Seismic Response of Reinforced Concrete Framed Building Resting on Hill Slopes

Aarya E R, Dr. C. Justine Jose

Abstract— Buildings situated on hill slopes are generally irregular, torsionally coupled and hence susceptible to damages during earthquake ground motion. Mass and stiffness centres of such buildings are varying along the vertical and horizontal planes, causes torsion failures. These unsymmetrical buildings require much attention in the analysis and design. Analysis of hill buildings is somewhat different than the buildings on levelled ground, since the column of hill building rests at different levels on the slope. The present study aims to evaluate the seismic response of step-back multi storey buildings using non-linear static analysis with the help of SAP2000 and comparison with regular buildings. Structural modification is proposed to mitigate the causes of failure. Roof displacement, base shear and column bending moment have been studied to assess the seismic performance. By introducing bracings at suitable locations, considerable reduction in the column building moment is observed in step-back building which is similar to that of regular building.

Index Terms— Step-back buildings, hill slopes, irregular, torsionally coupled, torsional failures, stiffness, non-linear static analysis.

1 Introduction

The structures are generally constructed on the level ground; however, due to scarcity of level grounds and rapid urbanization construction activities have been started on sloping grounds. The economic growth and rapid urbanization in hilly region have accelerated the real-estate development Due to this, population density in the hilly region has increased enormously. Therefore. there is demand for the construction of multi-storey buildings on hill slope in and around the cities. In such condition it is very difficult to excavate or levelling since it is very expensive. Structural Engineers are facing the challenge of striving for the most efficient and economical design with accuracy in solution while ensuring that the final design of a building must be serviceable for its intended function over its design life time.

An important feature in building configuration is its regularity and symmetry in the plane and elevation. Buildings on hill slope are highly irregular and asymmetric in plan and elevation. One of the major contributors to structural damage during strong earthquake is the discontinuities and irregularities in the load path or load transfer. In sloping ground, the height of the column is different at the bottom storey. It is asymmetric in plane and elevation. The short columns are most effects and damage occur during the earthquake. Mass destruction of the low- and high-rise buildings in the recent earthquakes leads to the need of investigation especially in a developing country like India. In north and north-eastern parts of India have large scale of hilly terrain which fall in the category of seismic zone IV and V. Recently Sikkim (201 1), Doda (2013) and Nepal earthquake (2015) caused huge destruction. Birajdar and Nalawade (2004) [2] studied seismic performance of buildings resting on sloping ground. From their study it is observed that the shear force in the column towards extreme left is significantly higher as compared to rest of the columns. Nagargoje and Sable (2012) [3] observed that the base shear induced in step back set back buildings is higher in the range of 60 and 260% than set back building. They suggested step back set back buildings may be favoured on sloping ground. Jitendra Babu et al (2012) [9] carried out pushover analysis of various symmetric and asymmetric structures constructed on plain as well as sloping ground subjected to various kinds of loads. They conclude that the structure with vertical irregularity is more critical than a structure with plain irregularity. Mohammad Umar Farooque patel e.tal (2014) [6] focused on performance study and seismic evaluation of RC building on sloping ground. Hence, they conclude that the performance of buildings on hill slopes suggests an increased vulnerability of the structure with formation of column hinges at base level and beam hinges at each story level at performance point. Zaid Mohammada et al (2017) [1] focused on Framed structures constructed on hill slopes which show different structural behaviour than that on the plain ground. They conclude that the step-back setback buildings perform better than step-back configuration when subjected to seismic loads.

Although, the researches carried out in past have provided a better view of structural behaviour of hill buildings but the performance of the hill building in different configurations has not been studied thoroughly. The present study aims to evaluate the seismic response of step-back multi storey buildings using non-linear static analysis with the help of SAP 2000 and comparison with regular buildings. Roof displacement, base shear and column bending moment have been studied to assess the seismic performance. By introducing bracings at suitable locations, considerable reduction in the column building moment is observed in step-back building which is similar to that of regular building.

