Seismic Analysis and Cost Comparison of Multistoried Building on Sloping Ground

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ABSTRACT:

Structures on the earth are generally subjected to two types of load i.e. static and dynamic. Static loads are constant with time while dynamic loads are time varying. In general majority of the civil structures are designed with the assumption that all applied loads are static. The aspect of neglecting dynamic forces may sometimes become the cause of disaster particularly in case of earthquake. An earthquake is a natural disaster that unlike the other disasters like floods etc. leaves no time for evacuation of people to safer places thus causing a huge loss of lives as well as prosperity. In this paper the seismic analysis of a multi storied RC G+10 building situated in seismic zone V has been carried out as per IS 1893-2016 on sloping ground having angle of inclination 0° and 20° on soft, medium and hard strata. The seismic analysis of a multi storied building situated in seismic zone V as per IS 1893-2016 on filled slope ground (level ground) having soft, medium and hard strata is investigated. The seismic responses of the above buildings as horizontal displacement, bending moment, shear force, torsion and storey drift in order to study its seismic behavior are obtained. Finally, the cost analysis of these two buildings (1 and 2) and to compare its cost is performed.

***KEY words*: Seismic Analysis, Response spectrum method, Stepback building, horizontal displacement, storey drift, seismic behavior, bending moment, shear force, torsion, Sloping ground, Mass Irregularity etc.**

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1. INTRODUCTION

In the last few years, many seismic studies have been carried out on sloping ground. Many problems occur on the sloping ground when considering irregularities configuration of structures. The lateral analysis of configuration of different methods has been suggested as below:
Chauhan and Banerjee (2021)[1]studied G+10 RCC Stepback building having each storey of height 3.6m with a horizontal angle of inclination 20°, 30°, 40º, and 45° on the sloping ground. They analyzed the building in seismic zone V by Response Spectrum method. The analysis and modeling of the Stepback building are carried out by ETABS ver. 18.0.2 software as per IS 1893:2016. They compared the building based on their dynamic response properties like mode Period, Base Shear, Story deflection, Story drift, and story shear and also find out the frame vulnerability in irregularities of structure on the sloping ground.
V Keneror and Halhalli (2020)[2]studied multistoried building on slopy ground of 0 and 24 degree.They analyzed G+20 storey building by using E-TAB and evaluate the seismic parameters such as story displacement, ground deviation, period of oscillation.They concluded that there is increased insertion of the shear wall to resist side loading. **Khan and Singh (2019)[3] ;** studied and analyzed of multistoried building (G+4) on sloped ground by considering gravity loads and seismic loads (response spectrum method used) and also includes slope stability analysis. The analysis has been carried out in the software. The reactions at the base of the building are taken from the software separately. The same reactions are further used for the analysis of slope to get the factor of safety by using software for varying sloping angles (0 to 30 degree). From this study it is observed that there is decrease in the factor of safety with increasing sloping angle and also noted that there is increase in the reactions with increase in sloping angle in both the cases i.e. gravity as well as seismic conditions. **Zafar, Mohammed and B Patil (2018)[4]**studied the combined effects of earthquake-triggered landslides and ground shaking on sloping ground. They carried out Dynamics characteristic of hill buildings in both horizontal and vertical directions.They have shown that results in center of mass and center of stiffness of a story not coinciding with each other and not being on a vertical line for different floors. They also analysed that when a multistoried building are subjected to lateral loads, these buildings are generally subjected to significant torsional response. **Naveen Kumar S M et. al (2017)**[5]; studied on "Analysis and Comparison of Step Back RC Frame Building on Sloping Strata and Plain Strata".They studied and analyzed G+ 10 story RCC building. A comparison has been made with the building resting on level ground. The modeling and analysis of the building has been done by using structure analysis tool ETAB 2015. The seismic analysis was done by the response spectrum analyses have been carried out as per IS: 1893 (part 1): 2002. They observed that the Overturning moment is same till story 4 because column height is same , but after story 4 it overturns due to column variation and also overturning moment gradually decreases for step back configuration on sloping ground compare to step back on flat ground for load. Hence they concluded that Base shear is more for sloping strata than plain strata and the over turning moment gradually decreases on sloping ground than compare to flat ground in both D-con 7 and D-con 9. **Shivakumar Ganapati et. al (2017)[6];**studied "R.C frame structure with floating column on sloping ground". They considered model consist

