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Study Of Plan Irregularity On High-Rise Structures

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Abstract:
This paper aims at studying description of different plan irregularities by analytical method during seismic events. In all the studied systems from which dual system is chosen for analysis and studying its effects on different irregularities in which analysis is based on the variation of displacements, with respect to structural systems. Analyses have been done to estimate the seismic performance of high rise buildings and the effects of structural irregularities in stiffness, strength, mass and combination of these factors are to be going to be considered. The work describes to the irregular plan geometric forms that are repeated more in the metro city areas such as Mumbai like T-section and Oval Shape plan geometry. These irregular plans were modelled in ETABS 9.7v considering 35 and 39 storied buildings, to determine the effect of the plan geometric form on the seismic behaviour of structures with elastic analyses. Also, effects of the gust factor are considering in T-shape and Oval Shape plans. Although these affects mainly on the architectural plan configuration, plan irregularity find better structural system solution such as dual system has been use for structural analysis. In structural configuration shear wall positions located are located in the form of core and columns are considered as gravity as well as lateral columns. Two types of models are going to be developed namely strength & serviceability models. In strength model all the lateral systems (i.e. shear walls and coupling beams) are to be analyzed.

Keywords:*Torsion, Plan Irregularity, Dual System, Dynamic Analysis, P-Delta Analysis, Strength, Stiffness.*

1.Introduction

Earthquake field investigations repeatedly confirm that irregular structures suffer more damage than their regular counterparts. This is recognized in seismic design codes, and 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 imposed demand. Elevation irregularities have been observed to cause storey failures due to non-uniform distribution of demand-to-supply ratios along the height. Plan irregularities, on the other hand, cause non-uniform demand-to-capacity ratios amongst the columns within a single floor. Quantitative measures of seismic assessment on a floor-by floor basis have been used for many years, in the form of storey drift ratios that provide a single number that portrays the demand-to-supply picture along the height of a structure. Quantitative, readily available and verified measures of demand-to-capacity ratios over the plan of a structure subjected to bidirectional transient dynamic loading and responding in the inelastic range are still lacking. In this paper, an analytical index is derived based on generic response characteristics. The index accounts for the multi directionality of earthquake motion as well as the asymmetry of the structure; hence it captures the true three-dimensional inelastic effects that govern the response of RC structures. The adoption of such a damage measure opens to door to the derivation of spatial fragility curves and surfaces.

1.1.Indian Code Criteria For Torsion Irregularity

To be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. 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.

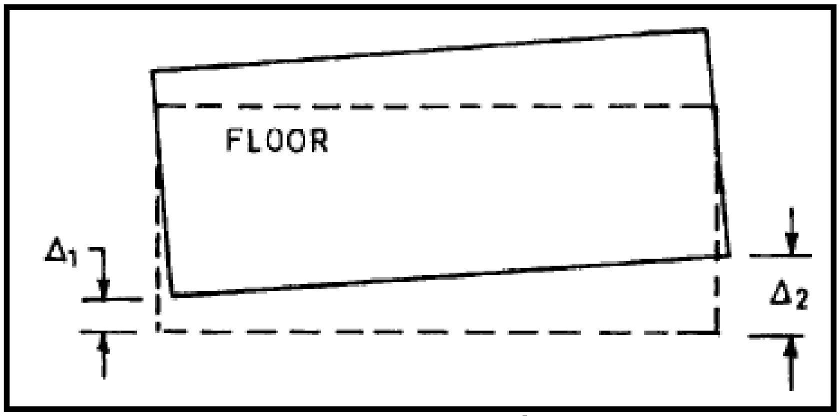

Figure 1: Torsion Irregularity

2.Structural Modeling & Analysis

2.1.Modeling Of Structures

Different types of analysis can be employed for the multiple design assessments. Detailed 3-dimensional finite element models have been prepared for analysis to capture translational and torsional effects.Elastic analysis is appropriate for the service-level assessment because component responses are generally smaller than those that cause yielding.

2.2.Functional Planning

The functional planning of building affects the way in which it can accommodate its structural skeleton, the principal categories of buildings from the point of view of lateral load resisting system are given As per IS1893(Part-1)-2002 Table 7 as below:

2.3.Dual System

These consist of moment-resisting frames either braced or with shear walls. The coupling of the above two systems completely alters the moment and shear diagrams of both the walls and the frame. The characteristic of this combination is that in the lower floors the wall retains the frame, while the frame in the upper floors the frame inhibits the large displacements of the wall. As a result, the frame an exhibits a small variation in storey shear between the first and the last floors. The two systems may be designed to resist the total design forces in proportion to their lateral stiffness.

