A Case Study on Irregularities Present in Tall Building and Review of Provisions on Indian Standard
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DOI: 10.36348/sjce.2021.v05i01.001 | Received: 18.01.2021 | Accepted: 01.02.2021 | Published: 04.02.2021

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Abstract

Irregularities are mainly categorized under the plan and vertical irregularity in IS 1893 (Part 1): 2016 along with precautions for design and analysis in case of occurrence of irregularities. In this paper, an effort is done to identify irregularities present in existing commercial cum residential building satisfying provisions of Indian Standard code, and the complications on the adaption of mitigating measures. It is concluded that re-entrant corner irregularity is rampant in residential apartments and a soft storey is likely with open parking floors and building with variation in storey heights. Also, the three-dimensional vertical analysis method is ambiguous to adopt and the use of equivalent diagonal strut is ineffective with current clauses. Furthermore, additional clarification of weak storey is requisite.

Keywords: Irregularity, re-entrant corners, soft storey, weak storey.

INTRODUCTION

Irregularity in mass or stiffness in plan and elevation makes a building more vulnerable in case of stability and lateral load resistance. Irregularity hinders uniformity of load path which may cause severe damage in the irregular building than a regular building. So efforts should be done to eliminate irregular configuration by modifying architectural planning. But sometimes irregularities are inevitable so IS 1893 (Part 1) has defined types of them with criteria for consideration and some remedial measures are included in 2016 revisions [2]. Irregularities are categorized under Plan and Vertical irregularity. Re-entrant corner, Diaphragm Discontinuity, Out-of-Plane Offsets, and Non-Parallel systems are five types of plan irregularities. Additionally, Stiffness, Mass, Vertical Geometric, In-Plane Discontinuity in Vertical Elements Resisting Lateral Force, and Strength Irregularity are defined under Vertical Irregularity in 2002 revision of IS 1893 (Part 1) [1]. Whereas two more kinds of irregularities namely Floating or Stub Columns and Irregular modes of Oscillation in Two Principal Plan Directions are added under Vertical Irregularity in 2016 revision and Diaphragm discontinuity is defined as Floor slabs having excessive cut-outs or opening.

Condition for the existence of some irregularities is revised mainly for Torsional Irregularity, Stiffness, Mass, Strength, Vertical Geometric, and In-Plane discontinuity. An irregularity check is performed for both the conditions mentioned as per the 2002 and 2016 revision.

Results from the equivalent static method are not appropriate in comparison to the response spectrum method as it doesn't consider irregularity effects and depends only on the empirical formula [3]. Buildings with complex shape should be designed duly taking care of their dynamic behavior [4]. Shorter structures with increased first storey height and taller structures with increased middle storey height generally produce greater inter-storey drift demands than regular storey [5]. Irregularities influence the height wise variation of story drifts with the effect of strength being larger than stiffness [6]. A requirement of Dynamic analysis for irregular buildings as per UBC is validated as Static analysis underestimates the column demands [7]. Distributions of total story shears were reproduced slightly more accurately by the dynamic methods than by the static methods [8].

Building Configuration

An existing seventeen storey multipurpose Tall building (2 Parking + 2 Commercial +13 Residential) was considered to study the irregularities that may present in the building and to analyze provisions of the code on addressing those irregularities. Irregularities checks were performed as per both the revisions of IS 1893 (Part 1) and discussions are done based on the...
procedures of quantification of irregularity, measures to be taken, and the discrepancies present in the code.

One of the parking floors was maintained at 3.96m so that it would be easy for parking and all the other floors are 3.05m. Residential floors are planned to maintain proper ventilation and lighting inside the room. Beam layouts of commercial and parking floors are identical whereas changed for residential floors. Dead loads and live loads on each floor are considered as per as per IS 875 (Part 1) and IS 875 (Part 2). The building was analyzed for earthquake loads for the load combinations as per IS 456: 2000. Beam layouts of commercial parking and residential floors are as shown in Fig 1 and 2. And the three dimensional rendered view of the building is shown in Fig-3.

Fig-1: Beam layout of Commercial and Parking floor

Fig-2: Beam layout of Residential floor

Irregularity Check

Irregularity in the building causes the ununiform distribution of mass and stiffness in plan and elevation which may cause damage. Irregularities and requirements to cope with them are mentioned in Table 5 and 6 [1, 2]. All the irregularity conditions are checked to identify if any present in the building. Also, irregularity is verified as per IS 1893 (Part 1): 2002.