of 3 bays with 10 story building, each bay having a dimension of 5m in X direction 5m in Y direction. The building is considered in the seismic zone V with medium soil. The models were analyzed using pushover analysis method in ETABS. They observed that in step back-set back building on sloping ground maximum displacement decreases when compared to step back building on sloping ground without floating column. **Arjun and Arathi (2016)**[7]studied that the buildings situated in hilly areas are much more prone to seismic environment in comparison to the buildings that are located in flat regions. The columns of ground storey have varying height of columns due to sloping ground. He concluded that the behavior of G+3 storied sloped frame building having step back set back configuration is analyzed for sinusoidal ground motion with different slope angles i.e., 16.7°, 21.8°, 26.57° and 30.96° using structural analysis tool STAAD Pro. by performing Response Spectrum analysis was carried out as per IS:1893 (part 1): 2002. The results were obtained in the form of top storey displacement and base shear. It was observed that short column is affected more during the earthquake.**Kalsait and Varghese (2015)**[8] **s**tudied the effect of earthquake on high rise building (G+15) resting on sloping ground using STAAD.Pro software for structural analysis and design, same loading conditions are considered in each case and comparative study is done considering different sloping angels as (0º, 7.5º, 15ºand 22º) and observed that buildings resting on sloping ground have more lateral displacement compared to buildings on plain ground. **Shivanand and Vidyadhara (2014)**[9] Studied the buildings located at hills of 12 storied symmetrical and asymmetrical shape with the effect of bracings and shear wall at different positions using analysis tool CSI ETABS considering linear and pushover analysis and concluded that The presence bracings, shear wall influences the overall behavior of structures when subjected to lateral forces. Joint displacements and story drifts are considerably reduced also determined that shear wall have large effect on the behavior of frames under earthquake excitation.

2. SLOPING GROUND AND CONFIGURATION OF BUILDINGS

The construction of building on a sloping ground has to face severe earthquakes. One conceivable reason is the non-symmetric geometry of step-like inclines, which entangles expository arrangements and supports for the most part site particular numerical reenactments. When these buildings are subjected to earthquake loads are generally subjected to significant tensional response.

3. OBJECTIVES OF THE PRESENT STUDY

The following are the major objectives of the present study:

1. To carry out the seismic analysis of a multi storied building situated in seismic zone V as per IS 1893-2016 on sloping ground having angle of inclination 0° and 20° on soft, medium and hard strata.
2. To carry out the seismic analysis of a multi storied building situated in seismic zone V as per IS 1893-2016 on filled slope ground (level ground) having soft, medium and hard strata.
3. To compare the seismic responses of the above buildings as horizontal displacement, bending moment, shear force, torsion and storey drift in order to study its seismic behaviour.
4. To carry out the cost analysis of these two buildings (1 and 2) and to compare its cost.

The seismic analysis of the multi-storied building is carried out using Etabs software.

4. SCOPE OF STUDY

The seismic analysis of a multi storied RC G+10 building situated in seismic zone V on sloping ground having angle of inclination 0°and 20° on soft, medium and hard strata has been carried out. The seismic analysis of a multi storied building situated in seismic zone V as per IS 1893-2016 on filled slope ground (level ground) having soft, medium and hard strata is investigated. The seismic responses of the above buildings as horizontal displacement, bending moment, shear force, torsion and storey drift in order to study its seismic behaviour are obtained. Finally, the cost analysis of these two buildings (1 and 2) and to compare its cost is performed. The seismic analysis is carried out using ETABS 2017 ver. 17.2.2 software.

5. METHODOLOGY

IS 1893 adopted a design philosophy to ensure that structures possess minimum strength to

1. Resist minor earthquakes (DBE value-0.18g) without damage,
2. Resist moderate earthquakes (DBE) without significant structural damage
3. Resist major earthquakes (MCE value-0.36g) with sever structural damage.

