ASSESMENT OF TORSIONAL IRREGULARITY OF BUILDINGS FOLLOWING THE PROVISIONS OF INDIAN STANDARD THROUGH A CASE STUDY

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ABSTRACT A building is considered to be less vulnerable to seismic forces if there are no plan and vertical irregularities present in it. The detrimental effects of irregularities are mainly experienced when a structure is subjected to earthquake which may lead to considerable damage and even collapse of the structure. Torsional irregularity is one such plan irregularity which must be properly addressed while designing a structure. Irregular buildings constitute a large amount of the modern urban infrastructure. The structural engineer needs to have a proper knowledge of the seismic response of irregular structures. The buildings with plan irregularity and elevation irregularity come under this area. Buildings with structural irregularities experience different drifts of adjacent stories, excessive floor torsion etc. according to irregularity type and may fail during an earthquake. Problems incurred due to Torsional Irregularity take place when the mass center and center of rigidity are not located at the same place. By increasing distance between center of mass and center of stiffness, building is forced to twist in floor plans and the corner lateral load resisting elements will be subjected to great torsional moments. Excessive torsion causes columns and concrete walls to fail or undergo heavy damage. The latest version of IS 1893 (Part 1): 2016 provides a guideline for the designer to assess the presence of Torsional Irregularity in buildings. The designer must check corner displacements of a floor for a static load applied on it and compute the displacements at the corners. It also requires checking the fundamental modes of vibration and their corresponding time-period. This paper is intended to explain the process to be adopted for Torsional Irregularity evaluation using a case study.

Keywords: Vertical irregularity, Torsional irregularity, Center of mass, Center of stiffness.

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INTRODUCTION

It has been observed that buildings having irregularity in plan and vertical direction have been badly damaged in the past earthquakes. The current trends of multi-storied buildings have moved more towards an irregular plan with unsymmetrical arrangements of lateral load resisting elements to enhance aesthetic view of the building. These structures become weak to withstand seismic forces and they are prone to damages during earthquakes. Newly released Indian Standard for Earthquake Resistant Design of Structures has specifically provided guidelines to determine irregularities in buildings and rectifications procedure. The irregularities have been classified into two major portions namely plan irregularity and vertical irregularity. Restrictions on abrupt changes in mass and stiffness are imposed. Irregularities in dimensions affect the distribution of stiffness, and in turn affect capacity, while mass irregularities tend to influence the distribution of uneven seismic forces. Torsional responses in structures arise from two sources mainly. Eccentricity in the mass and stiffness distributions, causing a rotation response coupled with translation response. The torsion can arise from accidental causes, including uncertainties in the masses and stiffness, the differences in coupling of the structural foundation with the supporting earth or rock beneath and wave propagation effects in the earthquake motions that give a torsion input to the ground, as well as torsion motions in the earth itself during the earthquake [1]. It is important to take necessary action to evaluate torsional irregularity in the building model and take proper measure to rectify it. Indian Standard for Earthquake Resistant Design of Structures has provided a clear procedure to be adopted to evaluate torsional irregularity in building. The focus of this paper is to evaluate torsional irregularity in the building using the provisions of Indian standard for Earthquake Resistant Design using a case study.

MODIFICATION SUGGESTED IN THE PRESENT VERSION IS: 1893 PART 1

The mother code for Indian Earthquake resistant design [2] has been revised. This standard has mandated the checks for plan irregularity and vertical irregularity. Plan irregularity has been subdivided into irregularities coming from Torsion Irregularity, Re-entrant Corners, Floor slabs having excessive cut-outs or openings, Out of plane offsets in vertical elements, Non-parallel lateral force system. Vertical irregularity consists of Stiffness Irregularity – Soft Storey, Mass Irregularity, Vertical Geometric Irregularity, In-plane Discontinuity in Vertical Elements Resisting Lateral Force.

Torsional irregularity [5] has been clearly cited in this standard. A building is considered to be torsionally irregular, when 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 the far end in that direction. These criteria have been explained in Figure 1.

