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A Case Study on Torsional Irregularity in Accordance with the Latest Amendment of IS 1893 (Part I) 2016-2020

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Abstract - *Ideally, a building should be of a regular geometric shape without any sort of non-uniform distribution of the mass or stiffness, but this is not possible in the real world. Sometimes a building with typical rectangular, regular shape in plan, may exhibit huge torsional moments due to asymmetric positioning of the lift well, which is a box-type shear wall and contribute a fair amount of stiffness to that location. This torsion is produced due to the locational difference between the center of mass (CM) and center of stiffness (CS) which may lead to collapsing of buildings during seismic excitation. The definition of torsionally irregular structure has been changing through the years and the latest amendment 2 of IS 1893:2016 (November 2020) is stricter than ever before. In the view of the severity of the torsional irregularity on buildings under seismic forces, a case study is conducted to evaluate maximum displacements at both ends of the building and check the acceptance limit.*

***Key Words*: Torsional irregularity, Seismic analysis, Stiffness, Displacement.**

1. INTRODUCTION

The code-specified recommendations have some great importance though they can resist moderate earthquakes and resist major earthquakes without collapsing. Actual forces strikes are more than the forces considered in the code as one cannot make the structure foolproof against severe ground shakings [1]. The new amendment of the code tries to narrow the gap between these two.

Code complaint structures surely exhibit excellent performances under seismic excitation up to a considerable extent. If the effect of the structural irregularities of higher degrees is ignored, it is carefully analysed with no stone unturned. IS Code allowing engineers to use it as a guideline and strictly following the guidelines may save a lot of life and property. One of the major irregularities which can cause devastating effect is torsional irregularity can twist the building in the horizontal plane. To resist the effect of torsional forces most common restraints are shear wall and rigid floor diaphragm. This study is aimed at the compatibility of torsional displacement results with the new amendment for the structure with the asymmetrical placement of shear walls.

2. PROBLEM STATEMENT

A typical regular building of an eight-story high is considered in seismic zone III. Though it is a regular one in shape and medium-high building situated at zone III. The architectural demand makes this building vulnerable to irregularity as the architect has placed the lift well on the extreme end of the plan. Moreover, there is no scope for providing shear walls at weaker direction in the opposite zone to balancing the rigidity and mass [2]. The front zone is to be used for commercial purposes and thus open stories are essential. Now the structure became torsionally irregular due to incorrect placement of the lift well [3].

3. OBJECTIVE

- To study and compare torsional irregularity recommendations in the latest amendment for IS 1893(Part-I) 2016-2020 [4] with the previous one.
- To study the amount of torsional irregularity, present as per the latest amendment.
- To find a possible solution if any without altering the architectural arrangement.

4. METHODOLOGY

4.1 IS Code Recommendation

The ratio of torsional displacement at two ends of a building is strictly specified at 1.5 for every floor of the building. Furthermore, if the ratio lies between 1.5-2.0, it is mandatory to observe that the natural period (in seconds) of the first torsional mode shall be smaller than the first two transitional periods for two horizontal orthogonal directions [5]. If the ratio comes out as more than 2.0, the structure must be reconfigured.

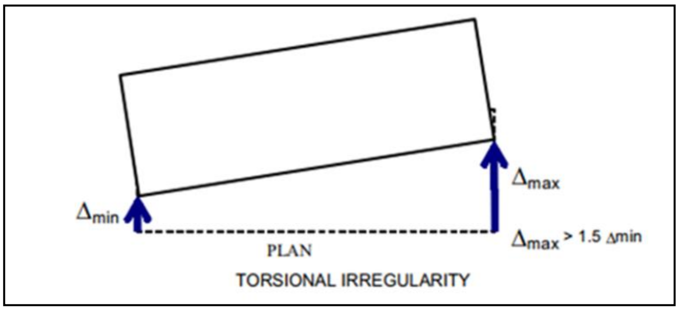

Fig -1: Torsional irregularity condition as per IS 1893(Part-1) 2016

The above recommendation has been completely altered in the new amendment-2 for IS 1983 (Part-1) 2016-2020. It states that if the maximum horizontal displacement Δ_{max} lies in between 1.2 Δ_{ave} to 1.4Δ_{ave}, torsional irregularity exists and if this value is more than 1.4 Δ_{ave}, the structure shall be revised.

