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Seismic Effect of Re-entrant and Torsional Irregularities On Multi-Storey Buildings

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Abstract -The present study aims at understanding the importance of codal provisions, which are particularly provided for the analysis of torsionally unbalanced structures. IS 1893-2002 Part 1 Code gives the information about number of parameters which influences the irregularity of the structure. However, in the present study the worst affected irregularity under the influence of torsion are studied, In the present study, seismic analysis has been performed by Equivalent Lateral Force Method (ELF) ie the codal method, for all zones and for all soil types irregularities such as Re-entrant irregularity and Torsional irregularity for 10, 15, 20 storey buildings

The results in form of torsional moment, fundamental time period and base shear results are compared for different irregularities and the analysis is done with Etabs 9.2 software.

STATEMENT OF THE PROBLEM

Seismic induced torsion in asymmetric RC buildings has been studied for various parameters. Equivalent Lateral Force Method (ELF) adopted to study the induced torsion as per IS 1893(Part 1): 2002 codal provisions. ETABS v9.5.software package is used to carry all the static and dynamic analysis. Since the present study is devoted for the investigation of torsional behaviour of asymmetric structures, in order to capture exact three dimensional behaviour, all the analysis are performed on complete three dimensional models of the structures.

OBJECTIVES OF THE STUDY

The present study aims at understanding the importance of codal provisions, which are particularly provided for the analysis of torsionally unbalanced structures. IS Code gives the information about number of parameters which influences the irregularity of the structure. However, in the present study the irregularity under the influence of torsion are studied in detail.

Hence, the following objectives were identified based on these parameters. The present study focuses on the discontinuities in a lateral force resistance path, such as out-of-plane offsets of vertical elements etc.

1. To study the influence of plan configurations of a structure and its lateral force resisting system containing re-entrant corners.

REVIEW OF LITERATURE

Anil K. Chopra et.al (2004) [2] study compares the seismic demands for vertically irregular and ''regular'' frames determined by rigorous nonlinear response history analysis (RHA), due to an ensemble of 20 ground motions. Forty-eight irregular frames, all 12-story high with strong columns and weak beams, were designed with three types of irregularities stiffness, strength, and combined stiffness and strength introduced in eight different locations along the height using two modification factors. The effects of vertical irregularity on the median values of story drifts and floor displacements are documented. Next, the median and dispersion values of the ratio of story drift demands determined by modal pushover analysis (MPA) and nonlinear RHA were computed to measure the bias and dispersion of (MPA) estimates leading to the following results: (1) the bias in the MPA procedure does not increase, i.e., its accuracy does not deteriorate, in spite of irregularity in stiffness, strength, or stiffness and strength provided the irregularity is in the middle or upper story, (2) the MPA procedure is less accurate relative to the regular frame in estimating the seismic demands of frames with strong or stiff-and-strong first story; soft, weak, or soft-and-weak lower half; stiff, strong, or stiff-and-strong lower half, (3) in spite of the larger bias in estimating drift demands for some of the stories in particular cases, the MPA procedure identifies stories with largest drift demands and estimates them to a sufficient degree of accuracy, detecting critical stories in such frames, and(4) the bias in the MPA procedure for frames with a soft, weak, or soft-and-weak first story is about the same as for the regular frame

Babak Rajaee Rad et.al (2007) [3] High-rise concrete shear walls are often supported near or below grade by stiff floor diaphragms connected to perimeter foundation walls. When a large portion of the overturning moment in the wall is transferred to the foundation walls by force couples in two or more stiff floor diaphragms, the maximum bending moment flexural plastic hinge occurs above the diaphragms and the shear force reverses below the flexural hinge. Depending on the stiffness of floor diaphragms, and on the shear rigidity and flexural rigidity of the high-rise concrete walls, the reverse shear force below the flexural hinge may be much larger than the base shear above the flexural hinge. Nonlinear dynamic analyses indicate the maximum reverse shear force is proportional to the bending moment capacity of the wall and inversely proportional to the accompanying base shear force. An upper-bound estimate of bending moment capacity of the high-rise wall combined with an assumed zero base shear force can be used in a simple nonlinear static analysis to estimate the maximum shear force below the flexural plastic hinge. A nonlinear shear model can be used to determine whether diagonal cracking of the wall and yielding of horizontal wall reinforcement will reduce the reverse shear force without causing a shear failure. Increasing the quantity of horizontal reinforcement in the wall above a certain limit may not prevent a shear failure and thus a different design solution will need to be found. An upper-bound estimate of floor diaphragm stiffness should be used in order to not underestimate the shear strain demand on high-rise walls.

