DYNAMIC ANALYSIS OF SET-BACK RC STRUCTURES DURING EARTHQUAKE

Hitesh Kumar[1], Gaurav Tanwar[2]

[1]*M.Tech research scholar, Department of Civil Engineering, BRCM CET, Bahal*
[2]*Assistant professor, Department of Civil Engineering,* BRCM CET, Bahal

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Abstract - *As per IS 1893:200, the vertical irregularities are classified as Mass irregularities, stiffness irregularities, parametric irregularities and weak storey. The set-back structures fall to the category of parametric or vertical irregularities. This set-back affects the mass, strength, stiffness, centre of mass and centre of stiffness of set-back building. Dynamic characteristics of such buildings differ from the regular building due to changes in geometrical and structural property. Set-back in buildings introduces stagger sudden reductions in floor area along the height of the building. The present research work deals with the determination of storey drift of the various types of models considered containing constant bay length with different loading cases. Three models having bay dimensions of 5m x 5m are subjected to variable set-back with total structural height of 87.5 m. The complete structure consists of total 25 storeys having 3.5 m of height at each storey to the roof level. The models are analyzed dynamically using STAAD.Pro V8i. The value of storey-drift are determined for the most optimum and critical set-back ratio having different conditions of soil such as soft, medium and hard soil. The most optimum set-back ratio is observed to be H = 8/25 and A/L = 0.75 for seismic waves in z-direction for all the various types of soil conditions. Moreover, for seismic waves along X-direction, the most optimum set-back ratio is observed to be different. The optimum is observed at A/L = 0.50 and H = 12/25 for soft soil and at A/L = 0.50 and H = 8/25 simultaneously, at A/L = 0.75 and H = 8/25 for medium soil condition and at A/L = 0.50 and H = 12/25 for hard soil condition. In addition to this, the critical value of set-back is found to be at A/L = 0.25 and H = 12/25 and A/L = 0.75 and H = 4/25 for seismic waves along Z-direction and X-direction respectively.*

Key Words: Set-Back Structure, Storey Drift, Stiffness, Set-Back Ratio, Dynamic Analysis

1. INTRODUCTION

The growth rate of population in urban areas has exceeded the general population increase rate since the industrial revolution. More recently i.e. over the last five decades, migration of rural population of metropolis cities has been so miraculous as to cause severe pressure on space for living and for office complexes. This has directed to construction in vertical direction.

For low to medium rise structures, the analysis and design with respect to lateral forces has generally a process of checking the vertical load resisting system for its ability to resist lateral forces. However, for tall building the vertical load resisting system cannot resist lateral forces efficiently. From economic, structural strength and stiffness consideration, it is crucial that the lateral force resisting system be carefully considered in the initial design stage and integrated as key features of total design. Therefore, in order to make the structure economically possible, various structural systems have been introduced in multi-storey building depending upon the member of storeys. The section of the structures that is used to resists the lateral earthquake forces is known as the lateral force resisting system (LFRS). This system of the structure may be of dissimilar types. The mainly general types of these systems in a structure are particular moment resisting frames, shear walls and frame-shear wall dual systems. The damage in a structure usually initiates at location of the structural weak planes present in the building systems. These weaknesses may leads to structural deformations and deteriorations additionally that can be resulted into the collapse of the structure. These weaknesses often happen due to existence of the structural irregularities in terms of their strength, mass distribution, lateral stiffness and shape of the building. The irregularity in the buildings may be classified as plan structural irregularities and vertical structural irregularities.

1.1 VERTCAL IRREGULARITIES IN STRUCTURES

Based on IS: 1893-2002, the vertical structural irregularities in the buildings are classified as follows:

- *Mass Irregularities*- As per Indian Standards, if the effective net mass of any upper storey is higher than the 200% of its effective net mass of the lower storey, such irregularity is known as Mass Irregularity.
- *Stiffness Irregularities*- The condition of this irregularity includes the following two conditions related to the variations in the values of lateral stiffness:
  - The lateral elastic stiffness of the structure is below 70% of the lateral elastic stiffness in the adjacent storey;
  - The lateral elastic stiffness of the structure is below 80% of the value of the average lateral elastic stiffness of the three stories just above in the same structure.

Any of the above condition may satisfy to fulfill the criteria of stiffness irregularity. Such structures are known as Soft Storey Structures or Stilt Structures.

