

# Study on Effect of Stiffness Modifiers in the Analysis of Irregular Building Using ETABS

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**Abstract** – Reinforced concrete high-rise buildings undergo extensive cracking of structural elements during earthquakes, leading to a reduction in the effective cross-sectional area and stiffness of members. This reduction in stiffness lowers the axial, flexural, shear and torsional capacities of the section, increases lateral displacement and inter-storey drift, and alters the distribution of forces between structural members. In the present study, a 30-storey plan-irregular reinforced concrete building is analysed in ETABS using the Response Spectrum Method for the four seismic zones of India (Zone II, III, IV and V). Two sets of models are considered for both design and service load combinations: one using gross (uncracked) section properties and the other using cracked section properties obtained by applying the stiffness modification factors recommended in IS 16700:2017. The time period, lateral displacement, storey drift, support moments, and beam and column forces obtained from the two sets of models are compared for each seismic zone. The results indicate that the application of stiffness modifiers increases the time period, lateral displacement and storey drift of the structure, while support moments and the shear force and bending moment in beams and columns reduce. The axial force in columns increases when the stiffness of the structure is reduced.

**Key Words:** *stiffness modifiers, cracked section, irregular building, ETABS, response spectrum method, seismic zones, effective moment of inertia.*

## 1. INTRODUCTION

The increasing demand for high-rise construction driven by urban land scarcity has made the accurate estimation of lateral stiffness a critical part of

structural design. Lateral loads such as earthquake and wind forces largely govern the sizing of beams and columns and the selection of the lateral load-resisting system in tall buildings. Because concrete has very limited tensile strength, flexural cracking of structural members is unavoidable under seismic stress reversals. Cracking reduces the effective moment of inertia of the cracked members, which in turn reduces the lateral stiffness of the building, increases lateral displacement and inter-storey drift, and redistributes moments from cracked members (such as beams) to relatively uncracked members (such as columns).

Most seismic codes therefore recommend the use of reduced, or 'effective', section properties rather than the full gross-section properties while carrying out the seismic analysis of reinforced concrete buildings, so that the estimated time period, displacement, drift and member forces reflect the true cracked behaviour of the structure rather than an artificially stiff, uncracked response.

Modern buildings are also frequently irregular in plan and elevation due to architectural and functional requirements. Irregularity causes eccentricity between the centre of mass and the centre of stiffness, resulting in an undesirable coupled lateral-torsional response under earthquake shaking. IS 1893 (Part 1):2016 classifies building irregularities into plan irregularities (torsional irregularity, re-entrant corners, floor slabs with excessive cut-outs, out-of-plane offsets and non-parallel lateral systems) and vertical irregularities (soft storey, mass irregularity, vertical geometric irregularity, in-plane discontinuity, weak storey, floating columns and irregular modes of oscillation). India is divided into

four seismic zones (Zone II to Zone V) of increasing seismic hazard, as per the seismic zoning map published by the Bureau of Indian Standards.

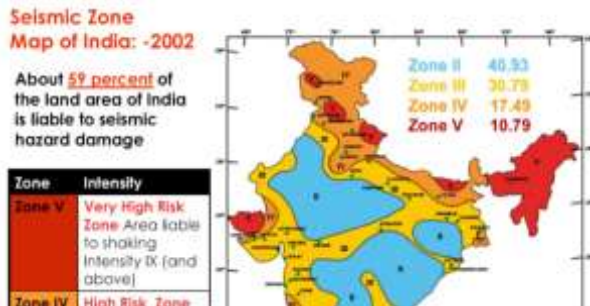


**Fig -1: Seismic zoning map of India**

This study investigates the combined effect of member cracking (through stiffness modifiers) and plan irregularity on the seismic response of a 30-storey reinforced concrete building situated in each of the four Indian seismic zones.

## 2. LITERATURE REVIEW

Priestley (2003) highlighted that most seismic codes do not provide accurate effective-stiffness values for reinforced concrete members, and that uncracked stiffness cannot be relied upon since cracking occurs even under earthquakes smaller than the design earthquake; once cracked, a member does not fully recover its uncracked stiffness. Paulay and Priestley (1992) similarly noted that use of uncracked stiffness in modal analysis leads to inaccurate estimates of elastic period and force distribution, since the latter depends on the relative stiffness of the various members.

Rethaliya et al. observed that using the full (uncracked) moment of inertia makes the structure artificially stiff, under-estimating storey drift and lateral displacement; using cracked-section properties gives more realistic, larger deflections, requiring larger lateral load-resisting members and hence a safer design. Kontoni et al. found that the axial load ratio significantly affects cracking, deflection amplification and the stiffness ratio of vertical members, and that increasing column stiffness reduces the natural period of the building.

