Verification of the Sufficiency of Adjustment of Mass for compensating the Accidental Eccentricitics IS 1893:2016 Clause7.8.2

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Verification of the Sufficiency of Adjustment of Mass for Compensating the Accidental Eccentricities (IS 1893:2016 clause 7.8.2)

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Abstract

Twisting of a building about vertical axis increases the shear force demand on lateral force resisting elements and it is not desirable as increased shear force results in brittle failure. Generally, twisting is induced in a building due to eccentricity between Centre of Mass (CM) and Centre of Stiffness (CS) at diaphragm level. Eccentricity can be induced in a structure due to mass, strength and stiffness arising out of various construction and design limitations. Code insists to apply design forces calculated according to equivalent static method or response spectrum method at displaced centre of mass (CM) so as to cause design eccentricity between CM and CS. The displaced centre of Mass resulting from design eccentricity consists of two terms i.e., static eccentricity and accidental eccentricity. Also, earthquake ground motion has the ability to induce torsion in a structure. Hence, in order to account for all the eccentricities, code suggests 5% accidental eccentricity to be included in design eccentricity. In current work, an adjustment of mass eccentricity is verified. For this purpose, three one storey models are created with 5% unidirectional mass eccentricity (CM), 5% unidirectional stiffness eccentricity (CS) and 5% unidirectional Mass-Stiffness eccentricity (CM-CS). Linear Incremental Dynamic Analysis is performed by considering Chamoli earthquake and edge displacements are obtained. Later, twist is calculated based on edge displacements. It is concluded that with same amount of mass and stiffness eccentricity (i.e., 5%), the twist incurred in stiffness eccentric model is significantly higher whereas no twist about vertical axis is noticed in mass eccentric model. Unless mass eccentricity has significant impact on torsional response, the torsional response of combined CM-CS eccentric model is approximately equal to CS eccentric model. The results conclude that universal adjustment of centre of mass will not provide the assumed conservativeness of safety against torsion. Apart from this, few countries guidelines like New Zealand [NZS, 2004] had revised accidental eccentricity from 5% to 10%. Hence,

design eccentricity needs revision considering the statistical evaluation of various parameters inducing accidental eccentricities, without adjusting mass centre for every eccentricity.

Introduction

One of the main issues of plan irregular structures is torsion. Problem of earthquake induced torsion is not new and it received attention from the past many years but still remains as an open problem. Studies on plan irregular buildings is divided into two groups i.e., one storey models and Multi storey models. One storey models are used when simplification is necessary whereas multi storey building models are used to understand the complex nature of plan asymmetric models. Formulating the guidelines requires simplification of the problem and hence most of the guidelines formulated by different countries are based on one storey models and the scenario of improving the existing nonlinear analysis methods or proposing new methods require multi storey models. Based on the studies conducted on one storey models, codes suggested considering accidental eccentricities for accounting uncertainties arising out of either ground motions or irregularities present in structure. Accidental Eccentricities occurs in a structure due to variety of reasons like configuration, displaced mass, strength and stiffness centres from geometrical centroid. Mass eccentricity arises in a structure because of live loads, placements of equipment, operational loads etc. Stiffness eccentricity arises in a structure due to column alignment, accidental variation in column cross section sizes; location of shear wall and staircase etc and strength eccentricity arises due to stiffness dependent strength distribution and variation in reinforcement distribution etc.

Though behaviour of structures subjected to torsion is ill understood, the impact of torsion on the building is well understood. Hence, code of practice recommends and sets limitations on various factors enhancing torsion. The Indian standard code of practice IS 1893:2016 addresses torsions with the help of the parameters outlined below. Same set of parameters are compared with other country codes in Table 1.

a. Torsional Irregularity

b. Consideration of accidental eccentricity

c. Amplification factor for static eccentricity

Table 1 : Comparison Torsion provisions adopted by different codes [IS 1893, 2016], [ASCE, 2016], [BS EN, 2004], [NZS, 2004]

Comparison parameter	IS1893:2016	ASCE 2016	BS EN 2004	NZS:2004
Torsional Irregularity	$\Delta_{min} > 1.5\Delta_{max}$ $T_\theta > T_x or T_y$	$drift_{ends} > 1.2 drift_{Avg}$	$e < 0.3r$ $r > l$	$\frac{d_{max}}{d_{avg}} < 1.4$
Accidental Eccentricity	$\pm 0.05\ b$	$\pm 0.05\ b$ or A(0.05b) $A_x = \left(\frac{\delta_{max}}{1.2\delta_{avg}}\right)^2$	$\pm 0.05\ b$	$\pm 0.1\ b$
Amplification factor for static eccentricity	1.5	-	-	-

