TORSIONAL BEHAVIOUR OF HILL SLOPE BUILDINGS: A CASE STUDY ON DIFFERENT PLAN ASPECT RATIOS AND SLOPE ANGLES

by

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TORSIONAL BEHAVIOUR OF HILL SLOPE BUILDINGS: A CASE STUDY ON DIFFERENT PLAN ASPECT RATIOS AND SLOPE ANGLES

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Abstract

Buildings on hill slopes are highly vulnerable due to its less resistive lateral load capacity. This type of buildings are unsymmetrical and are of in irregular configuration. There are variations in the column height which gives eccentricity to the structure as the center of mass and center of rigidity doesn't coincide. This irregularity leads to its torsional behavior and gives us the necessity for analyzing these buildings for its base conditions and its behavior by changing its plan configuration.

This paper contain the calculation of Twist which is an effective parameter to decide the behavior of the building, Axial forces on the members that can lead to collapse in the structure and about the twist variation with change in the aspect ratio so that we can know the suitability of the configuration of the building. The building on hill slopes does not behave similar to the buildings which are on plane ground. Change in the Aspect ratio means changing the length of the building in ridge direction. Changing the length in valley direction will disturb the load path of gravity load for each and every change in the structure and after some increment of the length in valley direction will fail the structure for its gravity load path. So we can't play with the length of the building along the valley direction but changing the length along ridge direction does not effect that much to the load path of gravity load and we can obtain a best aspect ratio of the structure for that region.

Keywords: Twist, Axial forces, Slope of the ground

1. Introduction

Bare RC Frame Building are not suitable on hill slopes due its high torsional properties like twist of the floor and base reactions of the floor These torsional properties can be decreased by using walls and bracings. Frames of building on slopes do not take the applied load uniformly. The shorter frames take the larger load and the longer frames takes a negligible amount of load with respect to shorter frame. which make us curious to study these load distribution pattern by increasing the number of bays of the building. The number of bays is increased in the ridge direction so that the gravity load distribution path doesn't change and all the building should take its own self-weight. The figure shown below is the normal or initial building considered for the analysis. The first figure shows (i)-side view (valley direction), (ii)-side view (ridge direction) (iii) plan view of both the case with wall and without walls.

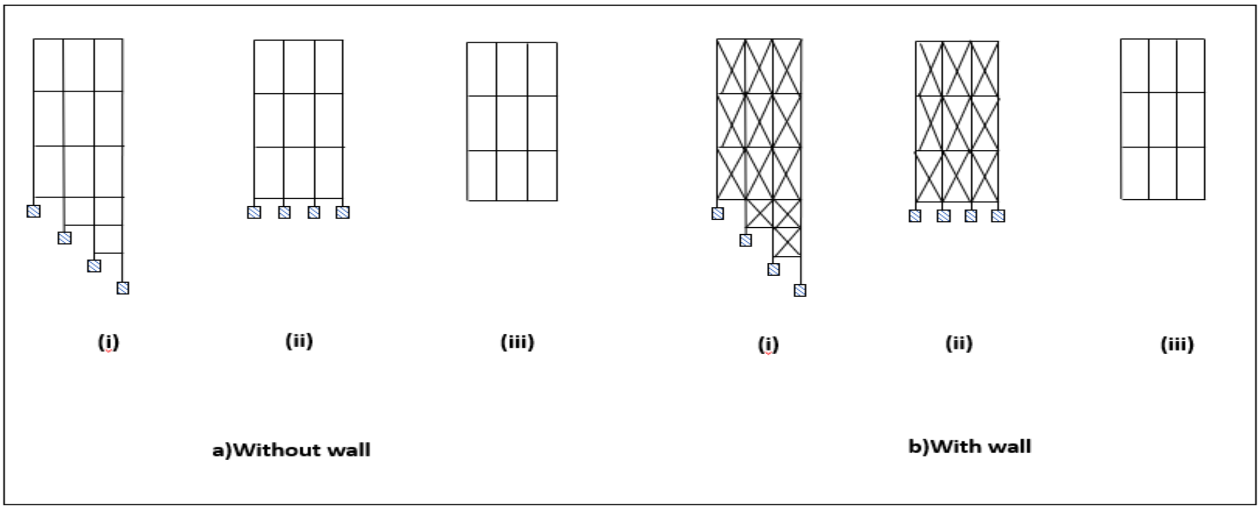

Fig.1- building diagram with wall case and without wall case

The objective of this study is to provide a best aspect ratio for the building on a particular slope with one edge of the plan is fixed i.e. in this paper 3 bays are fixed in valley direction.