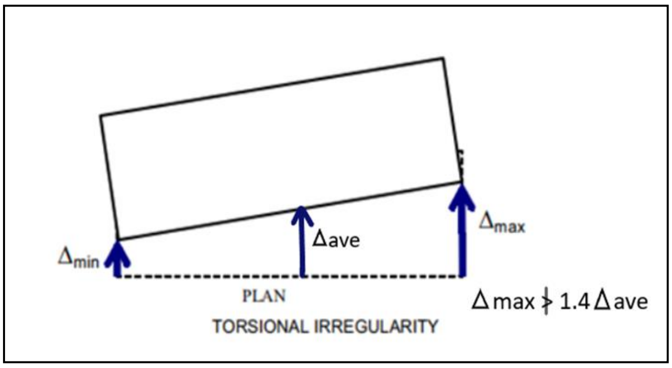

Fig -2: Torsional irregularity condition as per amendment-2 for IS 1893(P-1) 2016-2020

4.2 Modelling

The building structure is a 10mX30m regular structure with and without a shear wall. Column and beam size considering strong column-weak beam theory and slab used as the rigid diaphragm. The live load has been reduced as per code norms for the seismic analysis. All dead and live loads are taken as per IS:875 1987 [6] and the reduction of the live load is done for the seismic mass calculation.

Table -1: Building general specifications

Number of storey	8
Column Size	0.3mX0.8 m
Size of beam	0.3mX0.5m
Base Support	Fixed
Total number of bays per floor (x)	2 of 5.0m each
Total number of bays per floor (z)	6 of 5.0m each
Thickness of Slabs	150 mm
Thickness of Shear wall	200 mm
Height of each floor	3.0 m
Floor finish	1kN/m2
Partition Walls	1kN/m2
Live Load	3 kN/m2
Concrete Grade	M-30
Grade of Steel	Fe-500
Seismic Zone	III
Soil Condition	Medium
Software Used	STAAD.Pro Connect Edition

Three different arrangements for the same building are analysed as shown below named model 1, model 2 and model 3 with shear walls position marked.

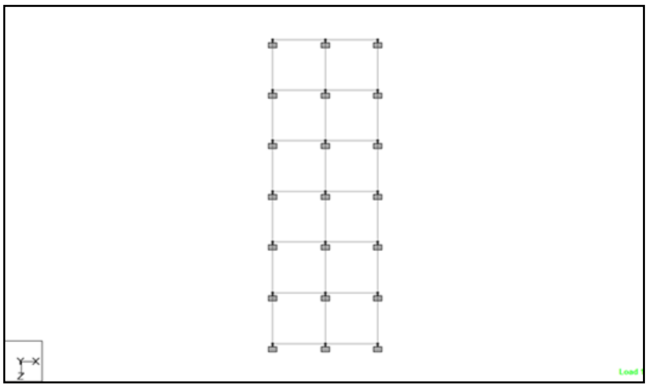

Fig-3: Plan view of bare frame with no shear wall, model 1

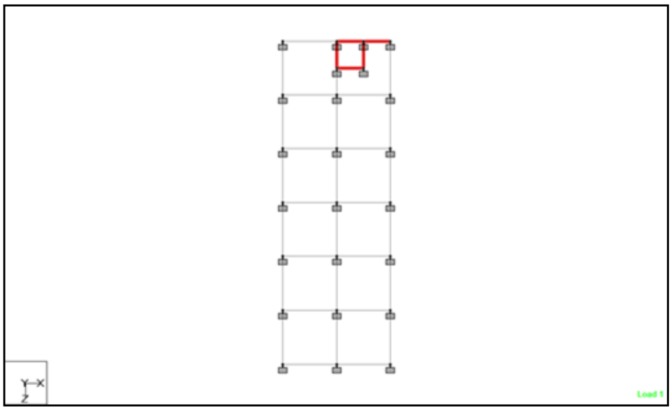

Fig-4: Plan view of structure with lift well as shear wall at back, model 2

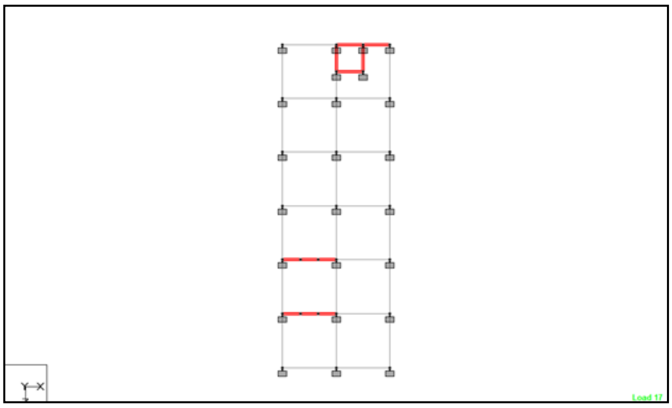

Fig-5: Plan view of structure with shear wall at front and back, model 3

These structures with torsional irregularities present are analysed with dynamic analysis following IS code guidelines using the response spectrum method.