Further, according to the code, the design eccentricity, e_di to be used at floor i is obtained by

$$e_{di} = \frac{1.5\, e_{si} + 0.05b}{e_{si} - 0.05b} \qquad (1)$$

Where,

e_{si} is the distance between centre of mass and centre of stiffness

b is the floor plan dimension perpendicular the direction of force.

Factor 1.5 represents the dynamic amplification factor. Code also mentions that factor 1.5 is not needed when Time history analysis is performed. The factor 0.05b represents the extent of accidental eccentricity. The design eccentricity is multiplied by lateral force to get the torsional moments.

It was understood that the above-mentioned suggestions by the code are an outcome of the extensive research on the one storey plan eccentric models, which started in the early 20th century. Ayre (1938) made the first attempt for conducting theoretical and experimental investigation of simple eccentric one storey and two storey models for identifying the coupling between the transitional and rotational motion. He pursued the torsion problem based on stiffness centre and principle axes of plan as it was thought stiffness centre is ideal parameter for pursuing torsion problem in early days. Later, Housner and Outinen (1958) used simplified 2DOF systems and concluded that stresses on flexible side are amplified. But it was Bustamante and Rosenblueth (1960) comments that changed the way in which plan irregular torsion problem is studied. They commented that the rough estimate of Multi-storey can be obtained from the response of single storey structures having same characteristics. These remarks set the tone for further research in simplified one storey plan irregular structures. Plenty of literature is available on one storey and multi storey plan eccentric models but papers contradict with other paper.

From the past two and half decades, accidental eccentricity remained the focus of study and percentage of accidental eccentricity to consider in deriving design eccentricity is always under study as this parameter addresses uncertainty associated with eccentricities incurred due to physical and ground motion characteristics as well. Some counties like New Zealand and Mexico increased the value of accidental eccentricity from 5% to 10%. The basis for such modification can be taken from the work of Pekau and Guimond (1990), who studied the sufficiency of accidental eccentricity to account for torsion. They concluded that code prescribed 5% accidental eccentricity is inadequate. Similarly, Duan and Chandler (1991) carried out analytical studies on single storey models and recommended change in design eccentricity value for Mexico code of practice. In order to study the sufficiency of current codal provision for restricting torsion, a case study is conducted on a simple plan asymmetry by modifying the Mass centre by 5% in model1, stiffness centre by 5% in model 2 and both stiffness centre and mass centre by 5% in model 3 and the torsional response is compared

Case Study : One story Mass and stiffness eccentric models

Eccentricity induced in a structure can be broadly classified as physical eccentricity (i.e., eccentricity created because of mass, stiffness and strength) and eccentricity created by ground motion due to variety of reasons associated with source, path and site effects. In order to cater to the needs of uncertainty associated with physical and ground motions characteristics, it was proposed to introduce a parameter, accidental eccentricity of 5% along lateral dimension perpendicular to the application of ground motion, in addition to static eccentricity. The total eccentricity is known as design eccentricity and the mass centre is moved by the value equivalent to design eccentricity. Later, design eccentricity is multiplied by lateral forces to get the torsional moments. But the question is the sufficiency of shifting mass eccentricity for compensating other physical eccentricities. For example, let us consider two scenarios i.e., i) operational load on one side of the frame is increased and centre of Mass (CM) is shifted from geometrical centroid by 0.05b and ii) slight difference in column cross-section sizes with an assumption linked to erection by same amount of eccentricity say 0.05b is created. Ideally for one storey framed structure, the torsional behaviour exhibited by both the models i.e., scenario 1 and scenario 2 should be almost same though slight differences do exist.

To verify the torsional response of models with different eccentricities, one storey regular building with orthogonal load resisting elements is considered. Figure 1 shows the 3 dimensional model with CM and CR coinciding with geometrical centriod (CG). Table 2 shows the geometric and loading details. The building is modelled using standard structural engineering software.

