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Comparison of Analysis and Design of Regular and Irregular Configuration of Multi Story Building in Various Seismic Zones and Short Column Effect through Various Types of Soils using in STAAD

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Abstract: *Short column effect is cause to failure of columns which may result in severe damages or even collapse during earthquakes. The scope of the study is mainly to reveal the effect of short column on the holistic behavior of the buildings. The adverse effect of the short column on the response of buildings is shown in terms of the total load factor and displacement capacity of building. The response of buildings in terms of ground storey displacements is presented in figures and discussed. Various other factors influencing the short column behavior are discussed. A G+4 storey RCC building responses are checked for both the building constructed on plane and at an inclined ground using STAAD pro. Both the static and dynamic analysis are performed on both the buildings. The buildings members are thus compared with various important components of structural analysis such as for shear force, bending moments, displacements, deflections and torsion. Shear wall as a solution to the prevention of short column effect is designed and used at different positions and checked for the changes in terms of the torsion, displacements, shear and frequency of vibration and time period of vibration through mode shapes.*

Keywords: Short Column Effect

I. INTRODUCTION

Post-earthquake damages investigation in past and recent earthquakes has illustrated that the building structures are vulnerable to severe damage and/or collapse during moderate to strong ground motion. In this investigation, the results of maximum response in terms of base shear, displacement, time history are evaluated. The aim of this paper is to represent a general study on the short column behavior originated on sloping lots during earthquake referring to hilly areas of zone IV. Reinforced concrete (RC) frame buildings that have columns of different heights within one storey, suffered more damage in the shorter columns as compared to taller columns in the same storey and also the short column could be due to presence of intermediate beams or due to other reasons such as staircase landing slab, half infill wall. The great stiffness of the short columns enables them to absorb large amount of energy.

The seismic analysis of G+4 storey RCC building on varying slope angles is studied and compared with the same on the flat ground. The structural analysis software STAAD Pro V8i is used to study the effect of short column on building performance during earthquake in zone IV. According to the study of past short column behavior results, short column are required to have more resistant sections and are suggested to be reinforced with more bars. 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 (i.e. shear) and bending moment significantly. In addition, more steel should be used as stirrups than as longitudinal bars. Also for existing structures, shear capacity of short columns should be retrofitted by FRP, steel jacket or other materials. North and northeastern parts of India have large scale of hilly regions, which are categorized under seismic zone IV and V. Major seismic events during the past years in hilly areas such as Kangra, 1905 earthquake M8, Kinnaur ,1975 earthquake M6.2 , Uttarkashi uphill‟s, 1991earthquake M6.6 ,Nepal/Sikkim (India) border area in 2011 earthquake M6.9 ,where there is level difference of sloping lot the short column failure is

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also seen in damaged buildings which is one of the vertical irregularity. 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. 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. Short columns demand special attention in building structures. As far as possible, such configuration shall be avoided during plan phase itself; as failure of such columns could be quite brittle in nature hence disastrous. A G+4 storey RCC building responses are checked for both the building constructed on plane and at an inclined ground. Comparison is made by using software such as STAAD. Pro, ETABS and manual calculations on MS-excel. The static and dynamic response for the building on plane and sloping ground are compared and checked for the changes in terms of shear force, bending moments and deflection in same elements at an earthquake shaking of same magnitude. In a static model for both the buildings a comparison is made between the bending moments and shear forces of the elements at same nodes in both the structures. Thereby, concluding the changes in the shear force and bending moments of same elements in structure constructed on plane and sloping ground.

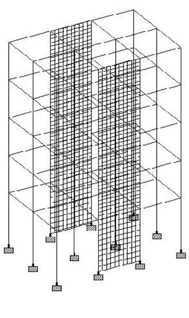
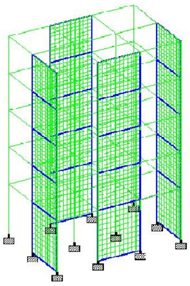
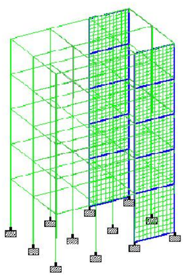
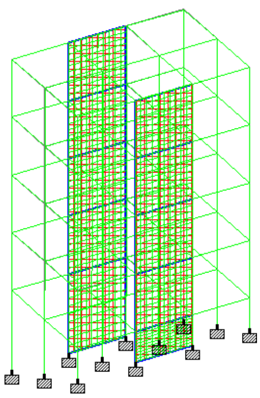
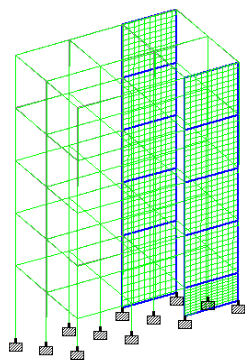
STAAD Pro V8i

STAAD Pro. V8i is a structural analysis and design computer program originally developed by research engineers at Yorba Linda, CA in year 1997. In late 2005, Research Engineers International was bought by Bentley Systems. STAAD Pro. Is one of the most widely used structural analysis and design software. It supports several steel, concrete and timber **design** codes.

STAAD Pro. V8i is a comprehensive and integrated finite element analysis and design offering program. It is capable of analyzing any structure exposed to static loading, a dynamic response, wind, earthquake and moving loads.

Shear wall

Shear wall may be defined as vertical elements of horizontal force resisting system, composed of braced panels to bear the effect of lateral load acting on a structure. Shear wall is designed using STAAD Pro. V8i to carry the seismic forces in (G+4) residential building safely to the foundation and reduce the effect of lateral forces in short columns at base of the building at sloping ground. It is a reinforced concrete (RC) vertical plate-like RC wall, in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. The thickness of the wall can vary from as low as 150 mm or as high as 400 mm in high rise buildings. Shear walls are usually provided along both length and width of buildings. These carry earthquake loads downwards to the foundation. Also, shear walls in buildings must be symmetrically located in plan to reduce ill- effects of twist in buildings. These are the various positions of shear walls for which results on displacements, torsion, time of vibration, frequency are studied.

