

Seismic Performance of Buildings on Sloping Grounds

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ABSTRACT: In hilly areas buildings are built on sloping grounds. When the hilly areas come under the seismic zones, these buildings are highly vulnerable to earthquakes. This is due to the fact that the columns in the ground storey are of different heights in such a way that column in one end is a short column and column in other end is a long column. Along with this if the building has an open ground storey, the seismic vulnerability is further increases. This paper deals with the comparison of seismic performance of soft storey building on sloping grounds and soft storey building retrofitted with shear wall. The aim of the paper is to check if the seismic performance of the structure is improved when it is retrofitted with shear wall.

KEYWORDS: Sloping grounds, Soft storey, Shear wall, Pushover.

I.INTRODUCTION

Earthquakes causes serious damage to buildings, such as failure of members in the building and if the intensity of earthquake is high it leads to collapse of the structure. In recent years population has been increased drastically and due to which cities and towns started spreading out. Due to this reason many buildings are being constructed in hilly areas. India has a large coastal line which is covered with mountains and hills. The Himalayan range also has large mountains and many towns are spread over these mountains. Many resorts are being constructed in hilly areas to provide arrangements for tourists. The buildings in these areas are constructed on sloping grounds. Most of the hilly areas in India come under the seismic zone II, III and IV zones in such case building built on sloping grounds are highly vulnerable to earthquake. This is due to the fact that the columns in the ground floor differ in their heights according to the slope of the ground. Columns on one end are short and on other end are long, due to which they are highly vulnerable. Poor behavior of short columns is due to the fact that short column is stiffer as compared to the long column, and it attracts larger earthquake force. Stiffness of a column is the resistance to deformation – the larger is the stiffness, larger is the force required to deform it. If a short column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. Along with this some buildings are built as soft storey buildings or buildings with open ground storey. These soft storey buildings have very less stiffness in their ground floor. When soft storey buildings are built on sloping grounds the failure occur due to the short column effect and also due to the reduced stiffness in the ground floor.

In this paper a five storey building built on a slope of 30° is analysed to find out the seismic performance. Then the building is retrofitted with shear wall and it is analysed to find if the seismic performance is been improved.

II. MODELLING TECHNIQUES

Structural modelling is the important part, in order to obtain accurate results when analysed. It should follow certain principles based on the performance of the earthquake. The model should possess three dimensional characteristics and it should represent all the properties of its elements. The model should clearly represent the behavior under different types of loading, it should represent the strength stiffness and deformability of its members. The beam and column members should be modeled as 3D frame elements. The properties of materials used for the

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beams and columns should be defined. The cross section of the beams and columns and their reinforcement details should be defined properly. The beam column joint are kept rigid by providing end offset in order to obtain moments and forces occurring in the beams and columns. Beams and column should be modeled for the moment of inertia to account for cracking. The slabs are modeled as rigid diaphragm that distribute the horizontal forces to the vertical resisting element in direct proportion to the relative rigidities. The slab is replaced by a diaphragm because the diaphragm does not deform itself due to horizontal forces and also it will cause each vertical element to deflect in the same amount. The structure is given fixed base and soil structure interaction is not considered. The loads applied to the structure are dead loads, live loads and the earthquake loads. The dead loads include self-weight of the members and the slab loads and infill loads are assigned as distributed loads on the beams. Earthquake loads are calculated by the seismic coefficient method as per [1].

III.MODELLING OF SOFT STOREY BUILDING

Open ground storey building on sloping ground considered in this paper is of 5 storey, according to the plan it has 5 bays in x-direction and 3 bays in y-direction having 4m bay width each, and storey height of 3 m. Beams have a width of 300 mm and depth of 450 mm and columns have a width of 500mm and depth 300 mm are designed accordingly. The columns are of different heights in the ground floor, the slope is considered as 30°. The short column is of 1m high and increases gradually to a height of 3.9m. The height of the columns in the ground storey is calculated by Pythagoras Theorem.