Devesh P. Soni (2006) [4] study summarizes state-of-the-art knowledge in the seismic response of vertically irregular building frames. Criteria defining vertical irregularity as per the current building codes have been discussed. A review of studies on the seismic behavior of vertically irregular structures along with their findings has been presented. It is observed that building codes provide criteria to classify the vertically irregular structures and suggest dynamic analysis to arrive at design lateral forces. Most of the studies agree on the increase in drift demand in the tower portion of set-back structures and on the increase in seismic demand for buildings with discontinuous distributions in mass, stiffness, and strength. The largest seismic demand is found for the combined-stiffness-and-strength irregularity. It can be concluded that a large number of research studies and building codes have addressed the issue of effects of vertical irregularities
Building codes provide criteria to classify the vertically irregular structures and suggest elastic time history analysis or elastic response spectrum analysis to obtain the design lateral force distribution.

Dhiman Basu et.al (2004) [5] made a detailed investigation on the importance of diaphragm rigidity for the seismic response of a structure. Even though a rigid floor diaphragm is a good assumption for seismic analysis of most buildings, several building configurations may exhibit significant flexibility in floor diaphragm. In this paper, the definition of centre of rigidity for rigid floor diaphragm buildings has been extended to unsymmetrical buildings with flexible floors. A superposition-based analysis procedure is proposed to implement code-specified torsional provisions for buildings with flexible floor diaphragms, similar to that of rigid floor diaphragms. The procedure suggested considers amplification of static eccentricity as well as accidental eccentricity. The proposed approach is applicable to orthogonal as well as non-orthogonal unsymmetrical buildings and accounts for all possible definitions of centre of rigidity.

In this investigation, the building is assumed to have a single wing only, i.e., buildings with multiple wings (e.g., L, V, Y, etc. shaped) are not considered. The no-torsion condition for flexible floor buildings is defined such that center nodes at either end of the diaphragm are constrained so that they undergo equal horizontal displacement. The proposed analysis procedure considers the final response as the superposition of three cases: the no-torsion case, amplification of the static eccentricity, and accidental torsion. The proposed procedure ensures that the resultant member force is close to that of rigid floor buildings as the floor diaphragm rigidity increases. It is seen that treating the diaphragms of such buildings as rigid for torsional analysis may cause considerable error.

Eduardo Miranda et.al (2004) [6] An approximate method is presented to estimate the maximum lateral drift demands in multi story buildings with non uniform lateral stiffness responding primarily in the fundamental mode when subjected to earthquake ground motions. The method is aimed at the estimation of the maximum roof displacement and of the maximum inter story drift ratio for a given response spectrum. A simplified model of the multi story building is used based on an equivalent continuum structure with non uniform lateral stiffness distribution consisting of a combination of a flexural cantilever beam and a shear cantilever beam. The effect of the type and amount of reduction in lateral stiffness along the height of the building and of the ratio of overall flexural and shear deformations on the ratio of the spectral displacement to the roof displacement and on the ratio of the maximum inter story drift ratio to the roof drift ratio is investigated. It is shown that reductions in lateral stiffness along the height have a negligible effect on the ratio of spectral displacement to maximum roof displacement and only a small effect on the ratio of maximum inter story drift ratio to roof drift ratio.

MODELLING

ETABS is a sophisticated, yet easy to use, special purpose analysis and design program developed specifically for building systems. ETABS Version 9 features an intuitive and powerful graphical interface coupled with unmatched modelling, analytical, and design procedures, all integrated using a common database. Although quick and easy for simple

ANALYSIS USING ETABS

The modelling and analysis of the building is carried out using ETABS Nonlinear v9.2.0 software package. ETABS is a powerful program developed by Computers and Structures Inc, Berkeley, California, USA which can greatly enhance an engineer's analysis and design capabilities for structures. Part of that power lies in an array of options and features. The other part lies in how simple it is to use.

The basic approach for using the program is very straight forward. The user establishes grid lines, defines material and structural properties, places structural objects relative to the grid lines using point, line and area object tool. All the types of loads that the structure is subjected to, can be defined and assigned to the appropriate structural components. Dynamic analysis properties like mass source, total number of mode shapes and its directions can be defined. The following topics describe some of the important areas in the modelling. Finally, the analysis can be performed and the results are generated in graphical or tabular form that can be printed to a printer or to a file for use in other programs. The following topics describe some of the important areas in the modelling.