II. MODELING, ANALYSIS AND DESIGN ASSUMPTIONS

Material and geometrical properties

Following properties of material have been considered in the modeling

- Density of RCC: 25 KN/m3
- Young's modulus of concrete: 5000 √fck
- The foundation depth is considered at 1.5 m below
- Beam cross section : 300 x 400 mm
- Column cross section : 300 x 450 mm , 300 x 300 mm and 450 x 300 mm
- Ht. of column (short) : 0.6 m , 2.3 m
- Ht. of column (long) : 4 m
- Ground level and the floor height is 4 m.
- Thickness of shear wall is 230 mm

Loading conditions

Dead Loads: as per IS: 875 (part-1) 1987 Self-wt. of slab
Slab = 0.15 x 25 = 3.75 kN/m2 (slab thick. 150 mm Assumed)
Floor Finish load = 1.47 kN/m2 Total slab load = 4.75 kN/m2
Live Loads: as per IS: 875 (Part-2) 1987
Response Spectrum Analysis: as per IS 1893 (Part-1) 2002 Design seismic base shear, Vb= AhW (Clause 7.5.3)
Design Spectrum Ah= ZISa/2Rg
Z (zone) = .24 (Clause 6.4.2) Table 2
I (Importance factor) = 1 (for all general buildings)
R (Response reduction factor) = 3 (ordinary moment resisting frame) = Average response acceleration coefficient
Soil strata = Soft soil as N<10 refers to the soft soil in Clause 6.3.5.2, where N is 13.8, so, have considered a medium soil, the corrected value, for the depth of foundation below ground is 1.5 m <5 ,so, the N values is referred as 15. As per the report (NIT, Kurukshetra), we have N= 13.8, so, for safe designing let us consider the soil be as soft soil. When calculating the seismic weight of the building, in clause 7.3.1 it is specified that the earthquake forces shall be calculated for the full dead load plus the percentage of imposed load on the floors and the live load on roof is considered to be as zero when design seismic forces are calculated. Table 8 gives percentage of imposed load to be considered in seismic weight calculation, since we have L.L of 2 KN/m2 on floor, we took 25 percent of imposed load on floors.
Wind Load as per IS (Part-3) 1987
Vz = Vb x k1 x k2 x k3
Where, Vb = 39 m/s (for Shimla) in Appendix A of IS 875 (Part-3) k1 = factor for maximum design life
Since, the building is a residential building, clause 5.3.1 and Table 1 of IS 875 (Part-3), k1= 1 (for all general buildings, having return period of 50 years)
K2= factor of terrain, height and structure clause 5.3.2
Category 3 is adopted as per the note which says this category includes well wooded areas and shrubs, towns and industrial areas full or partially developed.
Clause 5.3.2.2 states variation of wind speed with height for different sizes of structures in different terrains is k2 dependent. Assuming Class A structures and/or their components such as cladding, glazing, roofing etc, having maximum dimension (greatest horizontal or vertical dimension) less than 20 m. Also, the wind speed till 10 m height of the building is constant and varies after that.
Clause 5.3.3.1 states that the value is taken to be 1 for factor k3 when slope is less than 3˚. When slope is greater than 3˚ the value is taken to be 1 to 1.36 for slopes greater than 3˚.
Pz = 0.6 V 2
Where, Pz is the wind pressure
For the slopes greater than 3˚, Appendix C of IS 875 (Part-3)

Prevention

In buildings with heavy mass, earthquake induced forces are more so one way is to reduce the mass of the building. In modern overall high-rise buildings use of light weight prefab panels in place of brick masonry walls is done. Also hollow concrete blocks could be used to achieve the benefit of its light weight. Also, irrespective of all these asymmetric, irregular shapes and vertical irregularities in building configuration it can be made safe in earthquake if proper modeling and analysis of concerned structure were carried out. To make short columns more resistant sections and are suggested to be reinforced with more bars, in addition more steel should be used as stirrups. All these points are to be kept in mind at time of construction of a building. For existing structures shear capacity of short columns should be retrofitted by FRP, steel jacket, concrete jacketing or other materials.

III. LITERATURE REVIEW

Harumi Yashiro et al. (1990) studied "Shear failure mechanisms of reinforced concrete short columns", experimental and analytical study on the shear failure mechanisms of reinforced concrete short columns of shear span ratio of 1.5 was carried out. They used 31 specimens for the experimental study and finite element analysis was applied for the analytical study by considering bond-splitting cracks of concrete surrounding tensile steels, the failure processes, until the maximum shear load, were followed. As a result, of the study they carried was the failure processes and stress condition of reinforced concrete short columns of shear span ratio of 1.5 are as follows: first, bending cracks and bending shear cracks occur in the end positions; next, shear cracks in the end positions occur due to bending yielding. Therefore, the solution for a seismic design of reinforced concrete structures such as beams, columns are necessary to be ductile enough to make sure the structures should not fail in brittle state under earthquake shear loading. For all column specimens, the cross section is 25x25 cm, the length is 75 cm, the ratio of shear span to depth is 1.5 and tensile steel ratio (pt) is 0.96 %. To cut bond between tensile steel bars and concrete, tensile steels are coated with wax at first, coated with grease next and finally covered with soft paper. The region of end portion is 25 cm in length from the member end and the middle portion is the central 25 cm-length. After, the results were found, they concluded that specimens under higher axial load and with lower tie ratio are more brittle than those under lower axial load and with higher tie ratio. From the crack patterns, for specimens in which the bond of tensile steels at the middle portion is cut, shear failure is caused in the middle portion for the case of low tie ratio and bond splitting failure is caused in the middle portion for the case of high tie ratio. Shear load and deformation relationship is not greatly affected by the number of tensile steels but crack patterns are. The results conclude from analytical study, specimens of 15t of axial load, bending shear failure is caused.

K. Galal 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. Three layers of CFRP are applied. 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 fiber sheets rather than anchored glass fiber 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.

