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NUMERICAL INVESTIGATION ON SEISMIC PERFORMANCE OF RC FRAME IN SLOPED GROUND

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Abstract

Due to scarcity of plain ground rapid construction is taking place in hilly areas i.e., on sloping ground. Earthquake is such an unpredictable calamity that it is very necessary for survival to ensure the strength of the structure against seismic forces. Therefore there is continuous research work is going on around the globe, revolving around development of new and better techniques that can be incorporated in structures for better seismic performance. Obviously, buildings designed with special techniques to resist damages during seismic activity have much higher cost of construction than normal buildings, but for safety against failures under seismic forces it is a prerequisite. RCC structures are considered in seismic areas that may be main targets of seismic activities. Due to such conditions now a days there is a heavy demand of earthquake resisting RCC structural design. Not only seismic activities but also due to accidental failures, structure can fail. To analyse RCC structure for earthquake zone, we have to make model using ETABS software which can resist all types of loading such as dead load, live load, seismic load using IS 1893. In this study (G+5), (G+10) and (G+15) storey structures will be analysed by using Equivalent dynamic Response spectrum method used. This structure placed onPlain ground as well as on sloping ground of 10^0, 20^0, 30^0. After analysing models in ETABS the results for Storey displacement, Base shear, Storey drift, Time period and Modal participating factors are then obtained. After observing this result some conclusions are made.

Keywords: Sloped ground, Response spectrum method, Base shear, Storey drift.

1. INTRODUCTION

Throughout the course of history, earthquakes have remained a constant and perilous threat to human civilization, inflicting devastating consequences on lives, property, and man-made structures. A recent earthquake in Nepal, our neighboring country, served as a harsh reminder of nature's immense power, resulting in widespread destruction and profound impacts on the nation and its people.

During an earthquake, the ground undergoes unpredictable movements, radiating in all directions from the epicenter. Although vertical ground motions are rare, horizontal shaking consistently accompanies seismic events. This ground vibration sets structures in motion, giving rise to inertial forces within the buildings. As the earthquake changes direction, it can because stress reversals in structural components, converting tension into compression and vice versa. The substantial stresses generated during earthquakes can cause structures to yield and deform significantly, rendering them unusable and hazardous for habitation. Furthermore, substantial storey drift in buildings further jeopardizes the safety of occupants, necessitating their urgent evacuation from such precarious structures.

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1.1 Seismic Performance of Structure

The seismic performance of a structure pertains to its capacity to withstand and respond effectively to the forces and ground movements induced by seismic events, particularly earthquakes. It encompasses the structural integrity, resilience, and ability to absorb and dissipate seismic energy without experiencing catastrophic failure or compromising the safety of occupants. A structure with good seismic performance can effectively resist lateral forces and ground shaking, maintaining its stability and functionality during and after an earthquake. A structure may be considered serviceable if is able to fulfil its operational function for which it was designed.

1.2 Objectives

The main objective is to study response of RCC structure is against seismic load in analysis. For this analysis we have considered the structure is in different sloping ground and Consider 5, 10, 15 storey RCC structure in analysis for all types of load combinations. Using IS 1893:2002 we again analyzed same structure and find performance of structure against seismic analysis. Here we have considered linear dynamic analysis and to check performance of structure Base shear, Mode shape, Storey displacement, Storey drift and bending moment are consider and checked the structural performance on sloping ground.

2. LITERATURE REVIEW

B.G. Birajdar, S.S. Nalawade (2004), "Seismic analysis of buildings resting on sloping ground" In brief it is found that: The performance of STEP back building during seismic excitation could prove more vulnerable than other configurations of buildings. The development of torsional moments in Step back buildings is more than that within the Step back set back buildings. Hence, Step back Set back buildings are found to be less vulnerable than Step back building against seismic ground motion.

Sujit Kumar, Dr. Vivek Garg, Dr. Abhay Sharma (2014), "Effect of sloping ground on structural performance of RCC building under seismic load" The analysis is carried out to evaluate the effect of sloping ground on structural forces. 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. Thus, the section of those columns ought to be designed for changed forces thanks to the impact of sloping ground. The present study emphasizes the necessity for correct coming up with of structure resting on sloping ground.

Deepak Suthar, H.S.Chore, P.A. Dode (2014), "High rise structures subjected to seismic forces and its behaviour" The behaviour of high rise structure for both the scheme is studied in present paper. In this paper we got the results from mathematical model for model I and model II. The graph clearly shows the story drift, lateral displacement and time period is more in model I as compared to model II. It is also observed that the results are more conservative in Static analysis as compared to the dynamic method resulting uneconomical structure.

