Parametric study of seismic response of RC building with different shapes of plan considering soft storey at different levels

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Abstract The high-rise building in which the ground storey consists of open space is known as a building with a soft floor. Such a floor plays an important role in the seismic performance of the building. This is due to the abrupt changes in lateral stiffness and strength caused by such a storey. In the present era, there is an increase in population, and finding parking for flats in congested areas has become a significant issue. As a result, erecting multistory structures with open first floors is now a widespread practice. These Buildings that have all upper storeys enclosed by masonry walls but no infill masonry walls in the ground story are referred to as "Soft Stories " or "Open Ground Storey Buildings." This study investigates the study of seismic response of RC buildings with different shapes of plans considering soft storeys at different levels. The study is carried out on the G+15 storey buildings with five completely distinct shapes a square, an L-shaped building, a T-shaped building, a plus shape building and a C-shaped building model is used. ETABS 2018 version is used to analyze the entire set of models. Dynamic Analysis has been examined in the current work to assess the Base shear, Displacement, storey drift and overturning moment of all five-shape buildings with and without soft-storey considering different levels. The selected buildings are analyzed through four models and the comparison of results is carried out. After analysis and comparison of all parameters, suggest the guideline for the selection of optimum shapes of the plan are found to have good overall performance.

Keywords seismic behaviour, soft storey, story displacement, story shear, story drift, base shear

1. Introduction

The impact of urbanisation has been unusually consistent in recent history. In the modern day, the construction and advancement of higher structures are actually required. However, when seismic tremors occur, those structures might sustain severe damage [1]. High-rise structures are frequently built with reinforced concrete frames and masonry infills in urban and semi-urban regions all over the world. The phrase "infilled frame" refers to a composite structure made up of infill walls and a moment-resisting plane frame [2]. A multi-story building with one or more “soft “floors due to structural design is referred to as a soft-storey building. Buildings with soft stories typically have a considerable amount of open space on the ground floor, such as parking garages, expansive r or floors with lots of windows. Since soft stories are traditionally associated with retail establishments and parking garages, they are frequently found on the lower stories of a building, and the upper floors of the majority of buildings are more rigid than their base floors, this soft story creates a significant weak point in an earthquake [3]. The customary practice has been to use the ground level of the building for parking or reception areas on the first floor. These structures are referred to as "Soft stories" or "Open Ground Storey Buildings" because the ground floor lacks a brick infill and all of the above storeys are enclosed by masonry walls [4]. The configuration of a building has been classified as regular or irregular based on its size and shape, the arrangement of its structural components, and its mass. Two distinct sorts of irregularities exist.1) Horizontal irregularities consist of asymmetrical plan shapes (L, T, U, and F) or discontinuities in horizontal resistant parts such as re-entrant corners, broad apertures, cut-outs, and other alterations including torsion, deformations, and stress concentrations. 2) Vertical irregularities are rapid variations in the vertical direction of a structure's strength, stiffness, geometry, and mass [5]. The size and geometry of a high-rise building determine how it behaves towards earthquake shaking in high earthquake zones. Buildings having non-uniform geometry behave differently against seismic activity. Mostly, the high-rise buildings are irregular in both horizontal and vertical geometry. Irregularities and discontinuity give rise to eccentricity between the building mass and stiffness, producing damage to the structure. So, to design and analyse an irregular building a high level of engineering and designer effort are needed [6]. Because of the inclusion of parking spaces, the use of buildings for commercial purposes, and the improper use of masonry infill walls, many buildings experience abrupt changes in the structural stiffness of their stories, which can make them vulnerable to earthquakes. On the other hand, any irregularity in a plan, such as "mass eccentricity," may generate torsion in the structures, which may lead to the frame, on one side of the structure. This study focuses on determining the degree of damage to buildings that have soft story irregularities in height and torsional irregularities in their layout. Additionally, this study looks at how these two abnormalities interact to affect structures with steel moment-resisting frames [7]. when a multistorey building is subjected to seismic loading, the failure typically starts where the building is weakest. Due to this flaw, the structure deteriorates and eventually collapses structurally. The presence of abnormalities in a building's stiffness, strength, and mass is the main cause of this vulnerability. [8]. ASCE 7-05 Reference Section Table 12.6-1 defines that the lateral stiffness of the soft storey is less than 70% of that in the storey immediately above, or less than 80% of the average stiffness of the three stories above. Under substantial ground shaking, these structures behave like an inverted pendulum with the ductility demand concentrated at the soft-storey elements. These structures as a result tend to have limited stability and are vulnerable to severe ground shaking when the displacement demand can be very significant. Without structural walls to act as bracing elements, the columns that must resist the full axial gravity loading are forced to drift excessively which in turn leads to the collapse of the building as gravity loading takes over [9].