Sarkisian et al. noted that appropriate modelling of the effective stiffness of shear walls is critical to right-sizing lateral systems in tall buildings, since overly conservative stiffness assumptions lead to unnecessary and costly over-stiffening. Murthy et al.

explained that the ratio of effective to gross moment of inertia is higher for columns than for beams because columns are less damaged owing to the presence of axial compression. Causevic reported that reducing beam or wall stiffness changes the distribution of internal forces depending on the structural system and behaviour factor used, and that using about 50% of the original stiffness of beams or walls produces more realistic seismic behaviour and more evenly distributed reinforcement. Kumar and Singh identified reinforcement ratio and concrete compressive strength as the parameters with the most pronounced influence on the effective stiffness of RC members.

Branson's classical expression, along with the approximations proposed by Grossman, Wang, Elwood and Eberhard, and Priestley, are widely used to estimate the effective moment of inertia ( $I_e$ ) of a cracked reinforced concrete section as a function of the applied moment, the cracking moment and the gross moment of inertia. IS 16700:2017, the Indian code for structural safety of tall buildings, prescribes stiffness modification factors for slabs, beams, columns and walls for both design and service load combinations, which form the basis of the cracked-section models used in this study.

## 3. OBJECTIVES AND METHODOLOGY

### 3.1 Objectives

- To study the cracked behaviour of a plan-irregular reinforced concrete structure.
- To evaluate the effect of stiffness modifiers on the seismic performance of structural elements.
- To compare lateral displacement and storey drift of the structure with and without stiffness modifiers.
- To compare beam and column forces with variation in stiffness modifiers.
- To compare support moments with and without stiffness modifiers, for all four seismic zones of India.

### 3.2 Methodology

A 30-storey reinforced concrete special moment-resisting frame with an identical, plan-irregular floor layout at every level is modelled in ETABS 2019 as

a 3-D space frame, fixed at the base. For each of the four seismic zones (II, III, IV and V), four models are analysed: (i) a Design model with gross section properties (modifier = 1.0) under design load combinations, (ii) a Design-Modified model with IS 16700:2017 stiffness modifiers under design load combinations, (iii) a Service model with gross section properties under service load combinations, and (iv) a Service-Modified model with stiffness modifiers under service load combinations. The Response Spectrum Method (modal analysis) is used to obtain the equivalent static seismic response, combining the modal responses of the structure to a code-specified acceleration response spectrum.

#### 4. MODELLING OF STRUCTURE

The building considered is a 30-storey plan-irregular RC building of plan dimensions 35 m × 30 m, storey height 3 m and overall height 90 m, with column spacing of 5 m centre-to-centre. Beam sections are 450 mm × 600 mm; columns are 900 mm × 900 mm up to the 10th floor, 800 mm × 800 mm from the 10th to 20th floor, and 700 mm × 700 mm from the 20th to 30th floor. Slab thickness is 150 mm, and shear wall thickness is 230 mm. Concrete grades of M45 and M40 and reinforcement grades of Fe500 and Fe415 are used. Design live loads of 3 kN/m<sup>2</sup> (floors) and 1.5 kN/m<sup>2</sup> (roof) are applied per IS 875 (Part 2), and seismic parameters (zone factor, response reduction factor of 5 for SMRF, importance factor of 1.2, and 5% damping, Type II medium soil) are taken per IS 1893 (Part 1):2016.

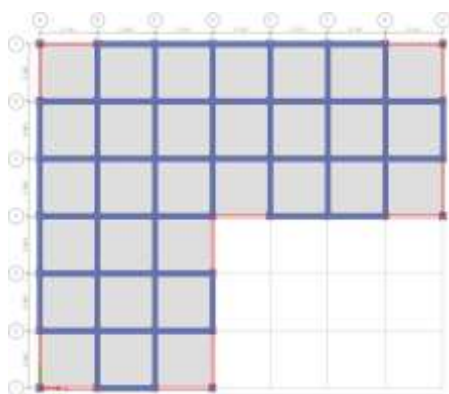


**Fig -2: Plan view of the irregular building**

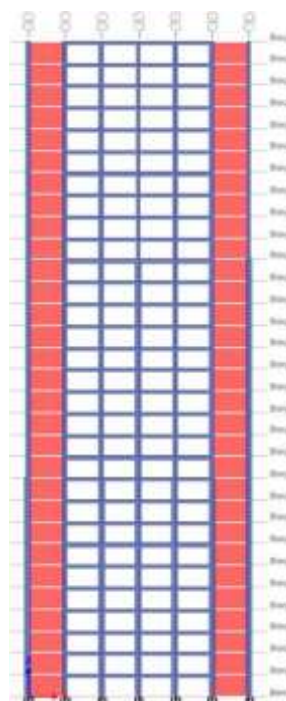


**Fig -3: Elevation view of the irregular building**

Table 1 lists the area and effective moment-of-inertia modification factors used for slabs, beams, columns and walls, as prescribed by IS 16700:2017, for both design and service load combinations.

