Seismic analysis of Reinforced concrete frames with stiffness irregularity

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Abstract. The earthquake occurs due to severe seismic in a particular region and causes devastation and havoc to human life. So, there is a need to assess vulnerability characteristics of the structures which are located in severe seismic regions. In this present work, seismic performance of stiffness irregular structure was studied by using the response spectrum method as per IS 1893 (Part 1) 2002. And the performance of structures with shear wall and bracings placed in the least lateral stiffness direction was studied. From the present study by comparing the seismic performance of the conventional structure and structure with shear wall/bracing it can be concluded that performance of RC frames with stiffness irregularity is more vulnerable than that of RC frames with shear wall/bracings in place. Also, RC frames with shear wall have reduced the seismic impact more than RC frames with bracings.

Keywords: R.C building; stiffness irregular frame, bracings, shear wall.

1. Introduction
Earthquake is a natural phenomenon which cannot be avoided and predicted but the damaged caused by an earthquake can be minimised by improving lateral force resistance of the structure through design and construction practices different from conventional methods. The failure of the structure begins at points of weakness in the structure. These weaker spots are may be due to irregularity/discontinuity in geometry, stiffness and mass of the structure. These irregular structures hold a large proportion of the urban infrastructure. Considerable difference in stiffness and mass from Storey to Storey makes the dynamic attributes of these structures not quite the same as the regular structure. According to IS 1893 (Part 1) 2002 [1] for regular structures of constrained height Linear static analysis can be used, as in this procedure, lateral forces are determined according to the code-based central timespan of the structure. The linear dynamic analysis gives more reliable results than that of direct static analysis, as dynamic analysis creates the higher modes vibrational impact and force distribution in a superior way. The present investigation focuses on seismic performance assessment of different RC frames with and without stiffness irregularity situated on hard soil and in Zone II utilizing Response Spectrum Method.

2. Literature Review
Rakshit Patil et al [2] concluded that in high rise structures by placing the shear wall at the centre core of the structure has reduced in storey drifts and displacements effectively. Cimellaro et al [3]
conducted bidirectional push over analysis (BPA) technique to evaluate the seismic reaction of irregular structures exposed to bidirectional ground motion. And it is concluded that BPA technique given better outcomes when contrasted with NTHA strategy and torsion issue can be overcome in irregular structures by exposing to bidirectional ground motion. Chatpan Chintanapakdee et al [4] have analysed the seismic requirements for vertically sporadic and conventional frames assessed by non-linear time history method. By utilizing strong column and soft Storey model structures with stiffness and strength irregularity were designed. Drift demands in upper stories are considerably more sensitive to irregularities in the lower stories than that of lower stories is influenced by irregularities in upper stories. Krishnan et al [5] studied different parameters such as Storey drift, Storey shear, deflection, in column reinforcement etc., of a structure subjected to lateral loading by changing the position of shear walls. Both linear and nonlinear analyses were carried out and the effect of shear wall position on different parameters was studied by carrying out both linear and non-linear analysis. In medium ascent structures arrangement of shear walls is seen as viable in improving the seismic capacity of the structure. Ravi Kumar et al [6] considered two kinds of irregularity (with geometry and diaphragm discontinuity) and three different lateral load patterns on the performance of various irregular buildings in pushover analysis. And concluded in pushover analysis the vertical distribution of lateral force as per IS code was found more detrimental in low rise models. Dhinam Basu et al [7] studied the application of super position-based analysis procedure to implement code-specified torsional specifications for flexible diaphragm floored structures. This was proven to be optimal for unsymmetrical buildings withand without orthogonality. Jack P Mohele et al [8] conducted an experimental and analytical investigation of the reaction to strong base movements of reinforced concrete structures having vertical irregularity. It was concluded inelastic static analyses were capable of accurately reproducing the measured envelope relations between top displacement and base shear. The investigation showed that that frame-wall interaction can be influenced altogether by inelastic part behaviour. The inelastic static and dynamic strategies were better in deciphering impacts of the structural discontinuities. Bhanu Sai Kumar et al [9] performed the Seismic fragility analysis of regular and setback RCC frames. Ponnada and Reddi [10] performed the Linear static analysis of multi-storey building with horizontally asymmetric architectures.