MODELLING OF REGULAR BUILDINGS:

Details of regular buildings considered in this work are as follows:

Column size 230X600 mm

Beam size is 230X450 mm

Slab size is 150mm thick

Height of the floor 3m

Live Load on roof slab 1.5 KN/m^2

Live Load on floor slab 3KN/m^2

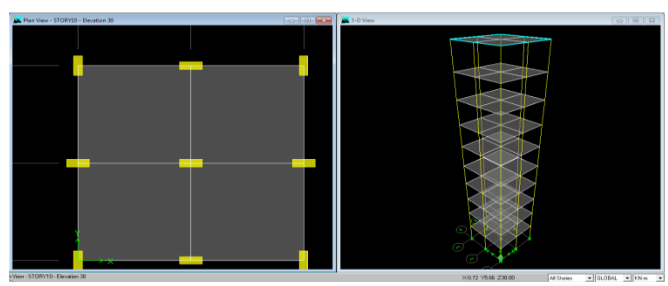
Floor Finish on roof slab 1.5 KN/m^2

Floor Finish on floor slab 1KN/m^2

All the columns are assumed to be fixed at their base

Characteristic compressive strength of concrete in slabs is M25

Characteristic compressive strength of concrete in Columns and Beams is M30



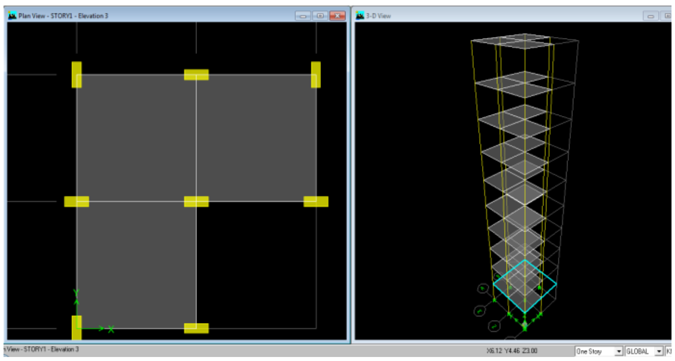
ETABS model screen shot of a regular 10 storied building

The similar models are generated using ETABS with & without irregularities are for 10, 15 & 20 storey's

MODELLING IN IRREGULAR BUILDINGS:

Re-entrant corners Irregularity

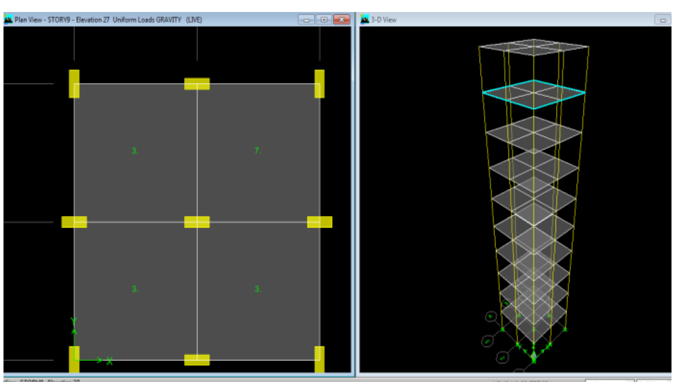
In this irregularity the changes with respect to Regular building is that the one grid has been deleted in order to make it re-entrant according to the IS code with respect to the regular building as per IS 1893-2002 part I.



ETABS model screen shot of a re-entrant corners irregular 10 storied building

Torsion Irregularity

In this irregularity the changes with respect to Regular building is that the live load has been increased by one grid throughout the building with respect to other grids to create torsion irregularity compared to regular building as per IS 1893-2002 part I.



ETABS model screen shot of a torsional irregular 10 storied building

SEISMIC ANALYSIS OF STRUCTURES

DESIGN LATERAL FORCE

The procedure recommended for the determination of lateral force in IS:1893-2002(Part 1) performing are based on the approximation that effects of yielding can be accounted for by linear analysis of the building using design spectrum. This analysis is carried out by either equivalent lateral force procedure or dynamic analysis procedure given in the clause 7.8 of IS:1893-2002 (Part 1). The main difference between the two procedures lies in the magnitude and distribution of lateral forces over the height of the building. In the dynamic analysis procedure, the lateral forces are based on properties of the natural vibration modes of the building which are determined by distribution of mass and stiffness over the height. In the equivalent lateral force procedure the magnitude of forces is based on an estimation of the fundamental period and on the distribution of forces as given by a simple emperical formula that is appropriate only for regular buildings. In the analysis of irregular buildings, equivalent lateral force method fails to capture the actual three dimensional behaviour of the structure. The following sections will discuss in detail the above mentioned procedures of seismic analysis.