The code considers the ductility in the form of a response reduction factor (R). It recommends different Importance factors (I) to consider the usage of the building. The code recommends two methods for calculating the design base shear of the building of analysis namely:

(i) Equivalent static load method and
(ii) Dynamic analysis ,

In equivalent static load method design horizontal coefficient (A) has to be found out using the seismic zone factor (Z). Importance factor (I). Response reduction factor (R) and spectral acceleration coefficient (S_a/g) obtained from the response spectrum curve for the specified soil type and the structures fundamental time period.The dynamic analysis is recommended for buildings of 40m in height situated in zones IV and V and for irregular buildings of 12m or more in height situated in zones IV and V.Code recommends response spectrum method of dynamic analysis with complete quadratic combination (CQC) method used for modal combination.

6 .STRUCTURAL MODEL OF ANALYSIS

Once the structural model has been selected, it is possible to perform analysis to determine the seismically induced forces in the structures. There are different types of analysis which provide different degree of accuracy. The analysis procedure can be categorized on the basis of three factors:

(i) The types of externally applied loads,
(ii) The behavior of structural materials,
(iii) The types of structural model selected

RC (G+10) building used in the present analysis. Figure shows the plan view of the building. Figure 3.3shows the buildings situated on sloping ground having an angle of inclination 0°and 20°.

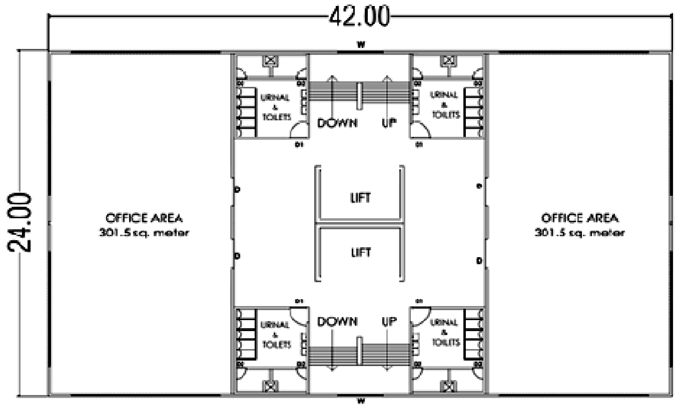


Figure 3.2(a) Plan view of RC G+10 building

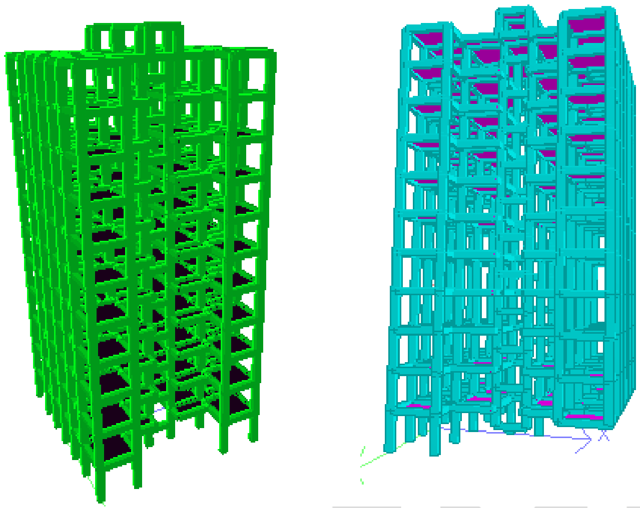
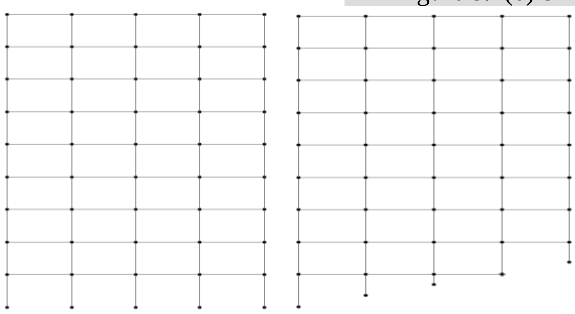
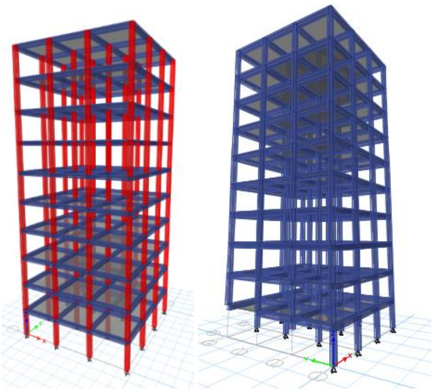


Figure 3.2(b) 3-D rendered view of RC G+10 building





0 º slope 20º slope

Figure 3.3 Elevation of G+10 building situated on different sloping grounds

Table 3.1gives the various load combinations for dead, live and seismic considered in the present study.