M. Moretti and T.P. Tassios (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. They concluded that 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 $\alpha s = 1$ failed in brittle manner along the main diagonals. The longitudinal reinforcement did not yield at the max. shear force, Vmax, as is usually the case of columns with $\alpha s < 2$, with the exception of specimen 2 (high axial load ratio $\mu = .60$) in which the longitudinal reinforcement yielded in compression. Specimens 7,8 with $\alpha s = 2$ and $\alpha s = 3$ failed relatively in more ductile manner despite the shear crack near the end sections. Specimen 8, with $\alpha s = 3$ 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 $\alpha s = 1$ induced non-linearity in distribution of strains along the longitudinal reinforcement, a fact which is not observed in specimen 8, they concluded that (a) the shear strength is larger compared to longer but otherwise identical columns due to low shear value also the mechanism of the diagonal concrete strut, is more activated compared to the truss mechanism of force resistance, a fact which leads to increased diagonal cracking of concrete and enhanced brittleness. Large bars and high percentage of longitudinal reinforcement ought to be avoided. To some extent higher transverse reinforcement improves ductility.

A. Kheyroddin and A. Kargaran (2009) studied "seismic behavior of short columns in RC structures", they have studied the short column phenomenon on sloping ground and duplex structures, storey floors with level difference relative to each other are made in two or different height levels. In this research, at first, seismic behavior of short column phenomenon is determined, then, 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 the concluded that the seismic degree damage of short column in floor building in all structures increase of structures height especially in upper storeys damage index of short column has been increased. Out of all the other storeys in 8 storey structures has the lowest failure in short column. The displacement history of last short column in 4, 8 and 10 storey structures is more than first short column in all structures by increasing PGA. 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 storeys structure and medium short column in 8 storeys structure and last short column in 10 storeys 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 storeys structure has more damage.

Xuhong Zhou and Jiepeng Liu (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.

Y. Singh et al. (2012) studied "Seismic behavior of buildings located on slopes- An analytical study and observations from Sikkim earthquake of September 18, 2011", they concluded the response of setback buildings at varying slopes. They have performed an analytical study to investigate the peculiar seismic behavior of hill buildings. Dynamic response of hill buildings is compared with that of regular buildings on flat ground in terms of fundamental period of vibration, pattern of inter-storey drift, column shear, and plastic hinge formation pattern. The seismic behavior of two typical configurations of hill buildings is investigated using linear and non-linear time history analysis. The irregular variation of stiffness and mass in vertical as well as horizontal directions held these buildings to significant torsional response. Unequal height of columns within a storey, results in drastic variation in stiffness of columns of the same storey.

Design of Pier

Conventionally the pier of a metro bridge is designed using a force-based approach. Recent studies (Priestley et al., 2007) show that the force-based design may not necessarily guarantee the required target performances. The codes are now moving towards a performance-based design approach, which consider the design as per the target performances at the design stage. As the present study focus on the application of displacement-based approaches to pier design, a brief introduction of the two methods, force-based and displacement-based design is summarized in the following sections.

Mahmoud F. Belal 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, which also concludes that the L/d ratio is less than 12 so, are termed as short columns. 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 gauges, 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.

Vinay Mohan Agrawal and Arun C (2015) studied "comparative study on fundamental period of RC framed building", they concluded it is difficult to quantify the irregularity in a setback building with any single parameter such as overall building height. Fundamental period of all the selected building models were estimated and Empirical equations given in the design codes and the results were critically analysed. The fundamental time period is calculated as per given in available design codes for earthquake resistant building including IS 1893:2002, ASCE 7:2010, Euro code 8 or New Zealand code of practice, recommends an empirical formula for the determination of Fundamental time period of building. The following formulas were checked and the results were calculated and the comparison of fundamental period of setback buildings with that obtained from equation based on IS 1893:2002 was carried out and is presented, it stated that empirical formula in IS Code provides the lower- bound of the fundamental periods obtained from Modal Analysis and Raleigh method. Therefore, IS 1893:2002 always gives conservative estimates of fundamental period of

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setback buildings with 6 to 30 storeys. It was also concluded that the Raleigh method underestimates the fundamental periods of setback buildings slightly which is also conservative for the selected buildings. ASCE 7:2010 does not consider the height of the building but it considers only the number of storeys of the building and this approach is most conservative among other code equations. This study indicates that there is very poor correlation between fundamental periods of three dimensional buildings with any of the parameters used to define the setback irregularity by the previous studies or design codes.

Vrushali S. Kalsait and Dr. Valsson Varghese (2015) studied "Design of earthquake resistant multistoried building on a sloping ground", The purpose of their paper was to perform linear static analysis of medium height RC buildings and investigate the changes in structural behavior due to consideration of sloping ground. They have studied the buildings at varying slopes and countered their behavior in terms of mode shapes, fundamental time of vibration, lateral displacements, moments in column and axial shear force. The response of G+15storey building at varying slopes of 0˚, 7.5˚, 15˚, 22˚ was studied and as per his conclusions made from STAAD Pro V8i, the displacement of building resting on sloping ground have more lateral displacement compared to the buildings on plain ground, the critical axial force in columns increases as slope increases. He found that critical bending moments increased on 22˚ slope than 7.5˚ slope and 15˚ slope ground. The calculated frequency decreases as slope of ground increases whereas time period increases as slope of ground increases. Also, the steel quantity on sloping ground is more than on plain ground for same cross section of column and beam, thus, it is concluded that cross section required more steel on sloping ground to make earthquake resistant structures.

Summary of Literature Review

Various software such as ETABS, STAAD Pro, ANSYS 12.0, SAP2000 are used for the analysis of combination of loads on which column would fail. The shear wall and cross bracings can be effective if used in a step back or step back set back buildings for better performance of a building in hilly areas having short column. For a better performance of a short column various parameters such as shear ratio α, energy dissipating property, ductility, shear resistance has to be checked and various preventive measures should be applied to repair and retrofitting of existing structures. Short columns can be made safe at the time of new construction and can be retrofitted in existing buildings by means of FRP, new ferrocement jacketing techniques. Cost effective measures can also be understood from the papers read so far. Short column with higher shear ratio value has high energy dissipation capacity and more ductile failure when subjected to cyclic displacements. To some extent higher transverse reinforcement improves ductility. More layers of FRP composites applied on a column with proper anchorage bars improves the strain and minor cracking also leading to a flexural ductile failure. CFRP gives more lateral force capacity and high strain bearing capacity as compared to the GFRP. The CFRP 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. For columns rehabilitation with CFRP, 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. 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 using earthquake record of Elcentro with different peak ground acceleration with IDARC software which is nonlinear dynamic analysis program. Comparison of 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. The RC columns strengthened with steel jacket 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. The behavior of hill buildings differs significantly from the regular buildings on flat ground. The hill buildings are subjected to significant torsional effects under cross- slope excitation. Under along-slope excitation, the varying heights of columns cause stiffness irregularity, and the short columns resist almost the entire storey shear. The linear and non- linear dynamic analysis shows that the storey at road level, in case of downhill buildings, is most susceptible to damage. . The buildings with same maximum

