should we design the buildings as Earthquake-proof or Earthquake-resistant?* The common practice is to make the structures earthquake-resistant. These structures may get damaged during the event of an earthquake but still would not collapse. Thus, safety of people & commodities is assured and it is achieved in lesser investment when compared to Earthquake-proof structures.

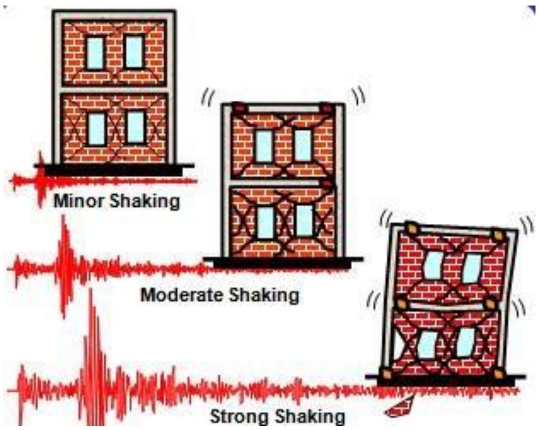


Fig. 4 – Effect on buildings due to ground shaking

The Earthquake Design Philosophy (EDP) can be summarized as follows:

- During the event of minor shaking, the main members of a structure that carry the vertical and horizontal forces should not get damaged. However the members of the structure which do not carry any loads can sustain repairable damages.
- During the event of moderate shaking, the main members of a structure may sustain repairable damages. Other non-load carrying members may get severely damaged and may even need to be replaced.
- During the event of severe shaking, the main members may sustain severe, sometimes irreparable damages but the building should not collapse completely guarantying the safety of the inhabitants of the building.

Modeling in STAAD.Pro:

The following conditions were selected before starting the modeling process:

- Only the main block of the building is considered. The staircases are not considered in the design procedure.
- The building is to be used for exhibitions and so no interior walls are provided.
- Only external walls 230 mm thick with 12 mm plaster on each side are considered.
- At ground floor, slabs are not provided and the floor is resting directly on the ground.

  The beam beams are resting centrally on the columns so as to avoid the conditions of eccentricity.

  For all structural elements, M30 & Fe500 are used.

  The footings are not designed. Supports are assigned in the form of fixed supports.

  Sizes of the members are as follows: (in mm)

Property	Concrete MRF	Braced Steel Frames
Columns	500 x 500	ISWB 600
Beams	500 x 300	ISMB 500
Slabs	20	20
Braces	-	ISMB 250

- Seismic loads are considered in the horizontal direction only and the vertical direction are assumed to be insignificant.
- The buildings are to be designed for the following conditions:
  Live load = 4 KN/m^2 (Typical floor); 1.5 KN/m^2 (Roof)
  Dead load of walls on beams = 4.9 KN/m^2
  Location = Seismic Zone V
  Wind Load = As per ASCE 7
  Seismic Load = As per IS-1893
  (Not designed as Earthquake loads are greater)
  Soil type = Soft; as per IS-1893(Part 1):2002
  Floors = G+4
  Floor height = 4 m

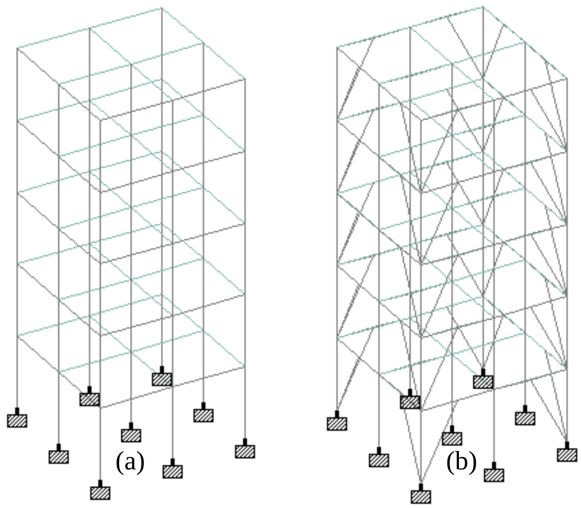


Fig. 5 – (a) Concrete Building with OMRF/SMRF,
(b) Steel Building with Braced frames