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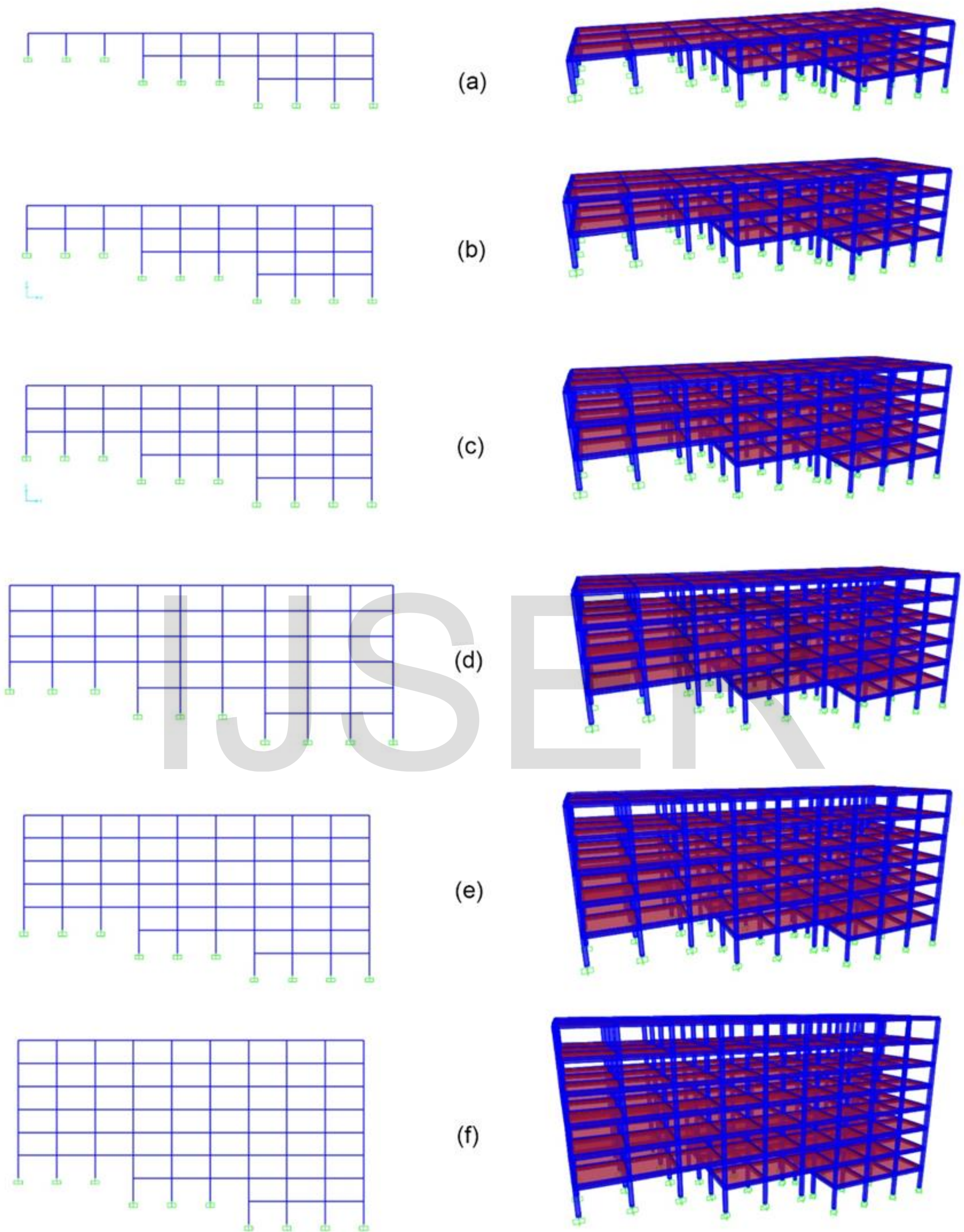

Figure 1 Elevation and 3D view of different step-back building configuration(a) 9M (b) 12M (c) 15M (d) 18M (e) 21M (f) 24M

