Effects of Irregularities on the Seismic Response of A High-Rise Structure in ETABS

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***Abstract*—Structural engineers often come across buildings, which exhibit certain degrees of plane symmetry. It may even exist in a nominally symmetric structure, because of the uncertainty in the distribution of floor loads, uncertainty in the evaluation of the center of mass and center of stiffness, inaccuracy in the measurement of dimensions of structural elements, or lack of precise data on the material properties. The performance of asymmetric buildings under seismic excitation is very bad and its behavior is highly complex when compared to that of regular buildings. This paper focuses on the seismically induced torsion in symmetric RCC buildings. The equivalent Lateral Force Method is adopted as per IS 1893(Part-1)-2002 codal provisions to study the induced torsion. ETABS software package is used to carry all the static and dynamic analysis by keeping these models in different seismic zones from Zone II to Zone V. The discontinuities in a lateral force resistance path, such as vertical offsets, are also considered here. The main framework involved studying the effect of the irregular distribution of mass, asymmetric distribution of stiffness, and irregular plan configurations and comparing it with the seismic response of a regular structure. The results showed that Base shear and lateral displacement were increasing with an increase in the seismic intensity from Zone II to Zone V. Also the Base shear for mass irregularity is found more compared to all other irregularities.**

Keywords—Plan asymmetry; mass irregularity; irregular plan configuration; ETABS, seismic response; RCC structures; IS: 1893 (Part-1) - 2002.

I. INTRODUCTION

Seismic forces are caused by the inertia of the structure, which tries to resist the ground motions. As the shifting ground carries the building foundations along with it, inertia keeps the rest of the structure in place for a short while longer. The movement between two parts of the building creates a force, equal to the ground acceleration, time and, mass of the structure. To have a minimum force, the mass of the building should be as low as possible since there can't be control on the ground acceleration. The point of application of this inertial force is the center of gravity of the mass on the floor of the building. Once there is a force, there has to be an equal and opposite reaction to balance this force. The inertial force is resisted by the building and the resisting force acts at the center of rigidity (CR) on each floor of the building. An earthquake Ground Motions (EQGMs) are the most dangerous natural hazards where both economic and life losses occur. Most of the losses are due to building collapses or damages. An earthquake can cause damage not only on account of vibrations that result from them but also due to other chain effects like landslides, floods, fires, etc. Therefore, it is very important to design the structures to resist, moderate to severe EQGMs depending on its site location and the importance of the structure. If the existing building is not designed for earthquake then its retrofitting becomes important. Real structures are almost always irregular, as perfect regularity is an idealization and it very rarely occurs. Structural irregularities may vary dramatically in nature and principle, are very difficult to define. Regarding buildings, for practical purposes, major seismic codes distinguish between irregularity in plan and the elevation, but it must be realized that quite often structural irregularity is the result of a combination of both. To identify the torsionally irregular structures, IS 1893(Part-1)-2002 has given clear definitions of irregular buildings in Clause 7.1. An expression for the design eccentricity, which is very much needed for the analysis of torsionally unbalanced structures, is given in Clause 7.9 of the same. According to Clause 7.8.1, the method of analysis to be used for a structure depends on its irregularity, in addition to the total height of the structure and the seismic zone where it is situated. To understand the importance of codal provisions, which are specially meant for asymmetric buildings, an attempt is made in the present study considering various parameters, which are contributing to torsional irregularity.

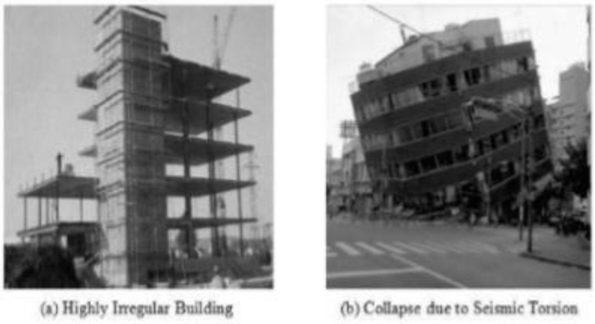
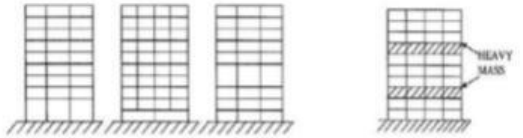