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K. Venkatesh, A. L. Neeharika (2016), "Static linear and nonlinear analysis of RC buildings on varying hill slopes" Seismic loads were considered acting along either of the two principal directions. Using ETABS a 4, 5 storey RC structure with typical ground slope is chosen in between 0° and 25°and building that which produce less torsion effect for set-back and step-back with irregular configuration in horizontal and vertical direction is modelled and analyzed.

3. METHODS

Seismic analysis is performed on the basis on behaviour of the structure, material of structure, type of structure, external action and the type of selected structural model. Depending on the type of behaviour of external action the analysis can be divided into 3 types. Our main objective is to analyze seismic performance of RCC structure on sloping ground by equivalent static analysis.

3.1 Equivalent Static Analysis

The equivalent static lateral force methodology could be a simplified technique to substitute the impact of dynamic loading of associate expected earthquake by a static force distributed laterally on a structure for design purposes. The total applied unstable force base shear is mostly evaluated in 2 horizontal directions parallel to the most axes of the building. It assumes that the building responds in its basic lateral mode.

3.2 Response Spectrum Method

Response spectra unit of activity terribly helpful tools of earthquake engineering for analyzing the performance of structures and instrumentality in earthquakes, since many behave principally as simple oscillators (also known as single degree of freedom systems). Thus, if you'll be able to verify the natural frequency of the structure, then the peak response of the building can be estimated by reading the value from the ground response spectrum for the appropriate frequency.

3.3 Time History Method

Time history analysis is the study of the dynamic response of the structure at every addition of time, when its base is exposed to a particular ground motion. Static techniques area unit applicable once higher mode effects don't seem to be vital. This is for the foremost half valid for brief, regular structures. Thus, for tall structures, structures with torsion asymmetries, or no orthogonal frameworks, a dynamic method is needed. In linear dynamic method, the structure is modelled as a multi degree of freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix.

3.4 Software of Analysis

ETABS is an acronym that stands for Extended Three Dimensional Analysis of Building Systems. The primary goal of this software is to design multi-story buildings in a systematic manner. The successful design and construction of earthquake-resistant structures is critical all over the world. So it is very useful for seismic performance of RC frame with earthquake loads. The main use of this software is to

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- Create and modify a model.
- Execute the analysis.
- Design a model as well as optimize the design.
- It displays results in graphical forms and also display real time- history displacements and generates reports.

3.5 Modelling And Parameters Considered For Analysis.

Various scenarios have been established to investigate the seismic response of a reinforced concrete (RCC) structure. The study involves the design and analysis of a typical RCC building, considering factors like dead load, live load, wind load, and earthquake load. The building's layout consists of 5 bays in both the X and Y axes, each spanning 3 meters from one column to another.

- Seismic zone, Z (IS 1893: 2002, clause 6.4.2, table 2)
- Response reduction factor, R (IS 1893: 2002, clause 6.4.2, table 7)
- Importance factor, I (IS 1893: 2002, clause 6.4.2, table 6)
- Soil type (IS 1893: 2002, clause 6.4.5, page 16)

Table 1: Model Details for RCC Structure

Parameters	Modelling Details		
No. of storey	G+5	G+10	G+15
Height of the building	18 m	33 m	48 m
Each storey height	3 m	3 m	3 m
Soil condition	Medium	Medium	Medium
Response reduction factor	5	5	5
Importance factor	1	1	1
Zone	3	3	3
Thickness of slab	200 mm	200 mm	200 mm
Live load	4 KN/m^2	4 KN/m^2	4 KN/m^2
Floor finish	1.5 KN/m^2	1.5 KN/m^2	1.5 KN/m^2
Grade of concrete	M30	M30	M30
Beam size	230×450 mm	230×450 mm	230×450 mm
Column size	300×600 mm	300×600 mm	300×600 mm

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4. RESULTS AND ANALYSIS

4.1 Mode Period

Table 2: Mode Period for Plain Ground

Mode	Mode Period For Stories		
	For Storey 5	For Storey 10	For Storey 15
	0.58	1.084	1.613
2	0.58	1.084	1.613
3	0.523	0.968	1.416
4	0.187	0.355	0.53
5	0.187	0.355	0.53
6	0.169	0.318	0.468
7	0.106	0.205	0.306
8	0.106	0.205	0.306
9	0.096	0.186	0.276
10	0.073	0.142	0.214