Table 3.1 Load combinations

Load case no.	Load cases
1	1.5(D-L+L-L)
2	1.5(D-L+E.Q._X)
3	1.5(D-L-E.Q._X)
4	1.5(D-L+E.Q._Z)
5	1.5 (D.L-E.Q._Z)
6	1.2(D.L+L.L+E.Q._X)
7	1.2 (D.L+L.L-E.Q._X)
8	1.2 (D.L+L.L+E.Q._Z)
9	1.2 (D.L+L.L-E.Q._Z)
10	0.9 D.L. + 1.5 E.Q.
11	0.9 D.L. – 1.5 E.Q

7. MATERIAL DATA

In present work in order to compare reinforced concrete frame structure on sloping strata for use in earthquake prone area G+10 multi storey building having plan dimension 24 m × 42 m is modeled and analyzed in Etabs 2017 version 17.2.2 integrated building design software. Equivalent static analysis and dynamic response spectrum analysis is performed on the structure. Table 3.2 gives the details of materials used for the building.

Table 3.2 Material data

Material	Weight (kN/m³)	Modulus of elasticity (E) (kN/m²)	Shear modulus (G)	Poisson ratio	Coefficient of thermal expansion
Steel (fe = 415)	78.5	2×10^8	76884615	0.3	11.7×10^{-6}
Steel (fe = 345)	76.9	2×10^8	80769230	0.3	11.7×10^{-6}
Concrete (fck = 25)	25	25×10^6	10416666.7	0.2	9.9×10^{-6}
Masonry	20	11×10^6	521739.13	0.15	7×10^{-6}

7.1 GEOMERTICAL DATA

The following is the geometrical data of the G+10 RC building.

Type of building : Commercial building

Building location : Northern region

Height of building : 39.5 m (including foundation depth 4.5 m)

Storey Height of building : 3.5 m

7.2 LOADING DATA

The following is the loading data of the G+10 RC building.

Live load : on ground floor 10 kN/m² (parking area)

: on office area 4 kN/m²
: on passage area 4 kN/m²
: on urinal area 2 kN/m²
: on stairs 4 kN/m²

Floor finish : 1.5 kN/m²
Water proofing : 2.5 kN/m² (terrace)
Earthquake load All frames are analyzed for (V) earthquake zone. The seismic load calculation are as per IS: 1893(part-1)-2002

Parameter	Value	Remarks
Zone Intensity	0.36	Table 2 (1893-part-1)
Damping ratio	0.5	Table-3 (1893-part-1)
Importance factor	1.5	School building Table 6 (1893-part-1)
Response Reduction factor	5	Ductile detailing (S.M.R.F.) Table-7 1893-part-1
Soil site factor	Medium	Adopt

Calculation of Sa/g

The infill walls in upper floors may contain large openings, although the solid walls are considered in load calculations. Therefore, fundamental time period T is obtained by using the following formula:

$T_a = 0.075\ h^{0.75}$ [IS 1893 (Part 1):2002, Clause 7.6.1]

$= 0.075 \times (15)^{0.75} = 0.571$ sec.

Zone factor, Z = 0.36 for Zone V IS: 1893 (Part 1):2002, Table 2

Importance factor, I = 1.5 (School building)

Medium soil site and 5% damping

$S_a/g = 1.36/0.571 = 2.381$

As per IS: 1893 (Part 1): 2002, Figure 2.

$V_b = A_h \times$ weight of building

7.3 MEMBER SIZES FOR PARTICULAR BUILDINGS

The following is the RCC member size of the G+10 RC building.

