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A Review on Short Column Seismic Behavior and Their Prevention on Sloping Ground

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Abstract—*The various earthquake damages investigation of past and recent earthquakes has illustrated that the building structures are vulnerable to severe damage and/or collapse during moderate to strong ground motion. The aim of this paper is to represent a general study on the short column seismic behavior originated from the level difference on sloping lots especially in hilly areas. Reinforced concrete (RC) frame buildings that have columns of different heights within one storey tend to suffer more damage in the shorter columns as compared to taller columns in the same storey. The great stiffness of the short columns enables them to absorb large amount of energy. The seismic analysis of RCC building on varying slope angles is studied and compared with the same on the flat ground. The study of short column behavior is needed to further improve their behavior during earthquake therefore short column are required to have more resistant sections. It has been observed that the footing columns of shorter height attract more forces, because of a considerable increase in their stiffness, which in turn increases the horizontal force and bending moment significantly. In addition more steel should be used as stirrups than as longitudinal bars, bracings and shear walls can be provided. Also for existing structures, shear capacity of short columns should be retrofitted by FRP, steel jacket or other materials.*

Keywords*: Earthquake, short columns, reinforced concrete structures, level difference, slope, Retrofit*

1. INTRODUCTION

North and northeastern parts of India have large scale of hilly regions, which are categorized under seismic zone IV and V. The building built on an area where there is level difference of sloping lot, the short column failure is seen to be significant and is one of the major vertical irregularities. Short column effect is cause to failure of columns which may result in severe damages or even collapse during earthquakes. Short columns are originated when the effective length by the least lateral dimension is less than 12. In the present study differently configured R.C framed building are described and studied from structural seismic safety point of view under the action of dead, live and earthquake loads. The structural analysis software STAAD Pro V8i, Response Spectrum Method, Pushover Analysis, Equivalent Static Method and non-linear Time History Analysis is used to study the effect of sloping ground on building performance during earthquake in various zones. Plane land in hill is scare and therefore sloping land is being increasingly used for buildings. The unequal height of the columns causes twisting and damage to the short columns of the building. It is because shear force is concentrated in the relatively stiff short columns which fail before the long columns.

2. REVIEW OF PAPERS ON SHORT COLUMN FAILURE AND ITS RETROFIT

Keyvan Ramin and Foroud Mehrabpour[1] (2014) studied seismic performance of buildings resting on sloping ground using STAAD Pro V8i. Also Sap2000 software had been used to show displacement of floors is greater for a flat lot building than a sloping lot building. Seismic behavior of buildings constructed on slopes. The chief role of this column is to transfer the inertia force originated from earthquake to columns. The main part of these forces is exerted on the short column since the stiffness varies from column to column. Thus, the short column shows an enormous potential for serious damage by earthquake in the case of an inappropriate design. Poor behavior of short columns is due to the fact that in an earthquake, a tall column and short column of same cross section move horizontally by same of building on a sloping ground (inclination say 7 and 15) under earthquake forces. The comparison of sloping ground and plane ground building is done for G+5 storey building and load is applied. The response of the building frames is studied for useful interpretation of the results.

Various steps involved in the comparison of horizontal forces

Step 1: Selection of building geometry and seismic zone. So, they have taken seismic zone IV as per IS code 1893 (Part-1):2002 for which zone factor Z is 0.24. Step 2: Load combinations are formed: The structural systems are subjected to Primary Load Cases as per IS 875:1987 and IS 1893: 2002. Six Primary load cases and thirteen load combinations are used for analysis. Step 3: Modeling of building frames using

STAAD Pro Software .Step 4: Study of structural behavior in terms of bending moments and horizontal footings, axial force and bending moments in columns. They compared two four-storey reinforced concrete moment resisting frame (MRF) buildings with medium deformability, one of which is located on a flat lot and the other one is on a lot sloped by 20 degrees . Flexural frame for building on slope and plane ground is shown in Fig. 1 and Fig. 2.