5. RESULT AND DISCUSSION

5.1 Displacements

Following figures are representations of deflected shape of the joints. Comparing these shapes, the difference in maximum joint displacement is critical for the model 2, in which the front side of the building is displaced much more than its backside due to the presence of a lift well at back. Thus, the torsional irregularity present in this model is maximum.

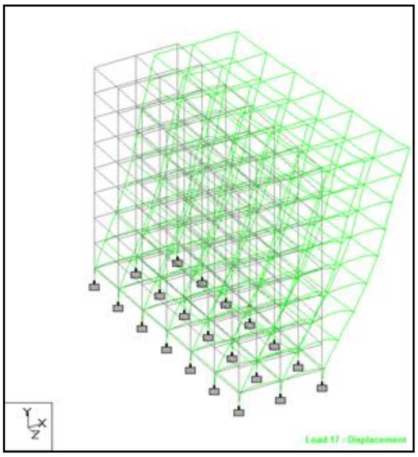

Fig-6: Deflected shape of bare frame, model 1

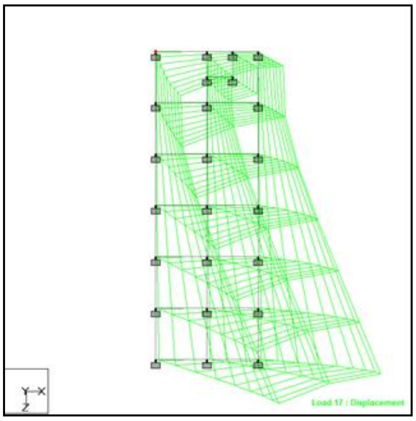

Fig-7: Deflected shape of structure having lift well at back side, model 2

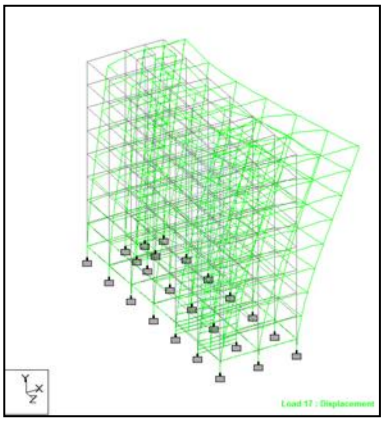

Fig-8: Deflected shape of structure shear wall at front and back, model 3

5.2 First torsional mode shape and fundamental period of vibration

Torsional mode shapes are shown in Figures below and corresponding fundamental time periods are tabulated. Model 3 shows a considerably lesser period value as expected [7,8].