Table 3.3 RCC structure member size

Reinforced concrete member size		
	RCC column	RCC beam
foundation to ground floor	0.85 m × 0.85 m	main beam 0.3 m × 0.6 m
		secondary beam -0.3X0.53m
ground floor to 5th floor	0.85 m × 0.85 m	main beam 0.3 m × 0.53 m
		secondary beam 0.3 m × 0.45 m
6th floor to 8th floor	0.7 m × 0.7 m	main beam 0.3 m × 0.53 m
		secondary beam 0.3 m × 0.45 m
9th floor to 10th floor	0.53 m × 0.53 m	main beam 0.3 m × 0.45 m
		secondary beam 0.3 m x 0.45 m
stairs cabin	0.53 m × 0.53 m	main beam 0.3 m × 0.45 m
		secondary beam 0.3 m × 0.45 m

8. SOFTWARE IMPLEMENTATION

ETABS is structural analysis software plays an important role for the seismic analysis of the models. Now a day for the construction of buildings and analysis of the models the software's are used for the analysis purposes. ETABS has been presented different features. The software have been highlight which was used to carry out the analysis work for various modeling systems.

9. ANALYSIS, RESULT AND DISCUSSION

The seismic responses of the buildings as horizontal displacement, bending moment, shear force, torsion and storey drift are determined, in order to study its seismic behavior are carried out.The results are evaluated with the help of the tables and figures. The maximum parameter is considered for the following analysis up to the top of the story level.

9.1 MAXIMUM BENDING MOMENT

Table 5.1 shows the values of maximum bending moment for each storey of building resting on soft, medium and hard soil. It can be observed that as the inclination of ground increases the bending moment also increases. It is also observed that for soft soil the bending moment increases as compared to medium and hard soil conditions. It is clearly observed in the table below that bending moment increases with higher slope, hence requires more reinforcement.

Table 5.1: Maximum bending moment in different soil conditions

Bending moment in kNm in soft soil			Bending moment in kNm in medium soil		Bending moment in kNm in hard soil	
Storeys	0º slope	20º slope	0º slope	20º slope	0º slope	20º slope
Story10	1018492	1099469	1018482	1099464	1018485	1099461
Story9	1188232	1282731	1188212	1282711	1188232	1282704
-						
Story1	2546155	2748831	2546055	2748691	2546011	2748652

9.2 MAXIMUM TORTION

It is observed that as the inclination of ground increases the torsion also increases. It is also observed that for soft soil the torsion increases as compared to medium and hard soil conditions. It is clearly observed that torsion increases with increase in the inclination of ground slope. The torsion is observed maximum in the initial stories of the building.

9.3 MAXIMUM BASE SHEAR

Figure 5.3(a), 5.3(b) and 5.3(c) shows the maximum base shear (kN)for building resting on soft, medium and hard soil having an inclination of 0° and 20°.The base shear is observed maximum at 20° inclined slope. The base shear is maximum at the base of the buildings.