Equivalent Lateral Force Method

The total design lateral force or design base shear along any principal direction is given in terms of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental period of the structure. The procedure generally used for the equivalent static analysis is explained below:

(i) Determination of fundamental natural period (Ta)of the buildings

$T_a = 0.075h^{0.75}$ Moment resisting RC frame building without brick infill wall

$T_a = 0.085h^{0.75}$ Moment resisting steel frame building without brick infill walls

$T_a = 0.09h/\sqrt{d}$ All other buildings including moment resisting RC frame building with brick infill walls.

Where,

h -is the height of building in m

d - is the base dimension of building at plinth level in m, along the considered direction of lateral force.

(ii) Determination of base shear (V_B)n of the building

$$V_B = A_h \times W$$

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Where,

$$Ah = \frac{Z}{2}\frac{I}{R}\frac{Sa}{g}$$ is the design horizontal seismic coefficient, which depends on the seismic zone factor (Z), importance factor (I), response reduction factor (R) and the average response acceleration coefficients (Sa/g). Sa/g in turn depends on the nature of foundation soil (rock, medium or soft soil sites), natural period and the damping of the structure.

(iii) Distribution of design base shear

The design base shear V_B thus obtained shall be distributed along the height of the building as per the following expression:

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2}$$

Where, Q_i is the design lateral force, W_i is the seismic weight, h_i is the height of the i^{th} floor measured from base and n is the number of stories in the building.

RESULTS AND DISCUSSIONS

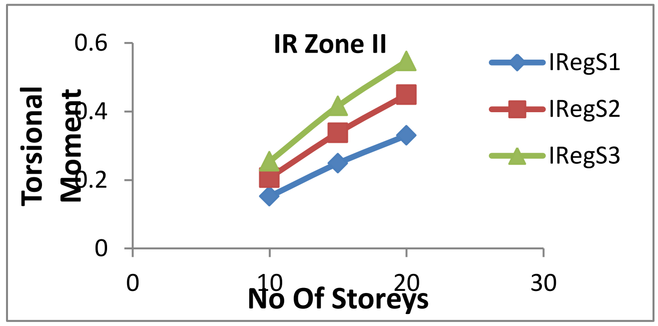
The results of each building models are presented in this chapter. The analysis carried out are equivalent static and seismic analysis, the results are obtained for ten, fifteen and twenty story buildings The result of Torsional moment, Fundamental time period and Base shear for different models are presented and compared to with different models for different irregularities, In addition to this all models are evaluated with different type of soils, all the zones, mass, rigidity and performance of different type of irregularities in different soil and zone types are presented.

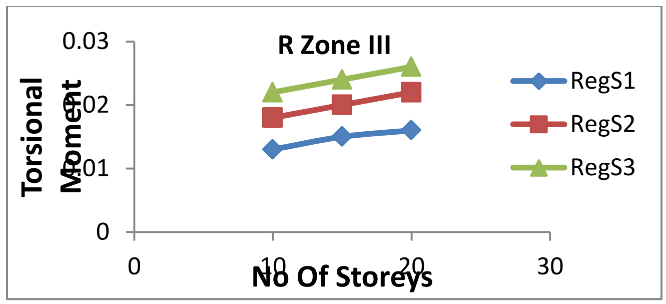
Note: The notations used below are as follows

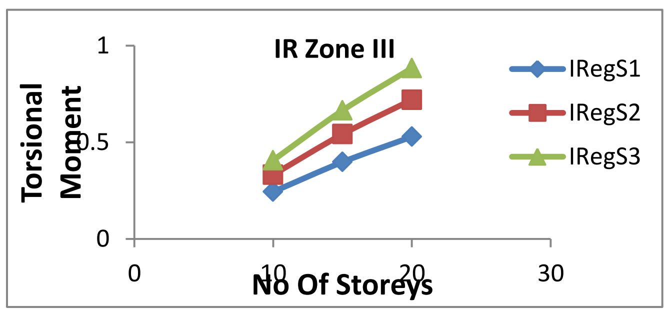
i) R= REGULAR
ii) IR= IRREGULAR
iii) REGS1= REGULAR SOIL TYPE 1
iv) REGS2= REGULAR SOIL TYPE 2
v) REGS3= REGULAR SOIL TYPE 3
vi) IREGS1= IRREGULAR SOIL TYPE 1
vii) IREGS2= IRREGULAR SOIL TYPE 2
viii) IREGS3= IRREGULAR SOIL TYPE 3

