Study of Seismic Behavior of Multi-Storied R.C.C. Buildings Resting on Sloping Ground

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Abstract- *The buildings situated on hill slopes in earthquake prone areas are generally irregular, torsionally coupled and hence, susceptible to serve damage when affected by earthquake ground motion. Such buildings have mass and stiffness varying along the vertical and horizontal planes, result the center of mass and center of rigidity do not coincide on various floors. The dynamic analysis is carried out using response spectrum method. The dynamic response that is fundamental time period, storey displacement and base shear action induced in columns has been studied for buildings of different heights. Building models are analyzed by ETABS software to study the effect of time period, storey displacement and base shear.*

Keywords- Earthquake, Response Spectrum Method, Storey Displacement, Base Shear, ETABS Software

I. INTRODUCTION

The study of earthquakes and the structure of the earth, by both naturally and artificially generated seismic waves. From the seismic history of our country, it is observed that majority of the devastating earthquakes have been occurred in northern and north-eastern states of India.

The economic growth and rapid urbanization in hilly region has accelerated the real estate development. Due to this, population density in the hilly region has increased enormously. Therefore, there is popular and pressing demand for the construction of multistory buildings on hill slope in and around the cities.

Hence construction of multistory R.C. frames buildings on hill slope is the only feasible choice to accommodate increasing demand for residential and commercial activities.

CONFIGURATION

1. Step-Back Building

In step back multi-storied building configuration top at same level but base unequal of all bays. The floors of such buildings Step back towards the hill slope. Center of mass of all floors does not lie on one vertical axis.

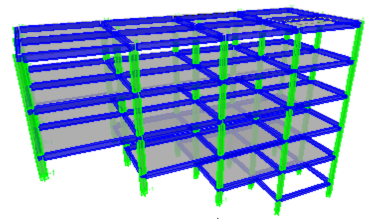

Fig. 1 Step-Back Building

2. Set-Back Building

In setback multi-storied building configuration top unequal but base equal level of all bays. The centre of mass of all the floors lies on the same vertical axis is true only for buildings which has symmetrical setback on all sides.

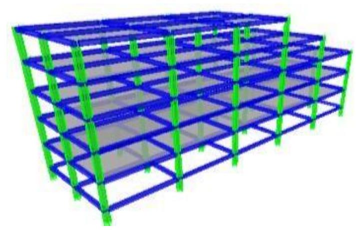

Fig. 2 Set-Back Building

3. Step Back – Set Back Building

In step back-Setback multi-storied building configuration top and base unequal of all bays. The floors of such buildings Step back towards and away the hill slope. Center of mass of all floors does not lie on one vertical axis.

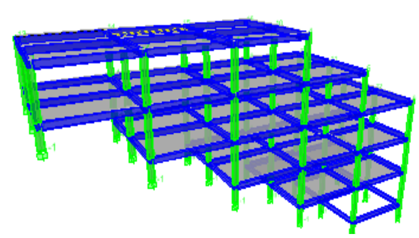

Fig. 3 Step Back – Set Back Building

4. Regular Building on Plain Ground

In regular building on plain ground top and base equal. Building having simple and clear geometry having minimum damage as compare to other irregular building configuration. Also, it has uniformly distributed mass and stiffness throughout the building.

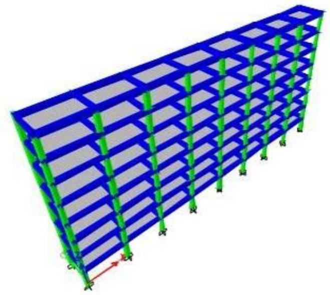

Fig. 4 Regular Building On Plain Ground

SCOPE OF STUDY

- A suitable configuration of building to be used in hilly area is suggested.
- This study is limited for linear static analysis.
- Further study of dynamic analysis can be performed by response spectrum and time history method also.
- This study is limited to five floors. Further analysis can be performed for higher number of stories.
- Further study may be done for building on different angles of slopes.