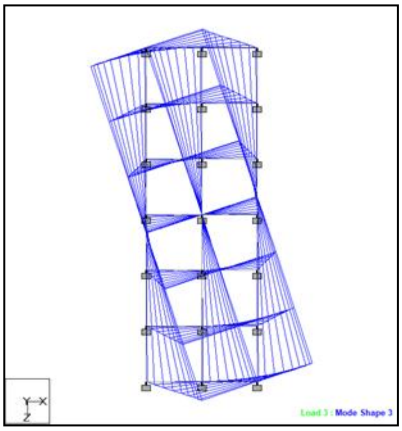

Fig-9: First torsional mode shape for model 1

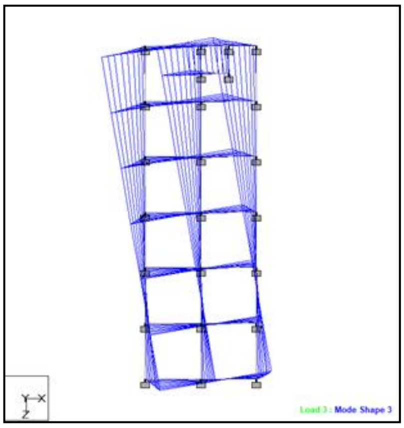

Fig-10: First torsional mode shape for model 2

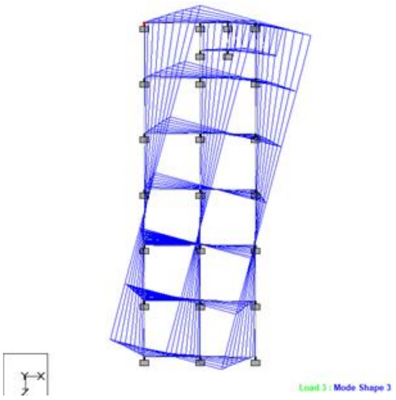

Fig-11: First torsional mode shape for model 3

Table -2: Period corresponding to fundamental natural frequency and first torsional mode.

Model	Mode	Period in seconds
1	1 (Translational)	2.142
	2 (Translational)	1.756
	3 (Torsional)	1.635
2	1 (Translational)	1.692
	2 (Translational)	1.348
	3 (Torsional)	0.781
3	1 (Translational)	1.388
	2 (Translational)	0.854
	3 (Torsional)	0.771

5.3 Torsional irregularity checks

Torsional irregularity checks and displacement values on each floor are checked as per code restriction and shown in Tables below. Two checks are performed as per the new amendment of the code, $\Delta_{max}/\Delta_{min}$ and $\Delta_{max}/\Delta_{ave}$ compared with their respective recommended value.

Table -3: Extreme points node and displacements for model 1

Floor	Extreme Points of Diaphragm in X				Extreme Points of Diaphragm in Z			
	Node	Disp.(mm)	Node	Disp.(mm)	Node	Disp.	Node	Disp.
1	63	0.00907	43	0.00907	45	0.02444	43	0.02444
2	84	0.02454	64	0.02454	66	0.05128	64	0.05128
3	105	0.04345	85	0.04345	87	0.07862	85	0.07862
4	126	0.06402	106	0.06402	108	0.10615	106	0.10615
5	147	0.08563	127	0.08563	129	0.13385	127	0.13385
6	168	0.10817	148	0.10817	150	0.16178	148	0.16178
7	189	0.13197	169	0.13197	171	0.18997	169	0.18997
8	210	0.15952	190	0.15952	192	0.21894	190	0.21894

Table -4: Torsion irregularity checks for model 1

Floor	X- Δ_{max} / Δ_{min}	Z- Δ_{max} / Δ_{min}	Ratio 1.5 check	X- Δ_{ave}	Z- Δ_{ave}	Ratio check 1.2-1.4		
						X- Δ_{max} /Δ_{ave}	Z- Δ_{max} / Δ_{ave}	Comment
1	1.0000	1.0000	OK	1.0000	1.0000	1.0000	1.0000	OK
2	1.0000	1.0000	OK	1.0000	1.0000	1.0000	1.0000	OK
3	1.0000	1.0000	OK	1.0000	1.0000	1.0000	1.0000	OK
4	1.0000	1.0000	OK	1.0000	1.0000	1.0000	1.0000	OK
5	1.0000	1.0000	OK	1.0000	1.0000	1.0000	1.0000	OK
6	1.0000	1.0000	OK	1.0000	1.0000	1.0000	1.0000	OK
7	1.0000	1.0000	OK	1.0000	1.0000	1.0000	1.0000	OK
8	1.0000	1.0000	OK	1.0000	1.0000	1.0000	1.0000	OK

Table -5: Extreme points node and displacements for model 2

Floor	Extreme Points of Diaphragm in X				Extreme Points of Diaphragm in Z			
	Node	Disp.(mm)	Node	Disp.(mm)	Node	Disp.	Node	Disp.
1	63	0.01110	43	0.00048	45	0.00437	43	0.00494
2	84	0.02974	64	0.00146	66	0.01012	64	0.01153
3	105	0.05218	85	0.00351	87	0.01845	85	0.02066
4	126	0.07621	106	0.00697	108	0.02970	106	0.03245
5	147	0.10099	127	0.01218	129	0.04416	127	0.04711
6	168	0.12629	148	0.01948	150	0.06234	148	0.06506
7	189	0.15239	169	0.02927	171	0.08515	169	0.08715
8	210	0.16219	190	0.04893	192	0.11446	190	0.11368