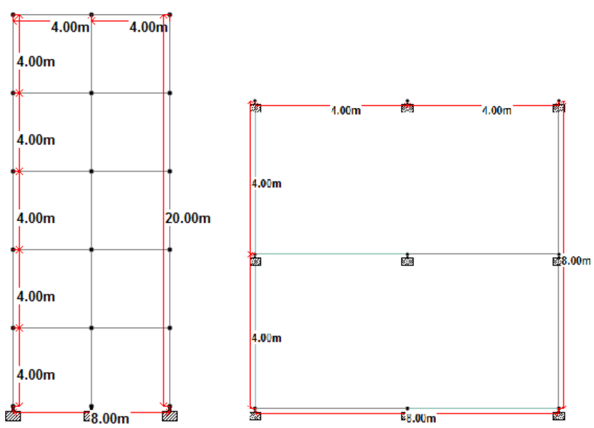


Fig. 6 – Plan & Elevation of the model

Analysis:

The following load combinations are considered during the analysis of the model:

- 1.5 DL + 1.5 LL
- 1.2 DL + 1.2 LL + 1.2 EQX
- 1.2 DL + 1.2 LL + 1.2 EQZ
- 1.2 DL + 1.2 LL + 1.2 WLX
- 1.2 DL + 1.2 LL + 1.2 WLZ
- 1.2 DL + 1.2 LL - 1.2 EQX
- 1.2 DL + 1.2 LL - 1.2 EQZ
- 1.2 DL + 1.2 LL - 1.2 WLX
- 1.2 DL + 1.2 LL - 1.2 WLZ

For asserting the simplest yet reliable method for analysis, the combined action of DL, LL & EQ forces are considered i.e. 1.2 DL + 1.2 LL + 1.2 EQX.

The structure with different framing system has been modeled using STAAD.PRO software with the above mentioned load conditions and combinations. The analysis is done for:

a) Ordinary Moment Resisting Concrete Frame
b) Special Moment Resisting Concrete Frame
c) Braced Steel Frame

Slabs are added in the form of 4-noded plates and the entire slab is divided into 4 segments (supported on beams on all four sides).

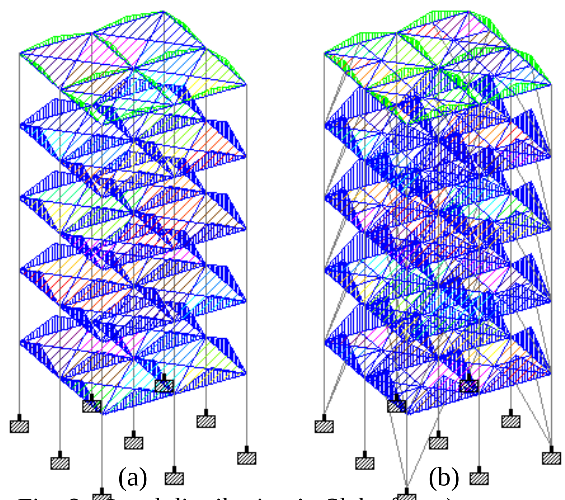


Fig. 6 – Load distribution in Slabs for: a) OMRF/SMRF & b) Braced Frames

Results & Discussions:

The behavior of all the three framing systems is taken as a basic study on the modeled structure. The lateral drift/deflection ratio is checked against the clause 7.11.1 of IS-1893:2002 i.e. under transient seismic loads.