The material properties of concrete and steel rebar including unit weight, modulus of elasticity, poisson's ratio, shear modulus, characteristic compressive strength, yield stress and ultimate stress has been provided. Beams and columns are then assigned the respective cross section dimensions, materials and reinforcement. Modification factor for moment of inertia of beam and column has been given as 0.5 and 0.7 to account for the effect of cracking respectively. Rigid beam column joints have been modeled by giving end length offsets to the frame elements. To take into account the structural effect of slabs, diaphragm constraint has been assigned at each floor level. User defined M3, V2 and PMM hinge properties have been assigned for beam and column respectively.

The brick in-fill is modeled as equivalent diagonal compression strut elements, using the method recommended by [2]. The width of the diagonal strut is obtained from the following equation.

$$\frac{W}{D} = \frac{0.43 \sin 2\theta}{\sqrt{\lambda H}}$$

Where,

W = Width of the strut,

D = Length of the strut,

t = Thickness of the infill (230mm),

H = Height of the column,

θ = Angle between strut and center line of the beam,

E_m = Modulus of elasticity of masonry infill,

E_c = Modulus of elasticity of columns,

I_c = Moment of inertia of columns

$$\lambda = \sqrt[4]{\frac{E_m t \sin 2\theta}{4E_c I_c H}}$$

Axial P hinge is modelled for infill members. Rigid joints connect the beams and columns, but pin joints at the beam to column junctions connect the equivalent struts. Dead load and live loads are applied as gravity loading. Earthquake load has been calculated as per [1] and applied as lateral load at the joints in the periphery. Pushover Analysis is performed. Fig. 1 shows the SAP model of the soft-storey building.

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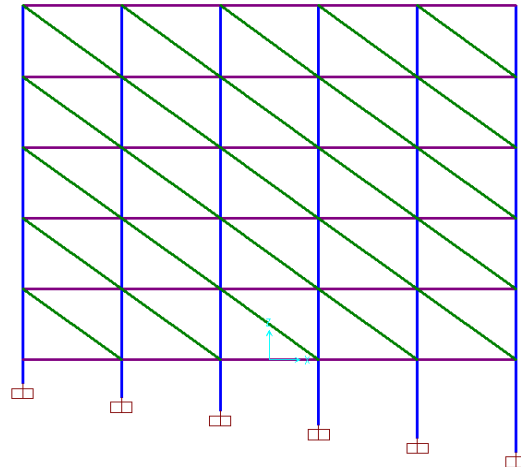


Fig: 1 SAP model of soft storey building on sloping ground

IV.MODELLING OF SOFT STOREY BUILDING WITH SHEAR WALL

In linear analyses of structures, shear walls are modeled utilizing different techniques either using shell elements or combination of frame elements. The most common modelling technique is to use a composition of mid-pier frame to represent the shear wall stiffness and a horizontal frame (rigid arm) to allow proper connections with intersecting beams and slab components. The horizontal frame is modelled as a rigid link, *i.e.*, all the displacements and rotations of the horizontal arm is kept as fixed.

The Shear wall has a width of 4m and thickness of 200mm. The shear wall is modelled in the corners of the external frame. There is difference in the columns so shear wall in ground floor is considered to have a height of the longest of the two boundary columns. The reinforcement for the shear wall is taken as 0.4% of its cross-sectional area. The hinges for the shear wall is modelled at the bottom of the shear wall. Also called wide column method, is convenient to use in the push over analysis. Fig. 2 shows the SAP model of the soft-storey building with shear wall. The material nonlinearity of the shear wall can be modeled considering a plastic hinge on Mid-Pier element.

