Study of Torsional Effect on tall Structure using Cracked and Uncracked Sectional Properties with Torsional Irregularity

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Abstract- **As India experienced rapid development, cities will continue to see huge spurt in the demand for housing and commercial real estate. Due to the scarcity of land in big cities, architects often propose irregular building to maximize utilization of available land. Most building has some degree of irregularities, in the geometric configuration or in the geometric distribution of mass. Due to this, the structural resistance to the ground motion is usually torsionally unbalanced creating large displacements and high force concentrations.**

This study first concentrates, in understanding the complex behavior of structure due to various irregularities. In the proposed study 5 cases are considered namely, Case I with torsion, Case II with torsion and SLS property modifiers, Case III without torsion, Case IV without torsion and SLS property modifiers and Case V without torsion and ULS property modifiers. Analysis was carried out in, commercially available FEA package ETABS using linear dynamic analysis. The guidelines lay by Indian Standard Code IS 1893(Part I):2016 and IS 16700:2017 will be used to compare the results. The results will be compared in terms of Modal mass participation ratio, time period for torsional mode, diaphragm displacements, p_t % in columns, Inter storey drift. It was observed that all the parameters are affected with the used of stiffness modifiers.

Keywords: **Torsional irregularity, cracked sectional properties, Stiffness irregularity, Mass irregularity.**

1.INTRODUCTION

Asymmetric building structures are almost unavoidable in modern construction due to various types of functional and architectural requirements. The lateral-torsional coupling due to eccentricity between center of mass (CM) and center of rigidity (CR) in asymmetric building structures generates torsional vibration even under purely translational ground shaking. During seismic shaking of the structural systems, inertia force acts through the center of mass while the resistive force acts through the center of rigidity. Due to this non-concurrency of lines of action of the inertia force and the resistive force a time varying twisting moment is generated which causes torsional vibration of the structure in addition to the lateral vibration.

1.1 Significance of the topic

Most seismic codes require an equivalent static load method for the design of asymmetric building against earthquake forces. Design eccentricities include a multiplier on the static eccentricity to account for possible dynamic amplification of the torsion. Also, the design eccentricities often include an allowance for accidental torsion that is supposed to be induced by the rotational component of ground motion, by possible deviation of the ECR (elastic centre of resistance) and centre of mass (CM) from their calculated positions or by unfavourable distribution of live loads. The design eccentricity formulae given in most of the building codes can be written in the following form:

$$e_{id=}\begin{cases}1.5e_{si}+0.05b_i \\ \\ e_{si}-0.05b_i\end{cases} \qquad \text{(Pg. 27 of IS 1893:2016)}$$

The torsion design provisions of Indian Standard (IS-1893:2016 (Part1)) specify the use of design eccentricity expressions Eq. 1 with α=1.5, β=0.05 and γ=1. Eq.1 result four possible design centre of mass (DCM) location in each floor of the building. To satisfy the design code one has to analyse a building multiple time considering all possible combination of DCM locations. This is time consuming and cumbersome exercise and generally not followed correctly in the design office. To address this problem it is important to know how different a code designed asymmetric building behaves from a similar building designed without considering the code provision. This is the principal motivation for the present study.

1.2 Torsional Irregularity

In torsionally irregular buildings, when the ratio of maximum horizontal displacement at one end and the minimum horizontal displacement at the other end is,

1. In the range 1.5 – 2.0,
   (a) the building configuration shall be revised to ensure that the natural period of the fundamental torsional mode of oscillation shall be smaller than those of the first two translational modes along each of the principal plan directions (b) Three-dimensional dynamic analysis method shall be adopted;
2. More than 2.0, the building configuration shall be revised

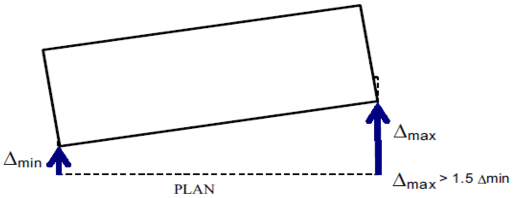

Fig. 1.1 Torsional Irregularity (IS1893:2016)

