Analysis of the Torsional Irregularity as per IS 1893 (Part 1): 2016 and IS 1893 (Part 1): 2002

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Abstract. The earthquake-resistant design of a building begins with its architectural design. Earthquake safety depends on many factors such as type of structural system, distribution of mass, and mechanical properties of structural material used in the construction of buildings. A building with regular configurations suffers much less damage as compared to building with irregular configurations. The irregularity criteria have been modified in the new IS 1893(Part): 2016 which is the sixth revision of the Indian Seismic Code. This paper aims to perform a comprehensive analysis on the torsional irregularity criteria (a type of plan irregularity) as per IS 1893 (Part 1): 2016 and IS 1893 (Part 1): 2002. The irregular buildings with different plans have been modelled by computer software STAAD.Pro Connect Edition and results of torsional irregularity checks as per IS 1893 (Part 1): 2016 and IS 1893(Part 1): 2002 have been compared. The criteria for torsional irregularity check as per new IS1893(Part 1): 2016 is found to be more elaborated and simpler as compared to old IS 1893(Part 1): 2002. New seismic code gives about 2.7 times clearer indication of torsional irregularity in the building model.

Keywords: Torsional irregularity, Rigid floor diaphragm, Indian seismic code, Response spectrum analysis, Centre of mass, Centre of Rigidity.

1. Introduction

India has witnessed very strong earthquakes in history, and hence earthquake resistant design of structures is very essential. Earthquake safety of a structure can be ensured by its architectural design, choice of structural material with good mechanical properties and by adopting advanced construction technology[1]–[4]. Earthquake safety of a building is closely related to its architectural design. To achieve a good seismic performance of the proposed building, architect and design engineer work together to design building with symmetrical plan and regular structural configurations but due to some factors such as property boundary lines, area topography, usage of the building and comfort of the occupants, some irregularities are introduced in the building design which can be detrimental to its good seismic performance.

In India, IS 1893 (Part 1): 2016 is referred as the standard for earthquake-resistant design of structures. In the year 2016, the Bureau of Indian standards published the sixth revision of IS1893(Part 1) which has new design criteria for earthquake-resistant design of buildings such as irregularity checks and seismic analysis methods. Many comparative studies have been done since the publication of IS 1893 (Part 1): 2016. Malviya and Pahwa (2017) [5] carried out response spectrum analysis of G+50 regular frame building and compared the results of bending moment, shear force and story displacement as per both IS 1893 (Part 1): 2002 and IS 1893 (Part 1): 2016. Surwase et al. (2018) [6] carried out...
“Seismic Analysis and Comparison of IS 1893 (Part-1) 2002 and 2016 of (G+4) Regular and Irregular Building.” Kumar and Chand (2019)[7] carried out “A comparative study of static analysis (as per IS: 1893-2002) & dynamic analysis (as per IS: 1893-2016) of a building for zone V.” These researches were mainly focused on seismic analysis and covered very less area of differences between old & new IS 1893 (Part 1): codes but Rethaliya et al. (2018)[8] covered this gap. they studied and listed out the various changes in clauses of new IS1893(Part 1): 2016 and old IS1893(Part 1): 2002 followed by critical comments on those changes. Debnath et al. (2019)[9] studied the changes of various design provisions of new IS 1893 (part): 2016 with old IS 1893 (part 1): 2002 and explained the applicability of static and dynamic analysis methods. There are many researches on structural irregularity as per IS 1893 (Part 1): 2002 while for IS 1893 (Part 1): 2016 are very less. The most of the researches on structural irregularity were based on single type of irregularity but Naveen et al. (2019)[10] performed a very detailed study on analysis of the irregular structures. They analysed 54 different configurations of irregular and regular structures as per new IS 1893 (Part 1):2016 by using computer software ETABS. They found that there are certain types of irregularities which affect the structure the most; mass irregularity, stiffness irregularity, vertical geometrical irregularity, re-entrant corners and torsional irregularity. The old and new limits of these irregularities are shown in Table 1.

| Name of Irregularity | Classification of irregularity | Limits |
|----------------------|-------------------------------|--------|
|                      |                               | IS 1893 (Part 1): 2016 | IS 1893 (Part 1): 2002 |
| Mass                 | Vertical                      | \( M_i < 1.5 M_a \) | \( M_i < 2.0 M_a \) |
| Stiffness            | Vertical                      | \( S_i > S_{i+1} \) | \( S_i > 0.7 S_{i+1} \) |
| Vertical Geometry    | Vertical                      | \( VG_i < 1.25 VG_a \) | \( VG_i < 1.5 VG_a \) |
| Re-entrant corners   | Plan                          | Projection size < 15% of Overall dimension | do |
| Torsion              | Plan                          | \( \Delta_{\text{max}} < 1.5 \Delta_{\text{min}} \) | \( \Delta_2 < 1.2 \Delta_{\text{avg}} \) |

Where:
- \( i \) = number of storey in consideration,
- \( a \) = number of adjacent storey,
- \( \Delta_{\text{max}} \) = max. storey drift,
- \( \Delta_{\text{min}} \) = min. Storey drift,
- \( \Delta_{\text{avg}} \) = average storey drift.