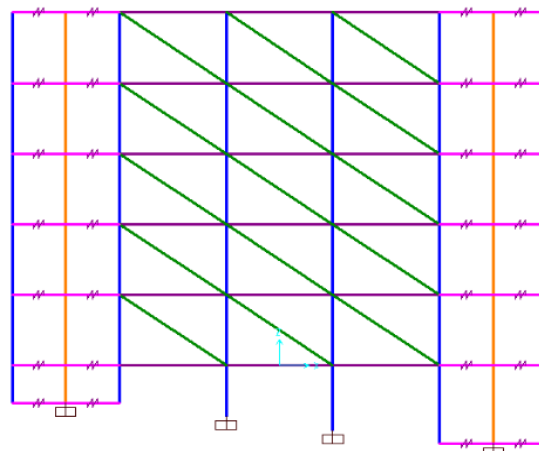


Fig: 2 SAP model of soft storey building with shear wall on sloping ground

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V.ANALYSIS TECHNIQUES

The Non-linear Static Pushover analysis is used for analyzing the structure. The main part of this analysis is the proper modelling of the structure in such a way to perform Non-linear analysis. Analysis is done to find out the failure mechanism of the elements of the structure and also to find out the displacement of the structure. The main part is to find out the relationship between base shear and displacement. The plastic hinges are formed for all six degrees of freedom, namely, axial force, transverse shear forces in X- and Y-direction, moments about Y- and Z-axis, and torsion. Therefore the failure modes are obtained due to the formation of hinges. SAP 2000 is a well-known and widely accepted, general-purpose, three-dimensional structural analysis program.

VI.PUSHOVER ANALYSIS

Static pushover analysis is used to find out the strength of the structure and it is a useful and effective tool for Performance Based Seismic Design (PBSD). Pushover analysis is a static, nonlinear procedure in which the magnitude of the lateral loads is increased gradually, maintaining a load pattern along the height of the building. With the increase in the magnitude of the loads, failure modes of the building are found. It can also determine the behavior of a building, including the ultimate load and the maximum inelastic deflection. Local nonlinear effects are modeled and the structure is pushed until a collapse mechanism is formed. At each step, the base shear and the roof displacement can be plotted to generate the push over curve. It gives an idea of the maximum base shear that the structure is capable of resisting. For regular buildings, it can also give a rough idea about the global stiffness of the building.

The concept of plastic hinge is extremely important in the nonlinear analysis. While a concrete element undergoes large deformations in the post-yield stage, it is assumed that all the deformation takes place at a point called "plastic hinge", which has approximately a length of the order of the effective depth (also called as plastic hinge length). The manual on [3] published by Applied Technology Council, is a popular design tool for engineers all over the world for PBSD. A typical response at a plastic hinge may be as shown in Fig. 1. Here, Point A is the origin; B is the point of yielding; BC represents the strain-hardening region's is the point corresponding to the maximum force; and DE is the post-failure capacity region. On the frame structure, the analyst identifies the possible locations for plastic hinge formation from his experience.

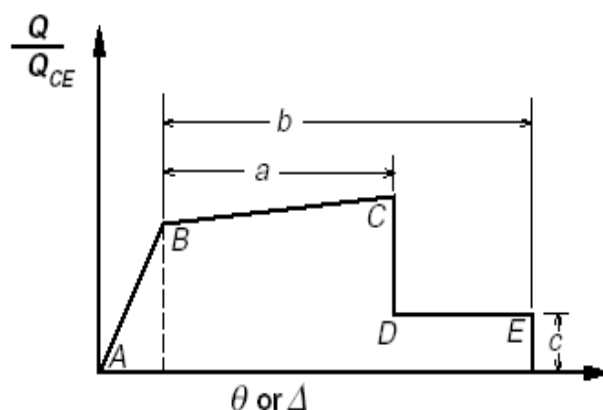


Fig: 3 Idealized force deformation curve for a plastic hinge

In the case of soft story buildings on the sloping grounds the structure has both short column and also long column. The short column failure occurs immediately when the earthquake attacks the building. Therefore shear hinges are also provided to the columns. To provide the shear hinges the shear capacity is found out from the following equation

$$V_s = \frac{\sigma_{sv} A_{sv} d}{S_v}$$

Where,

V_s = Shear capacity,

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σ_{sv} = Permissible Tensile stress in shear reinforcement,
 A_{sv} = Total cross-sectional area of stirrups,
 d = Effective depth,
 S_v = Spacing between the stirrups