Building with dual system consists of shear walls and moment resisting frames such that:

The two systems are designed to resist the total design lateral force in proportion to their lateral stiffness considering the interaction of the dual system at all floor levels.

The moment resisting frames are designed to independently resist at least 25% of the design base shear.

As per IS1893(Part-1)-2002 Table 7.1(Vii) Ductile shear wall buildings with Dual system used for analysis of T-Shape Model(M01), Oval Shape Model(M02).

2.4.Lateral Model Summary

Two different types of lateral models were prepared in ETABS.

One is the strength model (for code level design) for the code design level of lateral elements such as shear walls, coupling beams and foundations. Note that columns and beams are just a gravity system not designed to resist lateral loads, but are detailed as per provisions of ACI 318-08 which give specific criteria for designing elements not designed to resist lateral loads. The bending stiffness of the columns is minimized to 0.01 so that they do not draw any lateral load and all the lateral load is transferred to the shear walls which is the intent of the design. P-Delta Analysis was accounted for in the model using dead load of the structure.The second model is the serviceability model which reflects the true strength and stiffness properties of concrete for the 1 year or 10 year wind load as against code level wind load. Since the loads will be comparatively less than code level forces, the structure will be essentially elastic with very little cracking.

2.5.Design Parameter For Modelling

Grade of Steel: Fe500

Grade of Concrete: Slab/Beam M40

Coupling Beam 50/60

Column/Shear Wall M60-M40

Earthquake Parameter	T-Shape Model	Oval Shape Model
Z i.e. Zone Factor	0.16	0.16
I i.e. Importance Factor	1	1
R i.e. Response Reduction Factor	4	4
% of Live Load Considered in Seismic	0.25	25%
h i.e. Height of Building	125.5 m	125.5 m
d_x	22.95 m	58.76 m
d_y	41.45 m	16.35 m
W i.e. Seismic Weight of Building	429207 KN	1168217 KN
Soil Type	Rocky-(Type-I)	Rocky-(Type-I)

Table 1: Earthquake Parameter

Wind Parameter	T-Shape Model	Oval Shape Model
Category	3	3
Class	C	C
Basic Wind Speed	44 m/sec	44 m/sec
Maximum Wind Pressure	780 Kg / m^2	780 Kg / m^2
Force Coefficient	1.3	1.3
Gx - Gust Factor in X direction	2.41	2.04
Gy - Gust Factor in Y direction	2.32	2.21
Wind Base Shear in X direction	5101KN	3516 KN
Wind Base Shear in Y direction	8771KN	20237 KN

Table 2 :Wind Parameter

Model	T-Shape Model		Oval Shape Model	
Concrete Element	Serviceability Analysis	Code Level Wind / Seismic Analysis	Serviceability Analysis	Code Level Wind / Seismic Analysis
Core Walls/Shear Walls	Flexural: 0.9 Ig Shear: 1.0 A	Flexural: 0.8 Ig Shear: 1.0 A	Flexural: 0.9 Ig Shear: 1.0 A	Flexural: 0.8 Ig Shear: 1.0 A
Coupling Beams / Link Beams	Flexural: 0.5 Ig Shear: 0.5A	Flexural: 0.4 Ig Shear: 0.4 A	Flexural: 0.5 Ig Shear: 0.5 A	Flexural: 0.4 Ig Shear: 0.4 A
Beams	Flexural: 0.5 Ig Shear: 1.0 A	Flexural: 0.5 Ig Shear: 1.0 A	Flexural: 0.5 Ig Shear: 1.0 A	Flexural: 0.5 Ig Shear: 1.0 A

Model	**T-Shape Model**		**Oval Shape Model**	
Floor Diaphragms	Flexural: 1.0 Ig Shear: 1.0 A	Flexural: 1.0 Ig Shear: 1.0 A	Flexural: 0.7 Ig Shear: 1.0 A	Flexural: 0.25 Ig Shear: 0.25 A
Concrete Columns	Flexural: 0.9 Ig Shear: 1.0 A	Flexural: 0.8 Ig Shear: 1.0 A	Flexural: 0.9 Ig Shear: 1.0 A	No stiffness

Table 3: Stiffness Properties Assumption

2.6.Description Of The Structure For T-Shape Plan

The building has 35+Terrace story floor. A brief architectural and structural description of the building is given as below:

125.5 m tall (up to terrace) residential tower with parking space.