BACKGROUND

1. Past earthquakes [e.g. Kangra (1905), Bihar-Nepal (1934 and 1980), Assam (1950), Tokachi Oki-Japan (1968), and Uttarkashi-India (1991)] have proved that buildings located near the edge of stretch of hills or sloping ground suffered severe damages.
2. A major part of the peninsular India has also been visited by strong earthquakes but these were relatively few in number occurring at much larger time interval at any site and had considerably lesser intensity.
3. Hill buildings are different from those in plains; they are very irregular and unsymmetrical in horizontal and vertical planes, and torsionally coupled. Hence, they are susceptible to severe damage when affected by earthquake ground motion

II. METHOD OF ANALYSIS

SEISMIC ANALYSIS

Since earthquake forces are random in nature and unpredictable, the static and dynamic analysis of the structures have become the primary concern of civil engineers. The main parameters of the seismic analysis of structures are load carrying capacity, ductility, stiffness, damping and mass. IS 1893-2002 is used to carry out the seismic analysis of multi-storey building. It is used to understand the response of buildings due to seismic excitations in a simpler manner. There are different types of seismic analysis methods. Some of them used in the project are,

1. Equivalent Static Method or Linear Static Method.
2. Response Spectrum Method/ Linear Dynamic Analysis.
3. Time History Method/ Nonlinear Dynamic Analysis.
4. Non-Linear Static Method/ Pushover Method.
5. Consideration of Torsional Moment Due To Accidental Eccentricity.

1. Equivalent Static Method or Linear Static Method.

The use of this method is restricted with respect to high seismic zones and height of the structure (low rise), buildings having higher modes of vibration than the fundamental mode, structures having significant discontinuities in mass and stiffness long the height. However, it accounts for the dynamics of building approximate manner

2. Response Spectrum Method/ Linear Dynamic Analysis.

Dynamic analysis is carried by using response spectrum method. In this method peak response of a structure during an earthquake is obtained directly from earthquake response spectrum. Response spectrum method of analysis shall be performed using the design spectrum specified in Clause 6.4.2 or by a site specific design, spectrum mentioned in Clause 6.4.6 of IS 1893(Part 1):2002

3. Time History Method/ Nonlinear Dynamic Analysis.

In this method, the mathematical model of the building is subjected to accelerations from earthquake records that represent the expected earthquake at the base of the structure. It is the most sophisticated analysis method available to a structural engineer. This method based on limited suitable assumptions made for design of structures. It considers the structure's non-linear properties over time, and therefore gives results that are relatively more reliable than other forms of seismic analysis.

4. Non-Linear Static Method/ Pushover Method.

It applies calculated forces to the computer models that include non-linear properties that is, doubling the force applied does not cause an equivalent increase in response, but either a greater or a lesser response.

5. Consideration of Torsional Moment Due To Accidental Eccentricity.

First, the dynamic analyses of buildings without shifting the center of mass from their locations were carried out. Then the results due to the application of torsional moments at each floor level equal to the lateral force times the accidental eccentricity at that floor were superimposed on the results from dynamic analysis. The accidental eccentricity at each floor level was considered equal to 0.05 times the floor plan dimension perpendicular to the direction of seismic force.

LOAD ANALYSIS

1. Dead Load

Dead load is defined as "It is self weight of structure present as permanent or stationary loads which are transferred to structure or structural members throughout their life Span." Dead load is mainly due to self weight of structural members, permanent partition walls, fixed permanent equipment and fittings. Magnitude of dead load is calculated from unit weight of different materials. It does depend upon unit weight of material.

The IS Code 875 (part-I)-1987, Page No.08 and Table 1 used for unit weight of building materials. From the table 1, the unit weight of concrete is taken as 25kN/m^3, assuming 5% steel in the reinforced concrete.

Self-weight of the structural elements

a) Wall load on each floor beam = 13.66 KN/m
b) Wall load on roof beam = 5.22 KN/m and
c) Floor finish = 1.5 KN/m^2

2. Live Load

Live load defined as "It is movable and temporary load on floors and roofs on the structure without any acceleration or impact." These loads are assumed to be produced by the intended use or occupancy of the building including weight of movable partition or furniture etc. The imposed loads to be assumed in design of building are contained in IS: 875 (Part-2) 1987.

