Dynamic Analytical Observations of RC Frame

Muzafar Ahmad Ganie, Syed Mohd. Arif, Govind Ravish, Hemlata Sharma, Nancy Missan

Abstract: RC structures on sloping ground take columns of different height within one storey. Brittle shear failure is generally observed in short columns of RC frame as it takes the maximum shear during severe dynamic excitation by earthquake forces. Hence due to this immense problem, it is important to investigate practical and effective methods to rehabilitate these columns and the building as such. The objective of this research program is to assess the performance enhancement of short columns when strengthened with shear walls at specific locations of RC frame and with bracings exclusively. The strength attained with these two methods has been compared with one another assessment where most of the columns of RC frame are moved outside to the periphery, transforming the traditional grid of columns, which might demand the flat slab on each floor. It is possible that all the three might provide Solution for improvement in strength and stiffness of short columns of an RC frame on a sloping ground, but then these methods are compared and the one has been suggested which is cost effective. For this purpose 6 RC buildings are taken into consideration to carry out this research program, 3 on flat ground and 3 on sloping ground, one regular and one setback for each of the cases of ground geometry considered. The slope of the ground is taken as 16 degrees. Using Staad Pro v8i, the Response Spectrum Method for linear and Time History Analysis for non Linear dynamic analysis of these buildings can be done, to investigate various dynamic response characteristics and the respective strengthening technique can be applied and suggested as such.

Keywords : Short column, earthquake, sloping ground, level difference, brittle shear failure, dynamic excitation, strengthening, shear wall, bracings, stiffness, response spectrum analysis, conventional column grid.

I. INTRODUCTION

The north and northeast states of India are categorized in zone IV and V, and have a history of earthquakes that have proven catastrophic and have caused loss of precious lives and destruction to the RC structures. These regions generally have a hilly landscape available for the development of infrastructure. Hence RC structures are more prevalent on hilly ground in these regions. RC structure on hilly ground has foundation at different levels and hence the successive building floors tend to step back towards the rise of slope of hill. This leads to a peculiar irregular symmetry of building in both the horizontal and vertical directions.

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The stepping back of building gives rise to the formation of short columns within the same storey which induces the variation of stiffness and mass along the height of building and horizontal direction as well. Thus there is a mismatch of the stiffness and mass along vertical and horizontal directions of RC frame. Hence there is a prevalent inconsistency in centre of mass and centre of stiffness along the successive floors of the RC frame on sloping ground. This discrepancy results in torsional stress and hence demands special attention in this regard during its design. The short columns on the uphill side of storey tend to evoke the major percentage of storey shear which usually tends to its threshold capacity and hence makes the short column the most vulnerable structural component. Now a days, the setback configuration of building is well received compared to that of step back building. In this research study the two can be analysed on the same sloping ground and the response to a specific frequency of earthquake can be compared for which one is safer. In case of setback buildings, the centre of mass and centre of stiffness consequently tends to decrease along the height of building, as there is consequent drop in floor area along the height of RC frame. The seismic behaviour of RC structures has been far and wide subject matter since last decade; however the response enhancement and improvement of short columns of RC structures on sloping ground by comparing the strengthening methods mentioned in the objective below is still very limited. Rather considerable work is there for rehabilitating the short columns by adopting different retrofitting techniques which is of course useful for post-earthquake damages or overcoming the weakness of short columns after a certain period of time. The column shear failure is the most concerning and commonly observed failure in RC structures. Columns with low shear span-depth ratio i.e. short columns are more vulnerable to shear failure [3]. In seismically active zones, the short column is a menace and even if short columns are avoided but there are large number of columns that are susceptible to non-ductile shear failure. These columns originally designed as long columns are transformed to short columns due to Partial height of masonry infill walls between adjoining RC columns to leave space for windows. During earthquake these columns behave as fixed and exhibit stiffness and thus display low shear ratio. This results in the damage of these columns during earthquake of threshold frequency corresponding to the lateral load resistance of these columns and can result in partial or total collapse of the structure. It has been observed that the short columns when subjected to cyclic horizontal displacement, there is an increased initial stiffness and shear response i.e. they resist it actively.