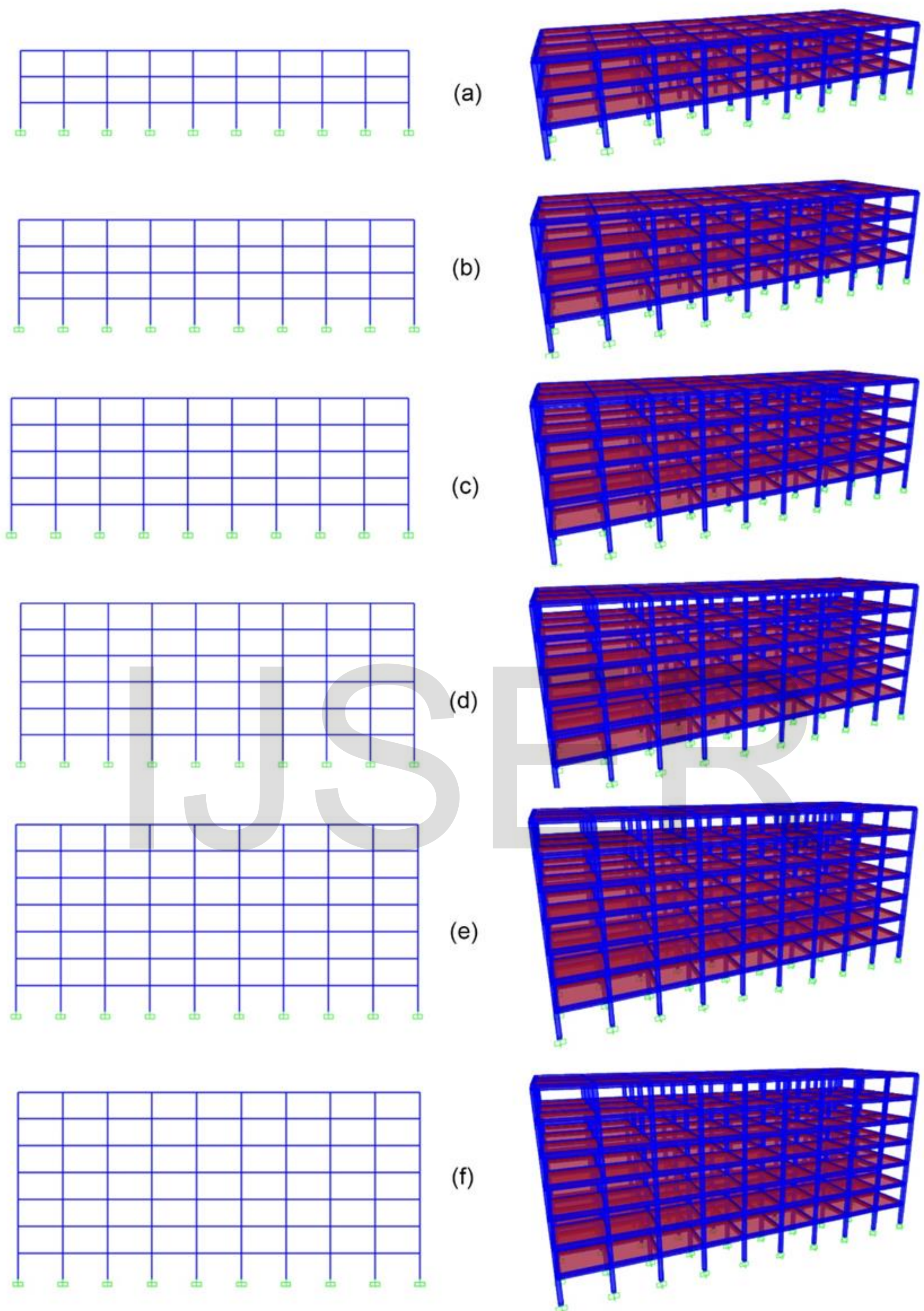

Figure 2 Elevation and 3D view of different RC Regular building configuration (a) 9M (b) 12M (c) 15M (d) 18M (e) 21M (f) 24M