3. Objectives
The objectives of this study are
1. Seismic analysis of the stiffness irregular structures.
2. Evaluation of Storey displacement and inter Storey drift of the RC frames by conducting dynamic analysis using SAP 2000.
3. Performance assessment of RC frames after adopting different lateral force resisting systems.

4. Methodology
Step 1: Modelling using SAP 2000.
Step 2: Applying different load combinations.
Step 3: Analysing the frames by changing the position of soft Storey.
Step 4: Assessing Storey displacements and inter Storey drifts for all the cases and identifying the most vulnerable RC frame.
Step 5: Adopting different lateral load resisting systems to the most vulnerable frame and calculating Inter Storey drifts and Storey displacements.
Step 6: Comparison of the results and suggesting the effective lateral load resisting systems with minimum displacements and drifts.

5. Modelling
5.1 Details of the Building considered
For the present study ‘G+5’ (Ground+5 Storeys) building located in the seismic zone II and soil zone III (hard strata) are considered. The elevation and plan of the building considered is shown in figure 1.
Height of the Building = 24.7 m
Length of the Building = 16 m
Width of the Building = 16 m
Number of bays in X and Y directions = 4
Number of Storeys in Z-direction = G+5
Spacing of bays in X and Y directions = 4
Length of each bay = 4 m

Figure 1. Plan and Elevation of the Building

5.2 Details of Structural Elements considered
Dimensions of the beams and columns of the building frame considered as follows

| Structural Member | Section   | Dimensions   | Material   |
|-------------------|-----------|--------------|------------|
| Beam              | Rectangle | 300 × 230    | Concrete   |
| Column            | Rectangle | 450 × 300    | Concrete   |
| Bracing           | I-Section | ISMB 250     | Steel      |

5.3 Details of the Slab and Walls Considered as follows

|                         |             |
|-------------------------|-------------|
| Thickness of the Slab    | = 0.180m    |
| Thickness of the external wall | = 0.300m    |
| Thickness of the internal wall | = 0.150m    |
| Thickness of the parapet wall | = 0.100m    |
| Height of the parapet wall | = 1.0m      |

5.4 Loads Considered

|                         |             |
|-------------------------|-------------|
| Unit weight of the Brick masonry | = 20 kN/m³  |
| Unit weight of the reinforced cement concrete | = 25 kN/m³   |
| Live load - Soft Storey | = 4.5 kN/m  |
| Normal Storey           | = 3.5 kN/m  |
| Super Dead –            |             |
| Wall load (external)(Normal Storey) | = 25.6 kN/m |
| Wall load (internal)(Normal Storey) | = 12.8 kN/m |
Dead load – Slab load (Normal Storey) = 28.8 kN/m
Slab load (Soft Storey) = 57.6 kN/m
Parking load (stilt) = 4.5 kN/m
Parapet wall load = 4.8 kN/m

5.5 Storey Stiffness and Stiffness Irregularity
Stiffness of normal storey (storey with 3.5m storey height) \( (K_N) = 2361.52 \text{ N/mm} \)
Stiffness of soft storey (storey with 4.5m storey height) \( (K_S) = 1111.11 \text{ N/mm} \)
From this it is evident that \( (K_S) < 0.7(K_N) \) and \( (K_S) < 0.8((K_N+K_N+K_N)/3) \)
So according to IS 1893-2002 Table No.5, the above structure is a stiffness irregular structure.

6. Results and Discussion
6.1 Seismic Analysis of Stiffness Irregular Structures with Soft Storey at Different Heights
In this seismic analysis, the analysis was conducted by placing soft storey at particular storey levels and then displacement & inert storey drifts are calculated at each storey level. The same procedure was repeated by placing the soft storey at different storey levels. Finally, the storey displacement and inter storey drifts are compared. The vulnerable position of the soft storey was identified.