Plan Irregularity

Torsional Irregularity

For displacement

Irregularity is said to exist if the displacement of one end of the floor is 1.5 times its minimum horizontal displacement of the far end [2] while the ratio is 1.2 for the same [1].

a. In X-Direction

\[ x_1 = 67.7 \text{ mm} \quad \text{and} \quad x_2 = 66.8 \]

\[ x_1 / x_2 = 1.01 < 1.5 \quad \text{ratio} \]

\[ y_1 = 58.6 \text{ mm} \quad \text{and} \quad y_2 = 59.8 \]

\[ y_1 / y_2 = 1.02 < 1.2 \]

\[ = 1.01 < 1.2 \]

For Natural Period

Irregularity exists if the time period of fundamental torsional mode is greater than that of the first two translational modes [2]. The time period for the respective fundamental modes is given in Table-1.

| Table-1: Modes with the respective time period |
|-----------------------------------------------|
| Mode                      | Period (sec) |
|----------------------------|--------------|
| 1  (Translation)          | 2.332        |
| 2  (Translational)        | 2.285        |
| 3  (Torsional)            | 2.095        |

Natural period in fundamental torsional mode = 2.095sec < 2.332sec,
= 2.095sec < 2.285 sec

As both the requirements are not satisfied Torsional irregularity is not present in the building

Re-entrant Corners

The re-entrant corner is said to exist if a projection of size greater than 15% of its overall plan dimension in that direction [1, 2].
From Fig.4 projection of 20.9m is observed for a span of 37.5m.
So, Projection percentage = \( \frac{20.9}{37.5} \times 100 = 55.7 \% \) > 15 %
Re-entrant corner exists in building hence three-dimensional dynamic analysis shall be adopted.

**Floor slabs having excessive Cut-outs or Opening**
No such openings are present in the building considered.

**Out-Of-Plane Offsets in Vertical Elements**
Offsets in vertical Elements are not present in building Considered.

**Non-Parallel Lateral Force System**
Irregularity is said to exist if all the structural systems resisting lateral forces are not oriented along two principal orthogonal axes in the plan. As shown in Fig-5. All the lateral load resisting elements i.e. Columns are oriented in two principal orthogonal directions in the building considered as shown in Fig-6. So the irregularity is not present in the building considered.

**Vertical Irregularity**
**Stiffness irregularity (Soft Storey)**
The soft storey is said to exist if lateral stiffness of any storey is less than that of the storey above i.e. \( K_{i+1} > k_i \) [2] while the soft storey was defined to be the storey which lateral stiffness is less than 70% of the above storey or 80 percent of the average lateral stiffness of three storeys above in previous revision [1].

**Table-2: Lateral Stiffness calculation of Parking Floor**

| Column Sizes (mm) | No. | \( I_{xx} \) (mm\(^2\)) | \( I_{yy} \) (mm\(^2\)) | \( E \) (N/mm\(^2\)) | \( H \) (mm) | \( K_x \) (N/mm) | \( K_y \) (N/mm) |
|-------------------|-----|----------------|----------------|----------------|-------|----------------|----------------|
| 910 x 460         | 6   | 173321330000   | 442878800000  | 27386          | 3960  | 917230         | 234375         |
| 910 x 530         | 6   | 67739035000    | 199696315000  | 27386          | 3960  | 358480         | 1036809        |
| 910 x 610         | 6   | 103276355000   | 229839155000  | 27386          | 3960  | 546547         | 1216327        |
| 910 x 610         | 6   | 103276355000   | 229839155000  | 27386          | 3960  | 546547         | 1216327        |
| 910 x 530         | 6   | 67739035000    | 199696315000  | 27386          | 3960  | 358480         | 1036809        |
| 910 x 460         | 6   | 173321330000   | 442878800000  | 27386          | 3960  | 917230         | 234375         |
| **Total**         |     | **3644515**    | **3015022**    |                |       |                |                |
Stiffness irregularity is checked for three different floor levels as shown in Fig-7 for which lateral stiffness is calculated as shown in Tables 2, 3 and 4 for parking, commercial and residential floor respectively.

Lateral stiffness of parking floor \( (K_p) \) with height 3.96m

\[
K_p = 3644514.5 \text{ kN/m}
\]

Lateral Stiffness of commercial floor \( (K_c) \) with height 3.05 m

\[
K_c = 7976745.3 \text{ kN/m}
\]

Lateral Stiffness of Residential floor \( (K_r) \) with height 3.05 m

\[
K_r = 6610245.6 \text{ kN/m}
\]

Lateral stiffness of commercial floor \( K_c > K_p \) Lateral stiffness of parking floor.

\[
\left( \frac{K_p}{K_c} \right) \times 100 = 45 \% < 70 \%
\]

So there is stiffness irregularity between Parking and commercial floor as per both revisions. But \( K_r < K_c \) so Stiffness irregularity does not exist between commercial and residential floor.

**Mass Irregularity**

Mass irregularity shall be considered to exist when the seismic weight of any floor is more than 150 \% \[2\] and 200\% \[1\] of that of the floors below respectively as shown in Fig-8.

Seismic weight is calculated for three different floors as shown in Fig-9 whose loads are different from one another and compared for the presence of mass irregularity.

Seismic weight of the commercial floor \( W_c = 10951.7 \) kN and

Seismic weight of the parking floor \( W_p = 10669.5 \) kN

Percentage seismic weight of commercial floor =102.6\% < 150\% < 200\%.