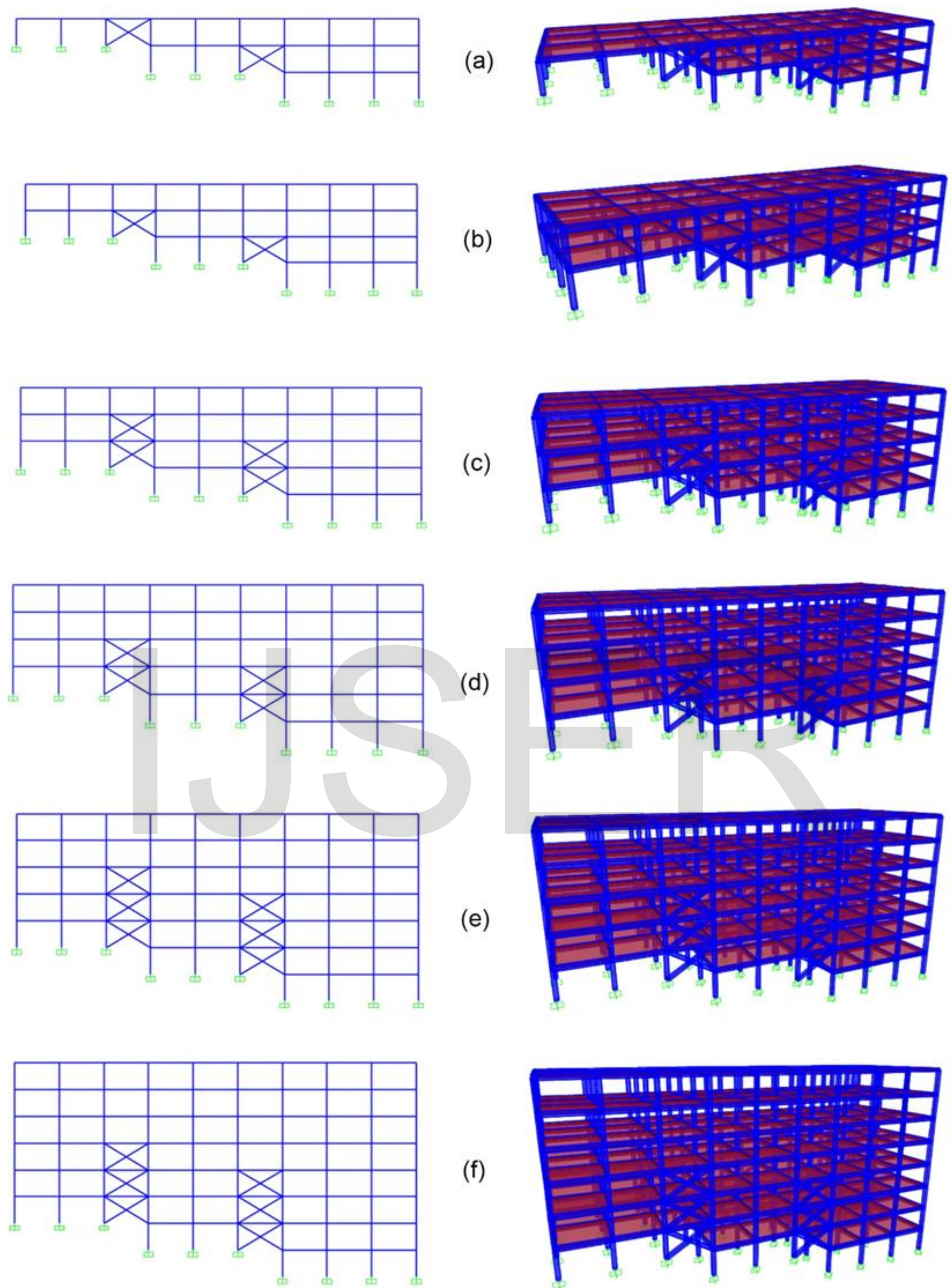

Figure 3 Elevation and 3D of different braced building configurations with (a) 9M (b) 12M (c) 15M (d) 18M (e) 21M (f) 24M

2 MODELLING

Three-dimensional space frame analyses of step back, RC regular and braced building configurations are performed. The seismic analysis is carried out by using non-linear static analysis method using finite element code SAP2000 v20. Here two sets of studies were carried out. In first study 6 sets of step-back building configurations (Figure 1) and RC regular building are compared (Figure 2). Pushover analysis is used to study performance of building configuration of overall height for one side 9M,12M,15M,18,21M,24M. And in second study 6 sets of step-back building configuration with x bracing system (Figure 3) and RC regular building configurations are considered and these three buiding configurations were compared. Bracings are provided at level of step change and provided at 50-70% height of the building with 400mm x 400mm crossection.

2.1 Materials and Section properties

Concrete, as constituent material, is assumed to be homogenous, isotropic and elastic in nature with modulus of elasticity and Poisson's ratio of concrete as 25000 N/mm^2 and value of Poisson's ratio is 0.2. The yield stress of reinforcement steel is taken as 415 MPa. For seismic analysis, the floor system in the all the configurations is modelled as rigid frame diaphragm and beam and column members modelled as two node beam elements. The foundation in all the models is assumed to be fixed support system.