1.2. Soft Storey

Reinforced concrete (RC) frame buildings with multiple stories are increasingly popular in nations like India. Buildings with an open ground story exhibit the most prevalent sort of vertical irregularity. Recent buildings frequently have the unique characteristic of having several floors left open for parking, a reception area, offices, services, etc. These structures are also known as open-storey, soft-storey, or buildings on stilts. Due to the lack of stone walls, these stories weaken and become softer than the other stories. Buildings with structural imbalances are dangerous and unhealthy, and soft-storey structures are known to be vulnerable to collapse during earthquakes.

2. Objectives of the study

The following are the objectives of this study,

1) To perform seismic analysis of RC building using Response Spectrum Analysis.
2) To analyze the G+15 RC building with different shapes of a plan provided with a soft story considering its location in different earthquake zones and soil types by using ETABS software.
3) To carry out a comparative study of the responses (storey drift, displacement and base shear and overturning moment) of RC buildings with and without the soft storey at different levels.
4) To suggest guidelines for the selection of different shapes of the plan.

3. Structure Details and methodology

This study deals with the analysis of multi-storied structures by using response spectrum analysis. The modelling and analysis of all the structures are done using FEM-based software named ETABS 2018. A total of 4 models are prepared which include 1 model without a soft storey and 2 models with a soft storey at the first level, 3 models soft storey at the eighth level and 4 models soft storey at the fourteenth level. The five shape buildings chosen for this study all have the same floor plan. The plan area of each shape of the building is 600 sq.m The structures considered in this study are the G+15 reinforced concrete frame structures. The total height of the structure is 50.4 m with a floor-to-floor height of 3.15 m. The steel of Fe500 and concrete of grades M30 and M40 are used for structural members. Seismic loading is defined as per specifications in IS 1893 (Part 1): 2016 [11]. The soil type considered for the analysis is soft soils (type A). The seismic zone factor (Z) is taken as 0.36 and 0.24 (seismic zone V & IV). The importance factor (I) is taken as 1.2. The damping ratio is taken as 5%. The support conditions are considered fixed. The structure is considered an ordinary moment-resistant frame building (OMRF).

In analysis IS 875 (Part 2): 1987 is used for defining imposed loads on models [12]. Imposed load is taken as 3kN/m2. Floor finish loads are considered as 1kN/m2 and wall loads are considered as 14.49 kN/m2 external, and 9.45kN/m2 internal respectively. Wind loads are defined as per specifications in IS 875 (Part 3): 2015 [13]. A wind speed of 44 m/s is considered. The load combinations for analysis are defined as per IS 1893 (Part 1): 2016. They are shown in Table 1.

Table 1. Load combinations

Sr. No.	Load Combinations	Descriptions
1	1.5 (DL+SIDL)	Load Combinations (Envelope 1)
2	1.5 (DL+SIDL+LL)	
3	1.5 (DL+SIDL+WLX)	
4	1.5 (DL+SIDL-WLX)	
5	1.5 (DL+SIDL+WLY)	
6	1.5 (DL+SIDL-WLY)	
7	1.5 (DL+SIDL+ELX)	
8	1.5 (DL+SIDL-ELX)	
9	1.5 (DL+SIDL+ELY)	
10	1.5 (DL+SIDL-ELY)	
11	1.2 (DL+SIDL+LL+WLX)	
12	1.2 (DL+SIDL+LL-WLX)	
13	1.2 (DL+SIDL+LL+WLY)	
14	1.2 (DL+SIDL+LL-WLY)	
15	1.2 (DL+SIDL+LL+ELX)	
16	1.2 (DL+SIDL+LL-ELX)	
17	1.2 [DL+SIDL+LL+ELY)	
18	1.2 (DL+SIDL+LL-ELY)	
19	0.9 (DL+SIDL) + 1.5 (WLX)	
20	0.9 (DL+SIDL) - 1.5 (WLX)	