(a) Highly Irregular Building (b) Collapse due to Seismic Torsion

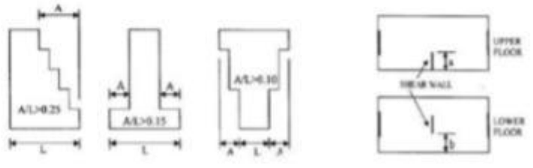
Figure 1:Asymmetric Structures and their Collapse

One of the greatest causes of damage to buildings has been the use of improper architectural-structural configurations. Building configuration is an important characteristic that affects building response. In more complex T-shaped or L-shaped buildings, forces concentrate at the inside corners created by those shapes. Earthquakes can severely damage irregular buildings when transmitted through them because the seismic forces often exceed the forces that the structure can sustain. Therefore, the structural codes state that the building configuration is the main issue in defining or selecting the method of structural analysis.

IS:18933(Part-1)-2002 gives information about several parameters that influence the irregularity of the structure. However, in the present study, the worst affected irregularity under the influence of the torsion is studied in detail. The following objectives were identified based on these parameters: (1) To study the effect of the irregular distribution of mass in the plan on the seismic response of structures.
(2) To study the influence of the asymmetric distribution of stiffness on the structural responses.
(3) To study the influence of plan configurations of a structure and its lateral force-resisting system containing re-entrant corners.
(4) To study the effect of the irregular distribution of mass, asymmetric distribution of stiffness, and irregular plan configurations, and compare it with the seismic response of a regular structure.
In the earlier versions of IS:1893 (BIS, 1962, 1966, 1970, 1975, 1984), there was no mention of vertical irregularity in building frames. However, in the recent version of IS:1893(Part-1)-2002 (BIS, 2002), an irregular configuration of buildings has been defined explicitly. Four types of vertical irregularity have been listed as shown in Fig. 2. They are: (a) Stiffness irregularity (soft story), (b) Mass irregularity, (c) Vertical geometric irregularity (set-back), and (d) In-plane discontinuity in lateral-force-resisting vertical elements. Apart from these four, there is also another type of irregularity which is the discontinuity in capacity (weak story). This is generally clubbed with Stiffness irregularity as shown below.



(a) Stiffness / Strength Irregularity (b) Mass Irregularity



(c) Vertical Geometric Irregularity or Set-back (d) In-plane Discontinuity when b>a (Plan)

Figure 2: Types of Irregularities in Structures

II. MODELLING IN ETABS

As per the code IS:1893(Part-1)-2002 provisions, the dynamic analysis shall be performed to obtain the design seismic force, and its distribution to different levels along with the height of the building and the various lateral load resisting elements, for the following buildings:
(a) Regular buildings — Those greater than 40 m in height in Zones IV and V, and those greater than 90 m in height in Zones II and III.
(b) Irregular buildings — all framed buildings higher than 12m in Zones IV and Zone V, and those greater than 40m in height in Zones II and III.
Dynamic analysis may be performed either by the Time History Method or by the Response Spectrum Method. The value of damping for buildings may be taken as 2 and 5 % of the critical, for dynamic analysis of steel and reinforced concrete buildings respectively. Details of Buildings considered in this work are as follows:

- Type of structure: Residential Building
- Number of stories: 16
- Height of typical floor: 3.2m
- Column size: 300 mm x 500 mm
- Beam size: 300 mm x 500 mm
- Slab thickness: 150 mm
- Masonry wall thickness: 230 mm
- Live load: 2 KN/m2
- Floor finish: 1 KN/m2
- Earthquake loads are calculated as per IS 1893(Part-1):2002 for seismic zones II, III, IV & V.
- Soil types are considered as type II – Medium soil.
- All the columns are assumed to be fixed at their base.
- Characteristic compressive strength of concrete, Fck: 20 N/mm2
- Grade of steel: 500 N/mm2
- Modulus elasticity of concrete: 2000 N/mm2
- Poison’s ratio of concrete, µ: 0.3
- The density of brick masonry, ρ: 19.2 KN/m3
- Modulus of elasticity of brick masonry: 14000 N/mm2
- Poison’s ratio of brick masonry: 0.2
- Damping ratio: 5%