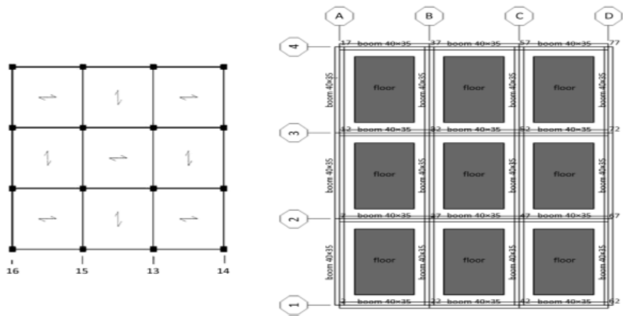


Fig. 1: The plan considered for both structures, Plans (along X- coordinate) of the studied structures

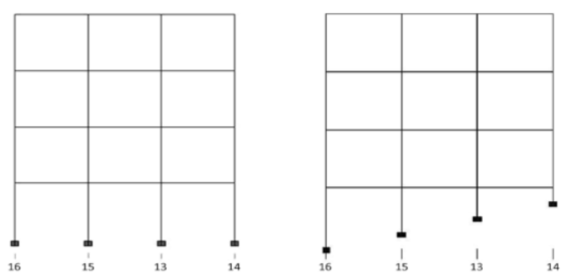
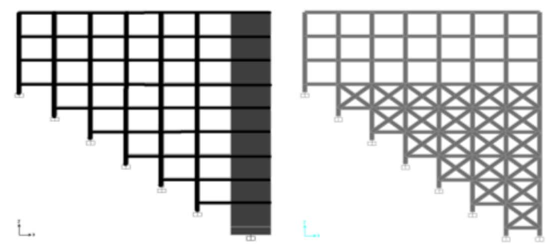


Fig. 2: The flexural frame for the structure on flat lot and on sloping lot

Sandeep Vissamaneni[2] (2014) studied seismic performance of buildings on hill slope. A parametric study is carried out on buildings considered, by using ground motion records for IDA (Incremental Dynamic Analysis). The short column is stiffer compared to the tall column. Stiffness of a column means resistance to deformation, the larger is the stiffness, larger is the force required to deform it. A study is carried out by changing the position of shear wall and varying column height of ground storey columns. He has carried out an experiment, by trial and error sizes placing shear wall on flexible side (bottom of hill across slope direction) achieved balanced stiffness of flexible side with rigid side to avoid torsion, or to make (Δmax/Δavg minimum). By placing the shear wall at top of the hill or bottom of the hill along the slope direction or providing by bracings reduce column forces that resting on sloping ground. Remedies for such buildings are given, by providing shear wall and bracings in step back buildings on slopes as shown in Fig. 3 (a), (b). He concluded that during earthquake when buildings are subjected to earthquake loads and lateral loads, they result in torsional response. He has compared the dynamic characteristics of hill buildings on slope and plane lots. The torsional response is due to irregular variation of stiffness and mass in vertical as well as horizontal directions, results in center of mass and center of stiffness of a storey not coinciding and not being on a vertical line for different floors. The buildings having step back and set back step back studied for their behavior during earthquake. The buildings were classified as Type S-I and Type S-II. Type S- I building, ground columns height varied from 1m to 3m also the shear wall is introduced to see the change in responses.



(a) **(b)**

Fig. 3: (a) Step back building with shear wall and (b) Step back building with bracing

The shear wall position was changed to various positions and results were noticed. In Type S-I building torsion is observed in all the storeys, whereas in Type S-II building torsion is observed in top three storeys (above road level) only. He has said that by providing bracings, ground supported columns in Type S-I building, and was relieved from excessive shear. However, the building were relieved from excessive shear but could not be torsionally balanced. Whereas increasing the height of ground supported columns to 2.5 m and placing the shear wall on the downhill side of Type S-I and Type S-II building resulted in torsionally balanced configuration and shear force in ground supported columns reduced to reasonable level.

Dinesh J. Sabu and Dr. P.S. Pajgade[3], 2012 studied Seismic Evaluation of Existing Reinforced concrete building and applied Response Spectrum analysis procedure for the evaluation of existing design of a reinforced concrete bare frame, frame with infill and frame with infill and soil effect. Retrofitting material requirement is checked through amount of reinforcement required in elements. After performing the analysis reinforcement required in each format is determined and retrofitting is suggested accordingly. He gave concrete jacketing as a method of retrofitting. Analysis is done using software STAAD Pro, it is concluded that the frame with infill gave much better result in terms of maximum displacement of the building and stiffness. Also, if actual reinforcement is more than reinforcement required in the brick infill and soil interaction effect than there is no need to retrofit the actual section, it is sufficient to carry the seismic forces. The bare frame requires more steel in its detailing as compare to the infill. He has said that the infill wall behave like a diagonal frame- strut system action and proves to be more stiff then bare frame. Hence, the infill frames takes the earthquake forces more safely then the bare frame.