**Table -1: Stiffness modification factors used (IS 16700:2017)**

| Element | Design Moment of Inertia | Service Moment of Inertia |
|---------|--------------------------|---------------------------|
| Slab    | 0.25 $I_g$               | 0.35 $I_g$                |
| Beam    | 0.35 $I_g$               | 0.70 $I_g$                |
| Column  | 0.70 $I_g$               | 0.90 $I_g$                |
| Wall    | 0.70 $I_g$               | 0.90 $I_g$                |

#### 5. RESULTS AND DISCUSSION

The structural response of the general (uncracked) model and the stiffness-modified (cracked) model is compared for time period, support moments, lateral displacement, storey drift, and beam and column forces, across all four seismic zones.

##### 5.1 Time Period

Applying stiffness modifiers increases the fundamental natural period of the structure, since a reduction in stiffness increases flexibility. For the design load combination, the time period increased from 2.20 s (general model) to 3.005 s (stiffness-

modified model), an increase of about 36.5%. For the service load combination, it increased from 2.20 s to 2.445 s, an increase of about 11.1%.

### 5.2 Support Moments

Support moments in both X and Y directions decrease when stiffness modifiers are applied, since the redistribution of stiffness reduces the moment attracted at fixed supports. The reduction ranged from about 5% to 10% (X-direction) and about 2.5% to 10% (Y-direction) moving from Zone V to Zone II.

### 5.3 Lateral Displacement and Storey Drift

Reduced member stiffness increases lateral displacement and storey drift in both principal directions. Displacement in the X-direction increased by 23.1%–40.2% and in the Y-direction by 12.1%–17.9%, moving from Zone V to Zone II. Similarly, storey drift in the X-direction increased by 20.9%–31.5% and in the Y-direction by 12.1%–18.5% across the seismic zones. In all cases the maximum storey drift remained within the 0.004 times storey height limit specified in IS 1893 (Part 1):2016.

### 5.4 Beam and Column Forces

Shear force and bending moment in the beam reduce with stiffness modifiers, by about 10.2%–17.2% and 15.6%–23.6% respectively, across the seismic zones. In columns, the axial force increases by about 17.8%–24.8%, while shear force and bending moment decrease by about 22.3%–23.6% and 17.7%–22.1% respectively, when stiffness modifiers are applied.

**Table -2: Summary of change in response parameters due to stiffness modifiers (relative to the general/uncracked model)**

| Response Parameter       | Trend with Stiffness Modifiers | Range of Change |
|--------------------------|--------------------------------|-----------------|
| Time period (design)     | Increase                       | up to 36.5%     |
| Time period (service)    | Increase                       | up to 11.1%     |
| Support moment (X, Y)    | Decrease                       | 2.5% – 10%      |
| Lateral displacement (X) | Increase                       | 23.1% – 40.2%   |

|                          |          |               |
|--------------------------|----------|---------------|
| Lateral displacement (Y) | Increase | 12.1% – 17.9% |
| Storey drift (X)         | Increase | 20.9% – 31.5% |
| Storey drift (Y)         | Increase | 12.1% – 18.5% |
| Beam shear force         | Decrease | 10.2% – 17.2% |
| Beam bending moment      | Decrease | 15.6% – 23.6% |
| Column axial force       | Increase | 17.8% – 24.8% |
| Column shear force       | Decrease | 22.3% – 23.6% |
| Column bending moment    | Decrease | 17.7% – 22.1% |

## 6. CONCLUSIONS

1. The natural time period increases with a decrease in stiffness of structural elements, for both design and service load combinations (36.5% and 11.1% increase respectively).
2. Support moments in both the X and Y directions reduce for the stiffness-modified structure compared to the general structure, by about 2.5%–10% across seismic zones.
3. Reduction of stiffness in structural members increases lateral displacement, by 23.1%–40.2% in the X-direction and 12.1%–17.9% in the Y-direction.
4. Storey drift increases for the stiffness-modified structure, by 20.9%–31.5% in the X-direction and 12.1%–18.5% in the Y-direction.
5. Shear force and bending moment in beams reduce for the stiffness-modified model, by 10.2%–17.2% and 15.6%–23.6% respectively.
6. Axial force in columns increases for the stiffness-modified column, by 17.8%–24.8%, compared with the general column.
7. Shear force and bending moment in columns reduce for the stiffness-modified model, by 22.3%–23.6% and 17.7%–22.1% respectively.