However when the displacement is higher, maximum shear response is reached which causes stiffness degradation and low energy dissipation capacity [3]. Hence there is a grave need to even evaluate the RC structures on flat ground and to investigate effective methods for the rehabilitation of these columns to make the building safe to earthquake.

II. ANALYTICAL STUDY AND SIMULATION

In the present investigation, a G+10 RC frame has been taken into consideration, one on a plane ground and the other on a sloping ground respectively as shown in figure. The dynamic response of the two buildings under certain seismic excitation is compared with one another where the plan of both the buildings is kept same. The dynamic behavior of two RC structures is compared using two different lateral force resisting systems including shear wall and bracings at certain locations shown in the fig. The building on flat ground with shear wall for the purpose of lifts is represented as model M-1. The same provided with shear walls in definite locations and then replaced with X-bracings at the same locations besides the shear wall for the purpose of lift is represented as model M-2 and M-3 respectively. The configuration of these lateral resisting force systems in case of building on sloping ground is step back at a constant slope of 16° and is represented as models M-4, M-5 AND M-6.

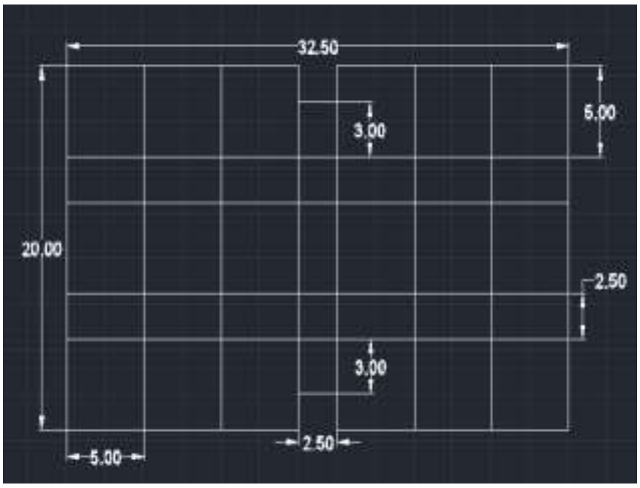


Fig. 1: Plan of building

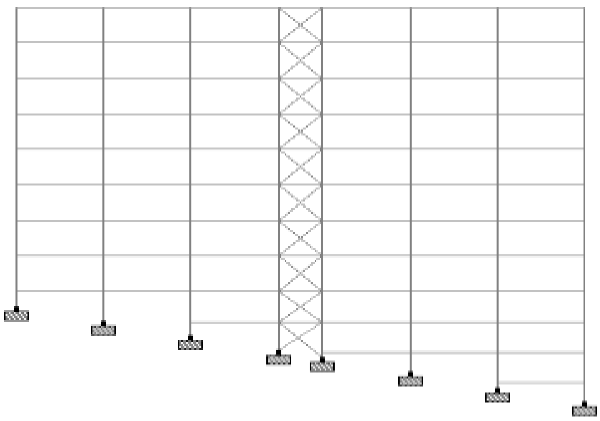
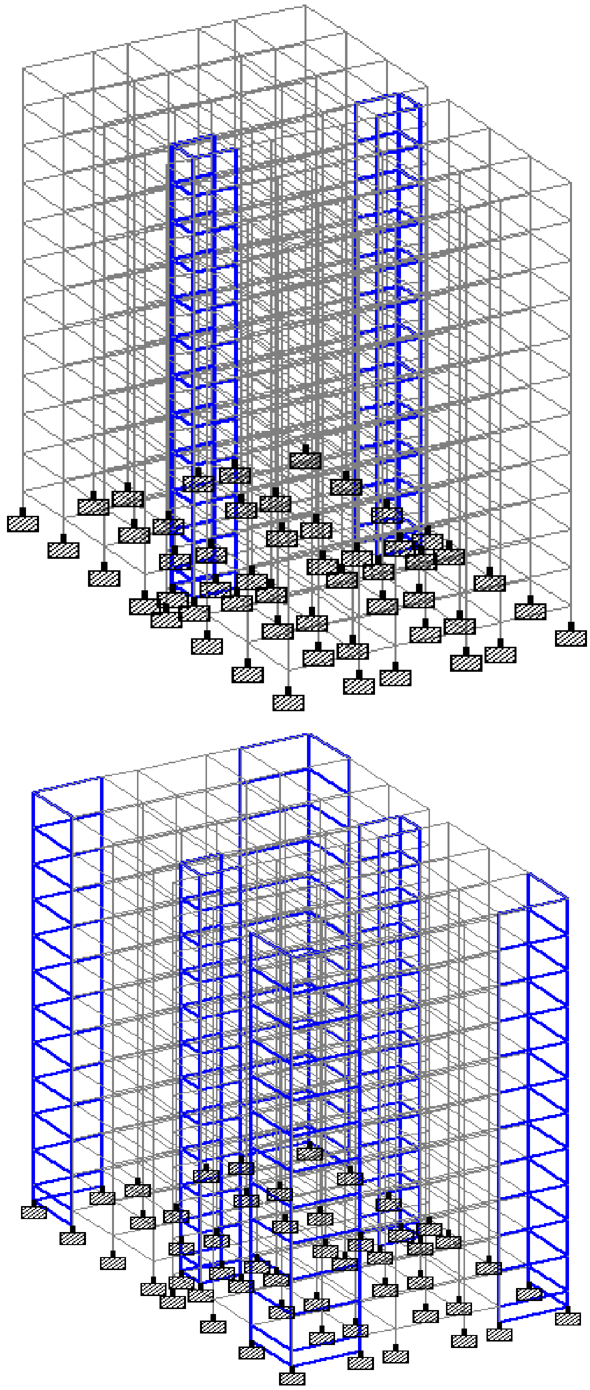


Fig. 2: Along slope orientation on sloping ground

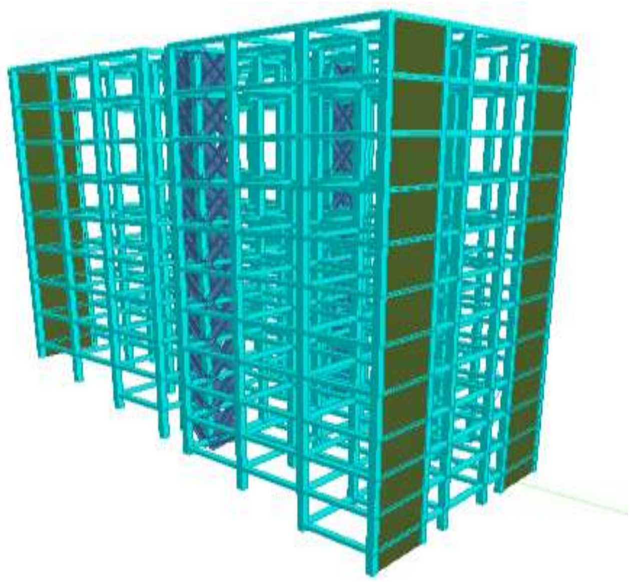


Model M-1 **Model M-2/3**

Fig. 3: (a) Building on flat ground with lift shear wall, (b) Building on flat ground with lift shear wall plus shear wall at corners.

The formation of short columns is evident as the building is stepping back along the slope, while the height of first three columns along the slope is utilized to formation of floors as the beams here act as tie beams and can help in strengthening of these columns along the slope.