A.B.M.A Kaish[4] et al. (2012) studied improved ferrocement jacketing for restrengthening of square RC short column, they have proposed improved techniques over conventional jacketing . Three new square ferrocement jacketing techniques were used, square jacketing with single layer wire mesh and rounded column corners (RSL); square jacketing using single layer wire mesh with shear keys at the center of each face of column (SKSL) and square jacketing with single layer wire mesh and two extra layers mesh at each corner (SLTL) are considered for this purpose. The specimens were tested under three categories firstly the not jacketed columns secondly with conventional technique and in third category columns were constructed with new ferro-cement technique jacketing. The tests were done under eccentric and concentric loadings. Test results and crack patterns of tested specimens showed that confinement with the ferro-cment encasement improves the ultimate load carrying capacity and the axial and lateral deflections of square RC column. SKSL was not tested for eccentric loading as the test results of SKSL did not give appropriate results in phase 1 when tested for concentric loading. Type SLTL jacketing shows highest load carrying capacity as well as good ductility properties over all other improved types of jacketing as well as non- jacketed specimens under concrete mode of loading whereas type RSL jacketing shows best performance under eccentric mode of loading.

Xuhong Zhou and Jiepeng Liu[5], (2010) studied seismic behavior and strength of tubed steel reinforced concrete SRC short columns. They tested eight specimens subjected to combined constant axial compression and lateral cyclic load. Out of which three were circular tube SRC and three were square tube SRC and two common SRC columns were taken for comparison. On comparison, they found that the steel prevented the shear failure of the concrete more effectively in the circular columns from that in the square ones. They also mentioned that shear connector studs should be used in CTSRC and STSRC short columns to prevent bond failure between concrete and flanges of the steel section. Tubed SRC short columns exhibit higher lateral load strength, displacement ductility, more stable hysteresis loops and greater energy dissipation ability than common SRC short columns in respect of the effective confinement of the thin tube to the core concrete.

M. Moretti and T.P. Tassios[6], (2006) studied behavior of short columns subjected to cyclic shear displacements: experimental results, they studied eight reinforced concrete columns subjected to constant axial load and reversed statically imposed displacement. The parameters tested were; (a) the shear ratio αs (b) the amount of longitudinal reinforcement (c) the amount of transverse reinforcement (d) the axial load ratio (e) two different main reinforcement layouts (conventional and a combination of conventional and bi- diagonal reinforcement from all the parameters above, they measured the strains of reinforcement (longitudinal and transverse) and of concrete along inclined force paths and concluded , the columns with low shear ratio had a brittle failure and as a remedial measure bi- diagonal reinforcement is provided in short columns for improved hysteresis behavior and energy characteristics. Specimens with shear ratio αs =1 failed in brittle manner along the main diagonals. The longitudinal reinforcement did not yield at the max. shear force, V_{max}, as is usually the case of columns with αs < 2, with the exception of specimen 2 (high axial load ratio μ= .60) in which the longitudinal reinforcement yielded in compression. Specimens 7, 8 with αs = 2 and αs = 3 failed relatively in more ductile manner despite the shear crack near the end sections. Specimen 8, with αs = 3 is characterized as normal 'long' column, because as compared to other columns, the onset of cracking along the diagonals ($V = V_{d,cr}$) of column with αs =1 induced non-linearity in distribution of strains along the longitudinal reinforcement. Large bars and high percentage of longitudinal reinforcement ought to be avoided. To some extent higher transverse reinforcement improves ductility.

K. Galal[7] et al. (2005), studied Retrofit of RC square short columns. They analysed the performance of seven reinforced concrete short columns under lateral cyclic loading and constant axial load. Carbon or glass fiber reinforced polymers were used to strengthen the short columns. It is demonstrated experimentally that it is possible to strengthen the shear resistance of short columns such that a flexural ductile failure occurs by developing plastic hinges at both ends of the column. Anchoring of the fiber wraps to the columns was found to be effective in increasing the shear resistance and energy dissipation capacities of the columns. Low shear span/depth ratio makes a brittle column failure. The unstrenghtened columns failed in shear were rehabilitated and later exhibited ductile behavior and enhanced shear resistance. The seven specimens had the same column overall dimensions. The specimens were divided into two groups: Group 1 includes SC 1 which is unstrengthened, SC2, SC1R, SC2R and SC1U and are strengthened with high content of transverse reinforcement. In Group 2 includes SC3 and SC3R has low content of transverse reinforcement. The column SC2 was strengthened using 3 layers of CFRP. SC1R included 4 layers of unidirectional glass FRP. SC1U was strengthened by 3 layers of CFRP similar to specimen SC2 but without anchors. In Group 2 (SC 3 and SC3R) had low transverse reinforcement ratio according to 1968 ACI design practice. SC3 was strengthened using 3 layers of CFRP. SC3R was retrofitted using 6 and 3 layers that provided by the 3 CFRP layers of SC3. Using anchored carbon fibre sheets rather than anchored glass fibre sheets for strengthening RC short columns increases both the shear force and the energy dissipating capacity. It also decreases the strains in the steel ties and the FRP along the column height.