- *Geometric or Parametric Irregularities*- In this types, the lateral and longitudinal dimensions of the LFRC in any of the structural storey is higher than 150% of that value in any above, or adjacent storey.
- *Weak storey*- If the lateral strength of storey is lower than 80% of its strength in the above or below storey, the storey is termed as weak storey.

The lateral strength of any storey represents the Base Shear and its distribution among all earthquake-resistant components of the structures that share the shear forces in a given particular direction.

1.2 SET-BACK STRUCTURES

Based on IS: 1893 - 2002, if A/L of a structure is above 0.25 as shown in the fig 1.1, the structure is known as Set-Back Structure.

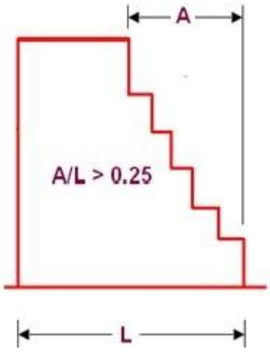

Fig. 1: A/L ratio as per IS: 1893-2002

This set-back affects the mass, strength, stiffness, centre of mass and centre of stiffness of set-back building. Dynamic characteristics of such buildings differ from the regular building due to changes in geometrical and structural property. Set-back in buildings introduces stagger sudden reductions in floor area along the height of the building.

2. RESEARCH OBJECTIVE

To address the requirement for research of vertical set-back structure under seismic loadings, response of twenty five storey RCC frames which is irregular in elevation is considered. The following research objectives are to be determined using the analytical approach:

- To develop three different models with different cases having same storey height i.e. 87.5 m.
- To analyze the set-back structure dynamically which is primarily subjected to lateral earthquake loads and various load combinations.
- To determine the storey drift criteria for the most optimum value most critical value of the set-back ratio for all the defined cases subjected to various conditions of soils i.e. soft soil, medium soil and hard soil.

3. DESCRIPTION OF THE BUILDING FRAMES:

The seismic response of twenty five storey RCC irregular frames in storey height has been considered. The building has a plan of dimension 20x40m. The storey height is 3.50 m uniform up to the roof level. Total height of the structure is taken as 87.5 m for all the structures which is of 25 storey. Storey drift criteria are measured for the critical and best value of A/L ratio with change in height where the ratio and height affecting the structure is in maximum and negligible amount among all the cases with different soil conditions i.e., hard soil, medium soil and soft soil in seismic zone V. All the structures are modeled in STAAD.Pro.V8i software. Following table 4.1 shows the description of all models with different A/L ratio with change in height:

Table 1: Description of Model

S. No.	A/L Ratio	Along the Height	Designation
		H=4/25	M1 A
1	0.25	H=8/25	M1 B
		H=12/25	M1 C
		H=4/25	M2 A
2	0.50	H=8/25	M2 B
		H=12/25	M2 C
		H=4/25	M3 A
3	0.75	H=8/25	M3 B
		H=12/25	M3 C

Table 2: Dimension detail of elements in a structure

S. No.	Elements	Dimension in mm
1.	Slab	200 mm
2.	Column	750 mm x 750 mm
3.	Beam	450mm x 650 mm

4. LOADINGS

4.1 Gravity Loads (DL+LL)

The loading intensities of the various floor levels and roof levels for a commercial building are listed below:

Table 3: Description of Floor loads

Description	**Load Calculations**	**Load in KN/m^2**
Weight of slab 200mm thick	1 X 0.20 X 25	5KN/m^2
Weight of floor finishing	1 X 0.050 X 20.80	1.04KN/m^2
Weight of plaster	1 X 0.012 X 20.80	0.2496KN/m^2
	Total Dead Load	**6.3KN/m^2**
Floor load at terrace		**7.3KN/m^2**
Live load as per IS: 875 – 1987 (Part – II)	1 X 1X 4	4KN/m^2
Live load as per IS: 875 – 1987 (Part – II)	1 X 1 X 1.5	1.5KN/m^2

Table 4: Description of Wall load

Description	**Load Calculation**	**Load in KN/m**
Weight of wall	3.05 X 19.2 X 0.25	14.64KN/m
Weight of plaster	0.035 X 20.8 X 03.5	2.548KN/m
	Total load	**17.18KN/m**
Parapet wall load	1 X 19.2 X 0.25	4.8KN/m
Weight of plaster	0.035 X 20.80 X 1.0	0.728KN/m
	Total load	**5.528 /m**