The RC buildings taken into consideration are designed for seismic zone-V (seismic zone of parts of J&K and Himachal Pradesh) as per IS-1893 (part 1): 2002. For facilitating the comparison of the dynamic response of these models, the beam and column sizes are taken constant throughout as 350x350 and 450x450. The properties of shear wall and bracings is taken as 230mm and I-824 of class B respectively. The rigid diaphragm constraints have been used for providing the in-plane rigidity to the floor slabs. The foundations of all the models has been considered fixed at a depth of 1.5m, considering the nature of soil as medium.



Model M-4/5/6

Fig. 3: Building on sloping ground with lift bracings plus bracings at corners.

A. Analytical Characteristic Behavior

The fundamental periods and the frequency of models on plane and sloping ground for the first three modes are mentioned in the tables below. It can be observed that the fundamental time period for models M-1 and M-4 are quite similar. The fundamental period for fundamental mode of model M-5 slightly higher than model M-2, while it is vice versa for model M-3 and M-6 where M-3 has slightly higher fundamental period to that of model M-6. The building on flat ground is vulnerable to less frequency compared to that of building on sloping ground as depicted by the graph below. It is concluded that the shear wall increases the frequency of building on flat ground while as it is reduced in case of bracings provided to building on flat ground. However frequency of building on sloping ground is increased by bracings compared to that of shear wall.

Table-1: Fundamental Time Period and Frequency for modes

Mode	Model M-1		Model M-2		Model M-3	
	T (Sec)	ν (Hz)	T (Sec)	ν (Hz)	T (Sec)	ν (Hz)
1	2.739	0.365	1.819	0.550	2.066	0.484
2	2.727	0.367	1.713	0.584	1.839	0.544
3	2.482	0.403	1.154	0.866	1.322	0.757

The frequency of model M-1 also increases by providing bracings by 14.02% in the fundamental mode of model M-3. The frequency of model M-4 on sloping ground increases by 8.18% in the fundamental mode as that of model M-1 on flat ground. The frequency of model M-5 with shear walls on sloping ground decreases by 11.68% in the fundamental mode as that of model M-2 with shear walls on flat ground.

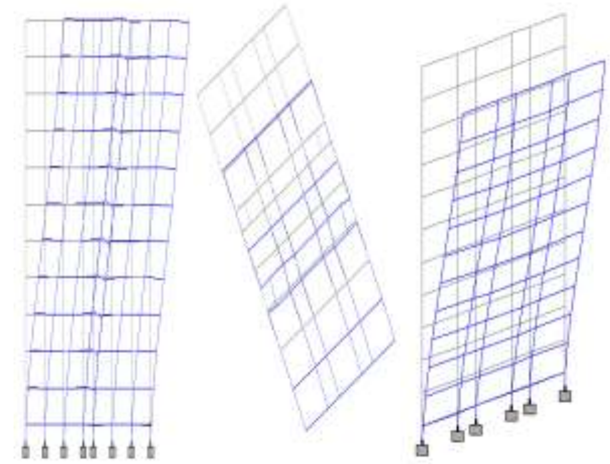
The frequency of model M-6 on sloping ground with bracings increases by 11.68% in the fundamental mode as that of model M-3 with bracings on flat ground.

Table-2: Fundamental Time Period and Frequency for modes

Mode	Model M-4		Model M-5		Model M-6	
	T (Sec)	ν (Hz)	T (Sec)	ν (Hz)	T (Sec)	ν (Hz)
1	2.324	0.430	2.296	0.435	1.634	0.612
2	2.273	0.440	1.569	0.637	1.543	0.648
3	2.031	0.492	1.259	0.794	1.082	0.925