Ground Floor Level: Parking Floor

Parking Levels 1 to 3: Parking floor and floor to floor Ht of 3.6 m

Podium Level 4 : Parking floor to floor Ht of 4.2 m

Above Recreational 31 upper floor:Residential tower with floor to floor height of 3.35 m.

Plan Dimension

: 22.95 m (X direction) (H/W Ratio 5.468:1)

: 41.45 m (Y direction) (H/W Ratio 3.027:1)

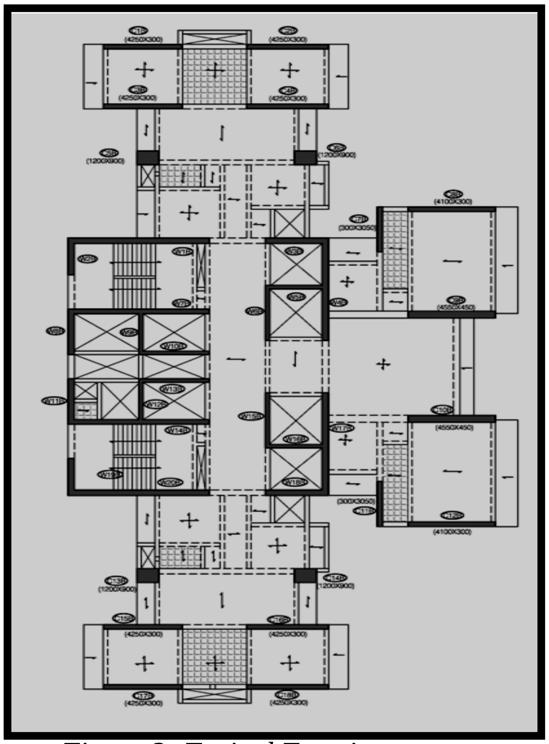

Figure 2: Typical Framing

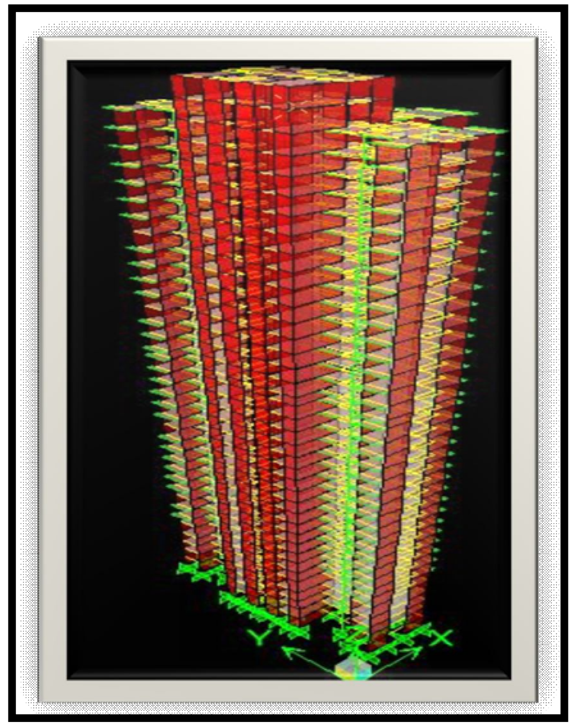

Figure 3: 3d View Of T-Shape Model

2.7.Description Of The Structure For Oval Shape Plan

The building has 4+35 story floor. A brief architectural and structural description of the building is given as below:

125.5 m tall (up to terrace) residential tower with parking space.

Ground Floor Level: Parking Floor

Parking Levels 1 to 4: Parking floor with tie beams at specified levels.

35 upper floor : Residential tower with floor to floor height of 3.1 m

Plan Dimension :

: 95.00 m (X direction) (H/W Ratio 1.31:1)

: 21.23 m (Y direction) (H/W Ratio 5.86:1)