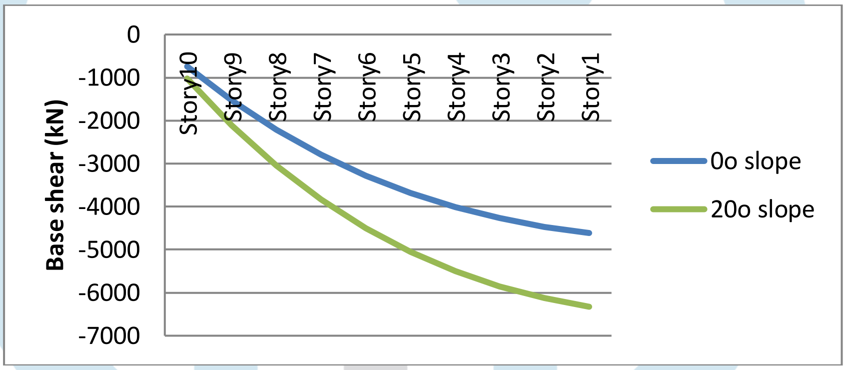


Fig 5.3(a) Maximum base shear in soft soil

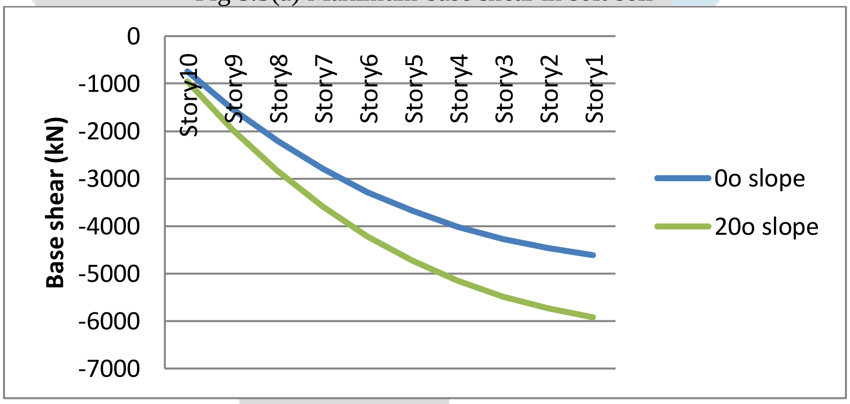


Fig 5.3(b) Maximum base shear in medium soil

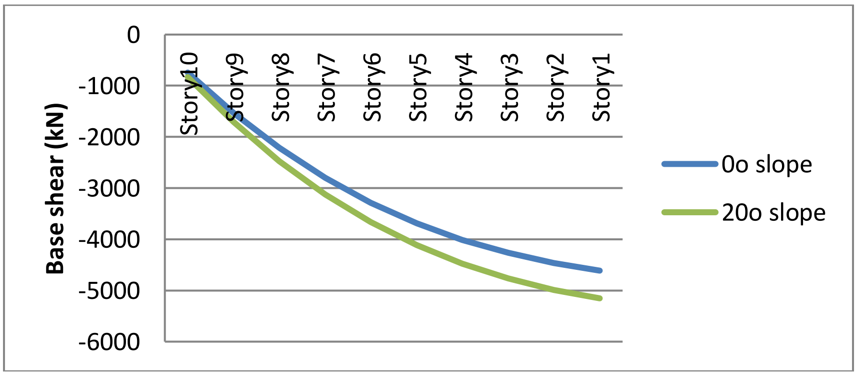


Fig 5.3(c) Maximum base shear in hard soil

9.4 TIME PERIOD

Figure 5.4(a), 5.4(b) and 5.4(c) shows the time period (sec)for building resting on soft, medium and hard soil having an inclination of 0° and 20°.As the inclination of ground increase the time period of building decreases. The time period is maximum at top storey and decrease towards the bottom storey.