2.METHODOLOGY

The present study aims at understanding the importance of codal provisions, which are particularly provided for the analysis of torsionally unbalanced structure. However, in the present study the irregularities under the influence of torsion are studied in detail. The first is computing torsional moment at each floor by using equations provided in various current seismic code provisions. After they are applied on each floor, the seismic analysis will be performed. The second is shifting the center of mass (CM) or stiffness (CS) to eliminate the eccentricity by putting additional masses, adding structural components such as braced frame systems or applying control systems on the structures, which can be passive or active. Torsion in the building during ground shaking may be caused by various reasons, the most common of which is, non-symmetric distribution of mass and stiffness. In the proposed study 5 cases are considered namely;

a) Case I -With torsion.(Uncracked Properties)
b) Case II -With torsion and SLS stiffness modifiers.
c) Case III -No torsion.(Uncracked Properties)
d) Case IV -No torsion and SLS stiffness modifiers.
e) Case V -No torsion and ULS stiffness modifiers.

Design of tall building is driven not by gravity alone, lateral load such as wind and earthquake play a defining role in conceptualizing the design. In this chapter various applicable clauses of IS 1893(Part I):2016 and IS 16700:2017 for the torsional requirement are given. ETABS analysis model is prepared for each case. The analysis is done, and torsional irregularity is checked. It there is torsion in the building the structural configuration is revised to ensure that the natural period of fundamental torsional mode of oscillation, shall be smaller than those of first two translational modes. Finally, the serviceability and strength checks are carried out and the results are compared as required.

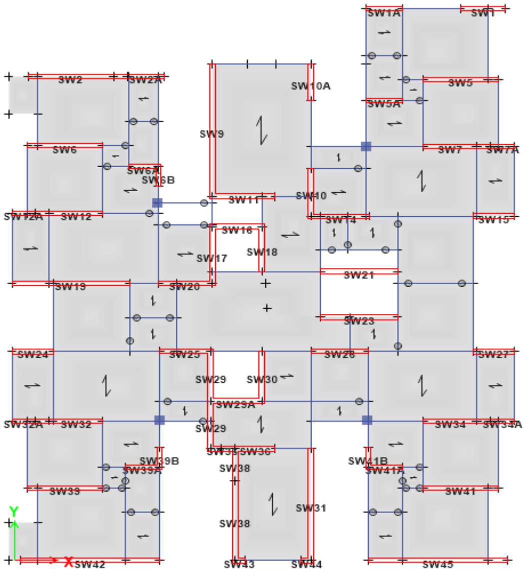

Fig 2.1 floor plan with torsion

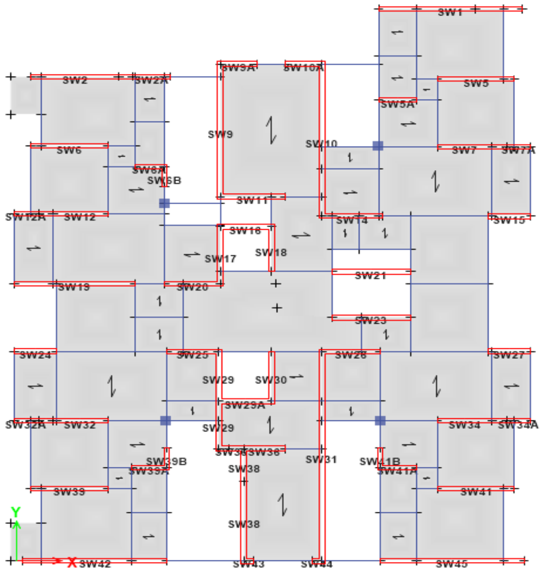

Fig 2.2 floor plan without torsion

Table 2.1: Description of building

Total No. of floors	1 Basement Floor + 2 Parking Floors +28th Residential Floor
Numbers of basements floors	1 No
Height of basement floor	4.625 m below ground floor
Numbers of parking floor	2 Parking floors (2nd & 3rd)
Height of parking floor	3.2 m & 3.85m
Height of residential floor	3 m
Total height of building	95.625m (From Base Level to Terrace Level)