6.2 Comparison of all displacements and drifts in all the frames to identify the frame with maximum displacements and drifts
From figure 2, it is observed that for a particular frame the storey displacements are increased from bottom storey to top storey. And as the soft storey moved from lower storey levels to higher storey level storey displacements have increased. In the frame with soft storey placed at 5th storey level maximum storey displacements are observed and they are, at 1st, 2nd, 3rd, 4th, 5th storey levels are 2.05mm, 15.93mm, 30.71mm, 45.04mm, 57.73mm, 67.86mm, 76.84mm respectively. The minimum storey displacements are observed when the soft story is placed at 1st storey level and they are, at 1st, 2nd, 3rd, 4th, 5th storey levels are 1.11mm, 8.66mm, 16.89mm, 25.19mm, 32.9mm, 39.32mm, 45.09mm.

![Figure 2. Displacement Curves of Different RC frames with Soft Storey at different levels](image-url)
From figure 3, it is observed that inter storey drifts are maximum when soft storey placed at 5th storey level and the minimum inter storey drift is observed when the soft story is placed at 1st storey level. It is also observed that the soft storey moved from lower storey levels to higher storey level inter storey drifts have increased. Maximum inter storey drift of 20.33mm is observed at 2nd and 3rd storey interface when soft storey placed at 5th storey level.

6.3 Provided lateral force resisting systems (Shear Walls and Bracings)

The plan and elevation of the frame with bracings placed on three external sides in the stilt is shown in figure 4. Table 2 shows the variation of storey displacement and storey drift with storey height.

Table 2. Storey Displacements and Drifts when Frame is provided with Bracings in the Stilt

| Sl.No. | Storey Height (m) | Storey Displacement(mm) | Storey Drift (mm) |
|--------|-------------------|-------------------------|------------------|
| 1      | 1.8               | 2.09                    | 0.00             |
| 2      | 5.8               | 16.25                   | 14.16            |
| 3      | 10.3              | 31.38                   | 15.12            |
| 4      | 13.9              | 46.05                   | 14.68            |
| 5      | 17.5              | 59.02                   | 12.97            |
| 6      | 21.1              | 69.32                   | 10.30            |
| 7      | 24.7              | 74.39                   | 5.06             |
Figure 4. Plan and Elevation of Frame provided with Bracings on three sides of the stilt

The plan and elevation of the frame with a shear wall provided on two opposite external sides is shown in figure 5. Table 3 shows the variation of storey displacement and storey drift with storey height.

Figure 5. Plan and Elevation of Frame provided with Shear walls

Table 3. Storey Displacements and Drifts for Frame with Shear Walls on Opposite Sides

| Sl. No. | Storey Height (m) | Storey Displacement (mm) | Storey Drift (mm) |
|---------|-------------------|--------------------------|-------------------|
| 1       | 1.8               | 2.70                     | 0.00              |
| 2       | 5.8               | 18.13                    | 15.42             |
| 3       | 10.3              | 35.24                    | 17.11             |
| 4       | 13.9              | 51.03                    | 15.79             |
| 5       | 17.5              | 62.09                    | 11.07             |
| 6       | 21.1              | 68.43                    | 6.34              |
| 7       | 24.7              | 73.72                    | 5.29              |
The plan and elevation of the frame with Shear walls at the centre and bracings placed on three external sides in the stilt is shown in figure 6. Table 4 shows the variation of storey displacement and storey drift with storey height.

![Figure 6. Plan and Elevation of Frame provided with Shear walls at the centre and external bracings](image)

| S.No. | Storey Height(m) | Storey Displacement(mm) | Storey Drift(mm) |
|-------|------------------|-------------------------|-----------------|
| 1     | 1.8              | 1.11                    | 0.00            |
| 2     | 5.8              | 8.66                    | 7.56            |
| 3     | 10.3             | 16.89                   | 8.23            |
| 4     | 13.9             | 25.19                   | 8.30            |
| 5     | 17.5             | 32.90                   | 7.71            |
| 6     | 21.1             | 39.32                   | 6.42            |
| 7     | 24.7             | 45.09                   | 5.77            |

The plan and elevation of the frame with Shear walls on two external opposite Sides and Bracings at Centre is shown in figure 7. Table 5 shows the variation of storey displacement and storey drift with storey height.