The floor slabs have to be designed to carry either uniformly distributed loads or concentrated loads, whichever produce greater stresses in the part under consideration. Since it is unlikely that at any one particular time all floors will be simultaneously carrying maximum loading, the code permits some reduction in loads in designing columns, load bearing walls, pier and their support and foundations. The imposed loads depend upon the use of building.

3. Seismic / Earthquake Load

Earthquake loads depend upon the place where the building is located. As per IS 1893-2002 (Part-I) (General Provisions for Buildings), India is divided into four seismic zones. The code gives recommendations for earthquake resistant design of structures. Now, it is mandatory to follow these recommendations for design of structures.

As per IS 1893(Part I) -2002 following parameters considered for earthquake Load analysis.

1) Moderate seismic zone (III)
2) Zone factor 0.16
3) Importance factor 1.0
4) Response Reduction factor 5.0
5) Presuming special RC moment resisting frame for all configurations and height of building.
6) Average response acceleration coefficient for rock or soil sites.

4. Load Combination

Four different load combinations considered as per the code (IS 1893PartI: 2002) which are as following

1) Combination 1 1.5 (DL+LL)
2) Combination 2 1.2 (DL+LL±EL)
3) Combination 3 1.5 (DL ±EL)
4) Combination 4 0.9 DL±1.5EL

Table 1. Load analysis for different configurations of building

A. Dead Load	**IS 875 Part 1:-1987**
1.Wall load on each Floor	13.66 KN/m
2.Wall load on roof floor	5.52 KN/m
3.Floor finish on each floor	1.5 KN/m^2
B. Live Load	**IS 875 Part 2:-1987**
1.Live load on each floor	4 KN/m^2
2.Live load on roof floor	2 KN/m^2
C. Seismic Load	**IS 1893(Part-1)-2002**
1.Zone factor	0.16 (Zone-III)
2.Soil type	I
3.Importance factor	1
4.Reponse reduction factor	5 (SMRF)
5.Damping percent	5 %

III. METHODOLOGY

The earthquake loads are estimated as per IS 1893 2002 by equivalent static force method.

The total design lateral force or design seismic base shear (VB) along any principal direction shall be determined by the following expression.

$$VB = AhW \qquad \text{.......... (1)}$$

where, Ah = Design horizontal seismic coefficient,
W = Seismic weight of the building.

The design horizontal seismic coefficient (Ah) is given by,

$$A_h = \frac{Z\ I\ Sa}{2Rg} \qquad \text{.......... (2)}$$

where, Z = Zone factor,
Z = 0.10 for zone-II, for zone III,
0.24 for zone-IV ,
0.36 for zone-V,
I = Importance factor,
R = Response reduction factor,
Sa/g = Spectral acceleration coefficient

The fundamental natural period (Ta) is taken for moment resisting frame building with brick infill panels as

$$T_a = \frac{0.09h}{\sqrt{d}} \qquad \text{........... (3)}$$

where, h = Height of the building in m.

Distribution of design force (Qi) is given by,

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2} \qquad \text{..........(4)}$$

where, Qi = Design lateral force at floor,
Wi = Seismic weight of floor,
hi = Height of floor measure from base,
n = Number of stories.

METHODOLOGY OF WORK

The economic growth and rapid urbanization in hilly region has accelerated the real estate development. Due to this, population density in the hilly region has increased enormously. Therefore; there is popular and pressing demand for the construction of multi-storey buildings on hill slope in and around the cities.

It is observed from the past earthquakes, buildings in hilly regions have experienced high degree of demand leading to collapse though they have been designed for safety of the occupants against natural hazards. Hence, while adopting practice of multi-storey buildings in these hilly and seismically active areas, utmost care should be taken, making these buildings earthquake resistant

Most of the constructions in hilly regions are constrained by local topography which results in the adoption of either a step back or step back and set back configuration. Due to this the structure is irregular by virtue of varying column heights leading to torsion and increased shear during seismic ground motion. The dynamic analysis is carried out using response spectrum method to the step back and step back and set back building frames. The dynamic response that is fundamental time period, storey displacement and drift, and base shear action induced in columns have been studied for buildings of different heights. These results show that the performance of step back and set back building frames are more suitable in comparison with step back building frames.