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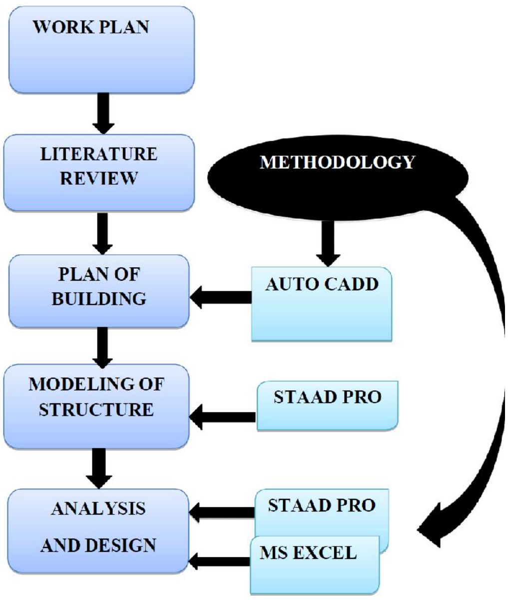
height and same maximum width may have different period depending on the amount of irregularity present in the setback buildings. The variation of the fundamental periods due to variation in irregularity is found to be more for taller buildings and comparatively less for shorter buildings. This observation is valid for the periods calculated from both modal analysis and Raleigh method are quite smaller. Comparison results for (G+15) building is done for different slope and same soil condition on varying slopes of 0˚, 7.5˚, 15˚, 22˚ concluded that the displacement of building resting on sloping ground have more lateral displacement compared to the buildings on plain ground, the critical axial force in columns increases as slope increases. He found that critical bending moments increased on 22˚ slope than 7.5˚ slope and 15˚ slope ground. The calculated frequency decreases as slope of ground increases whereas time period increases as slope of ground increases. Also, the steel quantity on sloping ground is more than on plain ground for same cross section of column and beam, thus, it is concluded that cross section required more steel on sloping ground to make earthquake resistant structures. It is also concluded from the literature that axial loading, tie ratio and bond conditions have significant effect on the critical deformation of reinforced concrete short columns.

III. RESEARCH METHODOLOGY

Work plan and methods used



EXPERIMENTS

Analysis

The following observations were made as a result of analysis done on software STAAD Pro for static analysis.

Maximum bending moments and shear forces in each floor in building on sloping ground

FLOOR	BENDING MOMENT (M z) kN-m FLOOR WISE (SLOPING GROUND)
GROUND FLOOR	87.347
FIRST FLOOR	93.973
SECOND FLOOR	87.347
THIRD FLOOR	77.357
FOURTH FLOOR	90.374
TOP FLOOR	38.757

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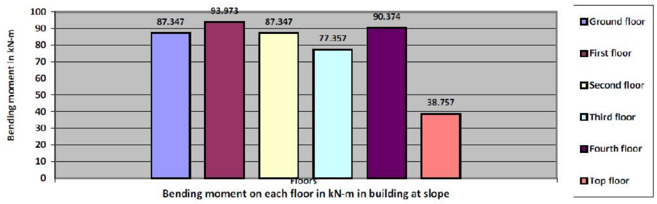
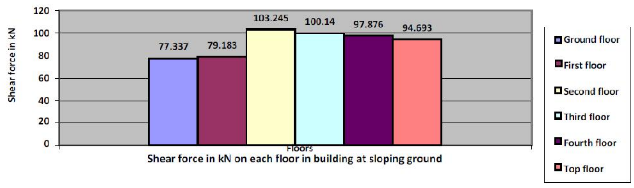
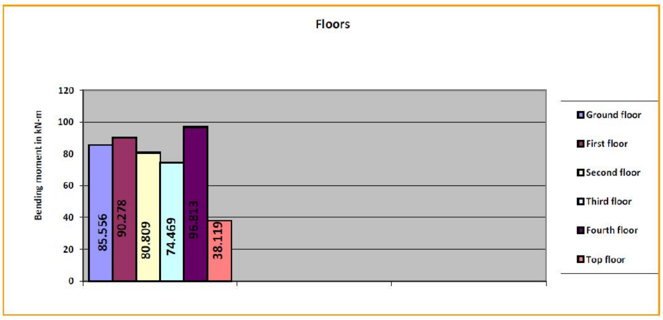


FLOOR	SHEAR FORCE (kN)
GROUND FLOOR	77.337
FIRST FLOOR	79.183
SECOND FLOOR	103.245
THIRD FLOOR	100.140
FOURTH FLOOR	97.867
TOP FLOOR	94.693

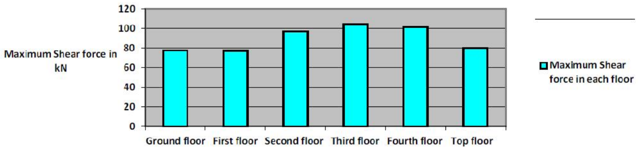


Maximum bending moments and shear forces in each floor in building on Plain ground

FLOOR	BENDING MOMENT (M z) kN-m FLOOR WISE (PLAIN GROUND)
GROUND FLOOR	85.556
FIRST FLOOR	90.278
SECOND FLOOR	80.809
THIRD FLOOR	74.469
FOURTH FLOOR	96.813
TOP FLOOR	38.119

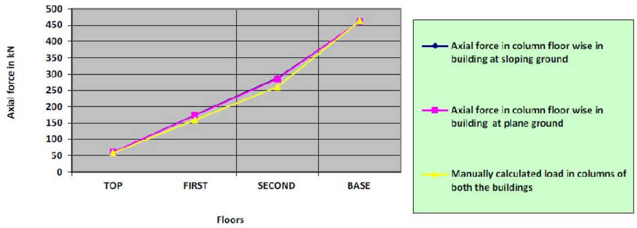


FLOOR	SHEAR FORCE (kN)
GROUND FLOOR	77.454
FIRST FLOOR	77.134
SECOND FLOOR	96.486
THIRD FLOOR	104.150
FOURTH FLOOR	101.091
TOP FLOOR	80.033