21	0.9 (DL+SIDL) + 1.5 (WLY)	
22	0.9 (DL+SIDL) - 1.5 (WLY)	
23	0.9 (DL+SIDL) + 1.5 (ELX)	
24	0.9 (DL+SIDL) - 1.5 (ELX)	
25	0.9 (DL+SIDL) + 1.5 (ELY)	
26	0.9 (DL+SIDL) -1.5 (ELY)	

(*Note: DL- Dead Load, LL- live load, SIDL- Super Imposed Dead Load, WL- Wind load, EL- Earthquake Load)

Sr. No.	Building model name	Soft storey type
1	M1	Without soft storey
2	M2	Soft storey at 1st level
3	M3	Soft storey at 8th level
4	M4	Soft storey at 14th level

Table 2. Building models and their respective soft-storey types

Figure.1 and figure 2. show the plan view and 3D view of the model without the soft storey of square shape building Figure.3 to Figure. 6 show another shape of a building. Figure 7 shows the elevation of the soft storey provided at a different level.

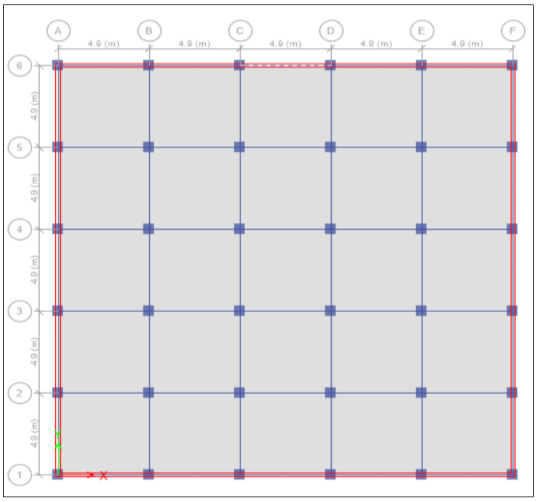

Figure 1. Square-shape plan

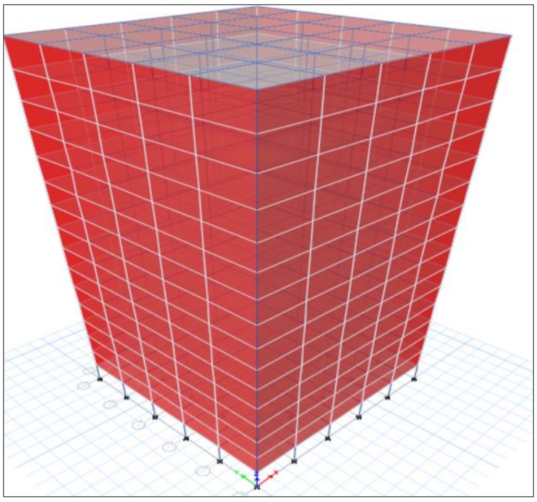

Figure 2. 3D view of the Square-shape model

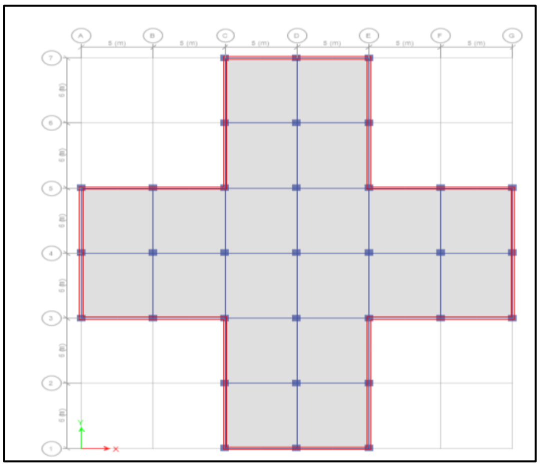

Figure 3. Plus-shape plan

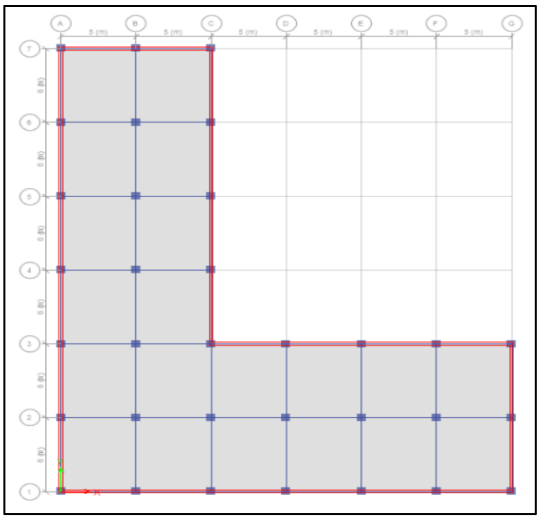

Figure 4. L-shape plan

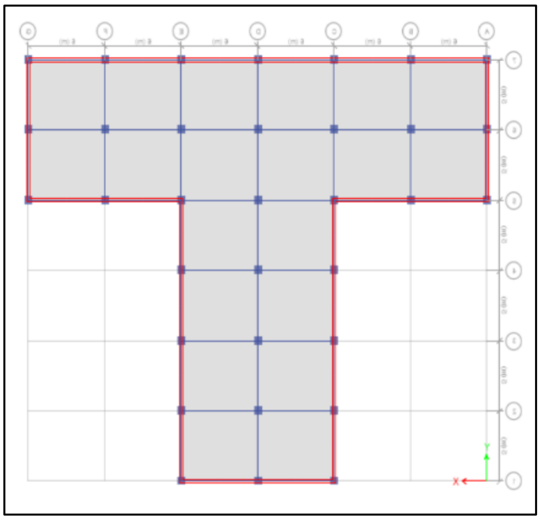

Figure 5. T-shape plan

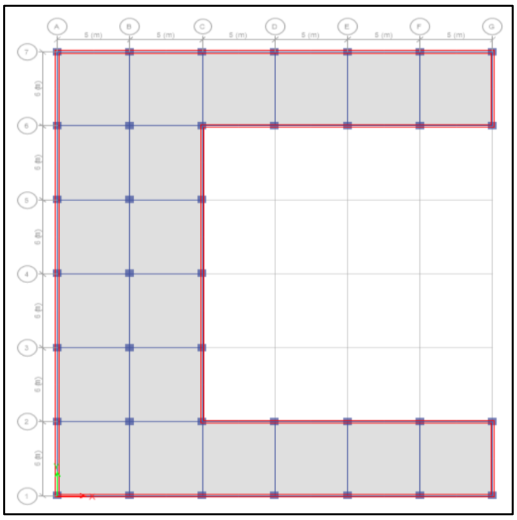

Figure 6. C-shape Plan

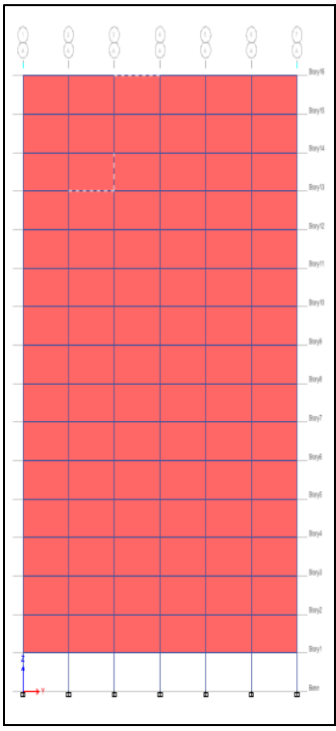