The following parameters were considered to present a comparison between the different frames:

a) Materials used

b) Maximum Nodal Deflection

c) Maximum Beam Shear & Moments

d) Maximum Plate Stresses

e) Storey Drift

f) Average storey displacement

Volume	OMRCF	SMRCF	BSF
Concrete (m^3)	16.800	16.800	NIL
Steel (KN)	8.312	9.821	505.126

Table 1 – Comparison of materials used

Using the above data, it can be stated that the percentage of steel in concrete frames varies as follows:

OMRCF= Taking as Base
SMRCF = Increase of 18.15 %

Deflection	OMRCF	SMRCF	BSF
Max. X (mm)	30.178	18.108	4.774
Min. X (mm)	0.000	0.000	0.000
Max. Y (mm)	0.000	0.000	0.000
Min. Y (mm)	-2.728	-2.450	-2.526
Max. Z (mm)	0.005	0.004	0.020
Min. Z (mm)	-0.005	-0.004	-0.020

Table 2 – Comparison of Nodal deflections

Parameter	OMRCF	SMRCF	BSF
Max. Fx (KN)	1407.323	1255.778	809.713
Min. Fx (KN)	-4.586	-3.223	-36.251
Max. Fy (KN)	98.410	67.184	54.708
Min. Fy (KN)	-117.111	-96.455	-59.010
Max. Fz (KN)	16.814	14.497	1.674
Min. Fz (KN)	-16.814	-14.497	-1.674
Max. Mx (KNm)	1.394	1.020	0.011
Min. Mx (KNm)	-1.394	-1.020	-0.011
Max. My (KNm)	33.960	29.090	3.376
Min. My (KNm)	-33.960	-29.090	-3.376
Max. Mz (KNm)	200.166	120.099	48.226
Min. Mz (KNm)	-193.475	-116.085	-42.392

Table 3 – Comparison of Beam Stresses & Moments

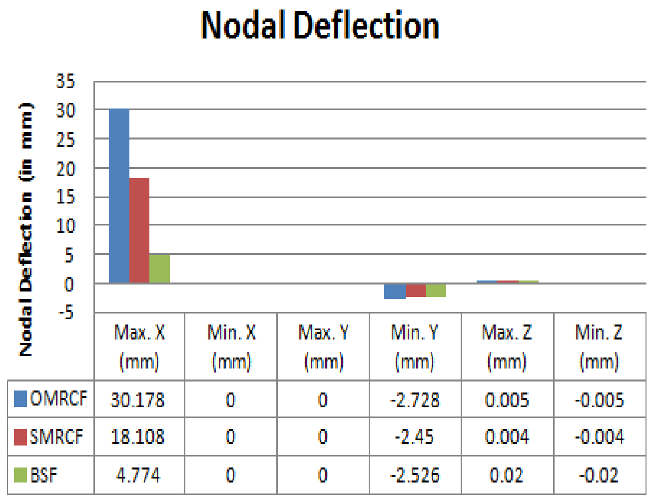
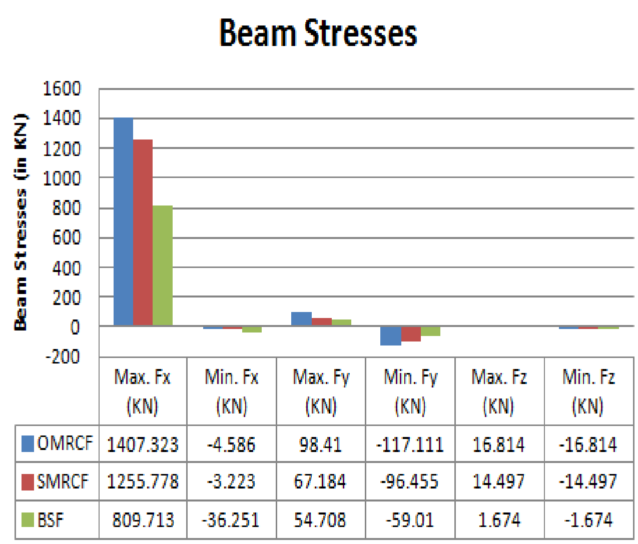


