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Seismic Response of Stepped Setback Building Stiffened with Reinforced Concrete Shear walls and Braces

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ABSTRACT: Structural irregularities are commonly found in constructions and structures. Architectural demands are usually the cause of such irregularities. A type of irregular structure for which some poor performances have been observed during past earthquakes is the vertically setback buildings. Buildings with vertical setback cause sudden jump in earthquake forces at the level of discontinuity. The general solution of a setback problem is the total seismic separation in plan through separation section, so that portions of the building are free to vibrate independently. When the building is not separated, the lateral-force-resisting elements such as shear walls, bracing systems can be used.

In this paper, performance of setback buildings with symmetrical and unsymmetrical arrangement of setback has been evaluated. For comparison purpose commonly shaped setback buildings such as stepped type building is selected. Various models are decided with incorporation of shear walls and braces at various locations. Performances of these various combinations are studied and compared. Linear dynamic analysis i.e. response spectrum analysis is carried out on the entire mathematical 3D models using the finite element software ETABS Version 9.7.4.

KEYWORDS: setback buildings, vertical irregularity, shear wall, bracing

I. INTRODUCTION

Earthquake resistant design of reinforced concrete buildings is a continuing area of research since the Earthquake Engineering has started not only in India but in other developed countries also. The buildings still damage due to some one or the other reason during earthquakes. Behaviour of multistory buildings during earthquake motion depends on distribution of weight, stiffness and strength in both horizontal and vertical planes of building. Design of public buildings such as theatres and museums as well as monuments is commonly dictated by either aesthetic or functional considerations that often preclude the simplicity of less important buildings. As a result, the shape of the majority of such structures is irregular, both in plan and in elevation. Because of the complex behavior of such structures they are proved to be vulnerable under earthquake excitations.

There are various lateral load resisting elements such as shear walls, braces etc. which can be used for improving seismic response of buildings. Up till now research on using these elements has been limited to symmetrical buildings only. It would be of great interest to check the effectiveness of these elements in seismic response control of asymmetrical buildings such as setback buildings.

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II. LITERATURE SURVEY

There are various authors who have worked on setback buildings, some of them and their work is discussed below:

Sharon L. Wood (1992) has investigated the seismic behavior of reinforced concrete frames with setbacks. Similarities and differences in the response of the regular and setback frames were identified. From his experimental study he has concluded that setback frames are not observed to be more susceptible to damage or more susceptible to higher mode effects than the frames with uniform profiles.

Bahrain M. Shahrooz and Jack P. Moehle (1990) have evaluated the effects of setbacks on the earthquake response of multistory building structures. They have concluded that, for setback structures identified as being irregular, there is excessive damage in tower, the design should impose increased strength on the tower relative to the base. They have also proposed the static analysis method that amplifies design forces in the tower.

Shaleen Mathur and Sajal Kanti Deb (2003) have proposed a new approach for seismic response control of reinforced concrete setback building with supplemental friction dampers. Preliminary numerical studies have been carried out to study the effectiveness of friction dampers provided in crossbraces in controlling the seismic response of setback building subjected to ground motion parallel to the direction of setback. An attempt has been made to obtain optimum seismic performance from the reinforced concrete setback frame by tuning the friction devices with respect to the frame and ground motion characteristics. They have concluded that properly tuned friction dampers are very effective in controlling seismic response of buildings having setback.

From the available literatures, it is observed that, the vertically irregular building such as setback building fails suddenly and become a cause of destruction. Hence to increase the seismic performance of such buildings, the use of various lateral load resisting elements such as shear wall, braces are proposed in this present paper.

The aim of this paper is to study the building system that will provide the best protection for both life and property in the future earthquake. There are various types of lateral load resisting elements available such as shear walls and Braces etc. Shear walls and braces are proved to be very effective in resisting earthquake force in regular buildings. It is necessary to strengthen the setback buildings which are formed commonly due to architectural purpose with the help of shear walls and braces etc.

In this paper the seismic response of various setback buildings with and without lateral load resisting elements such as shear walls, braces etc. are compared in terms of various parameters such as base shear, shear force, bending moment, storey drift, joint displacement etc.