Figure 7. Without soft storey

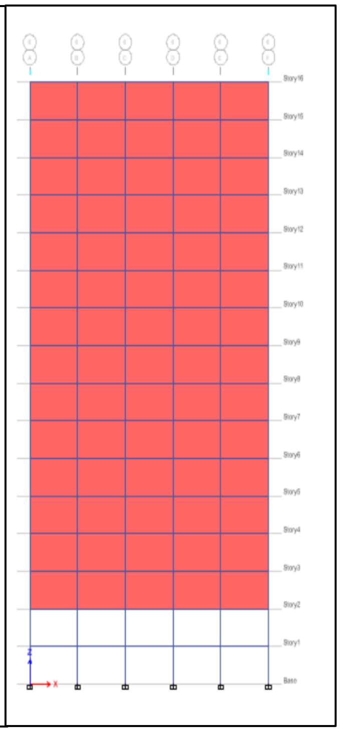

Figure 8. Soft storey at 1st level

Figure 9. Soft storey at 8th

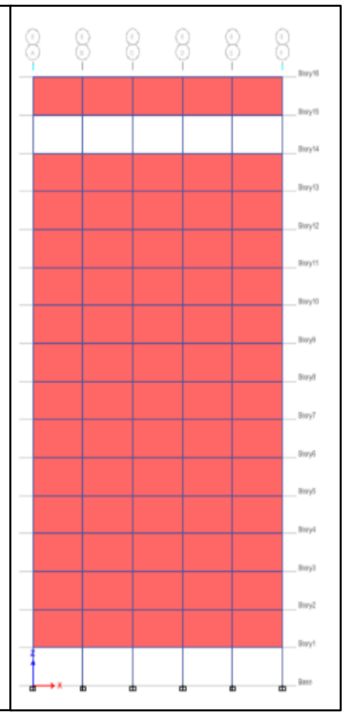

Figure 10. Soft storey at 14th level

4. Result and discussion

The results obtained after analysis of the above models are resented in this section. Parameters such as story displacement, story drift, story stiffness, overturning moment (from response spectrum analysis), and base shear are compared.

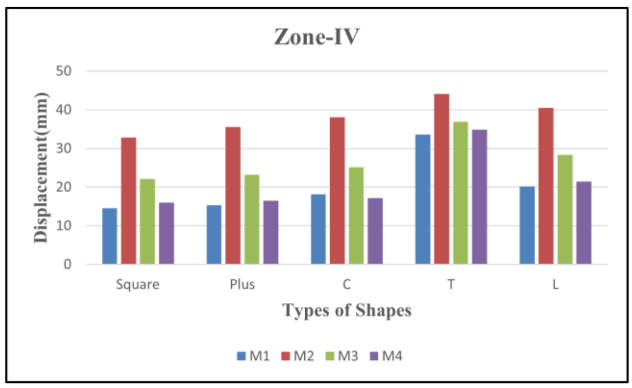

Figure 11. Story Displacement Graph

The maximum storey displacement values for earthquake load in the X-direction for building models with and without soft storey for soft soil are presented in Fig.8. The values of maximum storey displacement increase when soil type changes from medium to soft. It is understood that in the above graph, the storey displacement is more when the soft storey at the first floor as compared to another level (8^{th} and 14^{th}). The storey displacement is more when the soft storey is on the first floor(M1) compared to without a soft storey.

The values of storey displacement for soft and soil increase by 43%,39%,37%,34%, and 31% for the T-shape, L-shape, C-shape, Plus-shape, and square shape of the building model with zone IV.