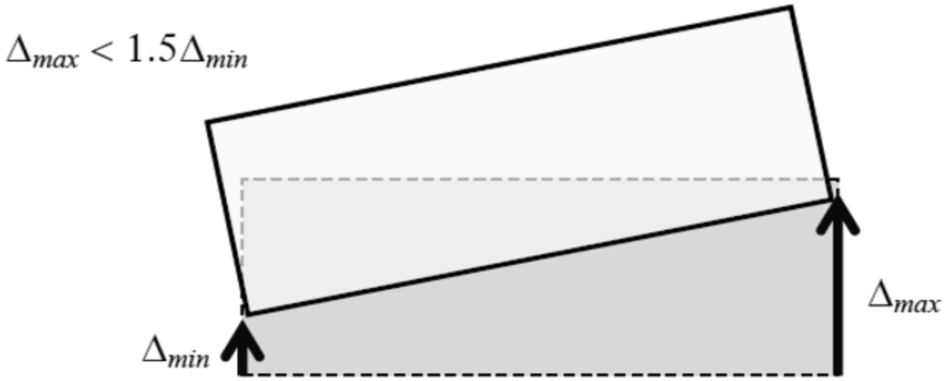

Figure 1 Condition for being torsionally irregular considering edge displacements [2]

Another check needs to be performed - to check whether the natural period [6] corresponding to the fundamental torsional mode of oscillation is more than those of the first two translational modes of oscillation along each principal plan direction to categorise the building to be a torsionally irregular [5]. The designer needs to perform modal extraction to get fundamental mode of oscillation and corresponding time-period. Provisions for torsional irregularity [5] have been investigated with respect to a real-life case study.

DETAILS OF CASE STUDY

A typical G+4 storied residential building in a residential area of Jalpaiguri, West Bengal has been identified as a typical model for case study. The model of the building has been developed using STAAD.Pro CONNECT Edition by designer. The span of the building is quite large in one dimension and structural walls are unsymmetrically placed. This building can be candidate for torsional irregularity and it is the guiding factor to consider it for this case study.

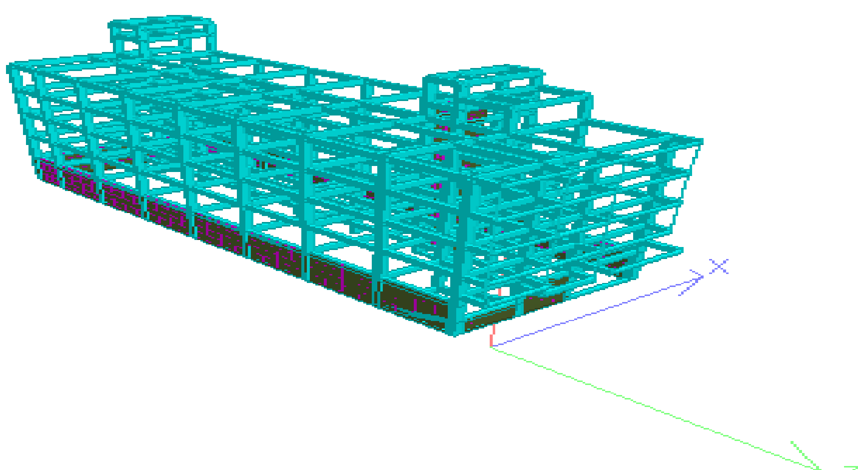

Figure 2 Isometric view of prototype model developed in STAAD.Pro CONNECT Edition

Plan dimension of the building are 40.625m and 13.135m. Height of the building is 15.2m. The building contains 250mm x 550 mm concrete beams and 500mm x 350mm columns. The model was created with moment resisting frames and 250mm thick retaining walls.

The model was analysed for Dead Load, Live Load, Seismic Load and Wind Load. Load combination was created considering the provisions of IS: 1893(Part 1): 2016[2] and IS: 456-2000[3]. Dead Load consists of self-weight of the building, dead weight of the slab (5.325 kN/m), brick infill load (15.811 kN/m). Live load intensity considered in the building was 4 kN/m^2. For wind load calculation, the following parameters were considered: Basic Wind Speed (V_b) = 50 m/s, Terrain category - 3, CLASS –B as per IS875 (Part3) [4]. The following parameters were considered for seismic analysis:

Table 1 Seismic Analysis Parameters

DESCRIPTION	VALUE
Seismic Zone (Z) =	0.24
Response Reduction factor (RF) =	5
Importance factor (I) =	1.2
Rock and Soil site factor (SS) =	2 (Medium soil)

DISCUSSION ON RESULTS

The structural model created in the software has been studied to investigate torsional irregularity following the provisions of Indian standard for Earthquake Resistant Design [6]. Third floor of the building has been considered to check the corner displacements. $\square_{min}$ and $\square_{max}$ obtained in this floor are 6.055 mm and 11.481 mm respectively. It has been observed that $\square_{max} > 1.5\ \square_{min}$ [2]. These results are reported in Figure 3.