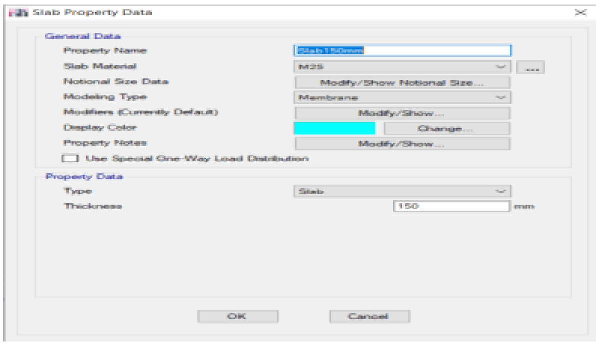
III. TYPES OF MODELS

- Regular Model
- Irregular Model (Mass) - In this irregularity, the changes made concerning the regular building are, in this model we introduce the concept of mass irregularity where a heavy mass of live load 5 KN/m2 is assigned at the fifth and tenth floors.
- Irregular Model (Stiffness) - In this irregularity, the changes made concerning Regular building are, the base story is made as to the soft story.
- Irregular Model (Re-Entrant) - In this irregularity, the changes made concerning Regular building are, the plan is irregular and is made as re-entrant corners.

IV. STRUCTURE DETAILS

This paper focuses on the study of seismic requirements and demands of different vertical, irregular RCC structures using the software package ETABS in different seismic zones of India. The configuration involves vertical irregularities with geometrical irregularity, stiffness irregularity, and mass irregularity. The performance was studied in terms of time-period, base shear, lateral displacements, using linear analysis according to IS 1893(Part-1)-2002.

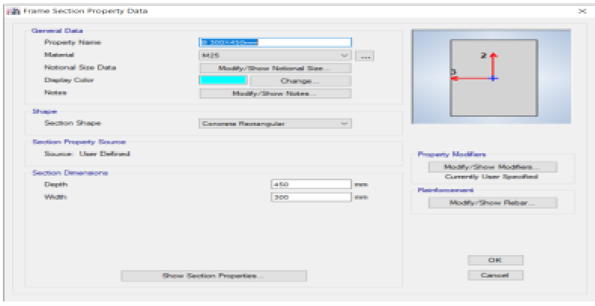
The details G+16 stories structure are as shown below:-


Slab Property Data

General Data
Property Name: Slab150mm
Slab Material: M25
Notional Size Data: Modify/Show Notional Size...
Modeling Type: Membrane
Modifiers (Currently Default): Modify/Show...
Display Color: Change...
Property Notes: Modify/Show...
☐ Use Special One-Way Load Distribution

Property Data
Type: Slab
Thickness: 150 mm

Figure: 3, Sectional property of RCC Slab


Frame Section Property Data

General Data
Property Name: B 300X450mm
Material: M25
Notional Size Data: Modify/Show Notional Size...
Display Color: Change...
Notes: Modify/Show Notes...

Shape
Section Shape: Concrete Rectangular

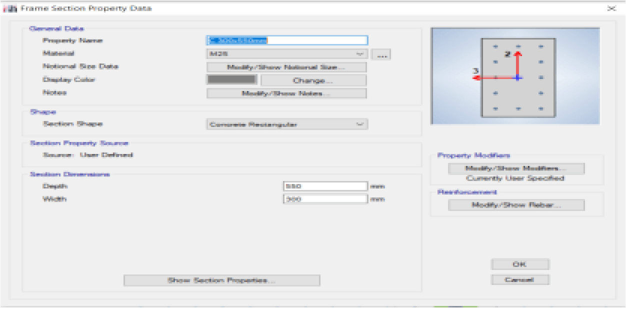
Section Property Source
Source: User Defined

Section Dimensions
Depth: 450 mm
Width: 300 mm

Property Modifiers
Modify/Show Modifiers...
Currently User Specified

Reinforcement
Modify/Show Rebar...

Figure: 4, Sectional property of RCC Beam


Frame Section Property Data

General Data
Property Name: C 300x550mm
Material: M25
Notional Size Data: Modify/Show Notional Size...
Display Color: Change...
Notes: Modify/Show Notes...

Shape
Section Shape: Concrete Rectangular

Section Property Source
Source: User Defined

Section Dimensions
Depth: 550 mm
Width: 300 mm

Property Modifiers
Modify/Show Modifiers...
Currently User Specified

Reinforcement
Modify/Show Rebar...