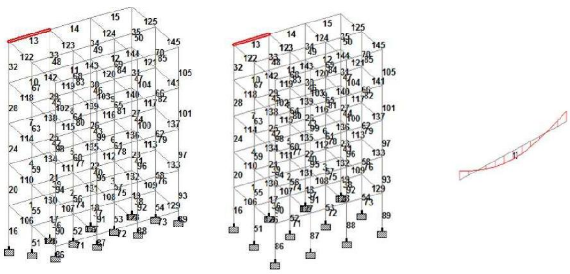
Maximum axial forces in columns from top to bottom

COLUMN AT SLOPING GROUND	AXIAL FORCE (kN)	COLUMN AT PLANE GROUND	AXIAL FORCE (kN)	MANUALLY CALCULATED AXIAL FORCES (kN)
TOP	60.141	TOP	60	58.08
FIRST	174.705	FIRST	173.54	159.38
SECOND	287.839	SECOND	285.39	260.685
BASE (SHORT COLUMN)	460.779	BASE (LONG COLUMN)	461.82	463.29

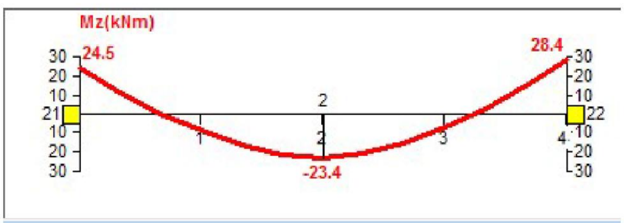


The axial forces in column from top to bottom were observed to be almost same to that calculated manually. Also, the axial force in columns of the building at slope is more in comparison to the building columns at plain ground as shown in Figure 4.5. This is the force calculated under static condition of load combination of 1.5 (D.L+L.L).

The moment and shear force in beam element 13 is seen to be almost same for both the buildings at slope and at plain, thus we can see from the figure 4.7, 4.8, 4.9 and 4.10 that the change in moment and shear forces in top element of building is almost alike. Therefore, the changes are to be noticed for the lower building elements for various parameters discussed above.



(a) (b) (c)



Bending Moment in beam 13 (top external) in building at sloping ground

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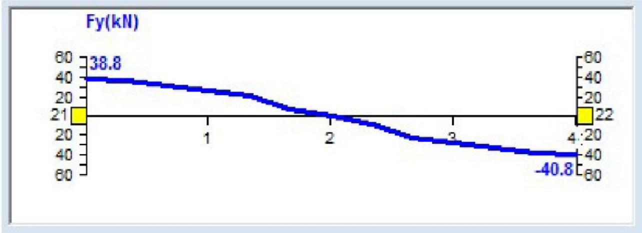


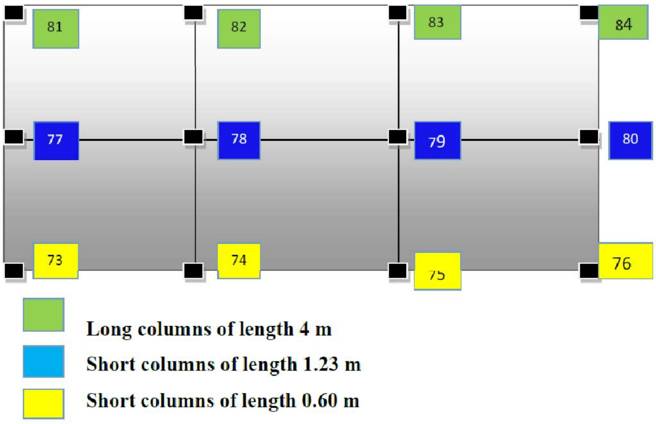
Shear force diagram of beam 13 (top external) in building at slope

Results and Discussion for response spectrum analysis

The models which were analyzed under static response were found to be safe against the Live loads and dead load criterion after that Response spectrum analysis is done for the same buildings and results in terms of shear forces, bending moment, displacements and torsion are taken out as shown below and compared.

Bending moment variation after application of dynamic load

The supports 73, 74, 75, 76 are the supports of short column of length 0.6 m in building at slope, which are exposed to maximum bending moments as compare to any other column in the same floor. Supports 77, 78, 79 and 80 are the supports of short column of length 2.3 m in building at slope, and have exposed to the moments which are almost equal or lesser then the moments at the base of long columns in building at flat ground. The positions of the columns are as shown in figure



81	-5.601	-5.523	161.588	155.466
82	0.043	0.077	182.735	174.559
83	0.042	-0.077	182.735	174.559
84	5.600	5.523	161.589	155.466

Supports	Bending Moment Mz in kNm (Plain)	Bending Moment Mz in kNm (Slope)	Bending Moment Mz in kNm (Plain)	Bending Moment Mz in kNm (Slope)
	Static Loading	Static Loading	Dynamic Loading	Dynamic Loading
73	-5.601	-8.532	161.643	219.022
74	0.043	0.440	182.784	242.583
75	-0.042	0.440	182.784	242.582
76	-5.600	8.532	161.642	219.023
77	-12.593	-14.134	393.074	237.518
78	-0.882	-0.767	115.220	54.441
79	0.882	0.767	115.220	54.441
80	-12.208	0.077	393.074	237.518

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Axial force variation in Long and short columns subjected to same forces

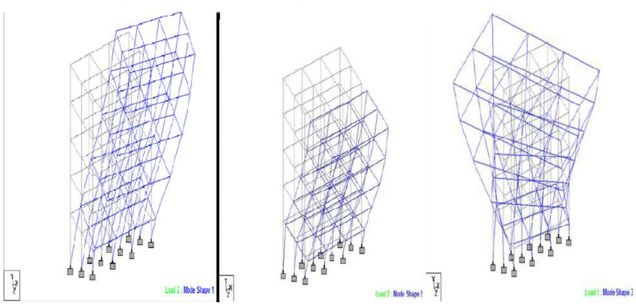
The increased dynamic load is found to be more on the columns above the supports 73 and 76 which are the shortest heighted columns in the building with biaxial loading can be seen from figure and thus will require good detailing work.