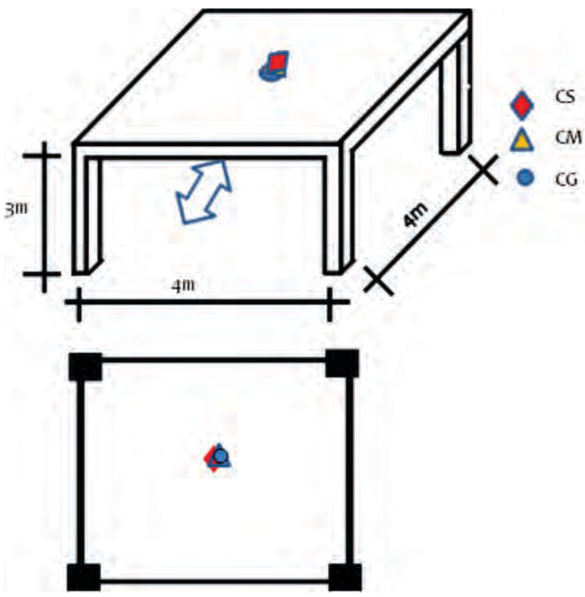

Figure 1 : 3D view and plan of one storey building

Table 2 : Geometric and Loading details of building considered

Geometric Details	
No. of bays in x and y directions	1
Length of each bay in x and y directions	4m
Floor to floor height	3m
No. of floors	1
Slab thickness	0.15 m
Loading Details	
Floor finish load	1 kN/m^2
Live load on slab	1.5 kN/m^2 on roof
Seismic weight in x and y directions	124.5kN
Time period in x and y directions	0.11 sec

Later, 3 models were created with an assumed accidental eccentricity of 5%. Figure 2(a) shows the model with displaced CM by 0.2 m (0.05b), Figure 2(b) shows the model with displaced CS by 0.2m (0.05b) and Figure 2(c) shows the model with displaced CM-CR.

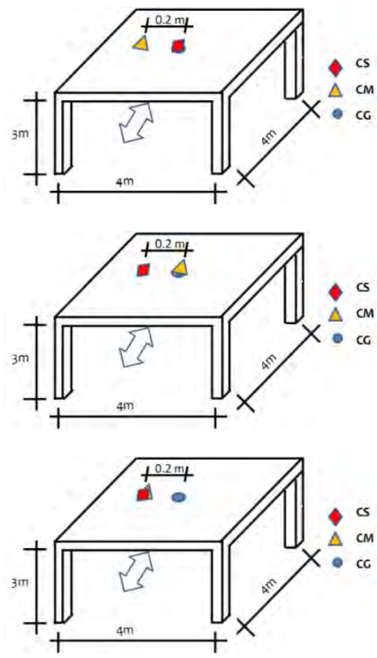

Figure 2 : (a) Mass eccentric model at a distance of 0.2m from geometric centroid; **(b)** Stiffness eccentric model at a distance of 0.2m from geometric centroid; **(c)** Mass- stiffness eccentric model at a distance of 0.2m from geometric centroid.

Results and Discussion

Linear incremental dynamic analysis is performed for the aforementioned building models with created eccentricities by modifying loads and column sizes. Building models are subjected to Chamoli ground motion record with PGA normalized from 0.1g to 1g. Later, edge displacements are taken out and twist is calculated, depending on whether the displacements are in phase or out of phase. Maximum twist is found out from all the sides of the building. Table 3 shows the twist calculated for different eccentric models like mass eccentric, stiffness eccentric and mass-stiffness eccentric models

Table 3 : Twist of a building models subjected eccentricities in CM, CS, CM-CS

PGA	Twist for 5% CM eccentricity.	Twist for 5% CS eccentricity	Twist for 5% CM-CS eccentricity
0.1g	0	0	0
0.2g	0	0.000932	0.000932
0.3g	0	0.001846	0.001846
0.4g	0	0.002769	0.002769
0.5g	0	0.003756	0.003756
0.6g	0	0.004635	0.004635
0.7g	0	0.005538	0.005538
0.8g	0	0.00646	0.00646
0.9g	0	0.007383	0.007383
1.0g	0	0.008308	0.008308

Similarly, figure 3 explains the twist profiles for mass eccentric model and stiffness eccentric models. In Figure 4, Twist is plotted against Peak Ground Acceleration

Table 4, Figure 3 and Figure 4 shows the impact of mass and stiffness eccentricity on different structural models. The torsional response exhibited by mass eccentric model is negligible when compared with the torsional response