2.2 Geometrical properties

The frames are usually spaced at distance of 5m with storey height of 3m using column dimension 400mm x 400mm and beam sections are 300mm x 500mm. The inter-storey height is taken as 3 meters and foundation depth is 1.5 m in all the buildings. The thickness of the slab at all floors in all the models is considered as 125 mm. Bracings are provided at level of step change and provided at 50-70% height of the building with 400mm x 400mm crossection.

2.3 Seismic parameters and loads

The seismic parameters considered in dynamic analysis of all the models are assumed as per IS 1893 (Part 1): 2002.The hill buildings are assumed to be in Zone V with the peak ground acceleration value of 0.36g. The importance factor, I is taken as 1.5 (for important building). Also, the response reduction factor R taken as 5 for SMRF system of the buildings. The soil strata beneath the foundation is assumed as medium soil. The gravity and imposed loads are taken as per IS 875 (Part 1 and 2): 1987, self-weight of the structure is calculated and imposed load is assumed to be 3 kN/m^2 for a typical residential building.

3 PUSHOVER ANALYSIS

In the pushover (non-linear static) analysis, a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behaviour until an ultimate condition is reached. Lateral load may represent the range of base shear induced by earthquake loading. The structure must have the capacity to resist a specified roof displacement (target displacement) for a specific earthquake. Non-linear static analysis is performed on the 3-D reinforced concrete buildings using different lateral load patterns to determine the effects of lateral load on the global structural behaviour through load displacement curve. In this study, displacement-controlled pushover analysis for all the example buildings were carried out.

4 RESULTS AND DISCUSSIONS

4.1 Comparison of Step-Back and Regular Buildings with varying height

Non-linear pushover analysis was conducted on each model to study the building configuration with different height. The evaluated parameters are column bending moment and plastic hinge formation.

4.1.1 Variation of roof displacement

Figure 4 and 5 shows the variation of building configuration with roof displacement at first hinge formation and just before collapse obtained by pushover analysis for step-back building and RC regular building. A significant amount of difference in roof displacement at time of hinge formation and just before collapse is observed between buildings.

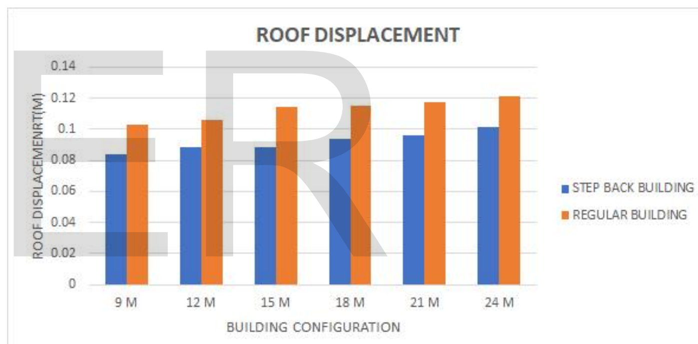

Figure 4 Variation of roof displacement at first hinge formation for step-back and

4.1.2 Plastic hinge formation

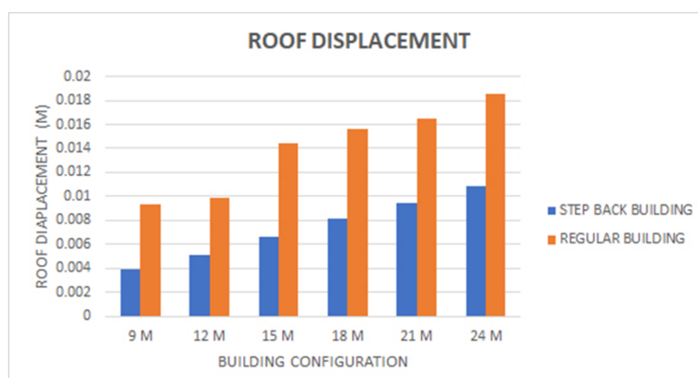

Figure 5 Variation of roof displacement just before collapse for step-back and

In the structural engineering beam theory, the term" plastic hinge" is used to describe the deformation of a section of a beam where plastic bending occurs. In earthquake engineering plastic hinge is also a type of energy damping device allowing plastic rotation [deformation] of an otherwise rigid column connection. Plastic hinge formation of the members in the frame are obtained after conducting static pushover analysis. It is observed that plastic hinges are first formed at uppermost support columns for step-back building frames and at ground level for regular building frames. Further, the collapse of the building occurs due to the failure of columns below the uppermost support for all respective frames. It is clear from the Figure 6 that for all step-back buildings only the columns below the uppermost support level need to be strengthened. The columns above the uppermost support level is stable as no hinges are formed during analysis.