III. MODELLING & ANALYSIS

Building Description

The building considered is the commercial building having G+11 storeys. Height of each storey is 3.1m. The building has plan dimensions 24m x 24m and is symmetric in both orthogonal directions as shown in the Fig. 1. It is considered to be located in seismic zone IV and is built on hard soil. The size of columns is 450mm x 450mm. Size of beams is 300mm x 450mm in both transverse and longitudinal direction. Thickness of slab is 120mm. The unit weights of concrete and masonry are taken as 25 kN/m³ and 20 kN/m³ respectively. Live load intensity is taken as 4 kN/m² for all floor level. Weight of floor finish is considered as 1.5 kN/m². In the analysis special RC moment-resisting frame (SMRF) are considered.

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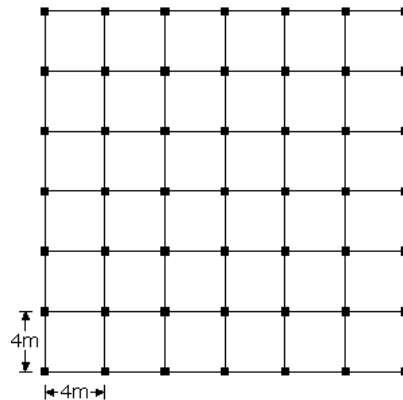


Fig 1: Plan of building

The building is modeled using the software ETABS. Response spectrum analysis is performed on the below mentioned 3D model. Beams and columns are modeled as two noded beam element with six DOF at each node. Slab is modeled as four noded shell element with six DOF at each node. Walls are modeled by equivalent strut approach. The diagonal length of the strut is same as the brick wall diagonal length with the same thickness of strut as brick wall, only width of strut is derived. The strut is assumed to be pinned at both the ends to the confining frame. In the modeling material is considered as an isotropic material.

The following models have been studied and presented in the paper.

Model I: Stepped structure without incorporation of any lateral load resisting elements as shown in figure 2.

Model II: Stepped structure with shear wall at peripheral central four bays as shown in figure 3.

Model III: Stepped structure with shear wall at peripheral five bays as shown in figure 4.

Model IV: Stepped structure with shear wall at plane of weakness i.e. setback level as shown in figure 5.

Model V: Stepped structure with L- type shear wall at external frames as shown in figure 6.

Model VI: Stepped structure with T- type shear wall at external frame as shown in figure 7.

Model VII: Stepped structure with braces in one floor above and below the setback levels as shown in figure 8.

Model VIII: Stepped structure with braces throughout setback levels as shown in figure 9.

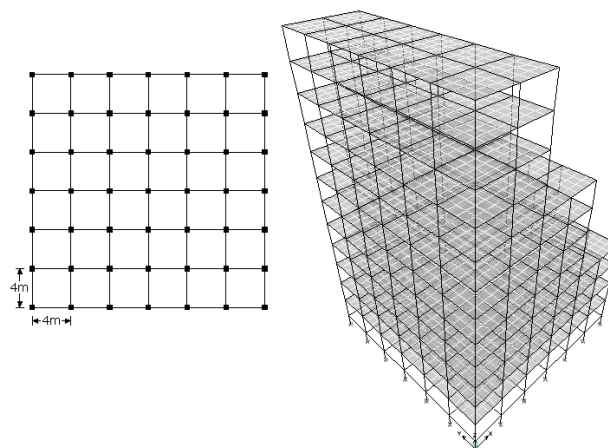


Fig 2: Stepped structure without incorporation of any lateral load resisting elements

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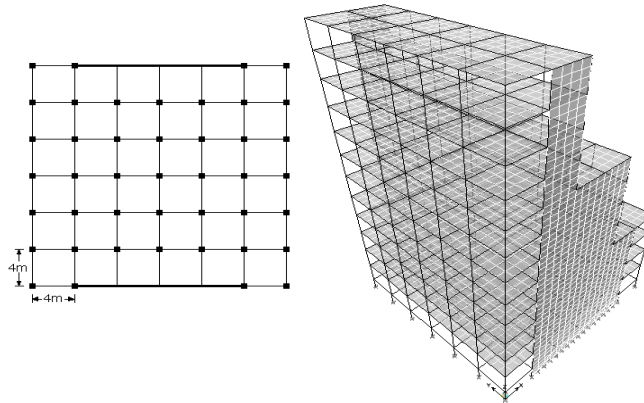