VII. ANALYSIS RESULT

The pushover analysis is performed on the soft storey building on sloping ground. Fig.4, shows that the hinges are formed in the ground storey and it is clearly shown that the short column exhibits maximum deformations and the hinges formed under the life safety performance level. This is due to the short column effect.

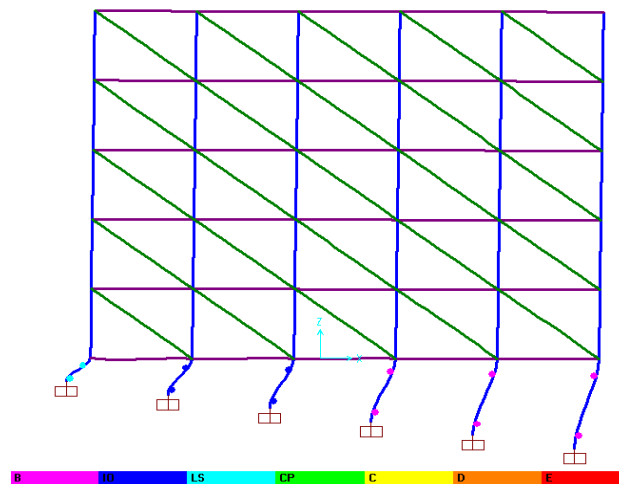


Fig. 4 Deflection mode and hinge formation of the soft-storey building on sloping ground.

When the shear wall is added the hinge pattern changes as shown in Fig.5, the hinges in the soft storey is taken over by the hinge formed in the shear wall. The short column effect is minimized by the addition of shear wall. This explains that the shear wall enhances the seismic performance of the building. From the Fig.5, it is clearly shown that the hinge formed lies below the immediate occupancy performance level.

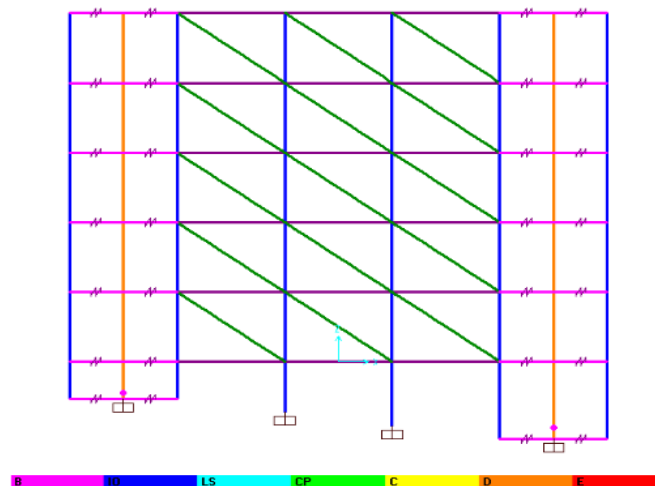


Fig. 5 Deflection mode and hinge pattern of the soft-storey building with shear wall

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VIII.COMPARISON OF RESULTS

The push over curve is obtained for both the cases. The curve gives an idea of the maximum base shear that the structure is capable of resisting. It also shows the ductility of the building. Fig.6, shows the pushover curve compared for both the cases. It is clearly shown that soft storey frame fails abruptly whereas the curve representing the soft storey with shear wall frame shows better displacement and also high base shear value. It also shows that the soft storey building experiences a ductile failure, where as soft storey with shear wall provides better ductility.