It is evident from Table 1, that new IS1893(Part 1): 2016 code is stricter on mass, stiffness and vertical geometrical irregularities. No change has been made to re-entrant corner irregularity criteria. But on the torsional irregularity check criteria, it cannot be said whether the new code has imposed any restriction on the torsional irregularity or not. Hence this paper aims to analyse the torsional irregularity check criteria as per both codes.

**Research objectives**
- To study the torsional irregularity.
- To study the torsional irregularity checks criteria as per new IS 1893 (Part 1): 2016 and old IS 1893 (Part 1): 2002
• Analytical modelling of irregular building on computer software STAAD.Pro CONNECT Edition and check them for the torsional irregularity as per new IS 1893(Part 1): 2016 and old IS 1893(Part 1): 2002 and comparison of results.

2. Torsional Irregularity

Torsional irregularity is a kind of plan irregularity and it occurs due to the eccentricity between the centre of mass (CM) and the centre of resistance (CR). The seismic load acts at the mass-centre of the structure while the resisting force acts at the centre of resistance of the structure. In a regular building, centre of mass and centre of resistance (or rigidity) coincides with each other and no torsional problem is experienced there. But when centre of mass (CG) and centre of resistance (CR) do not coincide with each other, torsional problem takes place in the building and if the eccentricity increases between these two centres, the building undergoes twisting around its rigid core and it is subjected to large amount of torsion (Figure 1).

Many studies have been conducted on the effects of torsion in recent years. Guevara et al. (1992)[11] studied that the shape of floor plan affects the seismic response of the structure. They performed seismic analysis of buildings having L shape and H shape plans. It was found that the torsional effect can be minimised by dividing the building into rectangular blocks. Gokdemir et al. (2013) [12] performed a comprehensive study on the effects of torsional irregularity on failure of the structures. Their research says that the torsion occurs due to the eccentricity between mass-centre and centre of stiffness. Great amount of torsion can severely damage the RC walls and columns of a structure and may lead to complete failure of structural members. This is why it is always preferred to design a building with regular configuration but it is not always possible in real world. Hence to ensure the earthquake safety, Seismic codes recommend the structures to check for irregularities.

As per IS 1893 (Part 1): 2016, “A building is called torsionally irregular if ratio of maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is more than 1.5 times its minimum horizontal displacement at far end of the same floor in that direction” [13] (Figure 2).

\[ \Delta_{\text{max}} > 1.5 \Delta_{\text{min}} \] (1)

In eq. 1, \( \Delta_{\text{max}} \) is the maximum relative displacement of the storey in consideration and \( \Delta_{\text{min}} \) is minimum relative displacement of the same storey.
Figure 2. Torsional irregularity check criteria as per IS 1893(Part 1): 2016[13]

And as per of IS1893(Part 1): 2002, “Torsional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure” [14]( Figure 3).

\[ \Delta_2 > 1.2 \left( \frac{\Delta_1 + \Delta_2}{2} \right) \]  

(2)

In eq. 2, \( \Delta_2 \) is maximum storey drift of the considered floor, \( \Delta_1 \) is minimum storey drift of the same storey and \( \left( \frac{\Delta_1 + \Delta_2}{2} \right) \) is average (\( \Delta_{\text{Avg}} \)) of storey drift.

Figure 3. Torsional irregularity checks as per IS1893(Part 1): 2002[14]

3. Modelling and Calculations

Two irregular building models with C shape and L shape plan were selected for experimental work. The models were generated by computer program STAAD.Pro CONNECT Edition (Structural Analysis and Design Program). Both the models had same sizes of beams and columns. All floors were rigid. Concrete walls were used to create torsional irregularity in the buildings (Figure 4aFigure 5). Seismic analysis was done by response spectrum method. Both the models were checked for same loading condition. The modelling data for the buildings is shown in Table 2.
Table 2: Modelling Data for C shaped and L shaped buildings

|                          |                         |
|--------------------------|--------------------------|
| Panel Size               | 5 m X 5 m                |
| Size of beam             | 350 mm X 250 mm          |
| Size of column           | 400 mm X 400 mm          |
| Thickness of plate       | 150 mm                   |
| Height of one storey     | 3.2 m                    |
| Material of beam, column and plate | Concrete             |
| Seismic Zone             | Zone V                   |
| Response reduction factor| 5                        |
| Importance factor        | 1                        |
| Soil condition           | Medium stiff             |
| Damping ratio            | 0.05                     |
| Floor diaphragm          | Rigid                    |

Figure 4. (a) C shape model plan (b) C shape model with concrete walls
C shaped model (Figure 4) was symmetric about X-axis and asymmetric about Z-axis while L shaped model (Figure 5) was asymmetric about both X and Z axis. For torsional irregularity checks, the extreme nodes and their displacements for both models were determined by STAAD.Pro which have been shown in Table 3 and Table 4.