Fig 3: Stepped structure with shear wall at peripheral central four bays

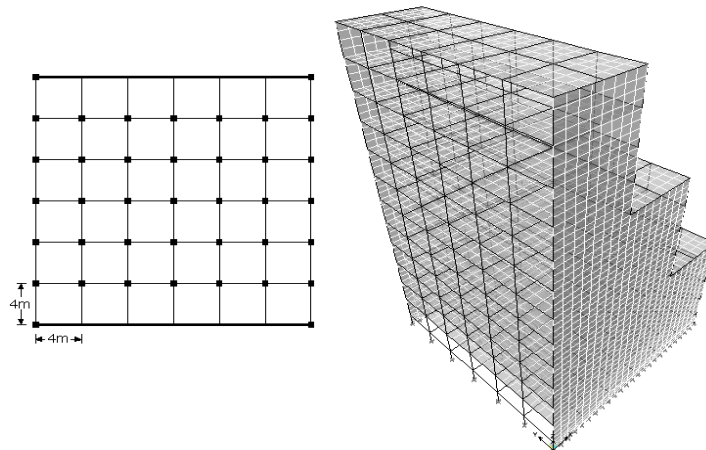


Fig 4: Stepped structure with shear wall at peripheral five bays

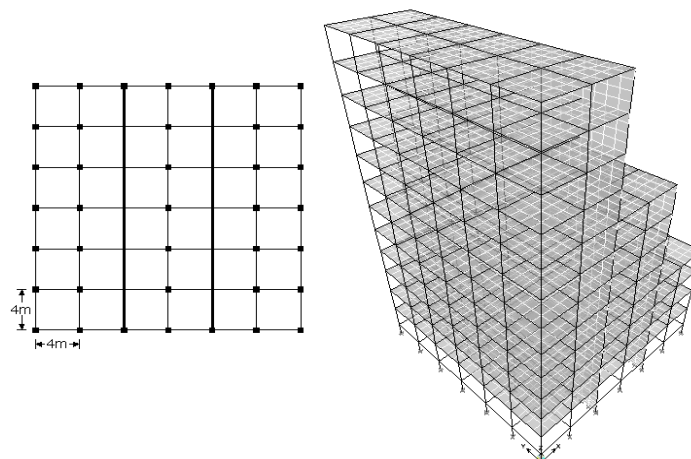


Fig 5: Stepped structure with shear wall at plane of weakness i.e. setback levels

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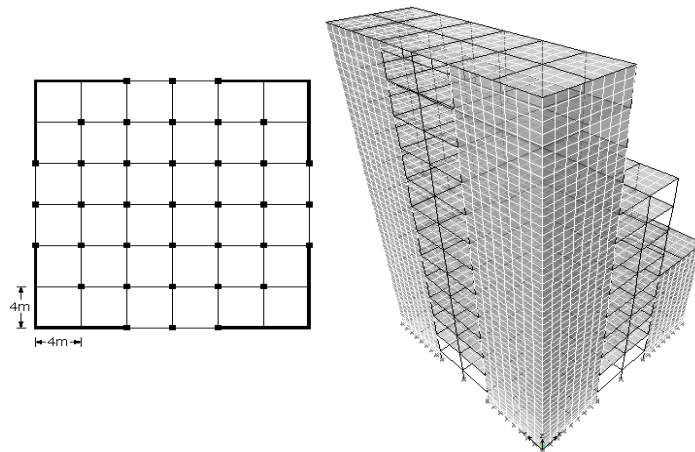