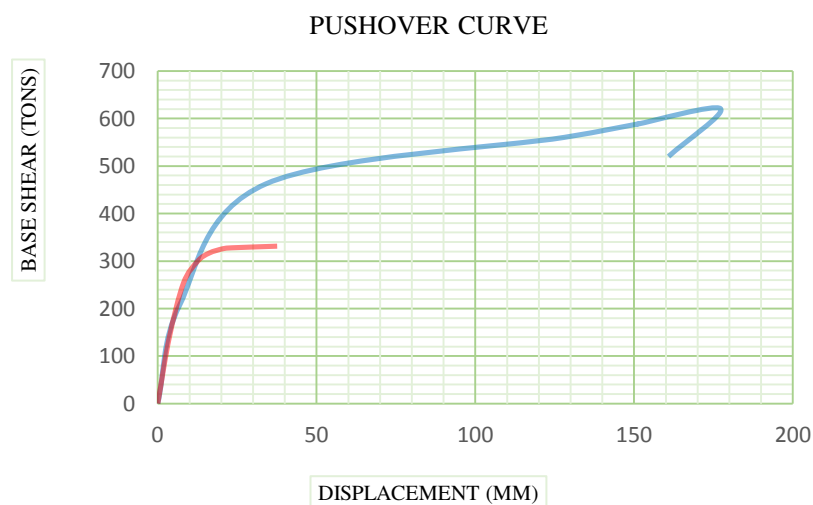


Fig.6 Pushover curves of soft story building and after addition of shear wall on sloping grounds

IX. SUMMARY AND CONCLUSIONS

Five-storied building with open ground storey on sloping ground is modelled and pushover analysis is performed. The seismic performance of open ground storey buildings is very less as shown in the results. The performance is improved by addition of shear wall. Addition of shear wall is an ideal solution to improve the seismic performance of open ground storey building constructed on a sloping ground. Improvement in performance is shown by the building with shear wall as the deformation is increased.

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REFERENCES

- [1] IS: 1893(Part 1). Indian Standard Code of Practice for Criteria for Design of Earthquake Resistant Structures, Bureau of Indian Standards, New Delhi, 2002.
- [2] Smith, S.B. and Carter, C. (1969) 'A method for analysis of infilled frames'. *Proc. of the Institution of Civil Engineers*, Vol. 44, pp. 31-48.
- [3] ATC-40 (1996) 'Seismic Evaluation and Retrofit of Concrete Buildings', Vol.1, Report No. SSC 96-01, *California Seismic Safety Commission*
- [4] SAP User Manual Version 14, Computers and Structures Inc.
- [5] H. B.Kaushik, D. C. Rai, and S.K. Jain, "Effectiveness of some strengthening options for masonry-infilled RC frames with open first story", *Journal of Structural Engineering*, ASCE, Vol. 135, No. 8, pp. 925-937, 2009.
- [6] IS:13920-1993, 'Indian Standard Ductile detailing of reinforced concrete structures subjected to seismic forces - code of practice', Bureau of Indian Standards, India
- [7] Shivanand.B and H.S.Vidyadhara, "Design of 3D RC Frame on Sloping Grounds", *IJRET: International Journal of Research in Engineering and Technology*, eISSN: 2319-1163 | pISSN: 2321-7308.
- [8] S.M.Nagargoje and K.S.Sable, "Seismic performance of multi-storeyed building on sloping ground", *Elixir International Journal*, Elixir Elec. Engg. 53 (2012) 11980-1198211. SujithKumar, Dr.VivekGarg, Dr.AbhaySharma, "Effect of Sloping Ground on Structural Performance of RCC Building Under Seismic Load", ISSN: 2348-4098, Volume 2 Issue 6 August 2014.
- [9] SujithKumar, Dr.VivekGarg, Dr.AbhaySharma, "Effect of Sloping Ground on Structural Performance of RCC Building Under SeismicLoad", ISSN:2348-4098, Volume2Issue6August2014.