**Figure 5.** (a) L shape model plan, (b) L shape model with concrete walls

For C shaped model, the displacements of extreme nodes in X-direction were found equal for all floors while in the Z-direction, the displacements were found different for all floors. This shows that the seismic response of C shaped building model was regular in X-direction and irregular in Z-direction.
Table 4: Extreme nodes and displacements in L shape model

| Diaphragm | Extreme Points of Dia. in X direction | Extreme Points of Dia. in Z direction |
|-----------|--------------------------------------|--------------------------------------|
|           | Node | Max. Disp. (mm) | Node | Min. Disp. (mm) | Node | Max. Disp. (mm) | Node | Min. Disp. (mm) |
| 1         | 1    | 0.00125         | 1    | 0.00093         | 13   | 0.00189         | 1    | 0.00112         |
| 2         | 65   | 0.00375         | 55   | 0.00279         | 67   | 0.00676         | 55   | 0.00371         |
| 3         | 92   | 0.00828         | 82   | 0.0615          | 94   | 0.01662         | 82   | 0.00879         |
| 4         | 119  | 0.01566         | 109  | 0.01164         | 121  | 0.03334         | 109  | 0.0173          |
| 5         | 146  | 0.02676         | 136  | 0.01995         | 148  | 0.05891         | 136  | 0.03028         |
| 6         | 173  | 0.04269         | 163  | 0.03167         | 175  | 0.09614         | 163  | 0.04895         |

For L shaped model, the displacements of extreme nodes in X-direction and Z-direction were found different for all floors. This shows that the seismic response of the L- shaped model was irregular in both X and Z-directions.

4. Results and discussion

The latest version of STAAD.Pro software has special commands for IS 1893 (Part 1): 2016[15]. It can also check for irregularities in the model and show the various irregularity checks in the output file. But STAAD.Pro cannot check for irregularities as per old IS 1893(Part 1): 2002 by itself. User has to do it manually. Torsional irregularity checks were performed for both the models. STAAD.Pro shows the torsional irregularity status as fail if the displacement ratio in any of the plan direction exceeds 1.5 as per new code (equation 1) while it is calculated manually as per old code (equation 2). Torsional irregularity checks for C-shaped model are given in Table 5.

Table 5 Torsional irregularity checks for C shape model

| Diaphragm | Torsional irregularity check as per IS 1893(Part 1): 2016 | Torsional irregularity check as per IS 1893(Part 1): 2002 |
|-----------|---------------------------------------------------------|---------------------------------------------------------|
|           | Ratio limit < 1.5 | Status | Ratio limit < 1.2 | Status |
| 1         | $\Delta X_{\text{max}}/\Delta X_{\text{min}}$ | 1.5686 | fail | $\Delta Z_2/\Delta \text{Avg}$ | 1.2213 | fail |
| 2         | $\Delta X_{\text{max}}/\Delta X_{\text{min}}$ | 1.6837 | fail | $\Delta Z_2/\Delta \text{Avg}$ | 1.2547 | fail |
| 3         | $\Delta X_{\text{max}}/\Delta X_{\text{min}}$ | 1.7397 | fail | $\Delta Z_2/\Delta \text{Avg}$ | 1.2699 | fail |
| 4         | $\Delta X_{\text{max}}/\Delta X_{\text{min}}$ | 1.7638 | fail | $\Delta Z_2/\Delta \text{Avg}$ | 1.2763 | fail |
| 5         | $\Delta X_{\text{max}}/\Delta X_{\text{min}}$ | 1.7742 | fail | $\Delta Z_2/\Delta \text{Avg}$ | 1.279  | fail |
| 6         | $\Delta X_{\text{max}}/\Delta X_{\text{min}}$ | 1.7828 | fail | $\Delta Z_2/\Delta \text{Avg}$ | 1.2813 | fail |

The displacement ratios in X-direction were 1.0 for all floors as per both the codes. This indicates that the model was torsionally regular in X- direction. In the Z-direction, displacement ratios exceeded their respective standard limits as per IS 1893(Part 1): 2016 and IS 1893(Part 1): 2002. This shows that the C shape model was torsionally irregular in Z-direction. As per both IS 1893(Part 1) codes, if the any...
building is torsionally irregular in either direction, it will be considered torsionally irregular. Hence C shape model was found torsionally irregular as per both IS 1893(Part 1) codes.