There is a high axial force on the hilly buildings in the ground floor beams of frame perpendicular to the direction of applied load under the lateral load action applied along the ridge direction (non-slope direction). This axial force also decreases with use of bracings and walls. Due to eccentricity in the floors of hilly buildings the floor rotates about its center of rigidity. These rotations are more in bare frame RC building and less in the Building with walls and bracing as this component resist both translational and rotational motion of the hilly building.

The stiffness of the frames increases as the number of bays increases, So which means the translational motion must be effected and this further effects the Twist of the structure and which further effects the axial force on the beam of the ground floor. Changing the stiffness of the frame changes the center of rigidity. The rotation of the floor depends on center of rigidity and center of mass of the floor i.e. eccentricity. So to minimize this eccentricity and to stable the structure we need to play with the eccentricity of the structure.

Twist of floor causes distortion in the member of the buildings as their will be both compression and tension will take place on the ground floor and will affect the base reaction due to this compression and tension force and will generate the axial force in the ground floor of the beam. This paper includes the effect on these parameter's twist, axial force and load distribution when the building is under the action of time history lateral force.

2.Methodology and Analysis

We will consider three slope angles 15, 30, 45 degree for the analysis of load distribution and Twist of the top floor and axial forces on the ground floor beam and will increase the number of bays in the ridge direction considering number of bays as 3,4,5,6,7,8,9,10,13 while a constant number of bays i.e. 3 in the valley direction.

In the first case we will observe the buildings without wall and without bracing and note the behavior of twist , axial force and load distribution among the frames with the increase in the number of bays and in the second case we will observe all the buildings with walls and will make the comparison between these wall buildings and bare frame building and will note the effect of the walls on the buildings on slopes with increase number of bays.

The twist calculation is done manually using diagonal vector. For finding the rotation two vectors are taken, First vector is the opposite corner points of the floor of the building in its initial state and second is same two opposite corner points of the floor after the deformation (maximum displacement because of earthquake).

The lateral load consider for the analysis of these structure is Chamoli which is normalized to 1g with frequency 50Hz as shown in the **figure below**.