Fig 6: Stepped structure with L- type shear wall at external frames

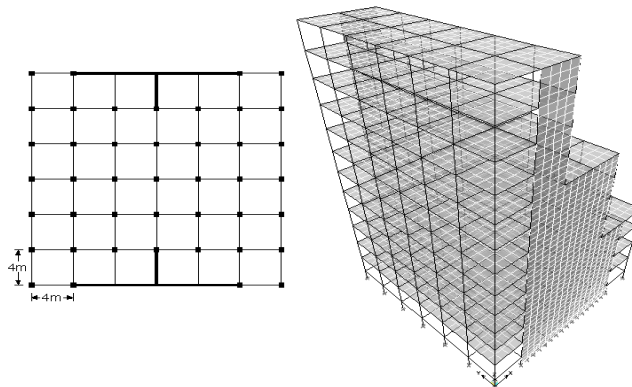


Fig 7: Stepped structure with T- type shear wall at external frame

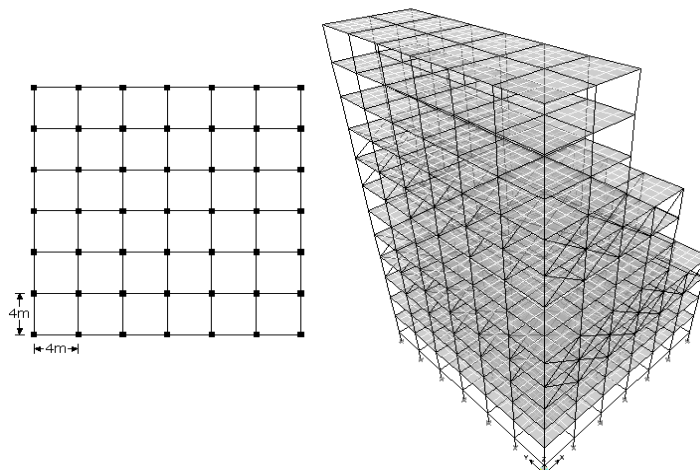


Fig 8: Stepped structure with braces in one floor above and below the setback levels

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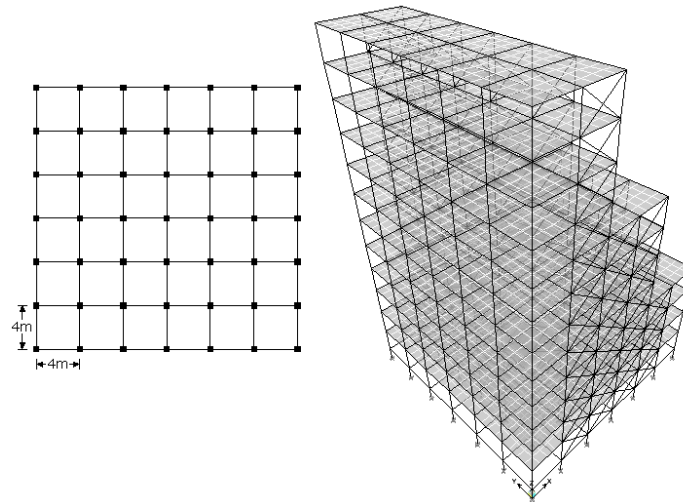


Fig 9: Stepped structure with braces throughout setback levels

IV. RESULT & DISCUSSION

As discussed above, there are total eight models under consideration, out of which first model is regular stepped type setback building without incorporation of any lateral load resisting elements. In other seven models, RC shear walls and braces are used at various positions to improve seismic performance of such type of building. For comparison purpose, maximum forces in columns at setback level i.e. at storey 5, storey 6, storey 9 and storey 10 are chosen as shown in figure 10.

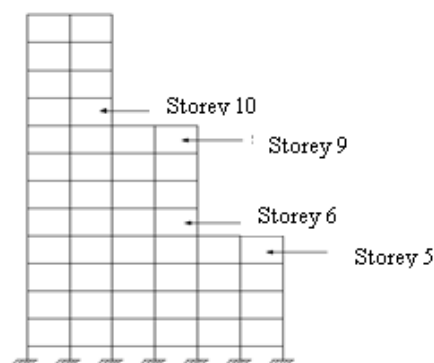


Fig 10: Location of setback level storeys in stepped type setback building

Bending moment in columns

The maximum bending moments in the columns in longitudinal and transverse direction are shown in figure 11 and 12 respectively. The bending moment and shear force demands are severely higher for setback level column in case of regular stepped type setback buildings (Model I). The bending moment is quite large in the storeys at setback level columns as compared to the other storeys. To reduce these maximum forces reinforced concrete shear walls and braces are introduced at various locations in the setback building. Maximum percentage reduction achieved in bending moments is in case of model II, VII and VIII i.e. 30%, 40% and 46% respectively for longitudinal direction force and for transverse direction force, maximum reduction is achieved in model II, III and VIII i.e. 42%, 40% and 36%