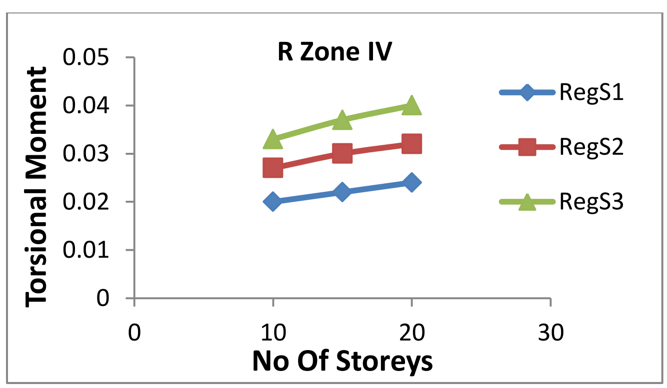
RE-ENTRANT CORNERS IRREGULARITY

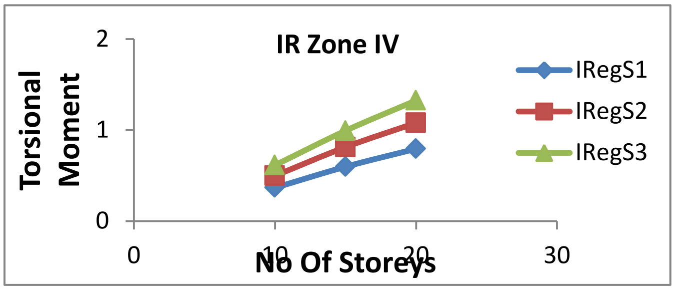
TORSIONAL MOMENTS

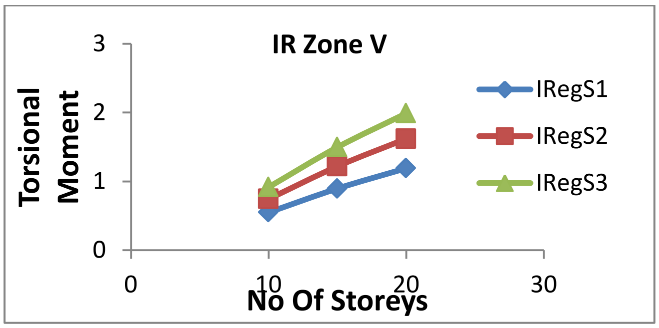




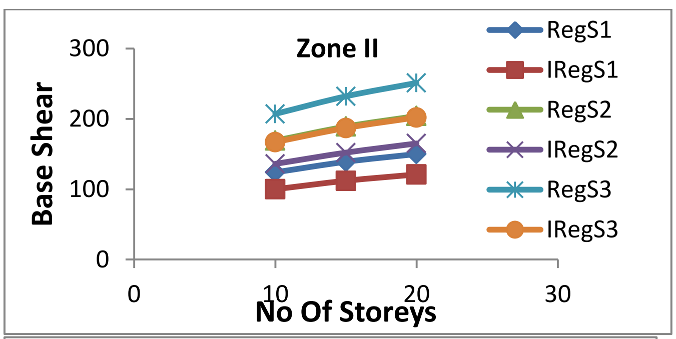


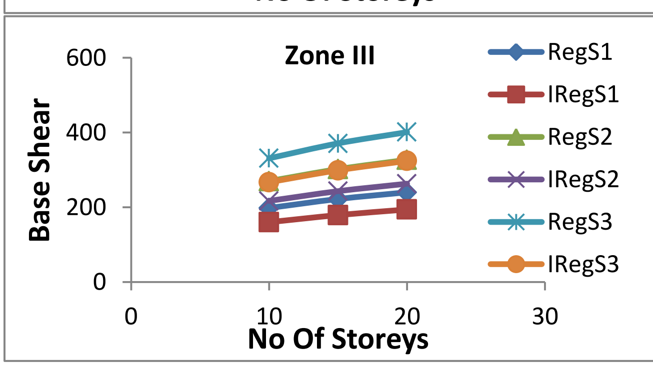


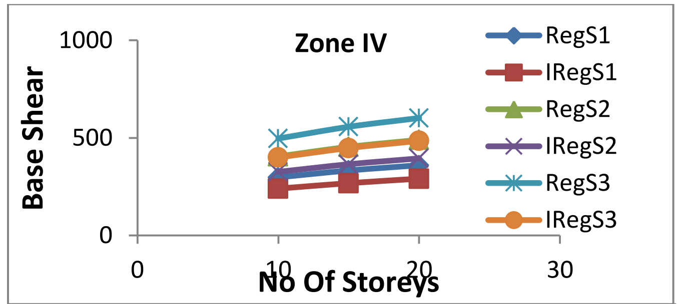


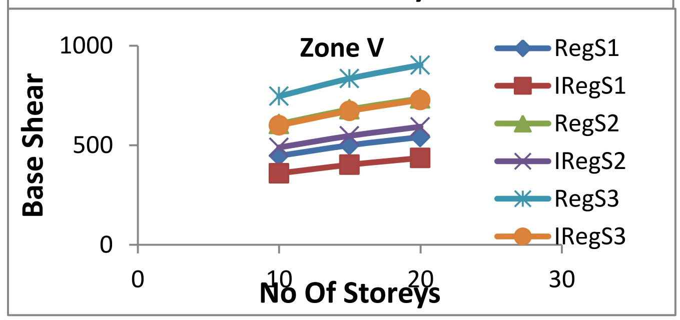


BASE SHEAR





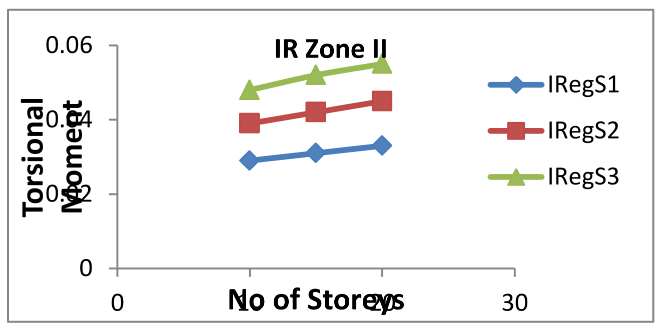


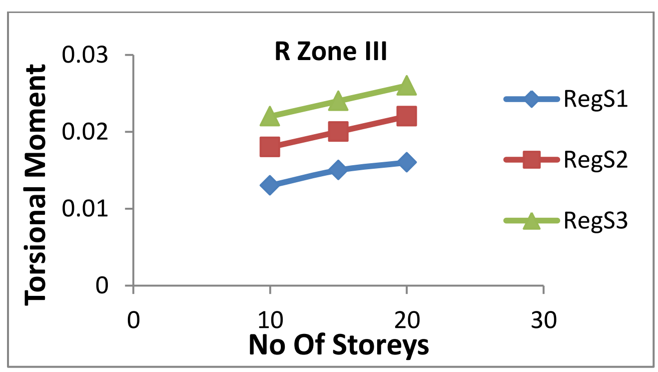


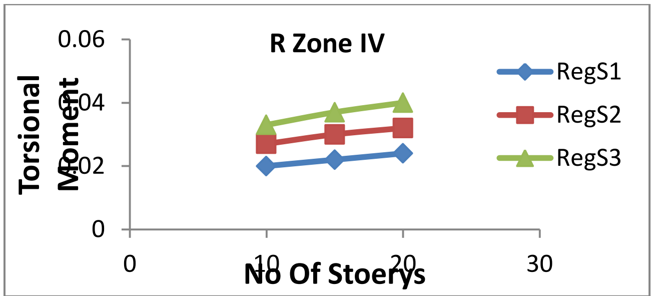
TORSIONAL IRREGULARITY

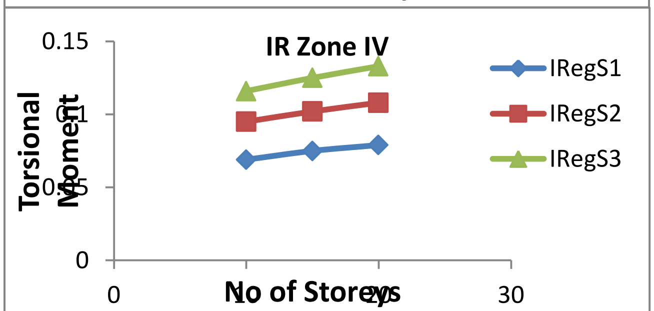
TORSIONALMOMENT

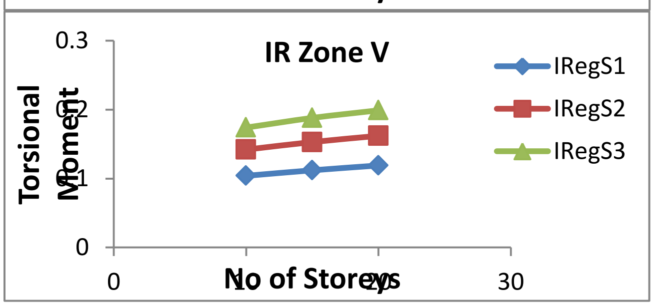
6.35(b