COMPARISON OF 3 CONFIGURATIO

1. Step back building Vs. Step back Set Back Buildings
2. Step back- set back buildings Vs. Set back buildings

1. STEP BACK BUILDING VS. STEP BACK SET BACK BUILDING

In Step back buildings uneven distribution of shear force in various frames suggests development of torsional moment due to static and accidental eccentricity, which has caused profound effect in Step back buildings.

An uneven distribution of base shear in various frames was also observed in Step back –Set back buildings. However, this uneven distribution of shear forces is low to moderate, indicating torsional moments of lesser magnitude under the action of seismic forces.

Based on the above observations, it can be stated that Step back buildings are subjected to higher amount of torsional moments as compared to Step back Set back buildings and may prove more vulnerable during the seismic excitation. The configuration of Step back Set back building has an advantage in neutralizing the torsional effect, resulting into better performance than the Step back building during the earthquake ground motion, provided the short columns are taken care of in design and detailing.

2. STEP BACK- SET BACK BUILDINGS VS. SET BACK BUILDINGS

Shear action induced in Step back Set back buildings is moderately higher as compared to Set back buildings on plain ground. It is to be noted that in Step back Set back buildings, higher stiffness is required in X direction whereas, in Setback buildings more stiffness is required in Y direction.
If, cost component of cutting the sloping ground and other related issues, is within the acceptable limits, set back buildings on plain ground may be preferred than the step back Set back buildings. In addition to this, issues viz. stability of slopes and vulnerability during the earthquake ground motion are less concerned in setback building.

IV. RESULT AND DISCUSSION

All buildings have been analyzed for seismic load. The seismic force was applied in X direction and Y direction independently. Important results are presented in terms of base shear, time period and top storey displacement. Results are compared according to building configuration frames such as step back , step back and set back, and regular building on plain ground frames under seismic loading.

Analysis of Results of R.C. Frames Building Configurations (2D) for 8 Storey by using Etabs 2015

1. Comparison of time period between step back, step back and set back, and regular building on plain ground frames of 8 storey building:

Time Period of Building Configurations for 8 Storey's

Mode No.	Time Period in Seconds		
	Step Back	Step Back - Set Back	Regular building
1	2.13	1.21	2.706
2	0.719	0.562	2.546
3	0.393	0.308	2.043
4	0.286	0.235	0.933
5	0.237	0.2	0.837
6	0.213	0.182	0.651
7	0.184	0.169	0.546
8	0.139	0.143	0.489

Result Conclusion: From the above graph time period for step back, step back and set back, and regular building on plain ground are more than step back-set back frames.

2.Comparison of storey shear between step back, step back and set back, and regular building on plain ground frames of 8 storey building:

Storey Shear of Building Configurations for 8 Storey's

Number of Storey	Storey Shear in KN with respect to X-direction		
	Step Back	Step Back–Set Back	Regular building
1	18.5925	77.61	640.74
2	47.2681	182.588	637.155
3	99.7293	332.028	622.699
4	181.4638	495.087	590.219
5	296.9171	713.0672	532.476
6	448.1019	1029.9723	442.253
7	631.3263	1538.2347	312.332
8	285.3291	589.58	135.494

Result Conclusion: From the above graph storey shear for first stories step back and step back - set back frames are less than regular building on plain ground.

V. CONCLUSION

1. The performance of step back building during seismic excitation could prove more vulnerable than other configuration of buildings.
2. The development of torsional moments in step back buildings is higher than that in the step back set back buildings. Hence, step back set back buildings are found to be less vulnerable than step back building against seismic ground motion.
3. In step back buildings and step back-set back buildings, it is observed that extreme left column at ground level, which are short, are the worst affected. Special attention should be given to these columns in design and detailing.
4. Although, the set back buildings on plain ground attract less action forces as compared to step back set back buildings, overall economic cost involved in leveling the sloping ground and other related issues needs to be studied in detail.
5. As number of storey increases time period and top storey displacement is increased.
6. The step back building frames give higher values of time period as compared step back and set back frames.

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