So mass irregularity is not present between the commercial and parking floor.

The seismic weight of the commercial floor \( W_c = 10951.7 \) kN

Seismic weight of residential floor \( W_r = 13026.8 \) kN

Percentage seismic weight of residential floor =118.9 \% < 150 \% and < 200%.

So mass irregularity is not present between the commercial and residential floor.

**Vertical Geometric Irregularity**

Irregularity is said to exist if the Horizontal Dimension of lateral load force-resisting system in any
storey is more than 125% and 150% of the storey below [2, 1]. No such projection is present in building considered.

**In-Plane Discontinuity in Vertical Elements Resisting Lateral Force**

Irregularity exists if In-Plane offset of the lateral force-resisting elements is greater than 20% of the plan length of that element [2] while 2002 revision has not fixed the percentage [1]. No such offset in lateral force resisting element is present in the building considered.

**Strength Irregularity (Weak Storey)**

The storey weak in stiffness can also be considered weak in strength thus strength irregularity exists in the building. As the lateral load resisting members are the same in the floors there seems no distinct way defines by the standard to determine the strength.

**Floating or Stub Column**

Such columns are not present in the building considered.

**Irregular Modes of Oscillation in Two Principal Plan Direction**

Irregularity of Irregular modes of Oscillation is newly mentioned provision in latest revision [2].

a. First three modes contribute less than 65% mass participation factor in each principal plane. Mass participation for all three fundamental modes is presented in Table 5.

| No of Mode | Mass participation factor in x | Mass participation factor in y |
|------------|-------------------------------|-------------------------------|
| 1          | 0.801                         | 4.165E-06                     |
| 2          | 4.469E-06                     | 0.8437                        |
| 3          | 9.144E-06                     | 0.0038                        |

Mass Participation factor in both orthogonal directions is 80.1% in X and 84.4% in Y > 65%.

b. fundamental lateral natural periods of the building in the two principal plan directions are closer to each other by 10 % of the larger value.

**Re-Entrant Corner**

Irregularity in plan mostly in residential apartment buildings is present for ventilation and lighting as shown in the above inspection of irregularity in the considered building. Three- dimensional dynamic analysis is recommended to cope with a re-entrant corner in 2016 revision in addition to the Cl. 6.3.3.1 about vertical earthquake effects and Cl 7.7.1 requirement of linear dynamic analysis for any irregular building. Which leaves a query that is it a necessity for vertical earthquake and dynamic analysis for apartment buildings of height around 15m also because the re-entrant corner appears to be unavoidable.
Vertical Irregularity (Soft Storey)

The soft storey is caused mainly due to increased storey height or open storey. Both 20021 and 20162 revisions have recommended some measures as

i. Placement of RC structural wall with proper foundation and connection with moment resisting frame which is only possible for a soft or open storey in the ground floor or so. But for the case of occurrence of a soft storey in upper floors for seminar halls or movie theatre shear wall is absurd which if provided also causes difficulties for practical implication and certainly will increase stiffness beyond the lower storey which again makes a lower storey a soft storey or should be provided throughout the height of the building which increases the cost of construction.

ii. Braced frame in selected bays of the building, which increases the lateral stiffness of the soft storey. In doing so additional torsion may occur because of limited stiffer bays and also stiffness should be checked not to be much larger than a lower storey which in turn creates another soft storey below that floor.

iii. Equivalent Diagonal Strut for Unreinforced Masonry Infill Walls in RC Frame.

Other than above-mentioned provisions 20162 revision recommends the estimation of stiffness contribution by Unreinforced Masonry URM infill by the introduction of an Equivalent Diagonal Strut in the analysis to address the additional stiffness and strength provided by infill.

A sample wall section was considered to check for the possibility of an equivalent diagonal strut as per Cl.7.9 of IS 1893 (Part 1): 2016 as shown in Fig-10.

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Stiffness and Strength Irregularity

Stiffness is the force needed to cause a unit deflection and can be calculated as the slope of force-displacement whereas strength is a total force that a system can resist. Though both irregularities are differently defined in IS 1893 (Part 1) both seems to be very closely interrelated as the storey with stiffness irregularity likely to be a week in lateral strength too. Furthermore, code has undefined how can we quantify week storey as there is ambiguity on the procedure to calculate lateral strength. So there is a need for clarification about the presence of soft and week storey.
whether can exist independently or co-exist in a building.

RESULTS
1. Irregularity of Re-entrant corners is present for lighting and ventilation purpose in apartment buildings regardless of their height.
2. Soft storey present in the building is most likely if the variation of the height of storey is done.
3. Three-dimensional dynamic analysis procedure and consideration required to be more distinctly described.
4. Recommended use of equivalent diagonal strut for unreinforced masonry infill wall cannot be effectively accomplished satisfying the current provision of height to thickness and length to thickness ratios.
5. Strength irregularity and approach of its determination should be further defined along with its occurrence with and without the soft story.

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