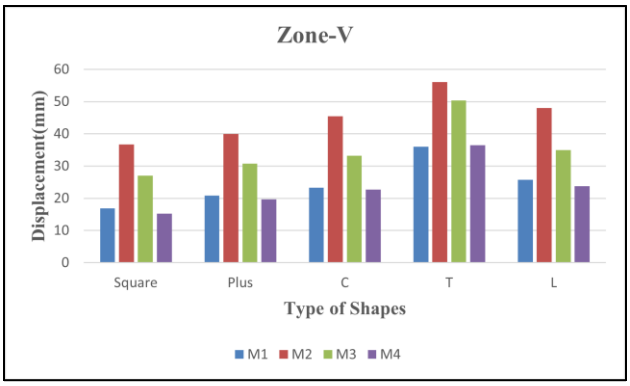

Figure 12. Story Displacement Graph

The maximum storey displacement values for earthquake load in the X-direction for building models with and without soft storey for soft soil are presented in Fig.9. It is understood that in the above graph, the storey displacement is more when the soft storey at the first floor as compared to another level (8th and 14th). The storey displacement is more when the soft storey at the first floor as compared to without a soft storey. The values of storey displacement for soft soil increase by 55%,47%,44%,39%, and 35% for the T-shape, L-shape, C-shape, Plus-shape, and square shape of the building model with zone V.

As per the IS 1893:2016(Part –I) under seismic load the sway at the top should not exceed H/250, [(50.4x10^3)/250] =201. 6mm. The maximum value of top-storey displacement is 56 mm which is less than the maximum permissible limit. Therefore, the building is safe for maximum storey displacement. As the zone changes the value of storey displacement changes, the maximum value of storey displacement that occurs for the seismic zone is V.