Figure: 5, Sectional property of RCC Column

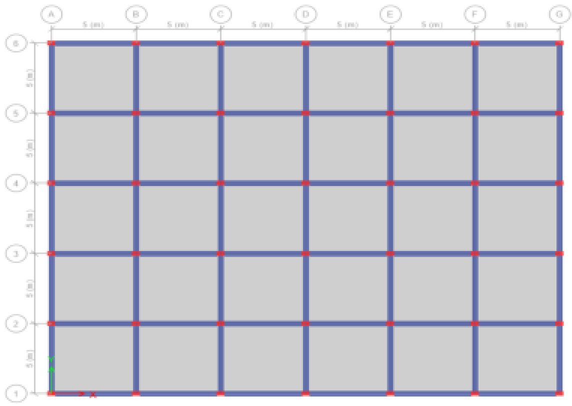


Figure: 6, Plan of RCC Structure

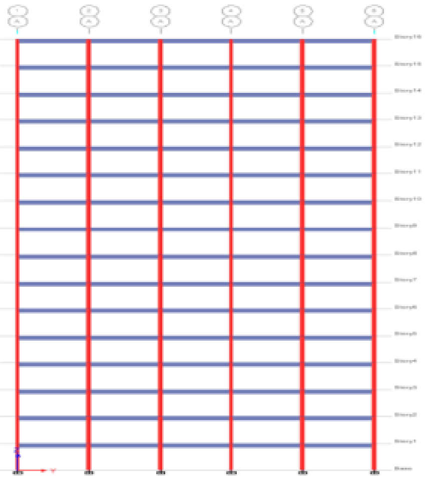


Figure: 7, Elevation of RCC Structure

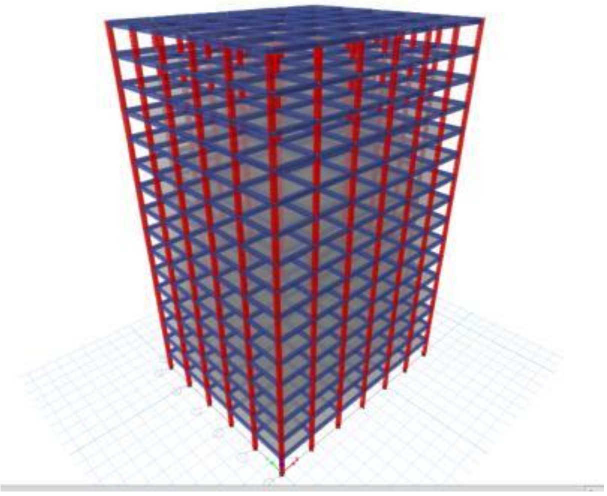


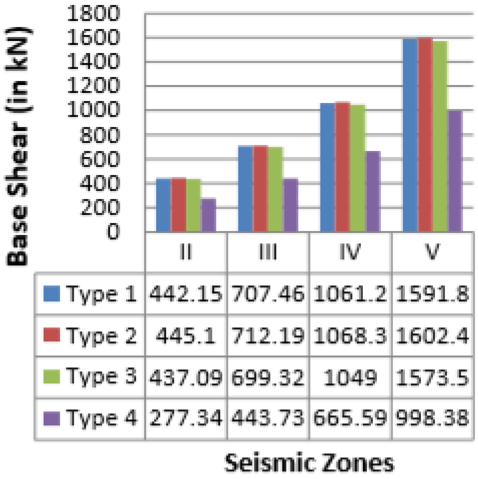
Figure: 8, 3D view of RCC structure

V. METHODOLOGY

The present comparative study deals with the equivalent static method for seismic analysis of G+16 stories structure building. The analysis of the building models is run in the software ETABS2016. For the analysis, the parameters like Story Stiffness, Time- Period, Frequency, and Base Shear were studied significantly for the loading. Then to prove that steel structure is safe. Seismic code varies with every region across the country. In India standard criteria for earthquake resistant design of structures IS 1893(PART-1):2002 is the main code that gives the idea about the seismic design force according to the various zones. Finally to prove that buildings are safe in seismic-prone zones.