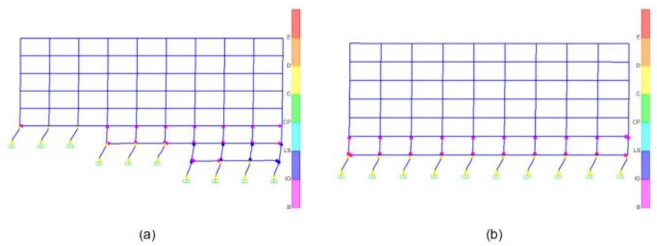

Figure 6 Plastic hinge for mation after collapse for 24M building configuration (a) Step-back (b) RC Regular

4.1.3 Variation of column bending moment

A bending moment is the reaction induced in a structural element when an external force or moment is applied to the element causing the element to bend. Figure 7 shows the variation of building configuration with column bending moment obtained by pushover analysis for step-back building and RC regular building.

As compared with RC regular building, values of step-back building show a higher column bending moment is likely to cause catastropic collapse of building under combined action of axial force, shear force and bending moment. The values of moment decrease as the overall height of the building increases. Further, stability of these building is jeopardized by slope instability that can be trigged by ground shaking.

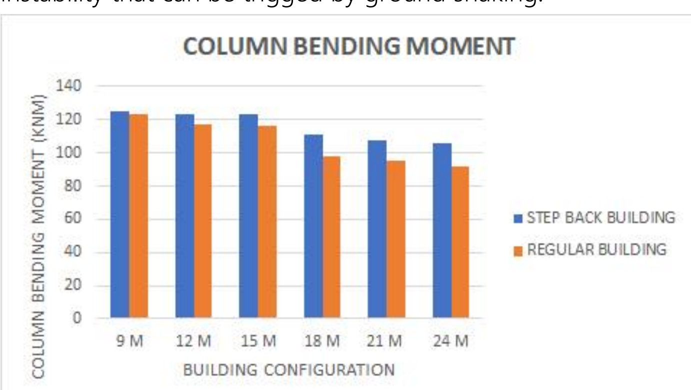

Figure 7 Variation of column bending moment for step-back and RC regular

4.2 Study of bracing as a mitigation procedure

Non-linear pushover analysis was conducted on each model to study the building configuration. The evaluated parameters are column bending moment and plastic hinge formation.

4.2.1 Plastic hinge formation

Figure 8 shows the plastic hinge formation for 24M braced building just after collapse. Plastic hinge formation of the members in the frame are obtained after conducting static pushover analysis.

From the analysis by introduction of bracings collapse of the columns on the support is shifted for all respective building configuration. The collapse of column is observed to be above the uppermost ground level in the braced building configurations.

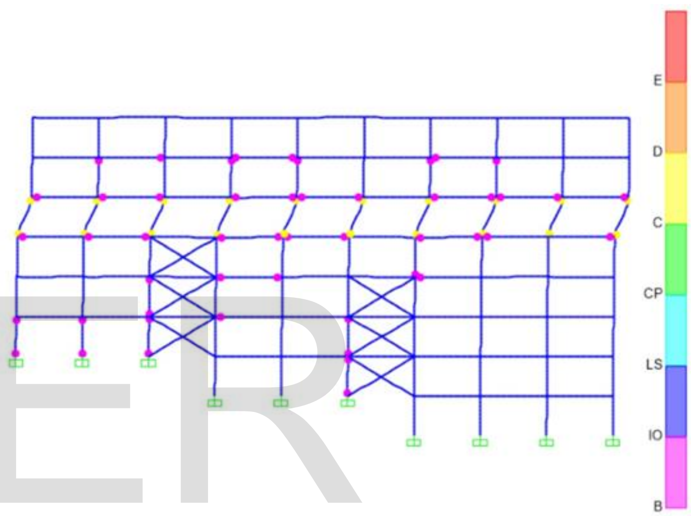

Figure 8 Plastic hinge formation for 24M braced building

4.2.2 Variation of column bending moment

Figure 9 shows the variation of building configuration with column bending moment obtained by pushover analysis for step-back building and RC regular building.