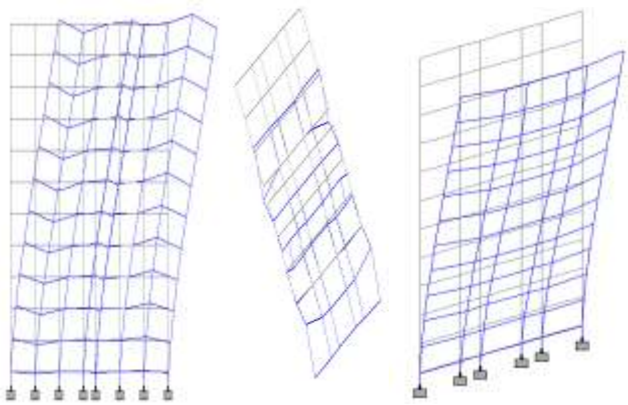
B. Dynamic Response Characteristics

The fundamental mode shapes of models M-1, M-2, M-3, M-4, M-5, and M-6 are represented by figure in both directions i.e. Along Slope orientation and Cross Slope orientation. The modal participation of M-1 for fundamental mode is 69.427% along Z, while as the Modal participation of M-4 for fundamental mode is 13.851% along X. In case of M-2 Modal participation for fundamental mode is 65.703% along Z, while as it is 64.927% along Z direction for M-5. The Modal Participation for fundamental Mode for M-3 is 65.142% along Z, while as that of M-6 is 64.175% along Z and 0.001% along Y direction. This concludes that Modal participation of M-4 model on sloping ground is 55.576% is less compared to that of model M-1 on flat ground because of the RC frame configuration irregularity and higher stiffness of model M-4 on sloping ground provided by varying height of columns along the slope in each floor. However it is evident that this difference is quite lesser in case of models strengthened by lateral force resisting systems i.e. (M-2 & M-5) and (M-3 & M-6) and is almost the same participation. It is observed that there is pure translational movement in fundamental modes along slope orientation of models while as in cross slope orientation, the movement of frame can be witnessed to be coupled with torsion effects.



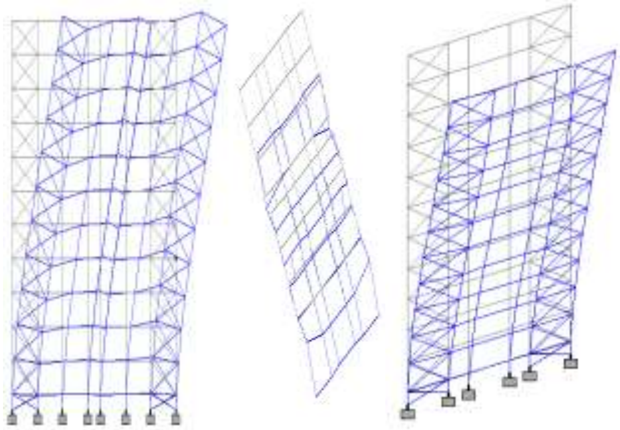
(a) (b)

Fig. 4: Fundamental mode shapes of model M-1: (a) Along Slope orientation (b) Cross Slope orientation.



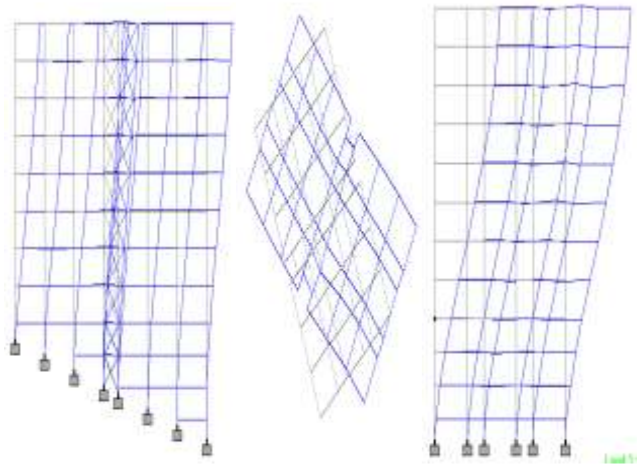
(a) (b)

Fig. 5: Fundamental mode shapes of model M-2: (a) Along Slope orientation (b) Cross Slope orientation.