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respectively. For all other models reduction is about 20-40%. Due to shear walls and braces stiffness of that storey increases which reduces the bending moment in the columns.

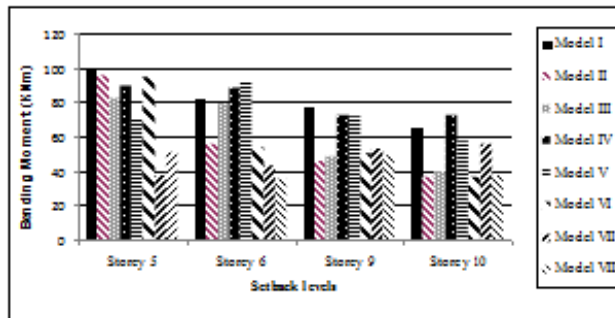


Fig 11: Comparison of maximum bending moment in longitudinal direction for stepped type setback building

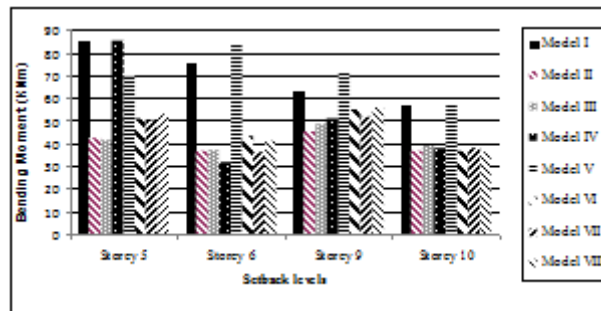


Fig 12: Comparison of maximum bending moment in transverse direction for stepped type setback building

Lateral Displacement

A graph is plotted taking floor level as the abscissa and the displacement as the ordinate for different models in the longitudinal and transverse direction as shown in figure 13 and figure 14 respectively. From the displacement profile it is observed that large displacement occurs in case of regular setback building at setback levels (Model I). Introduction of different shapes of reinforced concrete shear walls and braces at various locations reduces the displacement at setback level to much extent i.e. there is reduction in lateral displacements up to 10-70% in various models. Maximum reduction is achieved in case of model II, III and VI i.e. 78%, 83% and 78% respectively for longitudinal direction force and for transverse direction force, maximum reduction is found for model IV and VIII i.e. 85% and 68% respectively.

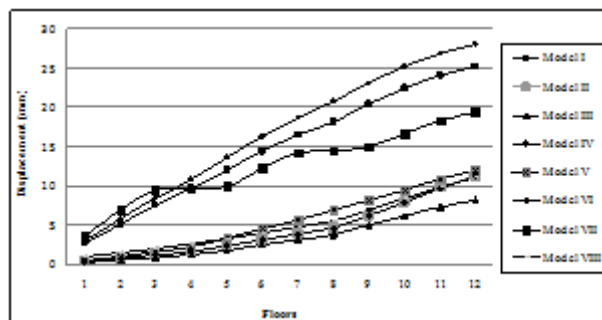


Fig 13: Displacement profile in longitudinal direction for stepped type setback building.

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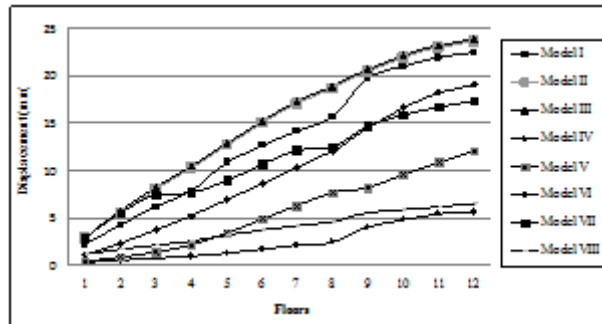


Fig 14: Displacement profile in transverse direction for stepped type setback building.