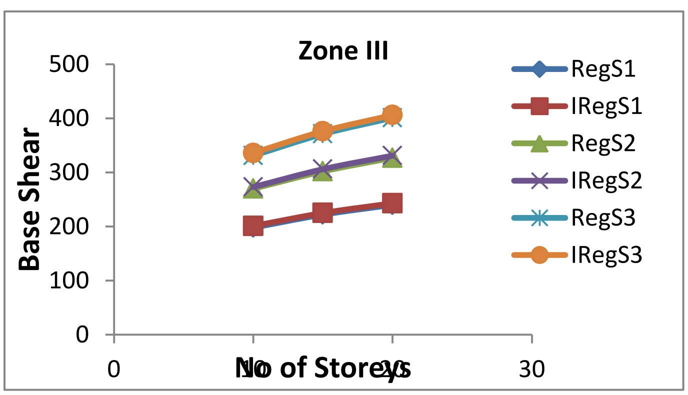


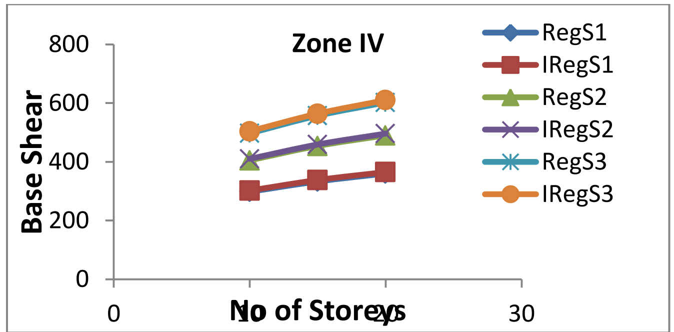


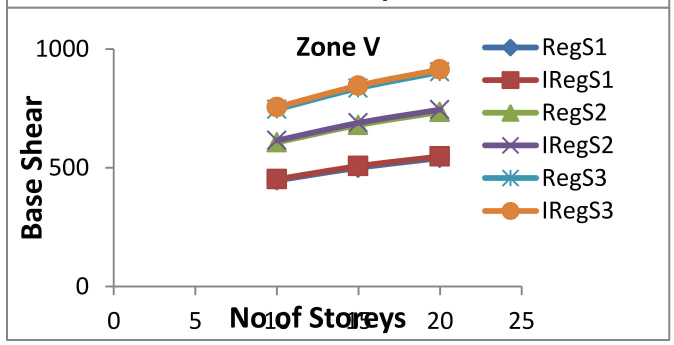




BASE SHEAR







CONCLUSION

From the study on Re-entrant corner irregularity following are concluded:

- The torsional moments, fundamental period & base shear increases with the increase in the height of a regular building.
- Torsional moments are high in a 20 storied building compared to a 10 or 15 storied building
- The effect of variation in the Base shear is high in 15 storied building compared to a 10 or a 20 storied building in soil type 2 in all zones.
- The effect of variation in the fundamental time period is high in a 10 storied building compared to a 15 or a 20 storied building.

From the study on Torsion irregularity following are concluded:

- The torsional moments, fundamental period & base shear increases with the increase in the height of a regular building.
- Torsional moments are high in 10 to 20 storied building in all seismic zones & all soil types.
- Base shear varies linearly from 10 to 20 storied building in all seismic zones & all soil types.
- The effect of variation in the fundamental time period is high in a 10 storied building compared to a 15 or a 20 storied building.

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