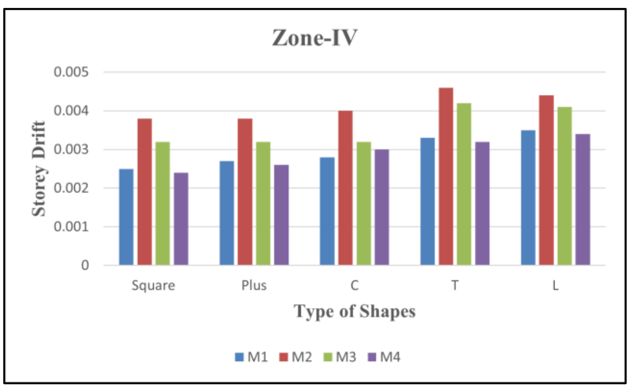

Figure 13. Storey Drift Graph

The storey drift values for earthquake load in X-direction for building models with and without soft storeys with different shapes of the plan for soft soil are presented in Fig.10. It is understood that in the above graph, the storey drift is more when the soft storey at the first(M1) floor as compared to other levels (8th and 14th). The storey drift is more when the soft storey at the first floor as compared to the without soft storey. The values of storey drift for soft soil increase by45%,43%,39%,37.28%, and 37% for the T-shape, L-shape, plus-shape, C-shape, and square shape of the building model with zone IV.

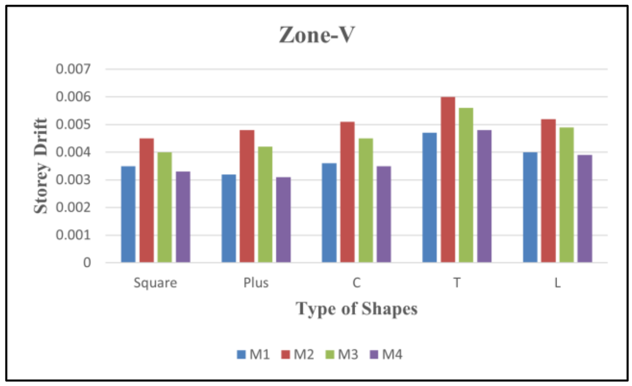

Figure 14. Storey Drift Graph

The maximum storey drift values for earthquake load in the X-direction for building models with and without soft storey with different shapes of the plan for soft soil are presented in Fig.11. It is understood that in the above graph, the storey drift is more when the soft storey at first floor as compared to another level (8th and 14th). The storey drift is more when the soft storey at the first floor as compared to without a soft storey. The values of storey drift for soft soil increase by 59%,51%,50%,47%, and 44% for the T-shape, L-shape, plus-shape, C-shape, and square shape of the building model with zone V.

As per IS 1893:2016(Part –I) cl. 7.11.1, story limitations shall not exceed 0.004 times the story height (0.004x3.15=0.126). The maximum value of top-storey drift is 0.0135 which is less than the maximum permissible limit. Therefore, the building is safe for maximum storey drift. As the zone changes the value of storey drift changes, and the maximum value of storey drift that occurs for the seismic zone is V.

Base Shear:

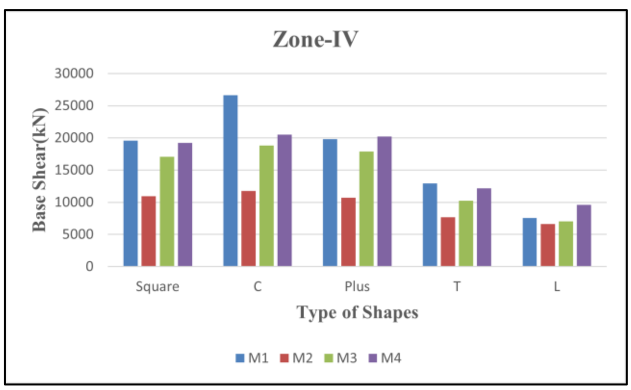

Figure 15. Base Shear Graph

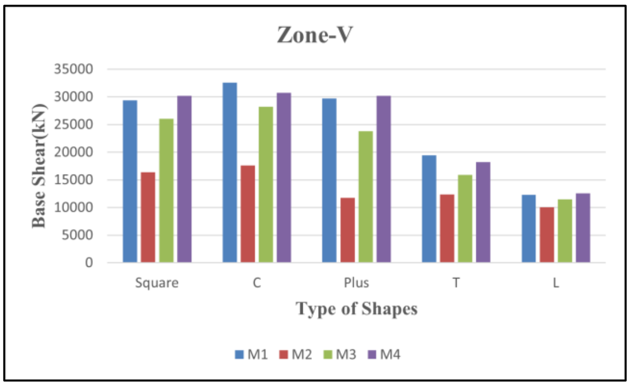

Figure 16. Base Shear Graph

The Base Shear values for earthquake load in the X-direction for building models with and without soft storey for IV&V zones of soft soil are presented in Fig.12&13. The values of maximum base shear increase when soil type changes from medium to soft. It is understood that in the above graph, the Base shear is less when the soft storey at the first floor(M1) as compared to another level (8th and 14th). The Base Shear is less when the soft storey is on the first floor as compared to without a soft storey. The Base Shear of a building without a soft storey and a building with a top floor with a soft storey have near values. Therefore, it can be concluded that the soft storey provided at the top floor is safer than at other levels. The maximum value of base shear 31672.5kN is for the building model in zone V with soft soil.

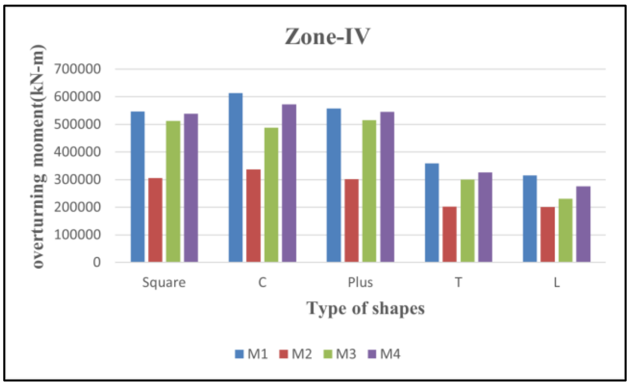

Figure 17. Overturning moment Graph

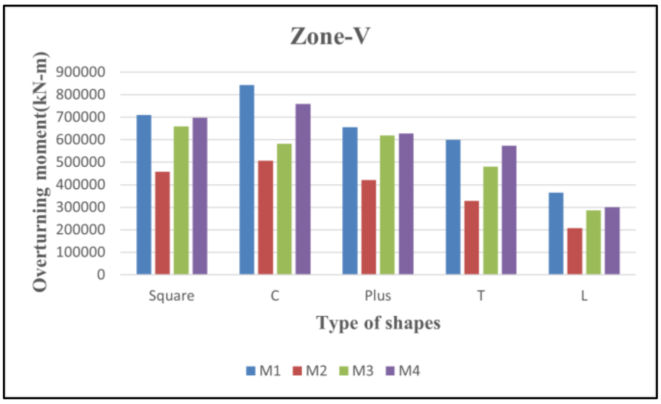

Figure 18. Overturning moment Graph

The Overturning moment values for earthquake load in the X-direction for building models with and without soft storey with different shapes of the plan of IV &V zones for soft soil are presented in Fig.14 &15. It is understood that in the above graph, the overturning moment is more when the soft storey at the fourteenth floor(M4) as compared to other levels (1st and 8th). The overturning moment is more when the soft storey at the fourteenth floor as compared to the without soft storey.

5. Conclusion

In this paper, analysis of G+15 storied RC buildings is carried out by using response spectrum analysis. The storey displacement of irregular buildings is more than that of the regular building. Considering storey displacement, for building model with the soft storey at the first floor (M2) is the most critical case because its displacement is 1.4 times more than that of the building model without a soft storey (M1) due to the reduced stiffness of the structure. The optimum location for the soft storey is on the top floor of the building. From this result, it is concluded that a regular building with a soft storey shows a less percentage increase in displacement as compared to an irregular building. As the location of the soft storey shifts to the upper floors, the maximum lateral drift value decreases. The Sudden increase in story drift at the first floor is observed in the model (M2) as compared to without soft storey (M1). This is due to the reduced stiffness of the structure. The base shear of a c-shape, plus shape, L-shape, T-shape, and square shape building with a soft storey at the top floor is approximately near the values of a building without a soft storey. Base shear is maximum when the soft storey is at the top floor, and it can be concluded that the soft storey at the top floor is safer. The overturning moment of a c-shape, plus shape, L-shape, T-shape, and square shape building with a soft storey at the top floor is approximately near the values of a building without a soft storey. After analysis and comparing all the parameters, the square- shape model building (regular building) and the position of the soft storey at the top floor are found to have good overall performance among all the models. The shape and location of the soft storey in the model (M4) are suggested as the most effective and well-behaved under seismic action.

6. References

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