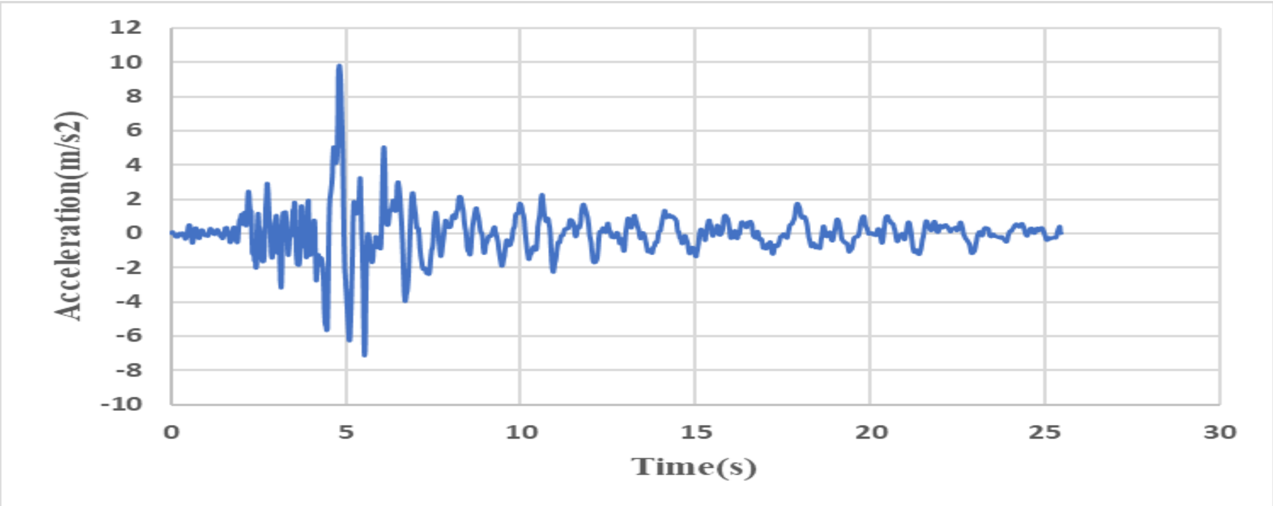

Fig.2- Chamoli earthquake normalized to 1g

3. Observation

The Load distribution percentage among the frames as shown in the table is calculated by the ratio of total base reaction taken by one frame by the total base reaction in the same direction i.e. ridge direction. By increasing the number of bays in ridge direction we haven't find a significant difference in the load difference pattern of one particular angle in both case with wall and without wall. The negative sign in the table indicates the opposite direction of base reaction which favor's the lateral loads

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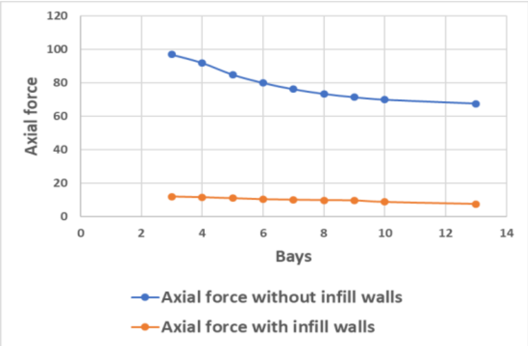
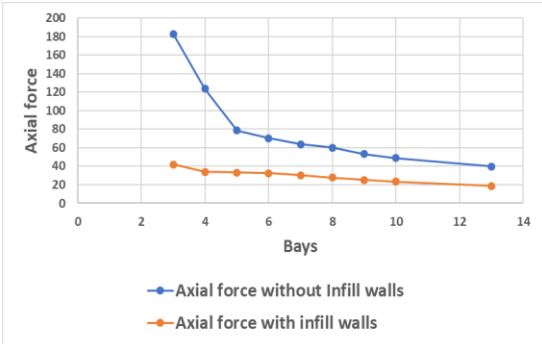
Table 1 – load distribution among individual frames (%)

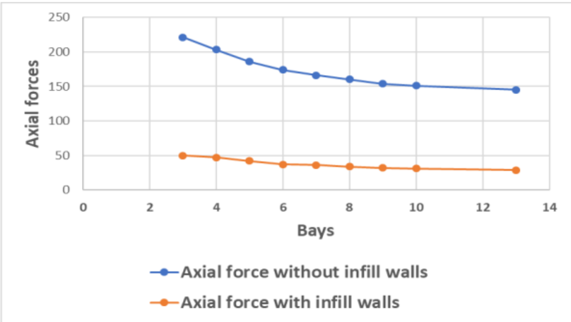
Slope angle (degree)	Conditions	Frames	Number of Bays in ridge direction								
			3	4	5	6	7	8	9	10	13
15	Without walls	A	-1.21	-0.98	-1.08	-0.87	-0.84	-0.88	-0.78	-0.75	-0.69
		B	3.25	1.97	1.53	1.08	1.02	1.01	0.80	0.99	1.06
		C	19.33	16.76	19.06	16.06	16.16	16.44	16.50	16.61	16.93
		D	78.62	82.24	80.48	83.74	83.67	83.43	83.48	83.15	82.71
	With walls	A	14.50	14.26	13.67	13.74	14.35	13.77	13.57	13.53	13.39
		B	23.08	22.84	22.36	22.64	23.69	22.77	22.62	22.53	22.37
		C	29.81	29.74	30.87	29.87	31.09	29.86	29.88	29.86	29.83
		D	32.61	33.17	33.10	33.75	30.87	33.61	33.94	34.08	34.40
30	Without walls	A	0.21	-0.25	0.09	0.04	0.02	0.00	0.00	-0.02	-0.07
		B	0.93	1.57	1.61	-1.79	-1.72	-1.64	-1.64	-1.60	-1.52
		C	9.03	8.76	4.87	-7.01	-7.84	-8.60	-8.96	-9.25	-9.77
		D	89.84	89.93	93.43	108.76	109.55	110.24	110.60	110.87	111.36
	With walls	A	13.23	12.26	14.03	13.58	13.25	13.20	12.96	12.78	12.80
		B	22.01	21.21	21.13	20.62	20.19	20.16	19.93	19.90	19.67
		C	29.41	31.08	27.25	27.32	27.20	27.51	27.63	27.72	27.67
		D	35.35	35.44	37.59	38.48	39.36	39.13	39.48	39.61	39.87
45	Without walls	A	-0.30	-0.08	-0.08	-0.06	-0.06	-0.05	-0.05	-0.06	0.06
		B	1.09	-0.56	0.04	-0.29	-0.09	-0.09	-0.07	0.01	0.13
		C	-4.11	-6.39	-6.64	-6.62	-7.16	-6.56	-6.47	-6.39	-6.18
		D	103.33	107.03	106.68	106.97	107.30	106.70	106.59	106.44	106.00
	With walls	A	3.49	4.05	4.37	4.80	5.00	4.99	4.96	5.02	5.22
		B	15.10	15.37	15.62	15.98	16.13	16.18	16.09	16.02	16.10
		C	30.86	30.78	30.64	30.63	30.54	30.56	30.62	30.54	30.42
		D	50.55	49.80	49.38	48.59	48.33	48.27	48.32	48.42	48.26