![Figure 7. Plan and Elevation of Frame with Shear walls on Opposite Sides and Bracings at Centre](image)
Table 5. Storey Displacements and Drifts when Frame is provided with Shear walls on Opposite Sides and Bracings at Centre

| Sl. No. | Storey Height (m) | Storey Displacement (mm) | Storey Drift (mm) |
|---------|-------------------|--------------------------|-------------------|
| 1       | 1.8               | 4.38                     | 0.00              |
| 2       | 5.8               | 12.48                    | 8.11              |
| 3       | 10.3              | 25.06                    | 12.58             |
| 4       | 13.9              | 39.46                    | 14.39             |
| 5       | 17.5              | 56.31                    | 16.86             |
| 6       | 21.1              | 65.81                    | 9.50              |
| 7       | 24.7              | 72.67                    | 6.86              |

The plan and elevation of the frame with bracings at the centre is shown in figure 8. Table 6 shows the variation of storey displacement and storey drift with storey height.

Table 6 Storey Displacements and Drifts when Frame is provided with Bracings at Centre

| Sl. No. | Storey Height (m) | Storey Displacement (mm) | Storey Drift (mm) |
|---------|-------------------|--------------------------|-------------------|
| 1       | 1.8               | 11.89                    | 0.00              |
| 2       | 5.8               | 13.97                    | 2.08              |
| 3       | 10.3              | 23.05                    | 9.08              |
| 4       | 13.9              | 33.77                    | 10.73             |
| 5       | 17.5              | 43.38                    | 9.61              |
| 6       | 21.1              | 51.37                    | 7.98              |
| 7       | 24.7              | 58.86                    | 7.50              |

The plan and elevation of the frame with shear walls at the centre is shown in figure 9. Table 7 shows the variation of storey displacement and storey drift with storey height.
Figure 9. Plan and Elevation of Frame provided with Shear walls at Centre

Table 7. Storey Displacements and Drifts when Frame is provided with Shear walls at Centre

| Sl. No. | Storey Height (m) | Storey Displacement (mm) | Storey Drift (mm) |
|---------|-------------------|--------------------------|------------------|
| 1       | 1.8               | 11.89                    | 0.00             |
| 2       | 5.8               | 13.97                    | 2.08             |
| 3       | 10.3              | 23.05                    | 9.08             |
| 4       | 13.9              | 33.77                    | 10.73            |
| 5       | 17.5              | 43.38                    | 9.61             |
| 6       | 21.1              | 51.37                    | 7.98             |
| 7       | 24.7              | 58.86                    | 7.50             |

From the figure 10, it is observed that for the vulnerable frame (frame with soft storey placed at 5th storey level) with shear walls are placed at centre and bracings at external sides in the stilt of the structure is causing minimum storey displacements when compared to that of the frame with any other lateral load resisting systems. And the storey displacements at 1st, 2nd, 3rd, 4th, 5th storey levels are reduced from 2.05mm, 15.93mm, 30.71mm, 45.04mm, 57.73mm, 67.86mm, 76.84mm respectively to 1.11mm, 8.66mm, 16.89mm, 25.19mm, 32.90mm, 39.32mm, 45.09mm respectively. So, of all lateral loads resisting systems shear walls are placed at centre and bracings at external sides in the stilt is effective in reducing the storey displacements.

From the figure 11, it is observed that for the vulnerable frame (frame with soft storey placed at 5th storey level) with shear walls are placed at centre and bracings at external sides in the stilt of the structure is causing minimum inter storey drift is observed when compared to that of the frame with any other lateral load resisting systems. And the maximum inter storey drift in the frame without any lateral load resisting system is 20.33mm and this is reduced to 9.08mm by placing shear walls at centre and bracings at external sides in the stilt. So, this lateral load resisting system was effective in reducing inter storey drifts.