Hugo Rodrigues[8] et al. (2015) studied Seismic rehabilitation of RC columns under biaxial loading, he has done an experimental characterization is done in order to improve the ductility and / or strength characteristics and it was obtained through concrete ductility with efficient jacketing or increasing the amount of longitudinal or transverse steel . The results are presented in terms of shear-drift, stiffness degradation, ductility and energy dissipation. The retrofitted results are comprised with the original ones, in terms of shear drift, degradation, ductility and energy dissipation. This campaign composed of 6 RC columns that were tested under different loading histories, in order to evaluate the influence of the biaxial loading in the cyclic response of the columns. After that, four of the tested columns were repaired and submitted to different retrofit strategies in order to replace the original characteristics, and mainly to provide the columns a good ductility capacity to respond well under cyclic loads. The retrofit techniques used in the present work were: increasing the number of stirrups, steel packet jacketing and carbon fiber reinforced polymer (CFRP) sheets and plate jacketing. After the retrofit these columns were biaxial tested. The results are presented in terms of shear- drift, shear drift envelopes, ductility, energy dissipation and stiffness degradation and are compared with the results of the original one. The experimental results on the column retrofitting show that the initial stiffness is typically lower and softening starts for higher drift demands. Also retrofitted columns tend to have an increase of the maximum strength around 20% maximum. The damage in original column is more pronounced when compared to the retrofitted for the same drift demand.

Hugo Rodrigues[9] et al. (2015) studied seismic behavior of strengthened RC columns under biaxial loading and concluded that the performance of 9 strengthened columns including one unstrengthened, it is kept original for the comparison of result. The column specimens were subjected to several loading condition. Cyclic displacements were imposed at the top of the column with steadily increasing displacement levels. The columns were retrofitted using CFRP plates and steel plates bonded with epoxy resin, retrofitted results are comprised with the original ones which were not retrofitted, in terms of shear drift, degradation, ductility and energy dissipation and the adopted load paths were diagonal and diamond. The experimental campaign was carried out on 9 RC columns with same geometries and reinforcement subjected to similar biaxial horizontal displacement paths with equal constant axial load. Their focus was on the influence of different strengthening strategies on the behavior of columns under certain load conditions. They found that the initial stiffness was not significantly affected. The strengthened columns present higher strength capacity of about 12% (in particular in columns under diamond biaxial horizontal load path). The strength degradation in strengthened columns starts for higher levels of drift demand. The strengthened columns tend to have lower levels of cumulative dissipated energy when compared with the original solution for the same drift levels. This fact is related with the concentration of damage in the base of columns. The columns submitted to the diamond horizontal load path, and also with the CFRP strengthening show higher energy dissipation capacity when compared with the diagonal load path.

V.Varalakshmi[10] et al. (2014) studied Analysis and Design of G+5 Residential building, which was constructed at Kukatpally, Hyderabad, India is designed (Slabs, Beams, Columns and Footings) using Auto CAD software. The loads are calculated namely the dead loads, which depend on unit weight of materials used (concrete, brick) and the live loads, which according to the code IS: 456-2000 and HYSD BARS FE415 as per IS: 1786 -1985. Safe bearing capacity of the soil is adopted as 350 kN/m^2 at a depth of 6 ft. and same soil should extent 1.5 times the width of footing below the base of footing. Footings are designed based on the safe bearing capacity of soil. For designing of columns and beams, it is necessary to know the moments they are subjected to. For this purpose frame analysis is done by LSM. Designing of the slab depends upon whether it is a one-way or a two- way slab, the end conditions and the loading. From the slabs, the loads are transferred to the beam. Thereafter, the loads (mainly shear) from the beams are taken by the columns. Finally, the section must be checked for all the floor components with regard to strength and serviceability.