Supports	Axial force in kN (Plain)	Axial force in kN (Slope)	Axial force in kN (Plain)	Axial force in kN (Slope)
	Static loading	Static loading	Dynamic loading	Dynamic loading
73	616.273	601.796	616.273 + 236.732 = 853.005	601.796 + 269.270 = 871.066
74	1041.9	1040.318	1041.9 + 36. 049 = 1077.949	1040.318 + 26.016 = 1066.334
75	1041.903	1040.314	1041.314 + 36.090 = 1077.404	1041.903 + 25.921 = 1067.824
76	616.270	601.793	616.270 + 236.733 = 853.003	601.793 + 269.197 = 870.99
77	1007.239	1013.434	1007.239 + 242.134 = 1249.373	1013.434 + 226.977 – 1240.411
78	1463.672	1460.678	1463.672 + 71.121 = 1534.793	1460.678 + 71.915 = 1532.593
79	1463.6	1460.672	1463.6 + 71.126 = 1534.726	1460.672 + 71.126 = 1531.798
80	1007.2	1013.429	1007.2 + 242.141 =1249 .341	1013.429 + 227.048 = 1240.477
81	616.273	626.891	616.273 + 236.799 – 853.072	626.891 + 194.134 – 821.025
82	1041.9	1050.688	1041.9 + 36.112 = 1078.012	1050 + 44.918 = 1094.918
83	1041.903	1050.684	1041.903 + 36.075 = 1077.978	1050.684 + 44.918 = 1095.602
84	616.27	626.88	616.27 + 236.804 = 853.074	616.88 + 194.218 = 811.098

Mode shapes

When a system is excited, to describe the response of the system mode shapes are used. A pattern of motion in which all parts of the system move sinusoidally with the same frequency. Calculating the natural frequencies and mode shapes means calculating the linear response of structures to dynamic loading and is called modal analysis. In modal analysis, the response of the structure is decomposed into several vibration modes. A mode is defined by its frequency and shape. The frequency is found to be more in building models at slope for various mode shapes and the time period is inverse to the condition.

Mode shapes for the building on slope



(a) (b) (c)

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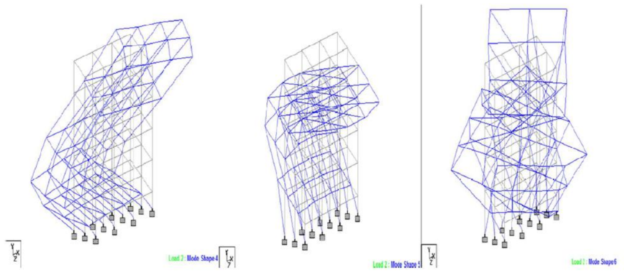
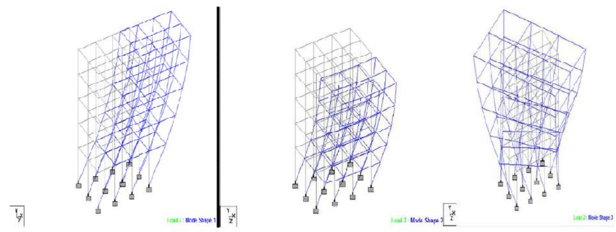


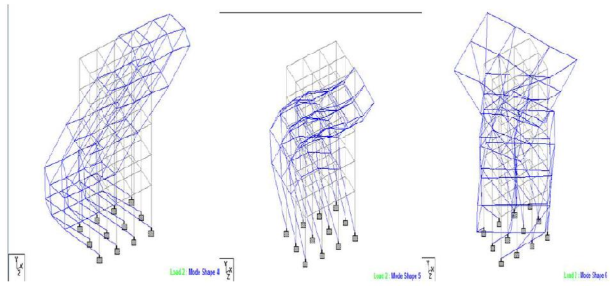
(d) (e) (f)

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
1	1.137	0.879	79.784	0.000	0.000
2	1.227	0.815	0.000	0.000	76.036
3	1.606	0.623	0.653	0.000	0.000
4	3.528	0.283	10.449	0.000	0.000
5	3.890	0.257	0.000	0.000	11.005
6	4.965	0.201	0.010	0.000	0.000

- Mode shapes of building resting on plain ground.



(a) (b) (c)



(d) (e) (f)

Torsion in beam and column elements of both the buildings on plain and on sloping ground

Torsion is defined to be twisting or wrenching of some element, and it can lead to a much catastrophic failure of a beam or a column. Therefore, the torsion has to be examined in both the elements namely, beam and columns.

Base shear calculated by STAAD Pro V8i

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of the structure. Base shear and mass participation factors in percent for both the buildings at plain and slope are shown below. The total design lateral force or design seismic base shear Vb along any principal direction is determined by the STAAD.

Participation factor Summ-X on 6th mode is calculated to be 98.528 for building at plain and 90.896 for the building at slope. Seismic weight has been achieved using the first three mode shapes. As per clause 7.8.4.2 in IS 1893, the number of modes to be used in the analysis should be such that the sum of total of modal masses of all modes considered as 90% of total seismic mass. The summation has come to be about 90% in STAAD Pro V8i, hence we can conclude that clause 7.8.4.2 has been satisfied

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	MASS PARTICIPATION FACTORS IN PERCENT						BASE SHEAR IN KN		
MODE	X	Y	Z	SUMM-X	SUMM-Y	SUMM-Z	X	Y	Z
1	90.61	0.00	0.00	90.610	0.000	0.000	625.80	0.00	0.00
2	0.00	0.00	88.07	90.610	0.000	88.069	0.00	0.00	0.00
3	0.00	0.00	0.00	90.610	0.000	88.069	0.00	0.00	0.00
4	7.18	0.00	0.00	97.795	0.000	88.069	103.27	0.00	0.00
5	0.00	0.00	8.67	97.795	0.000	96.739	0.00	0.00	0.00
6	0.00	0.00	0.00	97.795	0.000	96.739	0.00	0.00	0.00
				TOTAL SRSS	SHEAR		634.27	0.00	0.00
				TOTAL 10PCT	SHEAR		634.27	0.00	0.00
				TOTAL ABS	SHEAR		729.08	0.00	0.00
				TOTAL CSM	SHEAR		729.08	0.00	0.00

```
*********************************************************
*                                                       *
* TIME PERIOD FOR X 1893 LOADING =     0.46470 SEC      *
* SA/G PER 1893=     2.500, LOAD FACTOR= 1.000          *
*      FACTOR V  PER 1893=     0.0975 X     7477.72     *
*                                                       *
*********************************************************
```