Fig. 7 – Deflection comparison of the different frames



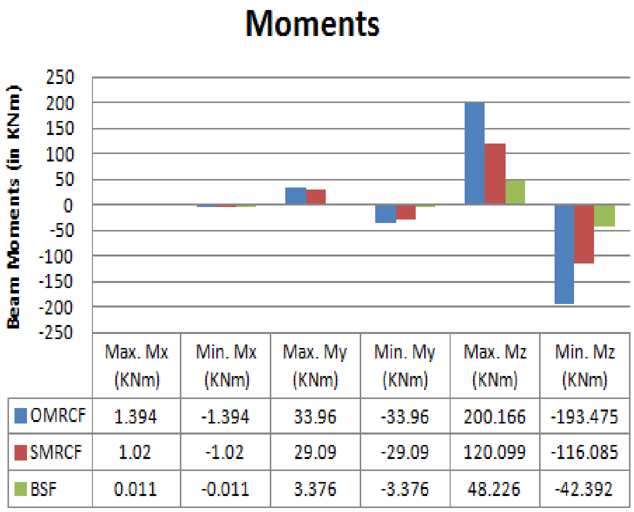


Fig. 9 – Comparison of beam moments in the models

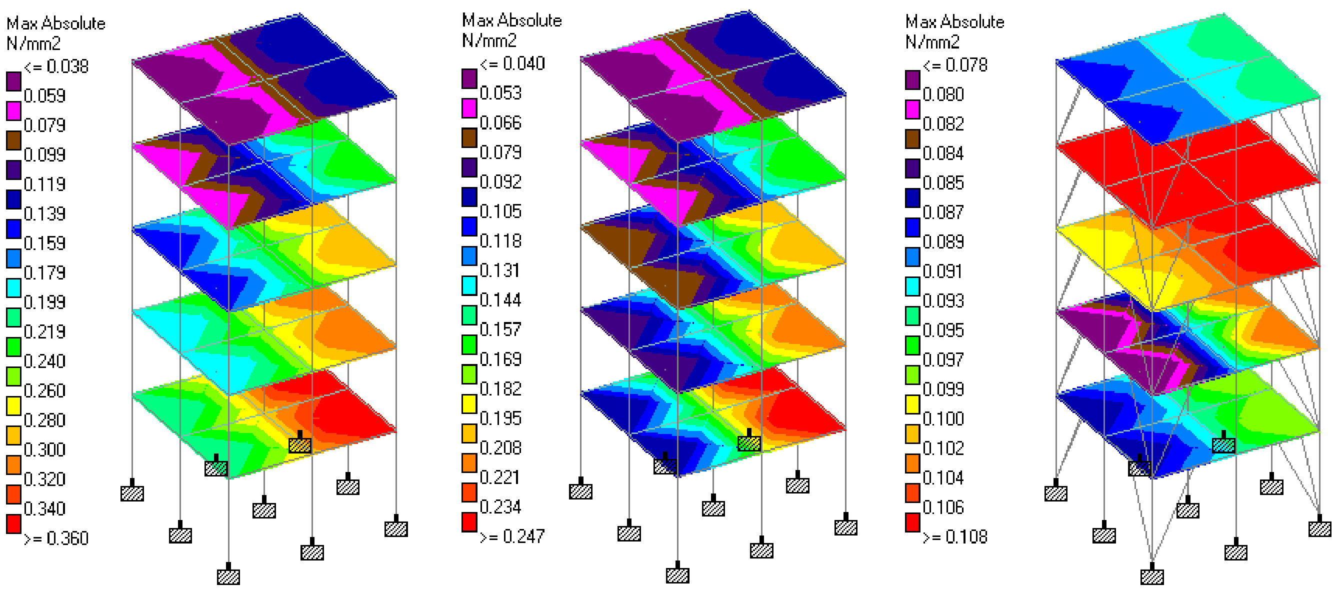


Fig. 10 – Plate Stresses due to acting load (1.2 DL + 1.2 LL + 1.2 EQX): (a) OMRCF, (b) SMRCF, & (c) BSF