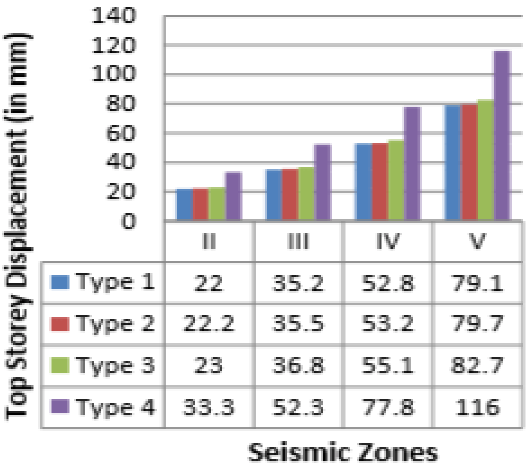
VI. RESULT&DISCUSSIONS

The results of each building model are presented in this chapter. The analysis carried out are equivalent static analysis and Dynamic analysis, the results are obtained for the different vertical irregular buildings. The results of Base Shear, Lateral Displacement, and Fundamental Time- Period are presented for different irregularities and compared with a regular model for different seismic zones of India.



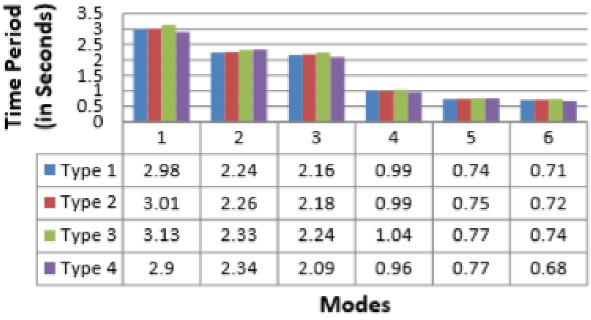
	II	III	IV	V
🟦 Type 1	442.15	707.46	1061.2	1591.8
🟥 Type 2	445.1	712.19	1068.3	1602.4
🟩 Type 3	437.09	699.32	1049	1573.5
🟪 Type 4	277.34	443.73	665.59	998.38

Figure: 9, Base Shear Comparison



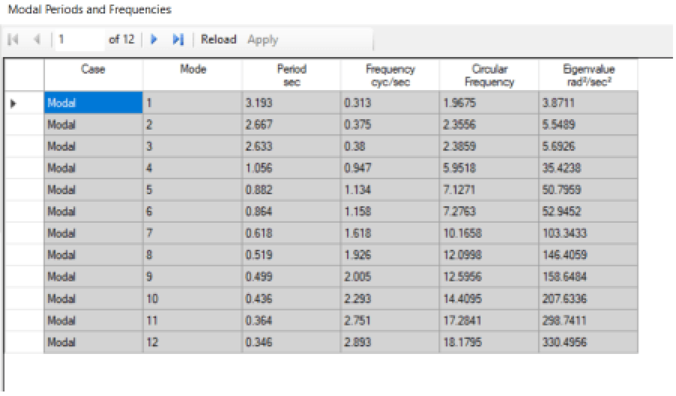
	II	III	IV	V
🟦 Type 1	22	35.2	52.8	79.1
🟥 Type 2	22.2	35.5	53.2	79.7
🟩 Type 3	23	36.8	55.1	82.7
🟪 Type 4	33.3	52.3	77.8	116

Figure: 10, Top Storey Displacement Comparison



	1	2	3	4	5	6
🟦 Type 1	2.98	2.24	2.16	0.99	0.74	0.71
🟥 Type 2	3.01	2.26	2.18	0.99	0.75	0.72
🟩 Type 3	3.13	2.33	2.24	1.04	0.77	0.74
🟪 Type 4	2.9	2.34	2.09	0.96	0.77	0.68

Figure: 11, Time- Period Comparison



Case	Mode	Period sec	Frequency cyc/sec	Circular Frequency	Eigenvalue rad^2/sec^2
Modal	1	3.193	0.313	1.9675	3.8711
Modal	2	2.667	0.375	2.3556	5.5489
Modal	3	2.633	0.38	2.3859	5.6926
Modal	4	1.056	0.947	5.9518	35.4238
Modal	5	0.882	1.134	7.1271	50.7959
Modal	6	0.864	1.158	7.2763	52.9452
Modal	7	0.618	1.618	10.1658	103.3433
Modal	8	0.519	1.926	12.0998	146.4059
Modal	9	0.499	2.005	12.5956	158.6484
Modal	10	0.436	2.293	14.4095	207.6336
Modal	11	0.364	2.751	17.2841	298.7411
Modal	12	0.346	2.893	18.1795	330.4956