Base shear

The base shear for different building models in both longitudinal and transverse directions is shown in figure 15. Base shear of all the above models with introduction of shear walls and braces get increased as because of their introduction seismic weight of building get increases. For various models it is increased up to 10-45%. Maximum increment in base shear found in model III i.e. 44% for longitudinal direction force and for transverse direction force, maximum increment found in model IV i.e. 94%.

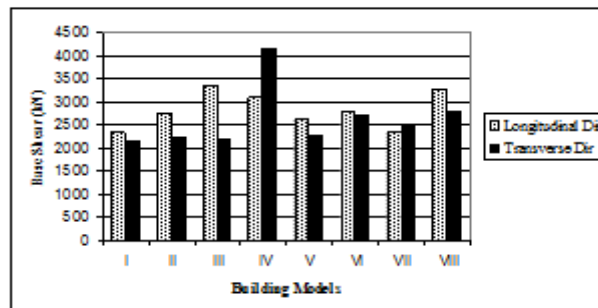


Fig 15: Base shear in longitudinal and transverse direction for stepped type setback building

Time period and frequency

A graph is plotted taking modes on the X axis and time period in second on Y axis for all the building models as shown in the figure 16. It is observed that the time period of vibration is more for models IV, while it is considerably reduced for models II, III, V, VI, VI, VII and VIII. Period of vibration is found to be minimum for models V and VI.

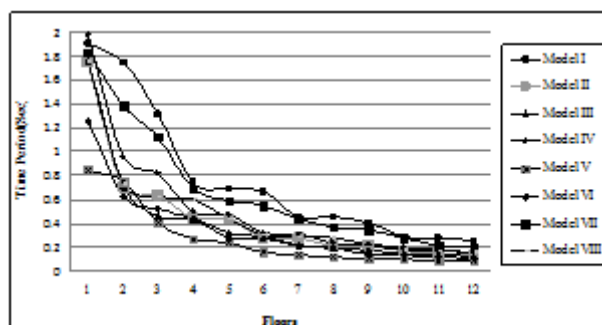


Fig 16: Comparison of time period for different modes for stepped type setback building

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V. CONCLUSION

Real structures are almost always irregular as perfect regularity is an idealization that very rarely occurs. Regarding buildings, architectural and functional demands dictate irregular shape. It is an important functional and architectural requirement that cannot be eliminated. To overcome this difficulty the alternative measures in the form of incorporation of different shapes of shear walls and cross bracings at various locations are suggested. From the analytical study following conclusions are made:

- It is observed that there is significant reduction in the member forces, and lateral drift demand, and hence the performance of members in setback level get improved if the described improving measures are used.
- Shear wall and cross bracings are found to be very effective in reducing the forces in the columns. Use of straight type of shear wall at external peripheral frame in setback building considerably reduces the forces in members at the setback level.
- Shear walls are found to be very effective in reducing the lateral displacements in setback buildings than bracings. However use of bracing reduces forces in columns more than using shear walls. This is due to reduction in effect of vertical irregularity in setback building.
- There is increment in base shear for all the models by of incorporating shear walls and braces this is due to increase in seismic weight of building.
- For stepped type setback buildings, incorporation of cross braces at one floor below and one floor above the setback level is suggested. With this type of combination we can achieve reduction in forces in columns of setback levels i.e. bending moments reduced up to 40%, shear forces reduced up to 48%, twisting moment reduced up to 33%, axial force reduced up to 5%, lateral displacement reduced up to 70%, period of vibration has also reduced.
- For stepped type setback buildings on sloping ground, incorporation of cross braces at two floors below and two floors above the setback level is suggested. With this type of combination we can achieve reduction in forces in columns of setback levels i.e. bending moments reduced up to 20%, shear forces reduced up to 26%, twisting moment reduced up to 5%, lateral displacement reduced up to 50%, period of vibration has also reduced.

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