(i)15°

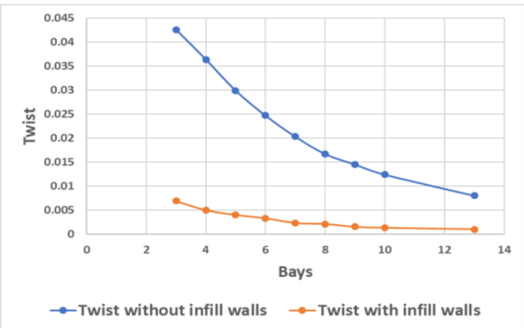


(ii) 30°

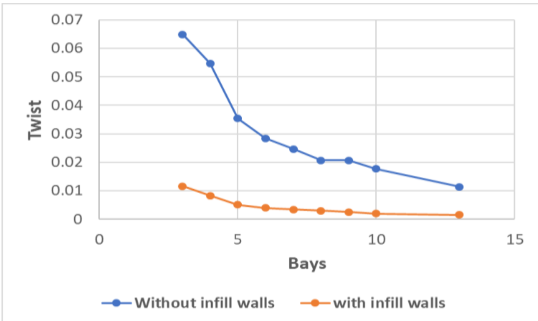


(iii) 45°

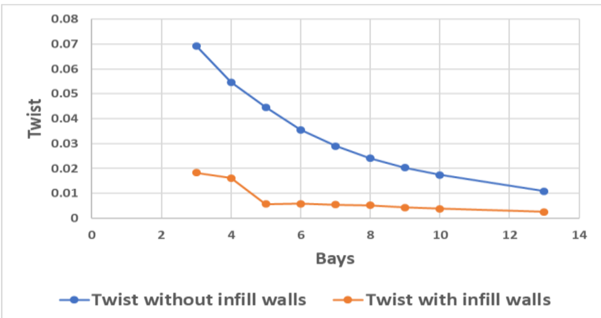
Fig. 3- Axial force on the ground floor beam



(i)15°



(ii)30°



(iii)45°

Fig. 4- Twist behavior with and without walls

Table 2 – Axial force and Twist relationship with increase in slope without wall case