3D structural model has further developed, and modal analysis performed using STAAD Pro CONNECT Edition. It has been observed that the first natural mode of vibration is not a pure translation mode rather it is a coupled torsional mode. Second mode is a translation mode (in Z direction) and the third mode is a torsional mode. These can be viewed graphically from the modal analysis results. Figure 4 shows the first three mode shapes.

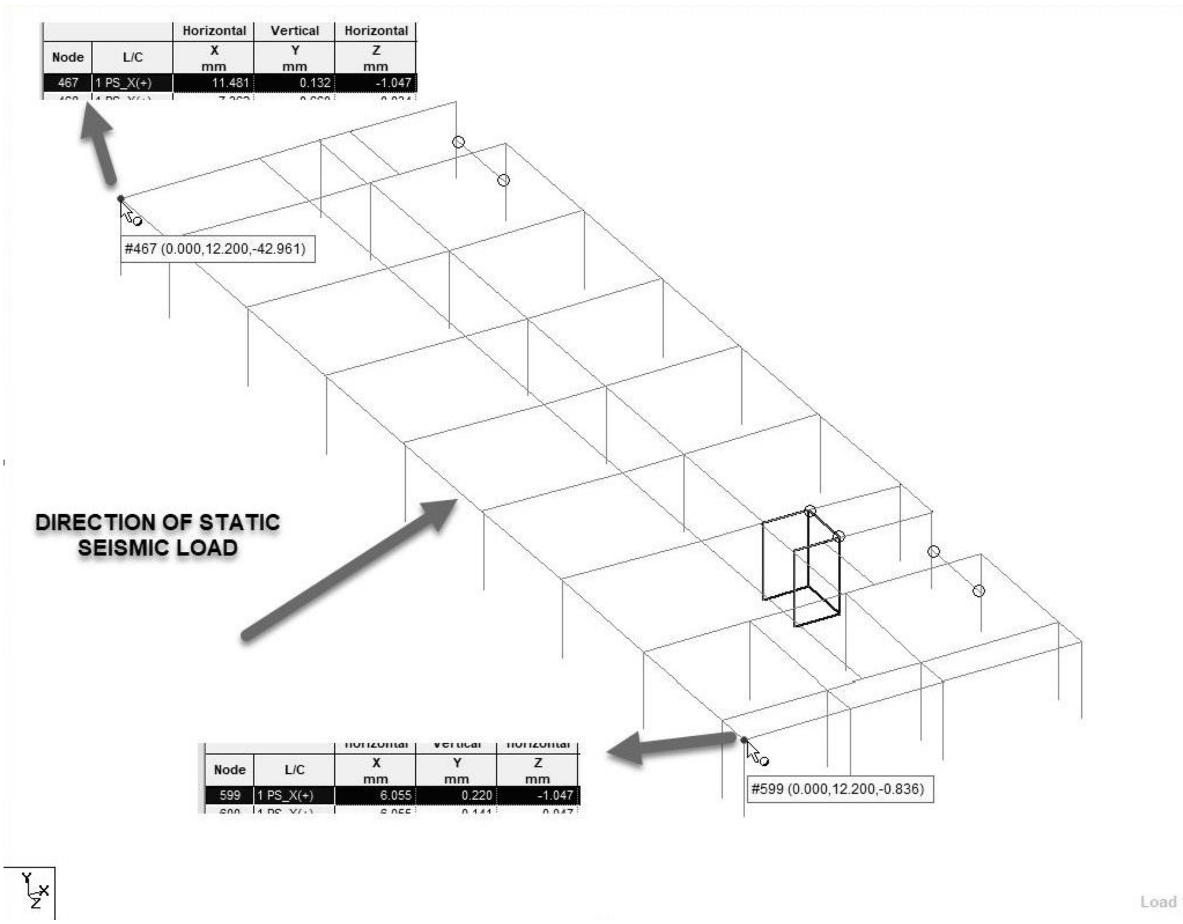

Figure 3   Displacements obtained at the corner nodes for static seismic force

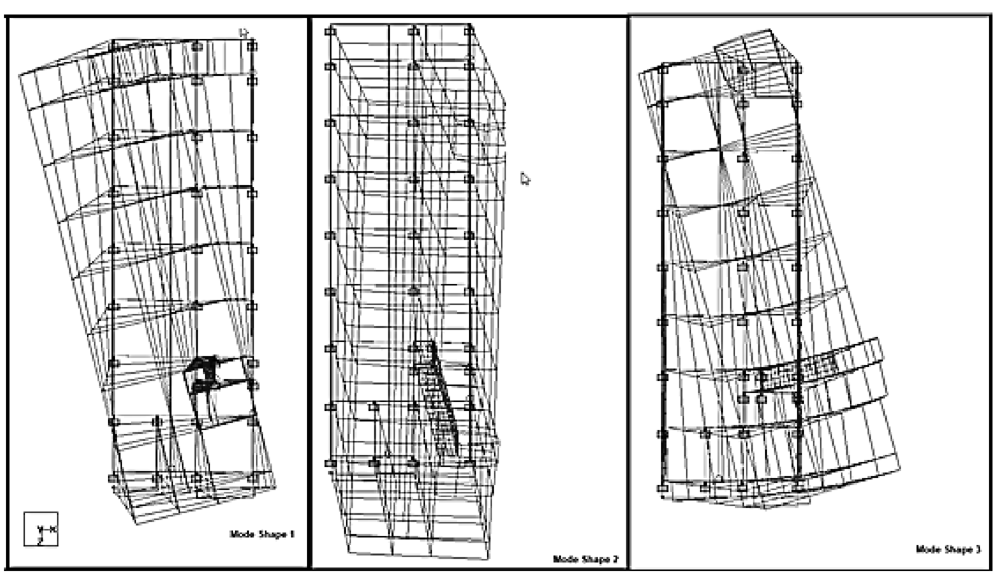

Figure 4   First three natural modes of vibration

Figure 5 shows time-period of different modes. Torsional mode is having higher time-period than the translational mode. These invariably indicates that this building is having torsional irregularity [5].

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %	Type
1	1.429	0.700	30.443	0.013	5.807	Elastic
2	1.557	0.642	7.393	0.001	57.666	Elastic
3	1.736	0.576	31.902	0.007	1.814	Elastic
4	4.203	0.238	2.864	0.042	0.472	Elastic
5	4.320	0.232	0.133	0.004	2.328	Elastic
6	5.686	0.176	3.032	0.112	6.606	Elastic
7	6.026	0.166	7.707	0.043	1.973	Elastic
8	6.486	0.154	0.067	0.000	0.227	Elastic
9	6.789	0.147	0.000	0.009	0.112	Elastic
10	6.924	0.144	0.000	0.026	0.073	Elastic
11	7.401	0.135	0.005	19.896	0.000	Elastic
12	7.452	0.134	0.021	4.428	0.000	Elastic
13	7.841	0.128	0.000	0.583	0.002	Elastic
14	7.863	0.127	0.003	0.337	0.000	Elastic
15	7.918	0.126	0.001	0.025	0.000	Elastic
16	8.068	0.124	0.066	0.009	0.000	Elastic
17	8.132	0.123	0.006	0.003	0.001	Elastic
18	8.231	0.121	0.000	0.020	0.000	Elastic
19	8.264	0.121	0.092	1.051	0.000	Elastic

Figure 5 Time period of different fundamental modes

GUIDELINE TO THE DESIGNER FOR REDUCING TORSIONAL IRREGULARITY IN THE BUILDING