2.1 Load cases used for modelling purpose will be as per Table 2.2.

Table 2.2: Load cases

Sr. No	Type	Description	Remark
1	dead load	self-weight of the structural members	-
2	super dead load	floor finish load	-
3	live load	live load as per is 875(part 3):2015	< 3kn/m2
4	live load	live load as per is 875(part 3):2015	> 3kn/m2
5	seismic static load	seismic load as per is 1893(part 1):2016	x direction
6	seismic static load	seismic load as per is 1893(part 1):2016	y direction
7	seismic dynamic load	seismic load as per is 1893(part 1):2016	x direction
8	wind load	wind load as per is 875(part 3):2015	x direction
9	wind load	wind load as per is 875(part 3):2015	y direction
10	gust load	wind load as per is 875(part 3):2015	x direction
11	gust load	wind load as per is 875(part 3):2015	y direction

2.2 Cracked Sectional Properties as per IS 16700:2017

As the structural members are designed as per limit state method the concrete member is considered as cracked member. To consider the effect of cracking stiffness modifiers are used. The stiffness modifiers used are given in table 2.3.

Table 2.3: Cracked sectional properties

Sr. No	Structural Elements	Un-Factored loads (SLS)		Factored loads (ULS)	
		For Serviceability		For Strength	
		Area	Moment of Inertia	Area	Moment of Inertia
1	Slabs	1.0 Ag	0.35 Ig	1.0 Ag	0.25 Ig
2	Beams	1.0 Ag	0.70 Ig	1.0 Ag	0.35 Ig
3	Columns	1.0 Ag	0.90 Ig	1.0 Ag	0.70 Ig
4	Walls	1.0 Ag	0.90 Ig	1.0 Ag	0.70 Ig

3.RESULT

The results are mainly categorized in two main parts serviceability requirement and strength requirement. All the result is extracted from

ETABS output and are tabulated for easy understanding. For the proposed study, the following results will be examined and will be compared to come to the conclusions,

1. Torsional irregularity
2. Displacement
3. Reinforcement coefficient

3.1 Torsional irregularity

The output value for the displacement in X and Y direction at terrace level has been provided in Table 3.1 where EQx & EQy stands for Static Base Shear, SPECx & SPECy stands for Dynamic Base Shear, Wx & Wy stands for Static Wind Load and Gx & Gy stands for Dynamic Wind Load in X & Y direction respectively and the ratio of max. Displacement to min. displacement is calculated to check torsional irregularity for various cases.

Table 3.1: Torsional irregularity in X direction

Sr.	Cases	Load Case	max (mm)	min (mm)	max / min
1	Case I	EQx	40.99	40.72	1.01
		SPECx	28.52	28.31	1.01
		WINDx	42.35	31.15	1.36
		GUSTx	40.29	39.41	1.02
2	Case II	EQx	49.81	49.09	1.01
		SPECx	32.49	32.3	1.01
		WINDx	51.31	37.87	1.35
		GUSTx	48.8	47.77	1.02
3	Case III	EQx	31.3	29.15	1.07
		SPECx	22.65	18.64	1.22
		WINDx	27.24	25.12	1.08
		GUSTx	28.4	28.52	1.00
4	Case IV	EQx	37.25	34.08	1.09
		SPECx	27.2	21.38	1.27
		WINDx	31.96	29.27	1.09
		GUSTx	33.83	33.31	1.02
5	Case V	EQx	56.72	49.68	1.14
		SPECx	40	29.03	1.38
		WINDx	46.89	45.59	1.03
		GUSTx	51.53	48.8	1.06