Storey	Height (m)	OMRCF	SMRCF	BSF
G	0	0.0000	0.0000	0.0000
1	4	0.4464	0.2678	0.0645
2	8	1.0836	0.6502	0.1584
3	12	1.6949	1.0170	0.2525
4	16	2.1972	1.3183	0.3343
5	20	2.5146	1.5088	0.3933

Table 4 – Comparison of Average Displacement (in cm)

Storey	Height (m)	OMRCF	SMRCF	BSF
G	0	0.0000	0.0000	0.0000
1	4	0.4464	0.2678	0.0645
2	8	0.6372	0.3823	0.0939
3	12	0.6113	0.3668	0.0941
4	16	0.5022	0.3013	0.0818
5	20	0.3174	0.1905	0.0590

Table 5 – Comparison of Storey Drift (in cm)

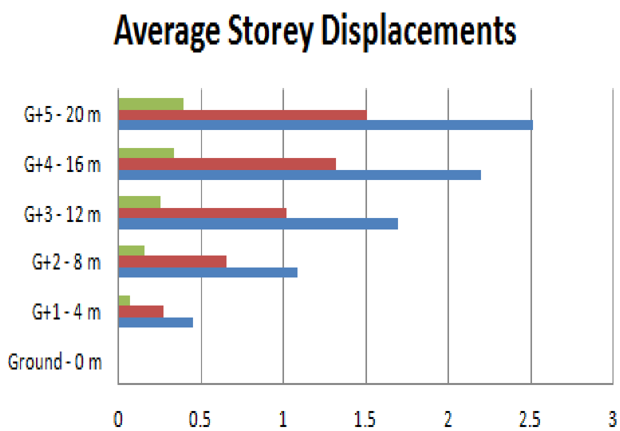


Fig. 11 – Average Displacement comparison

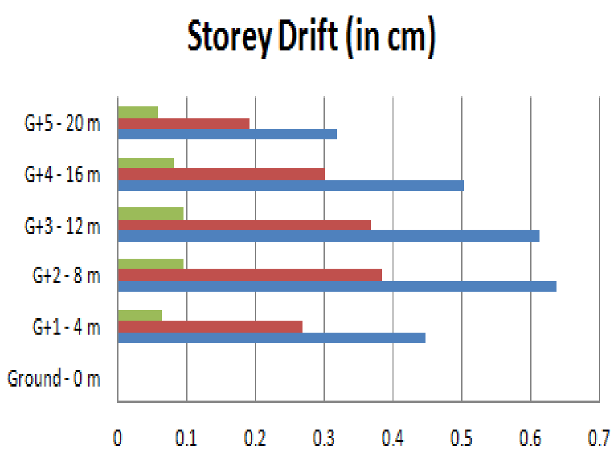


Fig. 12 – Storey Drift comparison of the different frames

Summary & Conclusions:

It is clear to all that the seismic hazard has to be carefully evaluated before the construction of important and high-rise structures. Based on the above analytical study carried out on 3 structures, the following deductions are made:

1. BSF clearly provides more safety to the designers but it proves to be extremely costly.

2. In all the systems, the storey drift is within the permissible limits as per IS:1893 (Part 1). However SMRCF showed better results when compared to OMRCF.

3. There is an increase of 18.5 % in the quantity of steel in case of SMRCF when compared to OMRCF. However this also results in a deduction of 66.12 % in the amount of storey drift in SMRCF.

4. The lateral loading is most effectively resisted in BSF. Thus the service life will be largest for this framing configuration.

5. Due to the falling of the zone, the earthquake hazard will also increase. In such cases, BSF or SMRF with shear walls are applicable.

6. Because of the presence of lateral braces, the stresses in columns are minimum in BSF.

7. The Response Reduction Factor plays an important role on the variation of cost.

8. Storey drifts are more in case of OMRCF & SMRCF. It is least in case of BSF.

9. To further increase the effectiveness of the structure, earthquake resisting techniques such as shear walls & base isolation can be used.

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