Number of bays	Slope of ground(degree)					
	15		30		45	
	Axial force (KN)	Twist (degree)	Axial Force (KN)	Twist (degree)	Axial force (KN)	Twist (degree)
3	97	0.0426	183.00	0.0649	221	0.0693
4	92	0.0364	123.45	0.0547	203	0.0547
5	85	0.0299	78.73	0.0354	186	0.0446
6	80	0.0247	70.21	0.0284	174	0.0355
7	76.2	0.0203	63.71	0.0247	166.25	0.029
8	73.41	0.0167	60.10	0.0207	160	0.0241
9	71.4	0.0145	53.19	0.0207	154	0.0203
10	69.95	0.0124	48.65	0.0177	151	0.0174
13	67.61	0.008	39.59	0.0114	145	0.0109

Table 3 – Axial force and Twist relationship with increase in slope with wall case

Number of bays	Slope of ground(degree)					
	15		30		45	
	Axial force (KN)	Twist (degree)	Axial Force (KN)	Twist (degree)	Axial force (KN)	Twist (degree)
3	11.96	0.0069	42.00	0.0116	50	0.0183
4	11.56	0.005	33.92	0.0083	47.3	0.0162
5	10.99	0.004	33.23	0.0051	42	0.0057
6	10.39	0.0033	32.31	0.004	37	0.0058
7	10.10	0.0023	30.37	0.0034	36	0.0055
8	9.86	0.0021	27.78	0.003	34	0.0052
9	9.70	0.0015	25.20	0.0026	32	0.0043
10	8.80	0.0013	23.26	0.002	31	0.0038
13	7.60	0.001	18.74	0.0016	29	0.0026

We can see that as we increase the slopes the load demand on the shorter frame increases i.e. the demand for the slope 15 degree for without wall case is in the range 75-85 for 30° 90-110 for 45° 100-110, with wall case it is in the range of 30-35 for 15° ,35-40 for 30° and 45 to 50 for 45°. So aspect ratio does not effect the load distribution among the frames but helps in reducing the twist and axial force value as shown in the figure 3 or figure 4

From figure 3 and 4 exponential variation can be seen of these Twist and axial force parameter's for cases with wall and without wall but the gradient of the both the curves changed drastically. The gradient for without wall condition is much more than that of gradient of wall case. The twist and axial force in the graph cannot be zero so their will be a constant twist and axial force after a long time i.e large number of bays. In non-wall and non-braced case after seeing the graph 4 we can say that the twist will be constant after 15 number of bays which is difficult for construction in a limited space and for the wall case it is coming to be for 6 number of bays. For graph 3 axial force is reducing exponentially but the steady state value of the non-wall case is much more than wall case. Using of walls and bracings drastically decreased the value of axial force on the ground floor beam that can be easily seen from the graphs and tables.

From table 2 and table 3 also we can observe the behavior of axial force on the ground floor beam and twist and how these two parameters are related. As the twist will decrease of the structure the value of stress and strain in the components of the building will decrease which will decrease the axial force in the ground floor beam. Axial force and twist also increase with the increase in the slope of the ground.

In all the graph of the figure 3 and figure 4 we can see that with wall and braced building behave much better than bare frame building and for number of bays more than 6 it behaves quite impressive with less value of twist, low axial force and with the proper load distribution among frames.

4. Conclusion

After the analysis of these structures on hill slopes we are able to conclude to propose that the plan aspect ratio for the sloppy region with a constant 3 number of bays along valley direction must be more than 2 with fully walled or braced i.e. minimum 6 number of bays in ridge direction. The graph's and table's shows that the graph line of axial force and Twist is becoming almost straight for the structure whose number of bays is more than and equal to 6. The building can't be bare frame but if it is so we need to consider to minimization of this higher risk for the construction of such buildings with larger twist and larger axial force on the ground floor beam based on the requirements. This paper is done for only 3 bays in the valley direction but in future it can be done for many more and can create a dataset of these parameters and can propose the best aspect ratio by a formula.

We need to try to maintain the load distribution among the frames that can be only done with the help of bracings and walls. Without walls and bracings, the structure has high chances of collapse it can't be done by increasing the aspect ratio or increasing the number of bays as we can see in the table 1 of load distribution among frames. The main observation and conclusion are that hill slope buildings are on higher risk than plain ground building but with the help of walls and bracings and using proper configuration we can minimize the risk of lateral forces in such areas though we can't fully make these structure's behave like plain ground building.

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