From the table 3.1 it has been observed that for all cases the ratio of maximum displacement to minimum displacement is less than 1.5. Hence building is safe in torsional moment in X directional loads

The output value for the displacement in Y direction at terrace level has been provided in Table 3.2 and the ratio of max. displacement to min. displacement is calculated to check torsional irregularity for various cases

Table 3.2: Torsional irregularity in Y direction

Sr. No	Cases	Load Case	max (mm)	min (mm)	max / min
1	Case I	EQy	52.44	34.42	1.52
		SPECy	36.35	28.81	1.26
		WINDy	31.94	26.85	1.19
		GUSTy	37.68	27.91	1.35
2	Case II	EQy	63.33	42.04	1.51
		SPECy	41.67	32.23	1.29
		WINDy	38.61	32.72	1.18
		GUSTy	44.6	33.03	1.35
3	Case III	EQy	32.44	29.3	1.11
		SPECy	22.61	17.52	1.29
		WINDy	20.46	19.61	1.04
		GUSTy	22.94	21.26	1.08
4	Case IV	EQy	38.39	34.94	1.10
		SPECy	26.45	20.73	1.28
		WINDy	24.4	23.14	1.05

		GUSTy	27.19	25.21	1.08
5	Case V	EQy	56.57	51.45	1.10
		SPECy	35.93	28.37	1.27
		WINDy	35.94	33.93	1.06
		GUSTy	40.37	36.67	1.10

From the table 3.2 it has observed that for all cases the ratio of maximum displacement to minimum displacement is more than 1.5 for case I & II whereas the ratio of maximum displacement to minimum displacement is less than 1.5 for cases III, IV & V. Hence building is unsafe in torsional moment in case I & II. In case III, IV, V we improve architectural plan to reduce torsion by adding shear wall therefore we got ratio less than 1.5.

3.2 Displacement

The output value for displacement in X direction at terrace level has been provided in graphical format in Figure: 3.1 for the different cases.

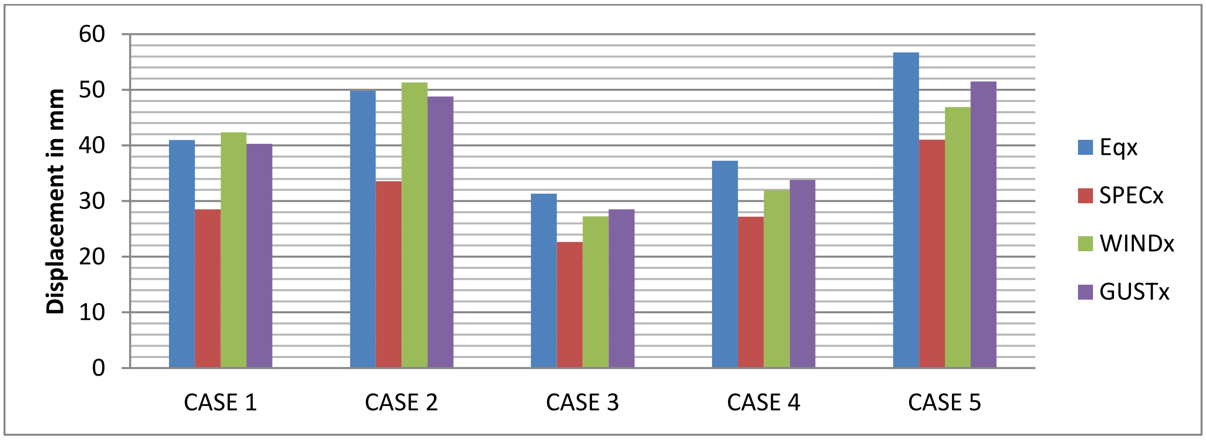

Figure 3.1: Displacement at Terrace Level in X direction

From the Figure 3.1 it has been observed that maximum displacement in X direction at terrace level is 28.528, 33.553, 34.134, 22.657, 27.203 and 41.046mm for Case I, II, III, IV, V and Case VI respectively.