The building model discussed in the case study requires a redistribution of stiffness of lateral load resisting elements according to the distribution of mass to overcome the torsional irregularity problem. Increasing the outer column dimensions along the periphery increases lateral stiffness and setting the outer column dimension to 500 mm x 500 mm may rectify the torsional irregularity problem. Behaviour of buildings under earthquakes is primarily controlled by configuration, stiffness, strength and ductility. Proper distribution of stiffness is required as per the distribution to the mass of the building. A well-proportioned building should not have any torsional irregularity.

It is not good to have buildings with large plan aspect ratio. During earthquake shaking, it is preferred to distribute this lateral inertia force to various lateral load resisting systems in proportion to their lateral load resisting capacities. This is achieved when the floor slabs do not deform too much in their own (horizontal) plane. This condition, when floor slab helps in distributing the inertia force to different lateral load resisting systems in proportion to their stiffness, is known as rigid diaphragm action. Floor slabs in buildings with large plan aspect ratio (>3) may not provide rigid diaphragm action [2]. Thus, this condition has to be considered while designing a building.

CONCLUSION

A well-proportioned building does not twist significantly about its vertical axis if stiffness distribution of the vertical elements resisting lateral loads is properly balanced in plan considering the distribution of masses lumped at each storey and the floor slabs are stiff in their own plane. If these criteria are properly followed a building model should not have torsional irregularity. In irregular buildings, it is hard to achieve these. The provisions stipulated in IS 1893 Part-1: 2016 for checking torsional irregularity should be adhered to evaluate torsional irregularity.

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