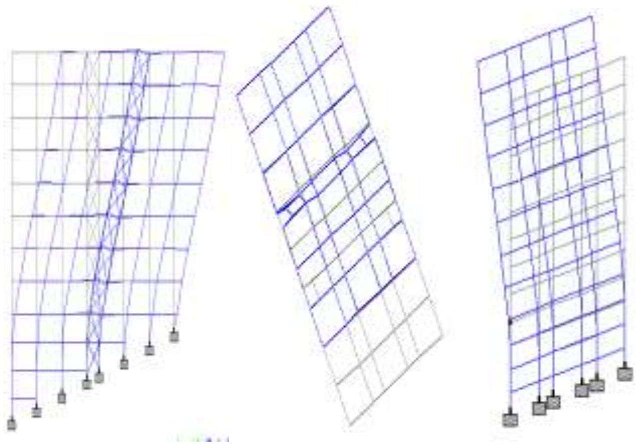
(a) (b)

Fig. 6: Fundamental mode shapes of model M-3: (a) Along Slope orientation (b) Cross Slope orientation.



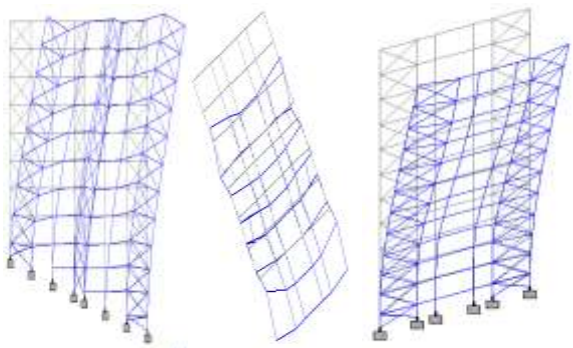
(a) (b)

Fig. 7: Fundamental mode shapes of model M-4: (a) Along Slope orientation (b) Cross Slope orientation.



(a) (b)

Fig. 8: Fundamental mode shapes of model M-5: (a) Along Slope orientation (b) Cross Slope orientation.



(a) (b)

Fig. 9: Fundamental mode shapes of model M-6: (a) Along Slope orientation (b) Cross Slope orientation.

The deformation configuration of the buildings on plane and sloping ground is represented by the different modes in along slope orientation and cross slope orientation vis a vis the respective excitation consideration. It has been observed by simulation that there is less significant deformation of structural frame on sloping ground compared to that of building on plane ground due to the presence of short columns along the variation of height, which tend to increase the rigidity and stiffness to the structure on sloping ground. It has been observed that the shear on columns of building on sloping ground is comparatively less apparent to that of the columns of building on plane ground. The less apparent shear on columns of building on sloping ground is because the short columns tend to resist the shear forces to a larger extent compared to the columns of building on plane ground. The mode shape observation shows that the deformation pattern of the building on sloping ground is different with respect to the deformation pattern shown by the regular building on flat ground. The linear dynamic analytical study further indicates the varying shear stress induced in the columns of higher and lower storeys of building on sloping ground, where it is seen lower shear stress is induced to the lower most columns as compared to the upper columns due to the presence of short columns of building on sloping ground.

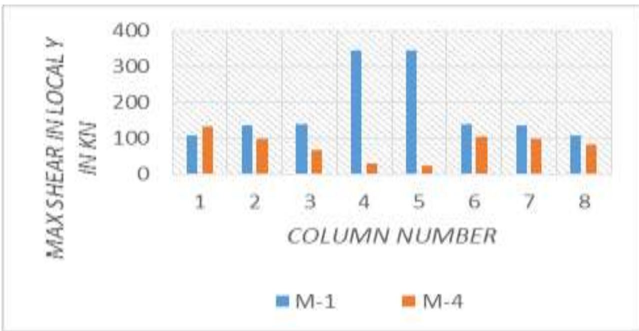
III. SHEAR MAXIMUM IN LOCAL Y

Table-3: Maximum shear in columns in local y.