Table 3: Mode Period for 10° Sloping Ground

Mode	Mode Period For Stories (10°)		
	For Storey 5	For Storey 10	For Storey 15
1	0.5	1.001	1.526
2	0.489	0.992	1.518
3	0.437	0.884	1.333
4	0.16	0.327	0.5
5	0.157	0.324	0.497
6	0.14	0.29	0.44
7	0.091	0.189	0.289
8	0.089	0.187	0.287
9	0.08	0.169	0.259
10	0.062	0.13	0.202

Table 4: Mode Period for 20° Sloping Ground

Mode	Mode Period For Stories (20°)		
	For Storey 5	For Storey 10	For Storey 15
1	0.405	0.903	1.426
2	0.378	0.879	1.403
3	0.341	0.788	1.237
4	0.129	0.294	0.465
5	0.12	0.285	0.457
6	0.109	0.258	0.408
7	0.074	0.17	0.269
8	0.069	0.164	0.264
9	0.063	0.15	0.24
10	0.052	0.117	0.188

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Table 5: Mode Period for 30° Sloping Ground

Mode	Mode Period For Stories (30°)		
	For Storey 5	For Storey 10	For Storey 15
1	0.248	0.738	1.256
2	0.218	0.715	1.235
3	0.196	0.643	1.092
4	0.102	0.239	0.408
5	0.075	0.23	0.4
6	0.073	0.209	0.359
7	0.068	0.139	0.236
8	0.062	0.132	0.231
9	0.059	0.121	0.211
10	0.051	0.103	0.165

In Plain ground, G+15 storey takes maximum period than G+5 storey and G+10 storey time to show the mode shapes. In 10° Sloping ground, G+15 storey takes maximum period.

In 20° Sloping ground, G+15 storey takes maximum period. In 30° Sloping ground, G+15 storey takes maximum time period. Thus, from these results for Sloping ground, G+15 storey RCC structure takes maximum period. This result shows the height of the structure increases then the Mode period of structure is increases.

4.2 Base Shear

Table 6: Base Shear of structure

Ground Profile	Base Shear (KN)					
	5 Storey		10 storey		15 Storey	
	X dir	Y dir	X dir	Y dir	X dir	Y dir
Plain Ground	612.341	612.341	332.855	332.855	223.782	223.782
10°	631.666	631.666	352.416	349.324	230.292	229.131
20°	564.493	564.493	356.229	346.508	223.116	219.487
30°	464.275	464.275	361.757	350.27	209.404	205.78

In Plain ground Base shear is maximum at 5 storey RCC structure along X- direction and Y-direction. In sloping ground Base shear is maximum at 10° sloping ground than 20° and 30° sloping ground. Base shear of G+ 5 storey structure is greater than all other structures, so that the results are suggesting that the base shear varies with the height of the structure, it goes on decreasing as the height of the structure decreases.

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4.3 Storey Displacement

Table 7: Storey Displacement for 5 Storey

Storey	Plain Ground		10° Sloping Ground		20° Sloping Ground		30° Sloping Ground	
	X dir	Y dir	X dir	Y dir	X dir	Y dir	X dir	Y dir
6	0.004201	0.004201	0.00311	0.003792	0.001856	0.002549	0.000598	0.001021
5	0.003901	0.003901	0.002808	0.003456	0.001566	0.002216	0.000354	0.00071
4	0.003362	0.003362	0.002267	0.002848	0.001063	0.001625	5.48E-05	0.000305
3	0.002605	0.002605	0.001525	0.002006	0.00044	0.000859	6.48E-05	0.000166
2	0.001682	0.001682	0.000675	0.001021	3.36E-05	0.000189	3.60E-05	7.07E-05
1	0.00069	0.00069	5.09E-05	0.000176	2.39E-06	4.96E-06	3.25E-06	7.13E-06
Base	0	0	0	0	0	0	0	0