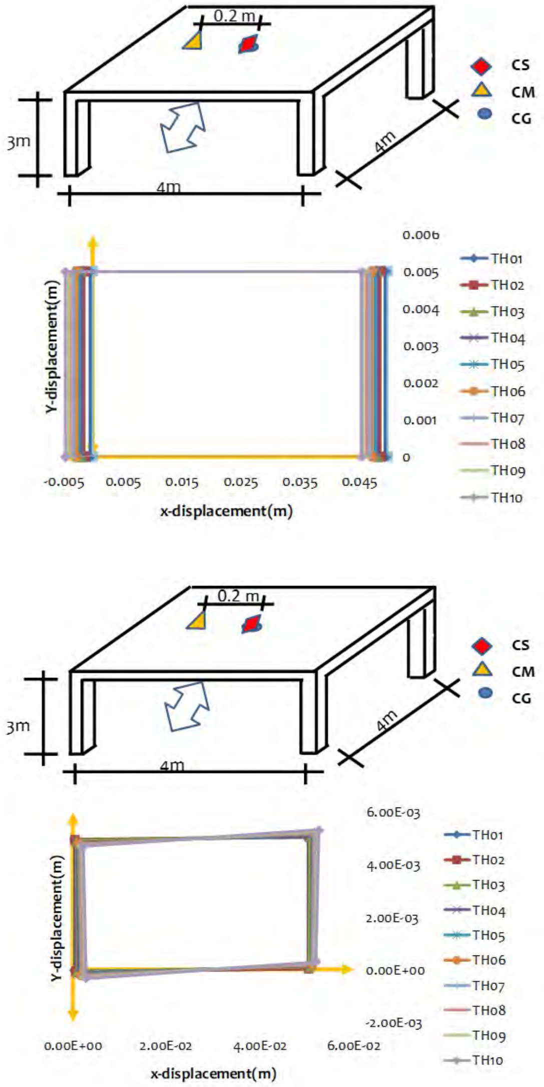

Figure 3(a) : Twist profile for Mass eccentric model from 0.1g-1.0g; **(b)** Twist profile for stiffness eccentric model from 0.1g to 1.0g

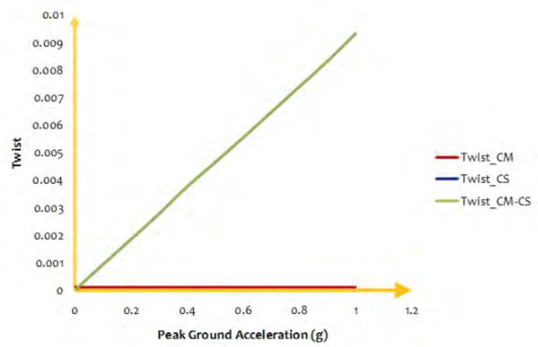

Figure 4 : Plot showing the Twist generated for different eccentric models

exhibited by stiffness eccentric model with same amount of eccentricity. In elastic state, the strength of stiffness eccentric model is significantly more than mass eccentric model. From this it is concluded that any stiffness eccentricity i.e., physical or accidental created because of column cross section variation, column inaccuracies, improper placement of shear walls, staircases may lead to torsion response many times greater than mass eccentricity created because of operational loads, equipment loads etc. It is clear that the adjustment of mass or accidental eccentricities are not sufficient for controlling torsion arising out of various reasons. Therefore, design eccentricity has to revisited like NZS code or Mexican code by increasing accidental eccentricity from 5% as an initial step.

Conclusions

From the study performed, the following conclusions are derived:

1. The torsional response generated by moving mass centre drifted geometrical centre is completely negligible when compared with drift in stiffness centre, even with same eccentricity. Also, the design eccentricity needs statistical evaluation of accidental parameters inducing torsion

2. When torsional response created by mass eccentric model is negligible, the torsional response obtained from combination of mass-stiffness eccentric model is close to the response obtained from stiffness eccentric model alone

3. Adjustment of mass is not the universal solution for addressing torsion created due various accidental parameters. In this line, few countries like New Zealand had already modified accidental eccentricity from 5% to 10%.

4. The constant value of 1.5 for dynamic amplification of static eccentricity need to be revisited as very few countries have associated a factor for amplification of static eccentricity. Rather, dynamic analysis in such case shall be made compulsory as suggested by codes of the other countries.

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