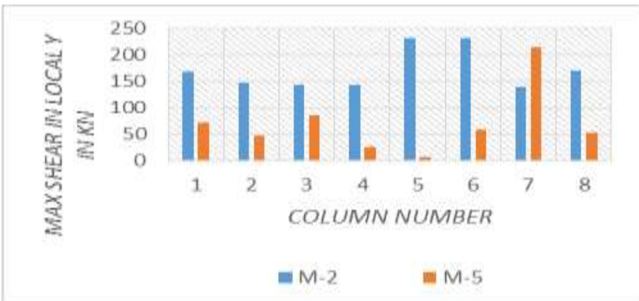
MODELS	Maximum Shear in Local Y in KN							
	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8
M-1	108.35	137.92	140.21	345.80	345.80	140.19	137.91	108.35
M-2	[illegible]	[illegible]	142.81	142.81	233.32	233.32	[illegible]	[illegible]
M-3	[illegible]	[illegible]	130.39	196.70	196.90	130.10	[illegible]	[illegible]
M-4	134.84	99.075	68.800	30.387	25.001	105.64	100.08	85.002
M-5	72.881	46.816	85.689	25.461	6.264	59.010	215.40	53.231
M-6	75.447	44.729	47.177	25.516	19.418	84.525	67.910	64.969

Note: Green representation of column shear values are safe for design consideration while as the shear values in red representation implies that these columns suffered non ductile shear failure to the design consideration. Column representation C-1 is the extreme left column to C-8 being the last column on extreme right on side view of all models.

It can be observed that the shear in column C-1 in model M-4 on sloping ground is 10.89% higher as that of shear in the same column in model M-1 on plane ground. However it is observed that the column shear in columns C-2, C-3, C-4, C-5, C-6, C-7 and C-8 in model M-4 on sloping ground decreases by 16.39%, 34.17%, 83.85%, 86.52%, 14.05%, 15.61% and 12.08% as that of shear in the same columns in model M-1 on plane ground. the shear in columns in model M-5 on sloping ground C-1, C-2, C-3, C-4, C-5, C-6 and C-8 decreases by 39.89%,52.02%, 24.99%, 69.74%, 94.77%, 59.63% and 58.48% respectively as that of model M-2 on plane ground. However it can be observed that the shear in column C-7 in the model M-5 increases by 21.09% as that of model M-2.It is clear from the graphical representation below that the shear in columns C-1 to C-8 in model M-6 on sloping ground strengthened by bracings decreases by 45.83%, 42.68%, 46.92%, 77.04%, 82.05%, 21.24%, 24.48% and 51.54% as that of model M-3 on plane ground strengthened by the same strengthening system.



Graph 4.6: Maximum Shear in columns in Local Y for models on plane ground and sloping ground.



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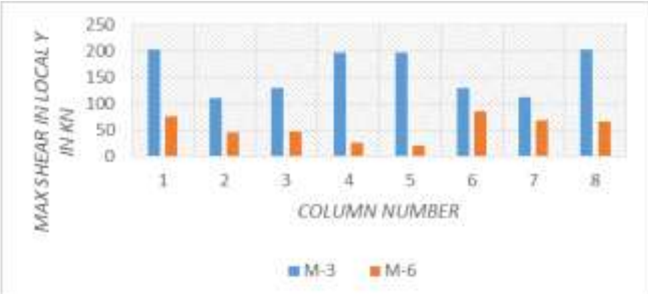
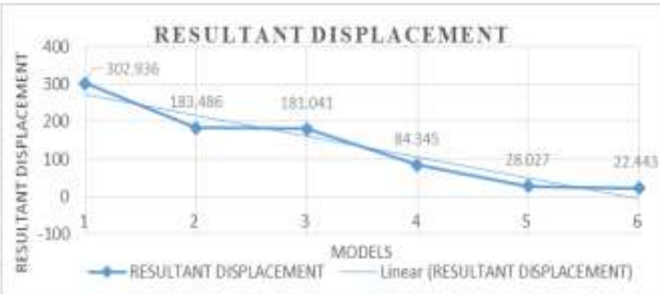


Graph 4.6: Maximum Shear in columns in Local Y for models on plane ground and sloping ground.