The output value for the displacement in Y direction has been provided in Figure 3.2 for the different cases.

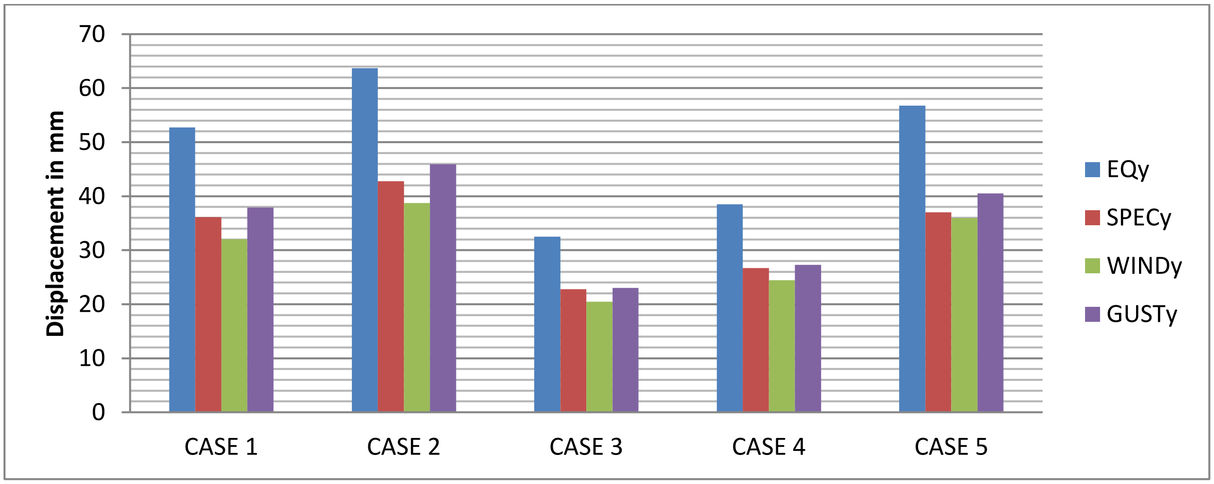

Figure 3.2: Displacement at Terrace Level in Y direction

From the figure 3.2 it has been observed that maximum displacement in Y direction at terrace level is 36.121, 42.752, 34.613, 22.794, 26.674 and 37.026mm for Case I, II, III, IV, V and Case VI respectively.

3.3 Reinforcement Coefficient

The reinforcement coefficient indicates the steel required in kg per unit concrete volume. In table 3.3 the steel reinforcement required in column at ground floor level is estimated in kg and is divided by total volume of column concrete.

Table 3.3: Steel coefficient

Sr. No	Cases	Column Volume (m^3)	Steel Required (kg)	Steel Coefficient (kg/m^3)
1	Case I	143.9	14371.63	99.83
2	Case II	143.9	15664.34	108.83
3	Case III	159.9	14961.70	93.57
4	Case IV	159.9	15060.80	94.19
5	Case V	159.9	15168.00	94.86

CONCLUSION

1. Positions of shear walls in building influenced the displacement due to seismic actions. Center of rigidity point of building it attracts towards the mass (i.e. shear wall). To remove the torsional irregularity from the building, structural walls & framing beams in Structural System can be added.
2. The maximum displacement values are higher for irregular structure as compared to the regular structure.
3. Due to introduction of stiffness modifiers in the model the overall stiffness of the structure will reduce. Due to the reduced stiffness, the structure will be relatively flexible and hence would attract the lower seismic forces. Therefore, consideration of the stiffness modifiers will reduce the seismic demand on the structure.
4. Reinforcement coefficient is decreases in case III, IV and V with respect to case I and II. Minimum reinforcement coefficient we get in case V without torsion building with use ULS modifiers. It can be observed that steel coefficient also decreases, with using ULS modifier steel coefficient decreases.

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