Table 8: Storey Displacement for 10 Storey

Storey	Plain Ground		10° Sloping Ground		20° Sloping Ground		30° Sloping Ground	
	X dir	Y dir	X dir	Y dir	X dir	Y dir	X dir	Y dir
11	0.007811	0.007811	0.007092	0.007805	0.00634	0.007242	0.005258	0.006184
10	0.007593	0.007593	0.006867	0.00757	0.006097	0.006987	0.004979	0.005885
9	0.007238	0.007238	0.006496	0.007179	0.00569	0.006558	0.004498	0.005371
8	0.006749	0.006749	0.00598	0.006637	0.005122	0.00596	0.003824	0.00465
7	0.006138	0.006138	0.005336	0.005956	0.004411	0.005208	0.002987	0.00375
6	0.005419	0.005419	0.004576	0.005154	0.003577	0.004324	0.002023	0.002706
5	0.004603	0.004603	0.003717	0.004245	0.002642	0.003327	0.000992	0.001574
4	0.003701	0.003701	0.002773	0.003243	0.001636	0.002243	0.000132	0.000577
3	0.002728	0.002728	0.001768	0.00217	0.00064	0.001128	2.70E-05	0.000212
2	0.001703	0.001703	0.000757	0.001071	4.69E-05	0.00024	1.20E-05	6.81E-05
1	0.000684	0.000684	5.60E-05	0.000182	3.59E-06	5.44E-06	7.90E-07	5.86E-06
Base	0	0	0	0	0	0	0	0

Table 9: Storey Displacement for 15 Storey

Storey	Plain Ground		10° Sloping Ground		20° Sloping Ground		30° Sloping Ground	
	X dir	Y dir	X dir	Y dir	X dir	Y dir	X dir	Y dir
16	0.011711	0.011711	0.011035	0.011767	0.010139	0.011071	0.008909	0.009899
15	0.011482	0.011482	0.010806	0.011532	0.009908	0.010833	0.008674	0.009653
14	0.011155	0.011155	0.010475	0.01119	0.009568	0.010482	0.008318	0.009279
13	0.010732	0.010732	0.010042	0.010743	0.009121	0.010018	0.007842	0.008779
12	0.010223	0.010223	0.009518	0.0102	0.008577	0.009453	0.007258	0.008165
11	0.009636	0.009636	0.008912	0.009572	0.007946	0.008797	0.006577	0.007448
10	0.008981	0.008981	0.008233	0.008867	0.007236	0.008059	0.005808	0.006638
9	0.008262	0.008262	0.007486	0.008092	0.006454	0.007246	0.004959	0.005744
8	0.007485	0.007485	0.006677	0.007252	0.005605	0.006362	0.004039	0.004773
7	0.006652	0.006652	0.005807	0.006348	0.004693	0.005411	0.003055	0.003732
6	0.005764	0.005764	0.004881	0.005385	0.003724	0.004399	0.002022	0.002634
5	0.004823	0.004823	0.003901	0.004366	0.002705	0.003332	0.000977	0.001509
4	0.003833	0.003833	0.002874	0.003295	0.001654	0.00222	0.000128	0.000544
3	0.002798	0.002798	0.001815	0.002184	0.000642	0.001109	2.78E-05	0.000174
2	0.001733	0.001733	0.000772	0.001071	4.66E-05	0.000235	1.25E-05	4.17E-05
1	0.000693	0.000693	5.68E-05	0.000181	3.67E-06	5.10E-06	8.28E-07	2.24E-06
Base	0	0	0	0	0	0	0	0

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As the base of the structure is fixed, lateral displacement at base is equal to zero. Lateral displacement is increases with increase in number of storey. Height of the structure is another factor which affects the displacement. Lateral displacement of G+5 storey structure is lesser than that of G+15 storey structure. Storey displacement is more in plain ground as compared to sloping ground.

4.4 Storey Drift

Table 10: Storey Drift for 5 Storey

Storey	Plain Ground		10° Sloping Ground		20° Sloping Ground		30° Sloping Ground	
	X dir	Y dir	X dir	Y dir	X dir	Y dir	X dir	Y dir
6	1.04E-07	1.04E-07	1.04E-07	1.17E-07	9.94E-08	1.15E-07	8.18E-08	1.06E-07
5	1.84E-07	1.84E-07	1.84E-07	2.06E-07	1.70E-07	1.99E-07	1.10E-07	1.42E-07
4	2.55E-07	2.55E-07	2.49E-07	2.83E-07	2.16E-07	2.57E-07	2.56E-08	6.11E-08
3	3.09E-07	3.09E-07	2.89E-07	3.29E-07	1.40E-07	2.25E-07	1.02E-08	3.39E-08
2	3.32E-07	3.32E-07	2.19E-07	2.84E-07	1.20E-08	6.15E-08	1.09E-08	2.12E-08
1	2.30E-07	2.30E-07	1.70E-08	5.87E-08	7.96E-10	1.65E-09	1.08E-09	2.38E-09
Base	0	0	0	0	0	0	0	0