Figure: 12, Time- period from validation

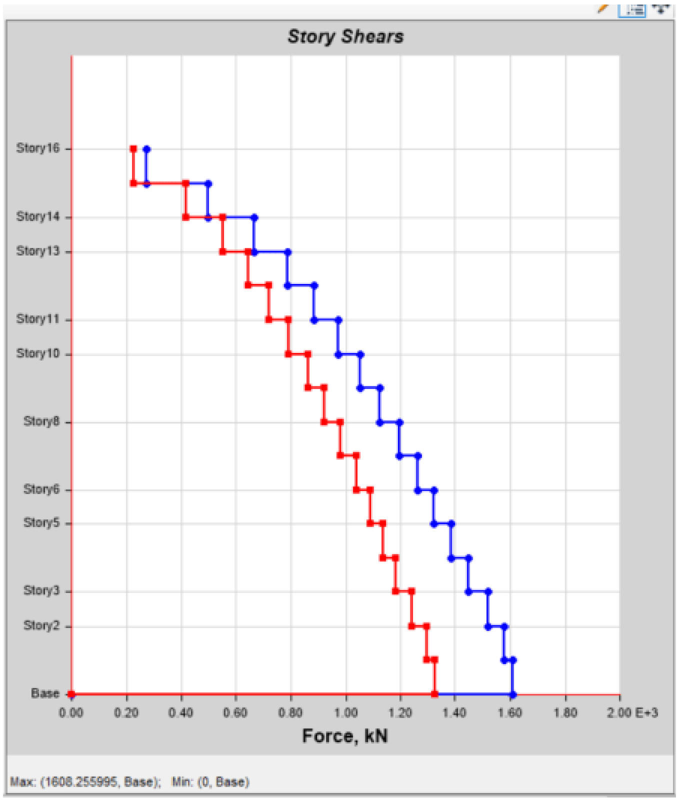


Figure: 13, Base shear from validation

Fig. 9 shows the graph of Zone v/s Base shear of all models, it shows that as the zone increases Base shear also increases. The maximum Base shear is in Type 4 i.e. Re-entrant corner in zone V which is the most vulnerable seismic zone of India. Fig. 10 shows the graph of Zone v/s Displacement of all models. It shows that as the zone increases Displacement also increases. Similar to Base Shear, the maximum Displacement is also in Type 4 i.e. Reentrant corner in zone V. Fig. 11 shows the graph of modes v/s Time- period of all models. It shows that in type 3 i.e. stiffness irregularity (soft story), the maximum time- period is 3.13 seconds in mode 1

VII.CONCLUSION

The present study makes an effort to evaluate the effect of stiffness on the seismic response of a vertical irregular building on the seismic zones II, III, IV, and V on medium soil. The study also extends to find the effect of Base shear, lateral displacement of buildings and, the fundamental natural period of the regular and irregular models. The study leads to the following broad conclusions:

- The Base shear and lateral displacements are gradually increased with an increase in zone factors for all models.
- The lateral displacement is less in the regular model compare to vertical irregular models with maximum lateral displacement in model type 4 i.e. the Re-entrant corner model and minimum in model type 1 i.e. the regular model
- The base shear is maximum in model type 2 i.e. mass irregularity and minimum in type 4 i.e. Re-entrant corner model. The vertical irregular models i.e. type 3 and type 4 showed the least base shear compare to other types of models.
- The time- period at first mode is highest in model type 3 i.e. stiffness irregularity and lowest in model type 4 i.e. Re-entrant model.

When irregular buildings are analyzed using linear equivalent static analysis and Response spectrum analysis considering different seismic zones according to code provisions, the results obtained highlight the importance of mass, stiffness, and geometry of the structure. Following broad conclusions can be made in this respect:

- This study quantifies the effect of vertical irregularities in mass and stiffness on seismic demands.
- From the overall study and observation, it can be concluded that Base shear and lateral displacement will increase as the seismic intensity increases from Zone-II to Zone-V which indicates more seismic demand the structure should meet.
- Base shear for mass irregularity is found more compared to all other irregularities since base shear depends on the seismic weight of the building.

VIII.REFERENCES

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