Overall, neglecting cracked-section stiffness modifiers leads to an under-estimation of lateral displacement and drift and an over-estimation of support moments and beam/column shear and bending forces, which can result in an unconservative estimate of serviceability response and an unrealistic distribution of design forces in tall, plan-irregular reinforced concrete buildings.

The study can be extended to other plan shapes and vertical irregularities, and to non-linear dynamic (time-history) analysis to further validate the trends observed using the linear Response Spectrum Method.

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### REFERENCES

- [1] Mayur R. Rethaliya, Bhavik R. Patel, R. P. Rethaliya, "A Comparative Study of Various Clauses of New IS 1893 (Part 1):2016 and Old IS 1893 (Part 1):2002", American Society of Civil Engineers, 2010.
- [2] Paulay, T., Priestley, M. J. N., Seismic Design of Reinforced Concrete and Masonry Buildings, 1992.
- [3] Ahmed, M., Dad Khan, M. K., Wamiq, M., "Effect of concrete cracking on the lateral response of RCC buildings", Asian Journal of Civil Engineering (Building and Housing), 9(1), 25–34, 2008.
- [4] Murthy, C. V. R., Goswami, R., Vijayanarayanan, A. R., Mehta, V. V., "Some Concepts in Earthquake Behaviour of Buildings", 2012.
- [5] Gangisetty Venkata Krishna, Ratnesh Kumar, "Issues in the design of tall concrete buildings in India with reference to IS 16700:2017".
- [6] Ratnesh Kumar, Yogendra Singh, "Stiffness of reinforced frame members for seismic analysis", ACI Structural Journal, Sept–Oct 2010.
- [7] Murty, C. V. R., Goswami, R., Vijayanarayanan, A. R., Kumar, R. P., Mehta, V. V., "Introduction to Earthquake Protection of Non-Structural Elements in Buildings", 2011.
- [8] K. Subramanian, M. Velayutham, "Seismic performance of lateral load resisting systems", Structural Engineering and Mechanics, 51(3), 487–502, 2014.
- [9] Micelli, F., Candido, L., Leone, M., Aiello, M. A., "Effective stiffness in regular R/C frames subjected to seismic loads", Earthquakes and Structures, 9(3), 481–501, 2015.
- [10] Mickleborough, N. C., Ning, F., Chan, C.-M., "Prediction of Stiffness of Reinforced Concrete Shear Walls under Service Loads", ACI Structural Journal, 1018–1026, Nov–Dec 1999.
- [11] Sozen, M. A., Monterio, P., Moehle, J. P., Tang, H. T., "Effects of cracking and age on the stiffness of reinforced concrete walls resisting in-plane shear", Proc. 4th Symposium on Current Issues Related to Nuclear Power Plant Structures, Equipment and Piping, Orlando, Florida, 1992.
- [12] Elwood, K. J., Eberhard, M. O., "Effective Stiffness of Reinforced Concrete Columns", Research Digest No. 2006-1, PEER, University of California, Berkeley, 2006.
- [13] Kumar, R., Singh, Y., "Stiffness of Reinforced Concrete Frame Members for Seismic Analysis", ACI Structural Journal, 607–615, Sept–Oct 2010.
- [14] Deger, Z. T., Yang, T. Y., Wallace, J. W., Jack, M., "Reinforced concrete core wall buildings with and without the moment-resisting frame", The Structural Design of Tall and Special Buildings, 24(7), 477–490, 2014.
- [15] Kumbhar, O. G., Kumar, R., Adhikary, S., "Effect of the staircase on the seismic structural performance of RC frame building", Earthquakes and Structures, 9(2), 375–390, 2015.
- [16] Priestley, M. J. N., "Myths and Fallacies in Earthquake Engineering, Revisited", 9th Mallet Milne Lecture, Rose School, Pavia, Italy, 9–31, 2003.
- [17] Nilupa, H., Priyan, M., Tuan, N., Nicholas, H., "Seismic performance of super-tall buildings", International Conference on the Sustainable Built Environment, 160–168, 2010.

- [18] IS 1893 (Part 1):2016, Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings, Bureau of Indian Standards, New Delhi.
- [19] IS 456:2000, Plain and Reinforced Concrete – Code of Practice, Bureau of Indian Standards, New Delhi.
- [20] IS 875 (Part 1):1987, Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Part 1 – Dead Loads, Bureau of Indian Standards, New Delhi.
- [21] IS 875 (Part 2):1987, Code of Practice for Design Loads for Buildings and Structures, Part 2 – Imposed Loads, Bureau of Indian Standards, New Delhi.
- [22] IS 875 (Part 3):2015, Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Part 3 – Wind Loads, Bureau of Indian Standards, New Delhi.
- [23] IS 16700:2017, Criteria for Structural Safety of Tall Buildings, Bureau of Indian Standards, New Delhi.