Table 11: Storey Drift for 10 Storey

Storey	Plain Ground		10° Sloping Ground		20° Sloping Ground		30° Sloping Ground	
	X dir	Y dir	X dir	Y dir	X dir	Y dir	X dir	Y dir
11	0.007811	0.007811	0.007092	0.007805	0.00634	0.007242	0.005258	0.006184
10	0.007593	0.007593	0.006867	0.00757	0.006097	0.006987	0.004979	0.005885
9	0.007238	0.007238	0.006496	0.007179	0.00569	0.006558	0.004498	0.005371
8	0.006749	0.006749	0.00598	0.006637	0.005122	0.00596	0.003824	0.00465
7	0.006138	0.006138	0.005336	0.005956	0.004411	0.005208	0.002987	0.00375
6	0.005419	0.005419	0.004576	0.005154	0.003577	0.004324	0.002023	0.002706
5	0.004603	0.004603	0.003717	0.004245	0.002642	0.003327	0.000992	0.001574
4	0.003701	0.003701	0.002773	0.003243	0.001636	0.002243	0.000132	0.000577
3	0.002728	0.002728	0.001768	0.00217	0.00064	0.001128	2.70E-05	0.000212
2	0.001703	0.001703	0.000757	0.001071	4.69E-05	0.00024	1.20E-05	6.81E-05
1	0.000684	0.000684	5.60E-05	0.000182	3.59E-06	5.44E-06	7.90E-07	5.86E-06
Base	0	0	0	0	0	0	0	0

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Table 12: Storey Drift for 15 storey

Storey	Plain Ground		10° Sloping Ground		20° Sloping Ground		30° Sloping Ground	
	X dir	Y dir	X dir	Y dir	X dir	Y dir	X dir	Y dir
16	0.011711	0.011711	0.011035	0.011767	0.010139	0.011071	0.008909	0.009899
15	0.011482	0.011482	0.010806	0.011532	0.009908	0.010833	0.008674	0.009653
14	0.011155	0.011155	0.010475	0.01119	0.009568	0.010482	0.008318	0.009279
13	0.010732	0.010732	0.010042	0.010743	0.009121	0.010018	0.007842	0.008779
12	0.010223	0.010223	0.009518	0.0102	0.008577	0.009453	0.007258	0.008165
11	0.009636	0.009636	0.008912	0.009572	0.007946	0.008797	0.006577	0.007448
10	0.008981	0.008981	0.008233	0.008867	0.007236	0.008059	0.005808	0.006638
9	0.008262	0.008262	0.007486	0.008092	0.006454	0.007246	0.004959	0.005744
8	0.007485	0.007485	0.006677	0.007252	0.005605	0.006362	0.004039	0.004773
7	0.006652	0.006652	0.005807	0.006348	0.004693	0.005411	0.003055	0.003732
6	0.005764	0.005764	0.004881	0.005385	0.003724	0.004399	0.002022	0.002634
5	0.004823	0.004823	0.003901	0.004366	0.002705	0.003332	0.000977	0.001509
4	0.003833	0.003833	0.002874	0.003295	0.001654	0.00222	0.000128	0.000544
3	0.002798	0.002798	0.001815	0.002184	0.000642	0.001109	2.78E-05	0.000174
2	0.001733	0.001733	0.000772	0.001071	4.66E-05	0.000235	1.25E-05	4.17E-05
1	0.000693	0.000693	5.68E-05	0.000181	3.67E-06	5.10E-06	8.28E-07	2.24E-06
Base	0	0	0	0	0	0	0	0

From the results it can be concluded that Storey drifts are increased with the increase in height of the structure. Storey drift increases from bottom storey to top storey. Storey drift is maximum at top storey. Storey drift is increases in plain ground structure and decreases in sloping ground structure. In Plain ground storey drift is maximum for G+15 storey structure. In plain ground it is maximum at G+15 storey structure.

5. CONCLUSIONS

- The sloping ground structure possesses relatively more maximum displacement which may give to critical situations than flat ground.
- Mode shape for 15 storey takes maximum period at top storey as well as at bottom storey.
- The Base shear is maximum at 10° slope compared to other storey models.
- Base shear is maximum in X- direction as compared to Y- direction for sloping ground structure.
- Mode time period decreases with increase in slope angle and Storey displacement is maximum at 10° slope.
- Displacement is maximum at top storey when compared with bottom storey in all other models along X- direction and Y-direction and Storey drift is maximum at 10° slope for all models.

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