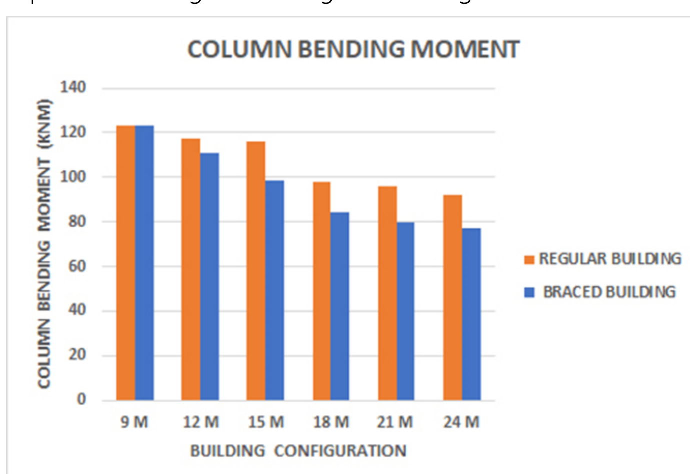

Figure 9 Variation of column bending moment at first hinge formation

As compared with RC regular building, values of step-back building show a similar column bending moment for 9M and 12M when the bracings are provided at the junction of changing level. For 15M and 18M building configurations four pair of bracings provided, while for 21M and 24M three pairs of bracings are provided to obtain the values as compared with RC building configuration.

4.3 Comparison of step-back, regular and braced buildings

Different step-back building configuration has been analysed by non-linear static analysis and variation of different engineering demand parameter had been found out and compared with regular building configuration. By analysing the parameter variation, it concluded that step-back buildings are more vulnerable to seismic actions. So, to mitigate all these effects a lateral load resisting system b racing have been introduced. The cross-section of bracings was 400mm x 400mm. Bracings is provided at step change of building at 50% - 70%of the storey height.

4.3.1 Variation of column bending moment

Figure 10 shows the variation of building configuration with column bending moment obtained by pushover analysis for step-back building and RC regular building.

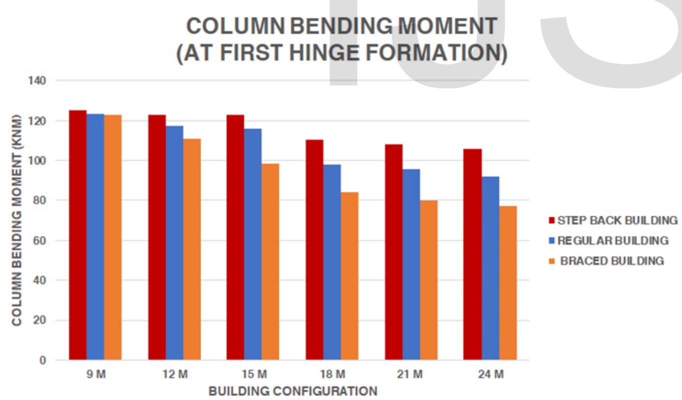

Figure 10 Variation of column bending formation at first hinge formation

On comparison, it is observed that step-back building has higher column bending moment than regular and braced building configuration for all respective frames due to discontinues in load transfer and pattern. As bracings are introduced in step-back building it become braced building and their seismic behaviour is made similar to regular building. For 9M, 12M bending moment for braced building is almost similar to regular building and for 15M, 18M, 21M, 24M their values are within the tolerance limit.

5 Conclusion

The primary objective of the project was to study the performance of stepback buildings and to identify weaker elements of building for better seismic performance. The study was conducted on the behaviour of step-back building along varying the height of the building. After that, results are compared with RC regular buildings. By introducing bracings, it leads to some inferences which are described in this section.

- Roof displacement for step-back building is less than regular building configuration due to lesser storey weight.
- Collapse of column only occur just below the uppermost support level so only these columns need to be strengthened.
- For strengthening of step-back buildings bracings are placed at junction of level change for better performance.
- Collapse of the column only occur just above the bracings by providing a stiffness to building.
- Column bending moment of braced building perform similar to the bending moment of RC regular building.
- Bracings are provided at 50- 70% of the total height of building for better performance.

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