4.2 SEISMIC LOADS

As per IS-1893 2002, earthquake analysis of the structure is performed. The design horizontal seismic coefficient A_b for the structure has been computed by taking the following values of the factors:

- Zone factor, Z=0.36
- Importance factor, I=1.5
- Response Reduction factor, R=5.0

4.3 LOAD COMBINATIONS

As per IS: 1893 (Part 1) 2002, the following load combinations have been accounted for:

- 1.5 (DL+LL)
- (DL+LL±EL)
- 1.5 (DL±EL)
- 0.9 DL±1.5 EL

When earthquake forces are considered on a structure, these loads shall be combined as per clauses 6.3.1.1 of IS: 1893 (Part 1) 2002.

5. RESULTS AND DISCUSSIONS

The following cases have been carried in the detailed study. Results are presented for all the models in the graphical form. For various setback ratios (M1, M2, M3) the values of storey drift for seismic waves in both X and Z direction with different soil conditions are compared. All the values are noted for the worst combination of load i.e. at 0.9DL+1.5EQX and 0.9DL-1.5EQZ for displacement and storey drift for seismic waves in X and Z direction respectively where the and storey drift of structure affected the most.

Case (i) Storey Drift of Hard Soil in Z Direction at all A/L Ratios

By plotting the graph between storey drift vs. storey height of hard soil for seismic waves in Z direction it can be seen that critical value of set-back ratio is comes out to at model M1 C i.e. when A/L ratio of set-back structure is 0.25 and H=12/25.

While optimum value of critical set-back ratio is comes out to be at model M3 B i.e. when A/L ratio of set-back structure is 0.75 at height H=8/25 as shown below:

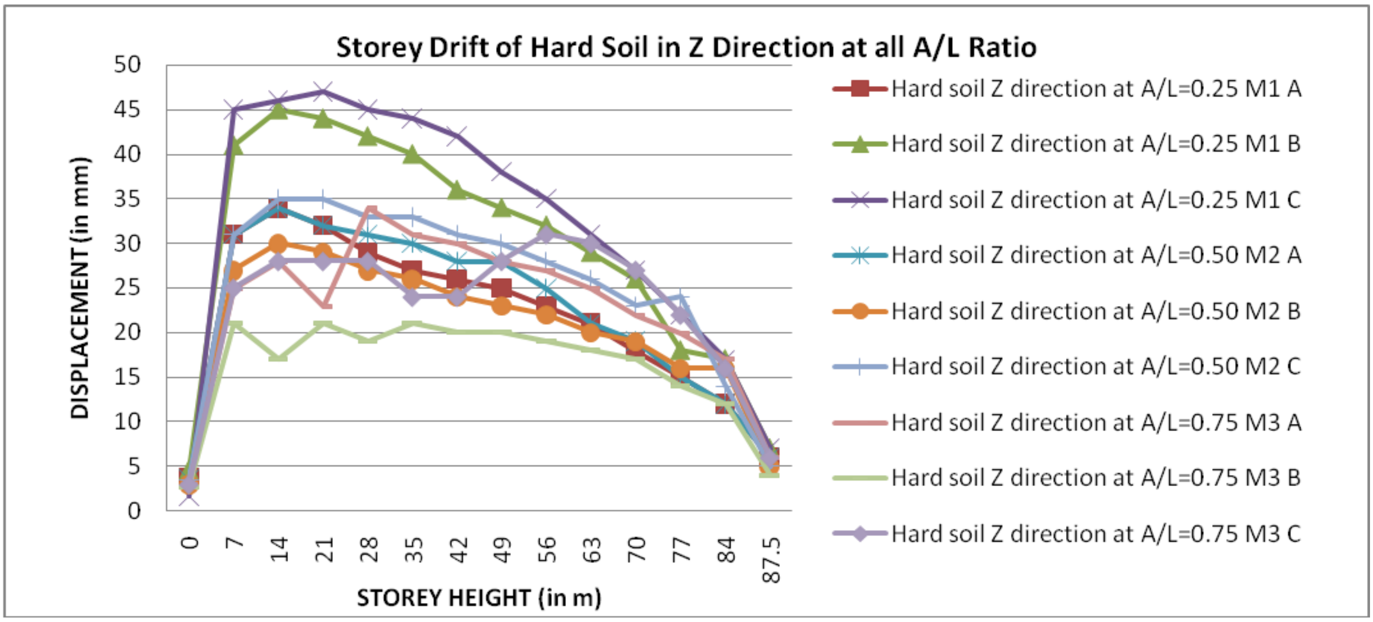

Fig. 2: Storey Drift of Hard Soil in Z Direction at all A/L Ratios

Case (ii) Storey Drift of Hard Soil in X Direction at all A/L Ratios

From the graph between storey drift vs. storey height of hard soil for seismic waves in X direction, critical value of set-back ratio is comes out to at model M3 A i.e. when A/L ratio of set-back structure is 0.75 and H=12/25. While optimum value of critical set-back ratio is comes out to be at model M2 B i.e. when A/L ratio is 0.50 at height of 8/25 as shown below:

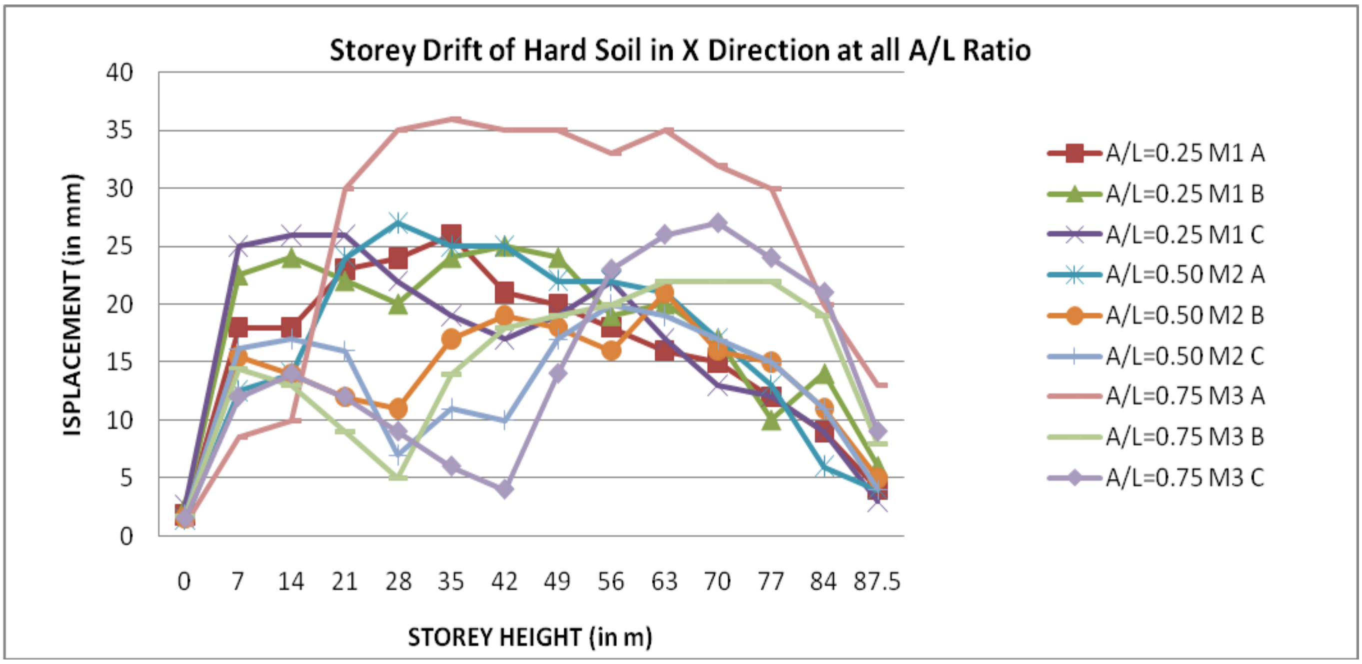

Fig. 3: Storey Drift of Hard Soil in X Direction at all A/L Ratio

Case (iii) Storey drift of Medium soil in Z direction at all A/L Ratios

By plotting the graph between storey drift vs. storey height of medium soil for seismic waves in Z direction it can be seen that critical value of set-back ratio is comes out to at model M1 C i.e. when A/L ratio of set-back structure is 0.25 and H=12/25. While optimum value of critical set-back ratio is comes out to be at model M3 B i.e. when A/L ratio of set-back structure is 0.75 at height h=8/25 as shown below:

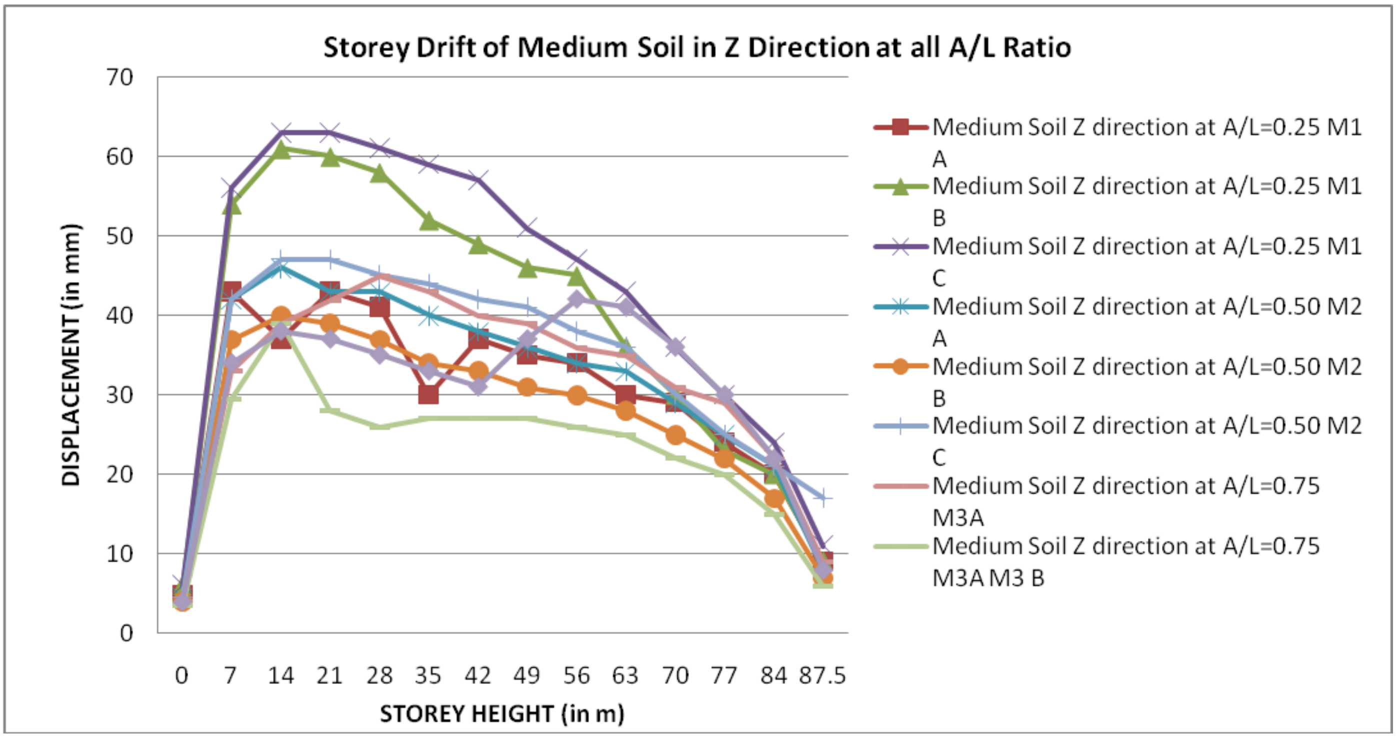

Fig 4: Storey Drift of Medium Soil in Z Direction at all A/L Ratio

Case (iv) Storey Drift of Medium Soil in X Direction at all A/L Ratio

By plotting the graph between storey drift vs. storey height of medium soil for seismic waves in Z direction it can be seen that critical value of set-back ratio is comes out to at model M3 A i.e. when A/L ratio of set-back structure is 0.75 and H=4/25. While optimum value of critical set-back ratio is comes out to be at model M3 B is shown below.