Table -6: Torsion irregularity checks for model 2

Floor	X- Δ_{max} / Δ_{min}	Z- Δ_{max} / Δ_{min}	Ratio 1.5 check	X- Δ_{ave}	Z- Δ_{ave}	Ratio check 1.2-1.4		
						X- Δ_{max} /Δ_{ave}	Z- Δ_{max} / Δ_{ave}	Comment
1	******	1.1291	FAIL	0.0058	0.0047	1.9138	1.0511	FAIL
2	******	1.1389	FAIL	0.0156	0.0108	1.9064	1.0676	FAIL
3	******	1.1195	FAIL	0.0278	0.0196	1.8770	1.0541	FAIL
4	******	1.0928	FAIL	0.0416	0.0311	1.8320	1.0434	FAIL
5	8.2914	1.0668	FAIL	0.0566	0.0456	1.7843	1.0331	FAIL
6	6.4833	1.0437	FAIL	0.0729	0.0637	1.7324	1.0218	FAIL
7	5.2055	1.0235	FAIL	0.0908	0.0862	1.6783	1.0110	FAIL
8	3.3149	1.0068	FAIL	0.1056	0.1141	1.5359	1.0032	FAIL

Table -7: Extreme points node and displacements for model 3

Floor	Extreme Points of Diaphragm in X				Extreme Points of Diaphragm in Z			
	Node	Disp.(mm)	Node	Disp.(mm)	Node	Disp.	Node	Disp.
1	63	0.00116	43	0.00072	45	0.00447	43	0.00449
2	84	0.00283	64	0.00202	66	0.01041	64	0.01029
3	105	0.00570	85	0.00437	87	0.01891	85	0.01851
4	126	0.01009	106	0.00809	108	0.03024	106	0.02941
5	147	0.01627	127	0.01346	129	0.04466	127	0.04326
6	168	0.02458	148	0.02082	150	0.06265	148	0.06051
7	189	0.03542	169	0.03056	171	0.08509	169	0.08201
8	210	0.04139	190	0.04978	192	0.11357	190	0.10832

Table -8: Torsion irregularity checks for model 3

Floor	X- Δ_{max} / Δ_{min}	Z- Δ_{max} / Δ_{min}	Ratio 1.5 check	X- Δ_{ave}	Z- Δ_{ave}	Ratio check 1.2-1.4		
						X- Δ_{max} /Δ_{ave}	Z- Δ_{max} / Δ_{ave}	Comment
1	1.6111	1.0044	FAIL	0.0009	0.0045	1.2889	0.9978	FAIL
2	1.4013	1.0117	OK	0.0024	0.0104	1.1792	1.0001	OK
3	1.3042	1.0218	OK	0.0050	0.0187	1.1400	1.0112	OK
4	1.2474	1.0282	OK	0.0091	0.0298	0.8890	1.0148	OK
5	1.2087	1.0324	OK	0.0149	0.0440	1.0920	1.0150	OK
6	1.1804	1.0354	OK	0.0227	0.0616	1.1366	1.0170	OK
7	1.1592	1.0376	OK	0.0330	0.0836	1.0733	1.0178	OK
8	1.2027	1.0485	OK	0.0456	0.1109	1.0917	1.0241	OK

6. CONCLUSIONS

It is clearly distinguishable from the deflected shapes of the models, that, in model 2, the backside of the building is restrained by the lift well shear walls which give an enormous difference of displacement on the front portion along the X-axis under the seismic excitation. In model 3, shear walls are provided in the front zone, able to reduce relative displacements at both ends of the building. The model 3 exhibits a low period value for the fundamental natural period which depicts that a building with higher period of vibration is more vulnerable to seismic excitations.

Model 1 shows no differences in displacement at two ends for both principal directions, no such torsional irregularity is found. In model 2, as the lift introduced at the back, it shows major differences in X direction and both the ratio checks are failed for all floors. This model 2 is not recommended at all.

Torsional irregularity checks show an interesting aspect of the new amendment of the code. When the ratio of $\Delta_{max}/\Delta_{min}$ is valid for all floors, the ratio of $\Delta_{max}/\Delta_{ave}$ comes out below 1.2 which is also valid for the newly introduced criteria and vice versa. Hence it is observed that, if the building passes as per the previous code in terms of torsional irregularity, it will surely pass following the criteria stated in the new amendment.

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BIOGRAPHIES

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