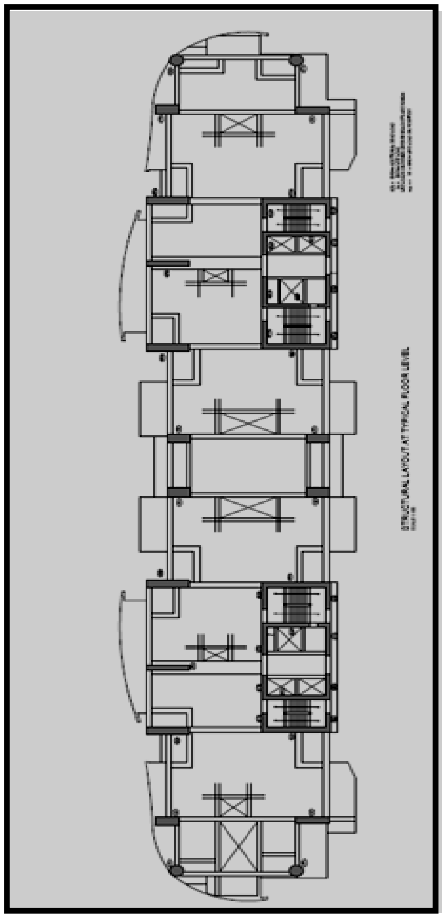

Figure 3: Typical Framing

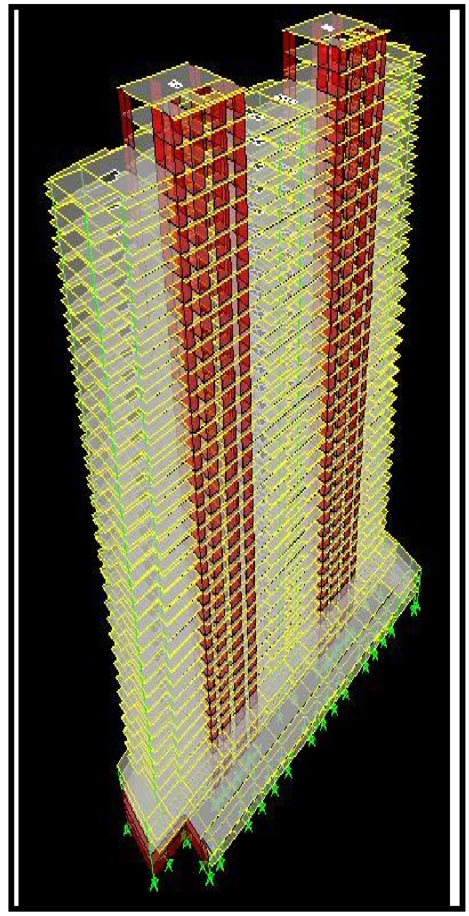

Figure 4:3d View Of Oval -Shape Model

3.Result And Disscussions

3.1.Earthquake Load For T-Shape Model

The X-direction base shear ($V_{bx,EQX}$) and the Y-direction base shear ($V_{by,EQY}$) generated from ETABS from the fundamental periods are compared with the same quantities obtained using hand calculations in Table. It can be seen that both these quantities are similar; hence validating the ETABS generated earthquake forces.Comparison of base shears of T-Shape/Oval-Shape Model obtained from fundamental period and dynamic analysis and derivation of scaling factors for response quantities.

Parameter	Value For T-Shape	Value For Oval Shape
EQX	3566KN	15158 KN
EQY	4792 KN	8007 KN
SPECX (unfactored)	2485 KN	6287 KN
SPECY (unfactored)	2097 KN	6794 KN
$V_{b,min}$ (1% of Seismic Wt)	4292 KN	11682 KN
Factor for SPECX	2.115	2.4225
Factor for SPECY	2.854	1.719
SPECX (scaled up)	4302 KN	16220 KN
SPECY (scaled up)	4886 KN	11441 KN

Table 4 :Base Shear From Strength Model

From Table 4 conclude that 1% seismic weight magnitude greater in Y-direction but In other direction 1% seismic weight magnitude lesser in X-direction, so Plan geometry weak in X-direction.

3.2.Building Behaviour / Building Modes For T-Shape Model

The following are the building modes. It can be seen that the building has a very sound behaviour.

Data from Dynamic Analysis (Time Period, Frequency, Modal Mass Participating Ratios).

Modes	Time Period	Frequency	Modal Mass Participating Ratios		
			X - Trans	Y - Trans	Rz - Rot
1	4.118	0.242	0.0151	66.221	6.2054
2	3.91	0.255	69.541	0.0137	0.0018
3	2.955	0.338	0.0001	5.7305	69.167
SUM OF 3O MODES			97.582	98.5668	97.742

Table 5: Data From Dynamic Analysis – Strength Model (T-Shape Model)

Modes	Time Period	Frequency	Modal Mass Participating Ratios		
			X - Trans	Y - Trans	Rz - Rot
1	3.7222	0.2686	0.034	65.799	6.316
2	3.624	0.2759	69.594	0.031	0.004
3	2.7032	0.3698	0.0001	5.629	69.409
SUM OF 3O MODES			97.586	98.593	97.746

Table 6: Data From Dynamic Analysis – Serviceability Model (T-Shape Model)

3.3.Torsional Irregularity Results From Analysis For T-Shape Model

Load	Corner - 1	Corner - 2	Corner - 3	Corner – 4	Corner - 5	Corner - 6	ΔAvg	ΔMax / ΔAvg
EQX	72.05	72.05	72.05	72.05	72.04	72.04	72.05	1.000
EQY	90.16	102.46	111.72	111.72	90.16	102.46	101.45	1.101
WLx	50.8	50.8	50.82	50.87	50.9	50.9	50.84	1.001
W	76	93.28	106.32	106.32	76	93.28	91.86	1.157

Table 7 :Torsional Irregularity (T-Shape Model)

Comment on Torsional Irregularity as per 1893(part-1)-2002 satisfy all load cases.