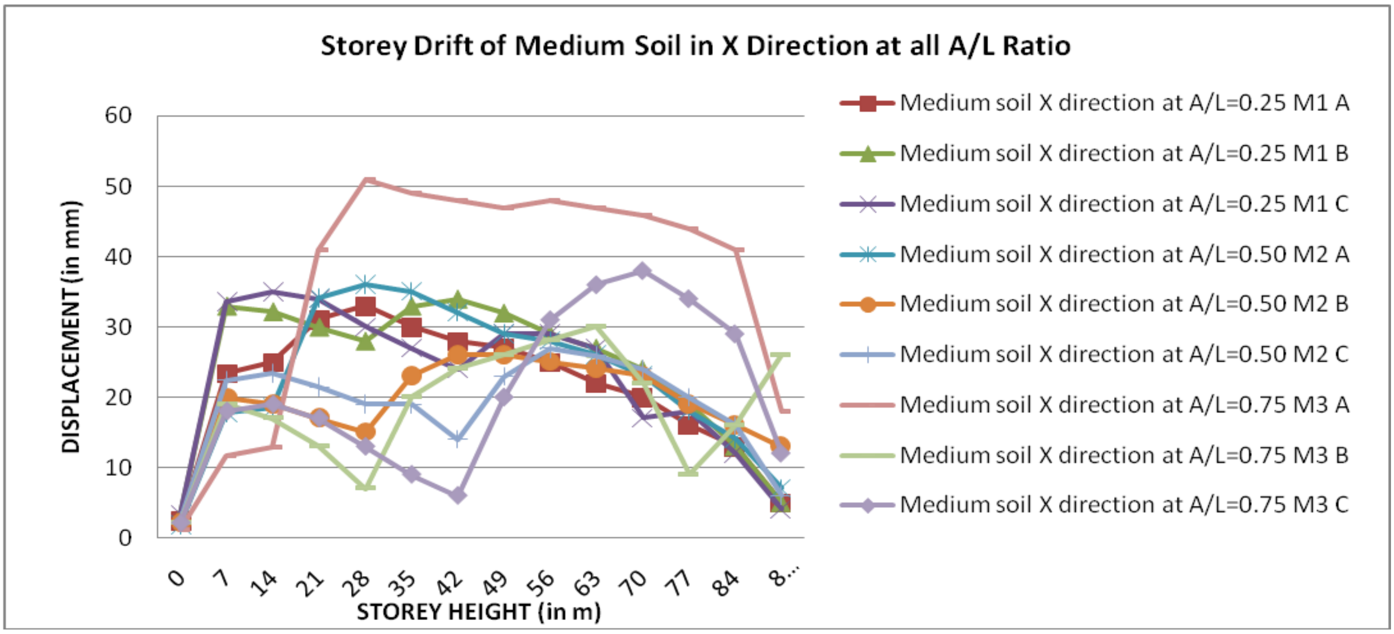

Fig 5: Storey Drift of Medium Soil in X Direction at all A/L Ratio

Case (v) Storey Drift of Soft Soil in Z Direction at all A/L Ratios

By plotting the graph between storey drift vs. storey height of soft soil for seismic waves in Z direction it can be seen that critical value of set-back ratio is comes out to at model M1 C i.e. when A/L ratio of set-back structure is 0.25 and H=12/25. While optimum value of critical set-back ratio is comes out to be at model M3 B i.e. when A/L is 0.75 with H=8/25 as shown below:

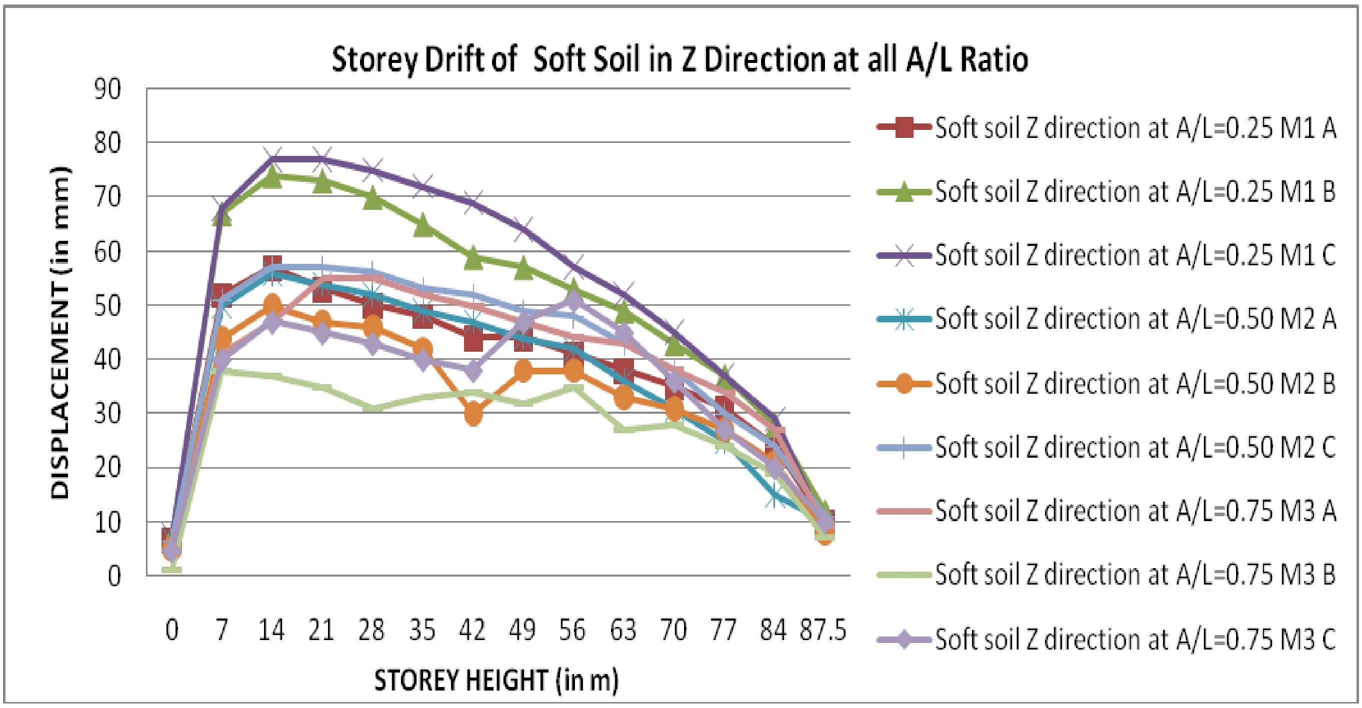

Fig. 6: Storey Drift of Soft Soil in Z direction in all A/L Ratio

Case (vi) Storey Drift of Soft Soil in X Direction at all A/L Ratio

By plotting the graph between storey drift vs. storey height of soft soil for seismic waves in X direction it can be seen that critical value of set-back ratio is comes out to at model M3 A i.e. when A/L ratio of set-back structure is 0.75 and H=4/25. While optimum value of critical set-back ratio is comes out to be at model M2 B i.e. when A/L ratio of set-back structure is 0.50 at height H=8/25 as shown below:

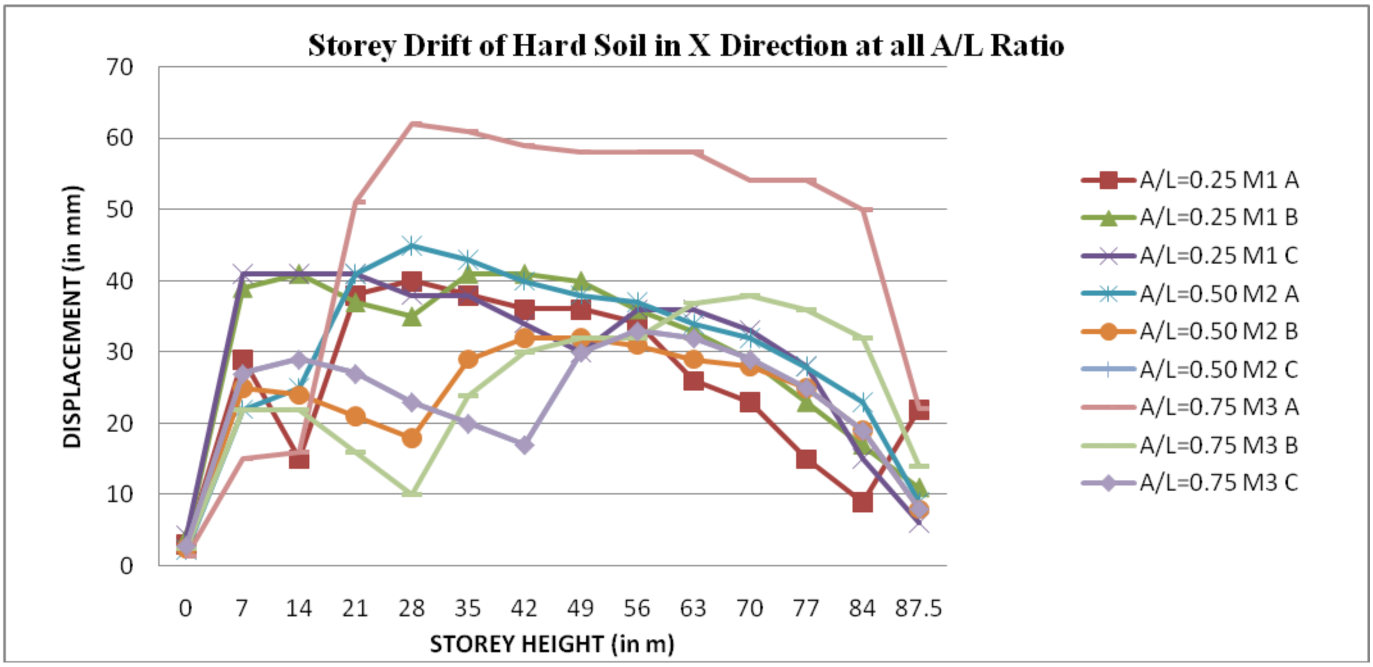

Fig. 7: Storey Drift of Soft Soil in X Direction at all A/L Ratios

From the above storey drift graphs i.e. fig. 5.13 to 5.18, it can be seen that there is first increase in storey drift in the structure and decreases as the height increases. The sudden variation occurs in storey drift which signifies the jumping of the forces due to unequal distribution of mass along the plan as well as along the elevation and as mass increases, storey drift also increases. For model M3 A i.e. at A/L=0.75 and H=4/25, storey drift increases because of low stiffness present in the upper storey of the structure and for model M1 C i.e. at A/L=0.25 and H=12/25, storey drift is most effected in middle part due to the increased in mass of the structure. As there increased in storey height at set-back i.e. at M3 B, there is increased in stiffness in lower part too, so that mass of the structure effects in less amount as compare to stiffness. So optimum value is comes out to be at A/L=0.75 at H=8/25. A slight storey drifts were found in the base and upper parts of set- back structure. Storey drift is depends upon the stiffness and mass of the structure. As mass increases, storey drift increases but as stiffness increases there is decreasing in the storey drift. Structures with constant variation of mass and stiffness in height give better seismic performance as compare to the structures with abrupt variations.

6. CONCLUSIONS

The comparative study of various cases formed by using STAAD.Pro V8i has led to the following conclusions:

- Critical set-back ratio for both the lateral storey drift point of view is at A/L=0.25 and H=12/25 for all kind of soil i.e. hard, medium and soft soil for seismic forces along the Z direction. However, for seismic forces along X direction it is observed that the critical setback ratio is 0.75 and H=4/25, which shows that critical value is depends on the geometry of the structure not upon the soil type.
- At A/L=0.25 and H=8/25, there is sudden variation of storey drift which signifies the jumping of the forces due to unequal distribution of mass along the plan as well as along the height.
- The most optimum value of set-back ratio for storey lateral drift criteria is observed to be at 0.75 and H=8/25 for seismic forces along Z direction for all the types of soil. But, for seismic forces along X direction of soft soil optimum value is observed to be at 0.50 and H=8/25. In case of medium soil, the most optimum value is observed to be at 0.75 and H=8/25 and in hard soil, the most optimum value is observed to be at 0.50 and H=8/25.
- Minor lateral storey drifts are observed in the base of the set-back structures and upper storey of the set-back structures when compared to that of the middle storey. The values of lateral storey drift depend on the elastic stiffness and mass configuration of designed structure. With increase in the mass of the structure, the lateral storey drift is observed to be

increased but with increase in the elastic stiffness of the structure, there is observed ro be decrease or fall in the lateral storey drift.

The above results concludes that the design of the irregular structures having mass irregularities or elastic stiffness irregularities must be with the exact understanding and based on the codal provisions of the respective countries. It can also be concluded that the modification of seismic codal provisions for variations in the geometrical irregularities along the height of structures appears to be very prominent in order to determine the restrictive structural limits or apply more exact analytical procedures to calculate the seismic performance of set-back structures. Therefore, as the course of seismic codes are followed, the amendment of codal provisions for the various vertical irregularities appears to be the most important when subjected to the seismic excitations, particularly for structures with critical set-back ratios.

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