A. Kheyroddin and A. Kargaran[11] (2009) studied seismic behavior of short columns in RC structures, they studied the short column phenomenon on duplex structures, storey floors with level difference relative to each other. In this research, nonlinear behavior of RC short columns in 4, 8 and 10 storey structures with storey level difference is investigated. Short columns and mentioned structures are analysed under the earthquake record of Elcentro with different peak ground acceleration with IDARC software which is nonlinear dynamic analysis program. In this investigation, the results of maximum response, base shear, global damage index and displacement time history and effect of short column in structural failure is evaluated. In this research, seismic behavior of short column in 3 duplex structures has been surveyed that have height level difference 1.6 meter. Plan of all 3 structures is same and have variable height and include 4, 8 and 10 storey. In results of Elcentro earthquake, they concluded that the seismic degree damage of short column in floor building in all structures increase with structures height especially in upper storeys damage index of short column has been increased. Out of all the other structures, in 8th storey structure there is lowest failure in short column. Displacement time history of first and medium short column in 4 storey structures and last short column in 10 storey Structures is high relative to other structures. Investigation of Shear force history concluded that the average of shear force history in first short column in 4 storey structures and medium short column in 8 storey structures and last short column in 10 storey structures has the most amount than other column. Damage index concluded that the part of last short column and down part of first short column in 8 and 10 storey structures has more damage.

Mahmoud F. Belal[12] et al. (2015) studied Behavior of reinforced concrete columns strengthened by steel jacket, he has performed an experimental and analytical method to show the appropriate results, RC columns often need strengthening to increase their capacity to sustain the applied load. This research investigates the behavior of 7 RC columns strengthened using steel jacket having dimension of 200x200 mm in cross-section with 1200mm height. The specimens were divided into two groups: the first group includes two control specimens without strengthening and second group includes five specimens strengthened with different steel jacket configurations. Vertical steel elements (angles, channel and plates) were chosen to have the same total horizontal cross sectional area. The specimens were placed in the testing machine between the jack head and the steel frame. The strain gages, load cell and linear voltage displacement transducer (LVDT) were all connected to the data acquisition system attached to the computer. The load was monitored by a load cell of 5000 KN capacity and transmitted to the reinforced concrete column through steel plates to provide uniform bearing surfaces. Behavior and failure load of the strengthened columns were experimentally investigated on seven specimens divided into two un-strengthened specimen and five strengthened ones. A finite element model was developed to study the behavior of these columns. The model was verified and tuned using the experimental results. The research demonstrated that the different strengthening schemes have a major impact on the column capacity. The size of the batten plates had significant effect on the failure load for specimens strengthened with angles, whereas the number of batten plates was more effective for specimens strengthened with C-channels. Then by using finite element (F.E) package ANSYS 12.0 their behavior was investigated analyzed and verified. Experimental results stated that modes of failure and failure loads varied depending on the configuration of steel jacket as well as its arrangement. Because the strengthening elements covered most of specimen, it was not possible to observe either the initial cracks or the cracking load for specimens. So, only failure load was recorded. Failure load is considered the maximum recorded load during testing and at which specimen could not carry any extra load. The results showed 20% of the minimum increase in the column capacity, also the failure turned from brittle to ductile with steel jacket. Specimens strengthened with angles or channel sections with batten plates recorded a higher failure load than that with strengthened plates. And the simulation of strengthened RC columns using F.E analysis in ANSYS 12.0 program is quite well since mode of failure, failure loads and displacements predicted were very close to those measured during experimental testing, for strengthened models, F.E package ANSYS 12.0 overestimated failure loads compared to experimental results.

3. CONCLUSION

1. In RC structures Short columns are required to have more resistant sections and are suggested to be reinforced with more bars. In addition, more steel should be used as stirrups than longitudinal bars.
2. In short columns, because of their shorter height, a considerable increase in stiffness of their section is observed while the percentage of shear force absorption and bending moment rises. Thus, the section of these columns is required to contain more steel to provide a greater resistance.
3. Results indicate more ductility of common structure and although more initial stiffness of sloping lot structure.
4. Shear wall and bracings can be of great use in increasing the columns stiffness and column can be relieved from excessive shear.
5. Infill panels have a large effect on the behavior of frames under earthquake excitation as it increases stiffness of the structure. Deflection is very large in bare frame compared to in-filled frame.
6. SLTL jacketing shows best performance under concentric loading and RSL jacketing shows best performance under eccentric loading.
7. A circular tube prevents the shear failure of concrete more effectively than a square tube in a tubed SRC column.
8. Columns with shear ratio values less than 2 behave in a particularly brittle manner when subjected to cyclic displacements.
9. Brittle shear failure reduces the energy dissipating capacity of the column.
10. Anchoring of the FRP jacket to the concrete cross section of short column subjected to lateral cyclic displacements increases the column’s shear force and energy dissipation capacities.
11. Increasing the number of FRP layers in short column strengthening decreases the strains in both the transverse steel members and fiber materials.
12. The most appropriate strengthening technique for short columns was found to be the use of anchored CFRP jackets over the height of the column.
13. The retrofitted columns tend to concentrate the damage in the base of the column, thus affecting stiffness degradation.

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