Value of torsional irregularity with in permissible limit i.e. ΔMax / ΔAvg <1.2

3.4.Building Behaviour / Building Modes For Oval – Shape Model

The following are the building modes. It can be seen that the building has a very sound behaviour.

Modes	Time Period	Frequency	Modal Mass Participating Ratios		
			X - trans	Y - trans	Rz - Rot
1	5.654	0.177	1.196	54.437	3.218
2	5.488	0.182	42.071	0.004	16.351
3	3.722	0.269	15.455	4.795	37.997
SUM OF 35 MODES			95.136	96.158	95.325

Table 8: Data from Dynamic Analysis – Strength Model (Oval-Shape Model)

Data from Dynamic Analysis (Time Period, Frequency, Modal Mass Participating Ratios)Strength Model (Oval-Shape Model).

Modes	Time Period	Frequency	Modal Mass Participating Ratios		
			X - Trans	Y - Trans	Rz - Rot
1	4.597	0.218	0.187	58.754	0.416
2	4.376	0.229	40.22	0.002	18.322
3	3.218	0.311	18.66	0.739	38.823
SUM OF 35 MODES			95.971	96.048	95.252

Table 9 : Data From Dynamic Analysis – Serviceability Model (Oval-Shape Model)

3.5.Torsional Irregularity Results From Analysis For Oval-Shape Model

Load	Corner - 1	Corner - 2	Corner – 3	Corner - 4	ΔAvg	ΔMax / ΔAvg
EQX	165.74	165.74	135.76	135.76	150.75	1.099
EQY	133.41	139.81	133.84	139.38	136.61	1.023
SPEC X	71.46	71.46	60.26	60.26	65.86	1.085
SPECY	141.57	153.35	134.95	145.26	143.78	1.067
WLx	27.11	27.11	22.73	22.73	24.92	1.088
WLy	228.76	240.99	229.56	240.15	234.87	1.026
From the above, it can be concluded that there is no torsional irregularity						

Table 10:Torsional Irregularity (Oval-Shape Model)

4.Conclusions

The purpose of study was to analyze plan irregularities on high-rise structures and to observe the behaviour of structures. For this, ETABS a linear dynamic analysis and design program for three dimensional structures has been used. Dynamic analysis has been carried out to know about deformations, natural frequencies, time periods, floor responses and displacements. The models that have been studied are :

T-Shape Model

Oval shape Model.

Form the results of analysis for both the models conclusions are as follows,

Modal mass participation for T-Shape & Oval shape models comes out to be 95% of the total building mass by response spectrum method, which is in the permissible limit i.e. 90% of total seismic weight as per IS 1893 (Part-I)-2002.For strength models estimated time period for first three modes in T-Shape model are as mode 1 is 4.1175sec, mode 2 is 3.9096sec & mode 3 is 2.954sec, also for Oval Shape model are as mode 1 is 5.654sec, mode 2 is 5.488sec & mode 3 is 3.7220sec.

For both the T-shape and Oval shape models in the first two modes the modal combination effects is below 33Hz along rotational direction, it is as per IS 1893(Part-I)-2002.

In the analysis Models are employed with the modern structural framings, materials and loading patterns that are not commonly used in the conventional seismic resisting structures, such as shear wall and columns constructed of high-performance concrete and Core mainly consist of ductile shear walls with coupling beams.As per analysis plan irregularity ratios for T- shape and Oval shape models are 1.157 and 1.099, which is within the permissible limit of $\Delta Max / \Delta Avg < 1.2$ criteria from IS1893-(Part-I)-2002.From the study of plan geometry for both the T-Shape and Oval shape models, it is found that staircase, lift duct, service duct and service lift ducts are weak parts, which are strengthen by providing core (i.e. ductile shear wall) with coupling beam. Due to this modal combination effects are going below 33 Hz, which ultimately results in the nullifying the torsion in the structures.

From this study it is proved that the dual system offered more economic construction along with the iconic architectural image.

5.Reference

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