IV. RESULTANT DISPLACEMENT



Graph: Comparison for Maximum Resultant Displacement.

From the graph, it is clear that model M-6 with bracings on sloping ground depicts minimum resultant displacement as that of all the other 5 models on plane and sloping ground.

This least resultant displacement can be attributed to the stiffness of the building provided by unequal height of basement columns on each floor to the step back building and by its irregular configuration.

Model M-1 on plane ground is observed to be vulnerable to the maximum resultant displacement with an increase in resultant displacement by 86.20% as compared to that of model M-6 on sloping ground strengthened by bracings. The resultant displacement of model M-2 with shear wall on flat ground reduces sharply by 24.06% as that of model M-1 on flat ground. The resultant displacement of model M-5 with shear wall on sloping ground reduces sharply by 50% as that of model M-4 on sloping ground. The resultant displacement of model M-6 with bracings on sloping ground reduces by 11.06% as that of model M-5 with shear wall on sloping ground and hence the bracings reduce the resultant displacement by 61.06% as that of model M-4.The resultant displacement of model M-4 on sloping ground is 56.44% less as that of model M-1 on flat ground. The resultant displacement of model M-5 with shear wall on sloping ground is 73.49% less as that of model M-2 with shear wall on flat ground. The resultant displacement of model M-6 with bracings on sloping ground is 77.94% less compared to that of model M-3 with same strengthening system on flat ground.

V. RESULT AND DISCUSSION

The building on flat ground is vulnerable to less frequency compared to that of building on sloping ground as explored through the dynamic analysis and formation of mode shapes. It is concluded that the shear wall increases the frequency of building on flat ground while as it is reduced in case of bracings provided to building on flat ground. However frequency of building on sloping ground is increased by bracings compared to that of shear wall. It is observed that the storey drift of each storey of models on plane ground is higher as compared to the storey drift experienced by the storeys of models on sloping ground. The lesser storey drift of models on sloping ground is due to its higher stiffness of floors generated by the unequal height of columns on the same floor and irregular orientation of building on sloping ground. It is seen that the storey drift reduces after providing the lateral force resisting systems to buildings on plane ground. The shear wall has reduced the storey drift more than that reduced by providing bracings but the resultant reduction in the drift is close in both the cases. It can be observed that bracings in case of building on sloping ground is more effective in reducing the storey drift as compared to that of shear wall in the building on plane ground. It is observed that a building strengthened with bracings on sloping ground depicts minimum resultant displacement as that of all the other 5 buildings on plane and sloping ground. This least resultant displacement can be attributed to the stiffness of the building provided by unequal height of basement columns on each floor to the step back building and by its irregular configuration.

VI. CONCLUSION

Past Earthquakes have depicted unusual failure patterns of buildings on sloping ground to various linear and nonlinear dynamic excitation. The response to dynamic excitation of building on sloping ground varies sufficiently as compared to the building on flat ground. The buildings on sloping ground experience sufficiently high torsion moments when subjected to excitation in cross slope orientation. The similar building on sloping ground experience lesser torsional moments when subjected to dynamic excitation in along slope orientation, due to the linearly varying stiffness of short columns along slope orientation. The short columns along slope orientation resist most of the shear stresses to a larger extent, where the high rigid nature of columns remains a concern for failure without buckling which is mitigated by using the lateral force resisting systems and following the ductile detailing for its transverse and longitudinal reinforcement.The linear dynamic analytical study further indicates the varying shear stress induced in the columns of higher and lower storeys of building on sloping ground, where it is seen lower shear stress is induced in the lower most columns as compared to the upper columns due to the presence of short columns of building on sloping ground. It is observed that the story drift of each storey of models on plane ground is higher as compared to the storey drift experienced by the storeys of models on sloping ground. The lesser storey drift of models on sloping ground is due to its higher stiffness of floors generated by the unequal height of columns on the same floor and irregular orientation of building on sloping ground.

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