From figure 11, it is observed that there is reduction in storey displacements in the frames soft storey placed at 5th storey level without any lateral load resisting system and with shear wall placed at the centre and external bracings in stilt. The storey displacements at 1st, 2nd, 3rd, 4th, 5th storey levels are reduced by 46.1%, 45.65%, 44.99%, 44.06%, 43% and 41.32% respectively.
From figure 13, the reduction in inter storey drifts in the frames soft storey placed at 5th storey level without any lateral load resisting system and with shear placed at the centre and external bracings in stilt is observed. The maximum inter storey drift is reduced by 59.17%.

**Figure 10.** Displacements Curves of the Frames with Different Remedial Measures with Maximum Displacement
**Figure 11.** Drift Curves of the Frames with Different Remedial Measures with Maximum Displacement.

**Figure 12.** Displacement Curves of frames with and without Revision.
7. Conclusions
Seismic vulnerability assessment for stiffness irregular buildings with and without lateral load resisting systems was carried out and the following can be concluded
1. As the soft storey shifted from lower storey levels to higher storey level storey displacements and inter storey drifts have increased. In the frame with soft storey placed at 5th storey level maximum storey displacements are observed and they are, at 1st, 2nd, 3rd, 4th, 5th storey levels are 2.05mm, 15.93mm, 30.71mm, 45.04mm, 57.73mm, 76.84mm respectively. And maximum inter storey drift of 20.8mm is obtained between 2nd & 3rd storey interface for the same frame. So, frame with soft storey placed at 5th storey level is the vulnerable frame.
2. Frames without any lateral force resisting systems have obtained more displacements when compared to that of frames with lateral load resisting systems.
3. Out of all lateral loads resisting systems when shear walls placed at the centre and external bracings in stilt of vulnerable frame minimum storey displacements and inter storey drifts are observed and they are, at 1st, 2nd, 3rd, 4th, 5th storey levels are 1.11mm, 8.66mm,16.89mm, 25.19mm, 32.90mm, 39.32mm, 45.09mm respectively.
4. By placing the shear wall at centre and external bracings in stilt for a vulnerable frame the storey displacements at 1st, 2nd, 3rd, 4th, 5th storey levels are reduced by 46.1%, 45.65%, 44.99%, 44.06%, 43% and 41.32% respectively and maximum inter storey drift is reduced by 59.17%.

References
[1] Indian Standard 1893 (Part 1) 2002 Criteria for Earthquake Resistant Design of Structures General Provisions and Buildings (Fifth Revision) Bureau of Indian Standards New Delhi
[2] Rakshit Patil, Avinash S Deshpande, Shrishail Sambanni 2016 Optimal location of the Shear wall in high rise building subjected to Seismic Loading International Journal for Technological Research in Engineering 3(10) p 2678-82
[3] G P Cimellaro 2014 Bidirectional push-over analysis of Irregular Structures Journal of Structural Engineering 140(9) (04014059) p 07-13
[4] Chatpan Chintanapakdee Anil k Chopra 2004 Seismic Response of Vertically Irregular
Frames: Response History and Modal Pushover Analyses *Journal of Structural Engineering* **130** (8) p 1177-84

[5] P A Krishnan, Anjaly Francis, V N Pradeep 2019 Effect of Shear Wall location in Buildings subjected to Seismic Loads *International Journal of Engineering Research and Management* **6** (7) p 34-37

[6] Ravikumar CM, Babu Narayan K, Sujith B, Venkat Reddy V 2012 Effect of Irregular configuration on seismic vulnerability of RC Buildings *Architecture Research* **2** (3) p 20-6

[7] Dhinam Basu 2004 Seismic Analysis of Asymmetric Buildings with Flexible Diaphragms *Journal of Structural Engineering* **130** (8) p 1169-76

[8] Jack P Moehle, Luis F Alarcon 1986 Seismic analysis methods for irregular buildings *Journal of Structural Engineering* **112** (1) p 129-36

[9] Siva Bhanu Sai Kumar S, Rama Rao G V, Markandeya Raju P 2016 Seismic fragility analysis of regular and setback RCC frames—a few hypothetical case studies *Asian Journal of Civil Engineering* **17** (5) p 551–69

[10] Ponnada M R, Reddi P 2020 Linear static analysis of multi-storey building with horizontally asymmetric architectures *Journal of Building Pathology and Rehabilitation* **5** (25) p 1-10