	MASS PARTICIPATION FACTORS IN PERCENT						BASE SHEAR IN KN		
MODE	X	Y	Z	SUMM-X	SUMM-Y	SUMM-Z	X	Y	Z
1	78.13	0.00	0.00	78.134	0.000	0.000	630.67	0.00	0.00
2	0.00	0.00	73.89	78.134	0.000	73.894	0.00	0.00	0.00
3	0.46	0.00	0.00	78.592	0.000	73.894	5.11	0.00	0.00
4	11.30	0.00	0.00	89.889	0.000	73.894	126.00	0.00	0.00
5	0.00	0.00	11.38	89.889	0.000	85.274	0.00	0.00	0.00
6	0.05	0.00	0.00	89.941	0.000	85.274	0.59	0.00	0.00
				TOTAL SRSS	SHEAR		643.15	0.00	0.00
				TOTAL 10PCT	SHEAR		643.15	0.00	0.00
				TOTAL ABS	SHEAR		762.36	0.00	0.00
				TOTAL CSM	SHEAR		756.69	0.00	0.00

```
*********************************************************
*                                                       *
* TIME PERIOD FOR X 1893 LOADING =     0.46470 SEC      *
* SA/G PER 1893=     2.500, LOAD FACTOR= 1.000          *
*      FACTOR V  PER 1893=     0.0975 X     7760.97     *
*                                                       *
*********************************************************
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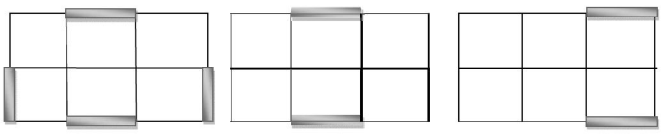
Shear wall

Shear wall is a reinforced concrete (RC) vertical plate-like RC wall, in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. The thickness of the wall can vary from as low as 150 mm or as high as 400 mm in high rise buildings. Shear walls are usually provided along both length

and width of buildings. These carry earthquake loads downwards to the foundation. Also, shear walls in buildings must be symmetrically located in plan to reduce ill-effects of twist in buildings. Details used for shear wall, for various panels is as follows:

```
PANEL  NO.   1 OF SHEARWALL       9  DESIGN PER IS 456-2000

WIDTH :        4.00 M              FC :            30.00 MPA.
HEIGHT :       4.00 M              FY :           415.00 MPA.
THICKNESS : 230.00 MM              CONC. COVER :   25.000 MM
```



Mode shapes after application of shear walls at different position

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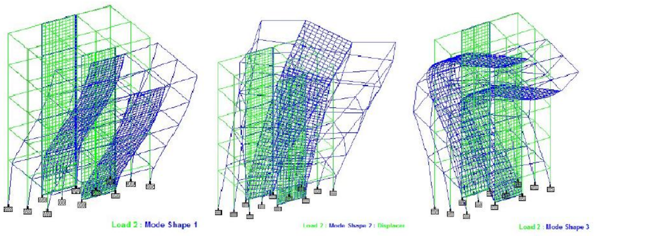
- Shear wall position at middle as shown in building at slope



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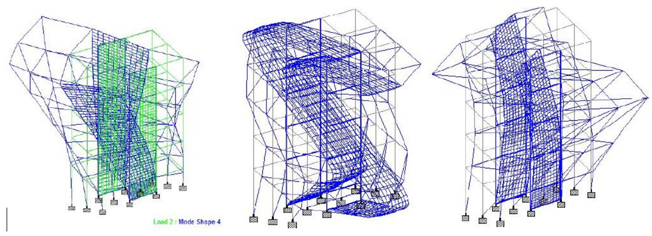
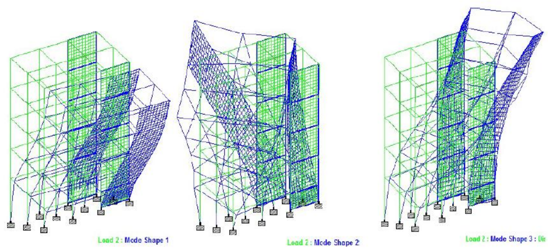
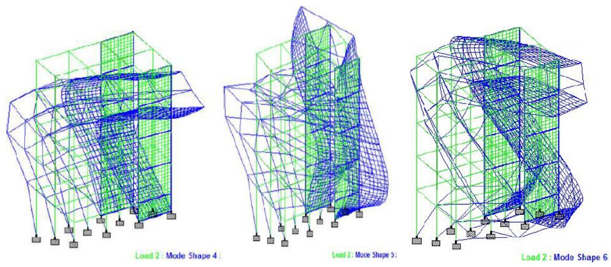


(d) (e) (f)

When the position of shear walls is revised and built at corner, the mode shapes obtained for the building is as below



(a) (b) (c)



(d) (e) (f)

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
1	0.763	1.310	0.000	0.000	86.432
2	2.248	0.445	0.000	0.000	0.021
3	2.447	0.409	73.591	0.027	0.000
4	2.485	0.402	0.000	0.000	8.092
5	4.655	0.215	0.000	0.000	2.201
6	5.005	0.200	0.000	0.000	0.049

Wind load study

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H	K_2	V_z (for plain)	P_z (N/mm^2) (for plain)	P_z KN/m^2 (for plain)	V_z (for slope)	P_z (N/mm^2) (for slope)	P_z (KN/m^2) (for slope)
1-10	.91	35.49	755.7240	.75572	42.3892	1078.10	1.0781
11	.922	35.958	775.78	.775786	42.948235	1106.730	1.1067
12	.934	36.426	796.11	.7961120	43.507214	1135.726	1.1357
13	.946	36.894	816.700	.816700	44.066193	1165.097	1.1650
14	.958	37.362	837.55	.83755	44.625172	1196.265	1.196265
15	.97	37.83	858.665	.858665	45.184415	1224.97	1.22497
16	1.01	39.39	930.9432	.93094	47.0474	1328.074	1.32807
17	1.05	40.95	1006.141	1.0061	48.9106	1435.34	1.43534
18	1.09	42.51	1084.26	1.08426	50.77394	1546.79	1.54679
19	1.13	44.07	1165.298	1.16529	52.63720	1662.404	1.66240
20	1.17	45.63	1249.25	1.249	54.50047	1782.18	1.78218

V. RESULTS AND DISCUSSIONS

Comparison of results

Comparing the results for models, it shows that base shear for the building at slope is more than the building at plain for about 4.5 % more at building at slope. Also, as mentioned in the objective of the study, the behavior of multi-storey building frame under dynamic response in terms of displacement, moment, shear, torsion and mode shapes. Response spectrum analysis has increased the effect of torsion, shears force bending moment and deflection in lower elements of buildings and thus are compared. Torsion effect is found to be more in short column in comparison to long column. The displacement of the lower elements in a building at slope is lesser as compared to the displacement of nodes 53, 54, 55, 56. The results obtained for the critical elements are represented in the tables below.

Maximum moments floor wise in kN-m

Floor	Sloping ground	Plain ground	Percentage increase %
Ground floor	87.347	85.556	2.05
First floor	93.973	90.278	3.93
Second floor	87.347	80.809	7.48
Third floor	77.357	74.469	3.733
Fourth floor	90.374	92.803	2.7
Top floor	38.757	38.119	1.64

Maximum shear force floor wise in kN

Floor	Sloping ground	Plain ground	Percentage increase %
Ground floor	77.337	77.454	.151
First floor	79.183	77.134	2.58
Second floor	103.245	96.486	6.54
Third floor	100.140	104.150	4
Fourth floor	97.867	101.001	3.2
Top floor	94.693	94.033	.69

Axial force in columns in kN

Column position	Sloping ground	Plain ground	Percentage increase %
Top	60.141	58.08	3.426
First	174.705	159.38	8.77
Second	287.839	260.685	9.43
Base	490.9	468.7	4.522

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Bending moments in kN-m at column bases after application of dynamic forces

Support no.	Sloping ground	Plain ground	Percentage increase %
73	219.022	161.643	26.2
74	242.583	182.784	24.7
75	242.582	182.784	24.6
76	219.023	161.642	26.2

Increase in Axial force in kN at base of buildings

Support no.	Sloping ground	Plain ground	Percentage increase %
73	871.066	853.005	2.07
76	870.99	853.003	2.06
82	1094.918	1078.8012	1.47
83	1095.602	1077.978	1.608

Displacement of top nodes in mm

Node	Sloping ground	Sloping ground (Shear wall position at middle)	Plain ground	Plain ground (Shear wall position at middle)
69	77.256	21.319	118.44	26.944
70	77.256	12.318	118.443	26.944
71	77.250	12.818	118.443	27.095
72	77.250	21.319	118.444	27.095

Displacement of bottom nodes in mm

Node	Sloping ground	Sloping ground (Shear wall position at middle)	Plain ground	Plain ground (Shear wall position at middle)
53	5.953	1.758	44.853	4.017
54	5.550	0.972	44.903	4.397
55	5.550	0.972	44.903	4.397
56	5.954	1.758	44.903	4.017

Reduction in shear force at beam element and column element nodes after application of shear wall is as given in the table.

The reduction in shear (Y) in kN after application of shear wall, in beam, 89% in building at slope and 98.2 %.

Reduction in maximum shear (Y) in kN (Beam element) after application shear wall

Node	Sloping ground	Sloping ground (Shear wall position at corner)	Plain ground	Plain ground (Shear wall position at middle)
55	63.739	1.150	79.263	1.420
56	-63.739	-1.150	-79.263	-1.420

Reduction in maximum shear (Y) in kN (column element) after application shear wall

Node	Sloping ground	Sloping ground (Shear wall position at corner)	Plain ground	Plain ground (Shear wall position at middle)
29	83.806	8.450	106.747	5.835
77	-83.806	-8.450	-106.747	-5.835

VI. CONCLUSION

1. 1.In this study, performance of residential building frames are studied considering dead load and live load combination, thus studying the static behavior of the building on plane and sloping ground to study short column effect. It has been concluded that a short column is safe under normal loading (D.L and L.L).
2. 2.In beam forces, maximum bending moment and maximum shear force are calculated and it is observed that ground floor is efficient because of direct contact with soil and foundation.
3. 3.In static analysis, there is no considerable difference found between bending moments and shear forces of two building components whereas during response spectrum analysis the change in bending moments of short column in building at slope and long columns in building at flat were noticeably higher to long columns.
4. 4.In column force, maximum axial force is calculated and it is observed that maximum load is in base columns because it resist complete load of residential building and as seen in top floor axial force is reduced up to 3 times of columns in lower floor. Also, that the building is found stable under static forces.
5. 5.Calculated frequency increases as for the building at slope.
6. 6.Calculated time period of vibration is lesser for the building at slope.
7. 7.Response spectrum analysis has increased the effect of torsion, shears force bending moment and deflection in lower elements of buildings and thus are compared. Torsion effect is found to be more in short column in comparison to long column. The displacement of the lower elements in a building at slope is lesser as compared to the displacement of nodes 53, 54, 55, 56.
8. Columns are more affected to torsion in comparison to the beams.
9. Shear walls has tended to reduce the shear effect to 89% in building at slope and almost about 90% in buildings at plain.
10. 10.Shear wall position at the middle is found to be more effective in terms of safer values for restricting displacement of top and bottom nodes.
11. By providing shear wall the buildings were relieved from excessive shear but are not torsionally balanced too much extent.
12. Results indicate more ductility of common structure and although more initial stiffness of sloping lot structures.
13. Also, wind load effect on building has made a change in the moments of beam and column elements.

VII. FUTURE SCOPE

1. The study can be further extended to analysis of building at varying slopes.
2. The building of higher degree of irregularities can be analysed.
3. Analysis can be done using software SAP2000, ETAB, ANSYS.
4. Dynamic analysis can be done using Time history method.
5. Comparison of varying analytical methods can be done, such as Time history method and Response spectrum analysis.
6. Analysis can be performed with different seismic zone.

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