Torsional irregularity checks for L-shaped model are given in Table 6. The displacement ratios in both X and Z-direction, exceeded their respective standard limits as per IS 1893(Part 1): 2016 and IS (Part 1): 2002. This shows that the L-shaped model was torsionally irregular in both the direction as per both IS 1893(Part 1) codes.

Table 6: Torsional irregularity checks for L shape model

| Diaphragm | Torsional irregularity check as per IS 1893(Part 1): 2016 Ratio limit < 1.5 | Torsional irregularity check as per IS 1893(Part 1): 2002 Ratio limit < 1.2 |
|-----------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
|           | \( \Delta X_{max}/\Delta X_{min} \) | \( \Delta Z_{max}/\Delta Z_{min} \) | Status | \( \Delta X_{y}/\Delta \Delta_{x} \) | \( \Delta Z_{y}/\Delta \Delta_{z} \) | Status |
| 1         | 1.3441                           | 1.6875                           | fail   | 1.1468                           | 1.2558                           | fail   |
| 2         | 1.3441                           | 1.8221                           | fail   | 1.1468                           | 1.2913                           | fail   |
| 3         | 0.1346                           | 1.8908                           | fail   | 0.2373                           | 1.3081                           | fail   |
| 4         | 1.3454                           | 1.9272                           | fail   | 1.1473                           | 1.3167                           | fail   |
| 5         | 1.3414                           | 1.9455                           | fail   | 1.1458                           | 1.3210                           | fail   |
| 6         | 1.3480                           | 1.9640                           | fail   | 1.1482                           | 1.3252                           | fail   |

Graphs have been plotted between the percentage of displacement ratios, by which these exceeded the standard torsional irregularity limits as per respective seismic codes, and floor levels. Error! Reference source not found. Figure 6 shows the percentage variation of displacement in each storey in C-shaped model as per both IS 1893(Part 1) codes. The curve 1C and 2C are as per IS1893(Part 1): 2016 and IS1893(Part 1): 2002 respectively. From curve 1C and 2C, it was found, by calculations, that the percentage variation of displacement ratios for curve 1C was approximately 2.7 times more than that for curve 2C.

Figure 6. percentage variation of story displacement in C-shaped model

Figure 7 shows the percentage variation of displacement in each storey in L-shaped model as per both IS 1893(Part 1) codes. Curve 1L and curve 2L are as per IS1893(Part 1): 2016 and IS1893(Part 1): 2002 respectively. It was found that the percentage variation of displacement ratios for curve 1L was
approximately 2.8 times more than that for curve 2L. Hence new IS1893(Part 1): 2016 gives a clearer representation of torsional irregularity.

![Graph showing percentage variation of storey displacement in L-shaped model](image)

**Figure 7.** Percentage variation of storey displacement in L-shaped model

Although, the method of determination of torsional irregularity in new IS1893(Part 1): 2016 is different from the method described in old IS1893(Part 1): 2002, but it was found that C shaped model which was symmetric in one plan direction and L shape model which was non-symmetric in both plan directions, were torsionally irregular as per both old and new IS1893(Part 1) codes. Hence it can be said that a model which is torsionally irregular as per both old and new IS1893(Part 1) codes. Hence it can be said that a model which is torsionally irregular as per old IS1893(Part 1): 2002 code, is also torsionally irregular as per new IS1893(Part 1): 2016. Thus, we can say that new IS1893(Part 1): 2016 has not imposed the restriction on the torsional irregularity while the code has imposed restriction on other irregularities. The method for torsional irregularity check was found much simpler and gives clearer indication of torsional irregularity as compared to old IS1893(Part 1): 2002.

5. Conclusions

From the above calculations and observations, it can be concluded that:

- IS1893(Part 1): 2016 has not imposed any new restriction on torsional irregularity provision.
- The criteria for torsional irregularity check as per IS1893(Part 1): 2016 is more elaborated and simpler as compared to old IS 1893(Part 1): 2002. New seismic code gives about 2.7 times clearer indication of torsional irregularity in the building model.
- A building which is torsionally irregular as per old IS 1893(Part 1): 2002 will still be torsionally irregular as per new IS 1893(Part 1): 2016.
- Symmetry in plan direction of a structure extremely affects the seismic response of the structure. If structure has symmetry in one plan direction, then also story drift will be less in the building as compared to the building lacking symmetry in both plan direction.
- As Indian Seismic code has been revised, similarly seismic codes and structural design codes of other countries are also revised. Hence to analyse the performance of the building based on different design codes to determine the most efficient structure without compromising its earthquake safety, further comparative study of Indian Seismic Code and Seismic codes of other countries can be really beneficial for structural and earthquake engineers.
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