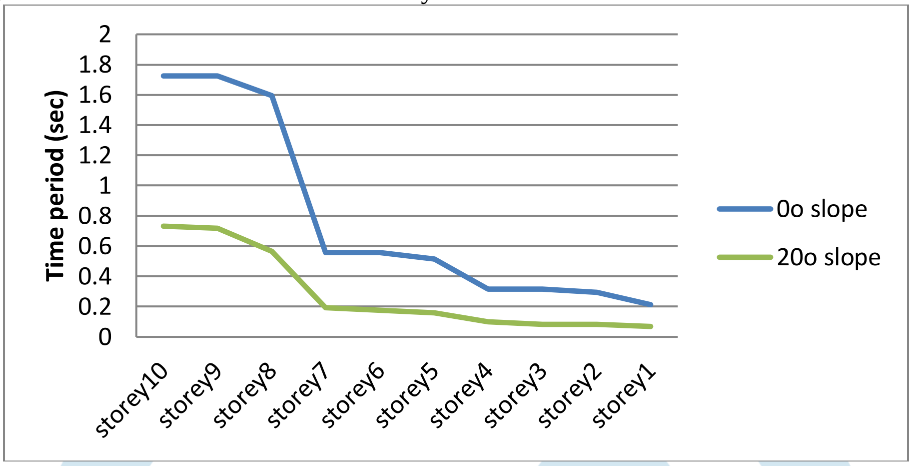


Fig 5.4(a) Time period (sec)for building resting on soft soil

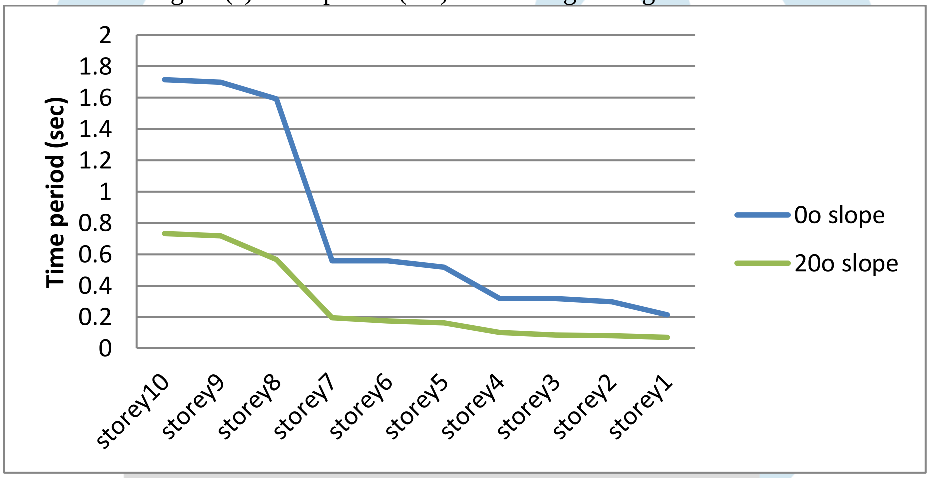


Fig 5.4(b) Time period (sec) for building resting on medium soil

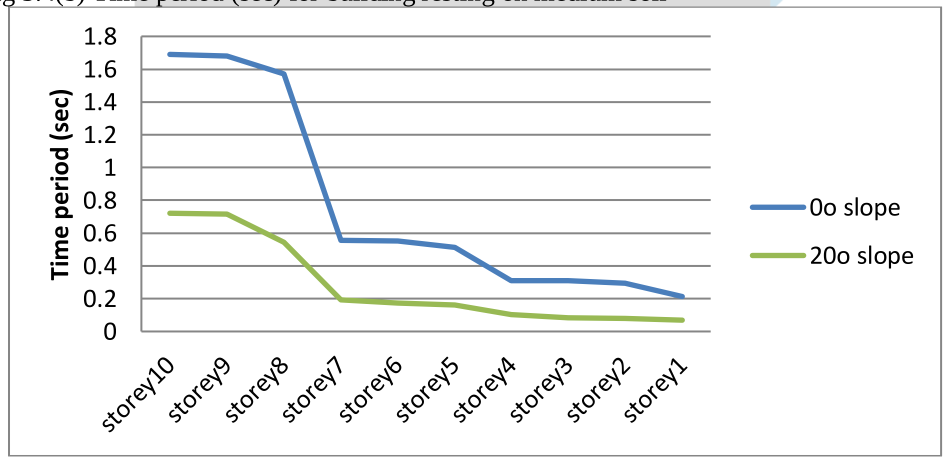


Fig 5.4(c) Time period (sec)for building resting on hard soil

9.5 STORY DRIFT

Figure 5.5(a), 5.5(b) and 5.5(c) shows the storey drift (sec) for building resting on soft, medium and hard soil having an inclination of 0° and 20°.The storey drift is maximum in zero degree ground almost a plain ground.

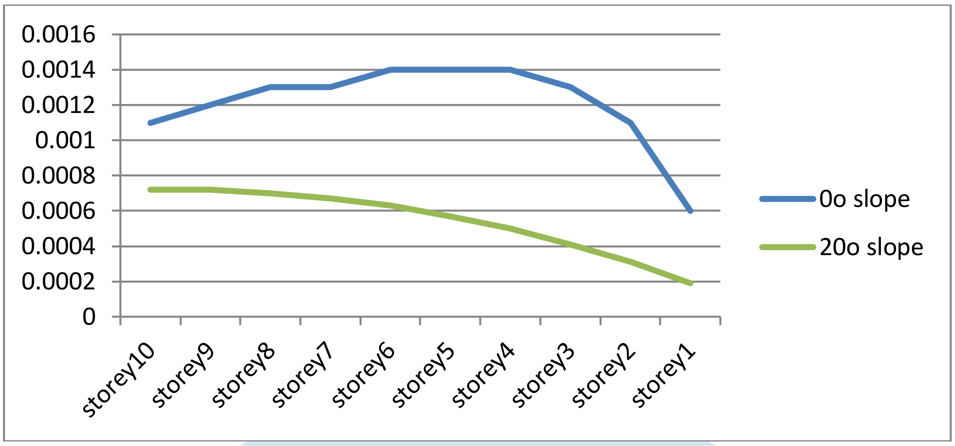


Fig 5.5 (a) Storeydrift for building resting on soft soil

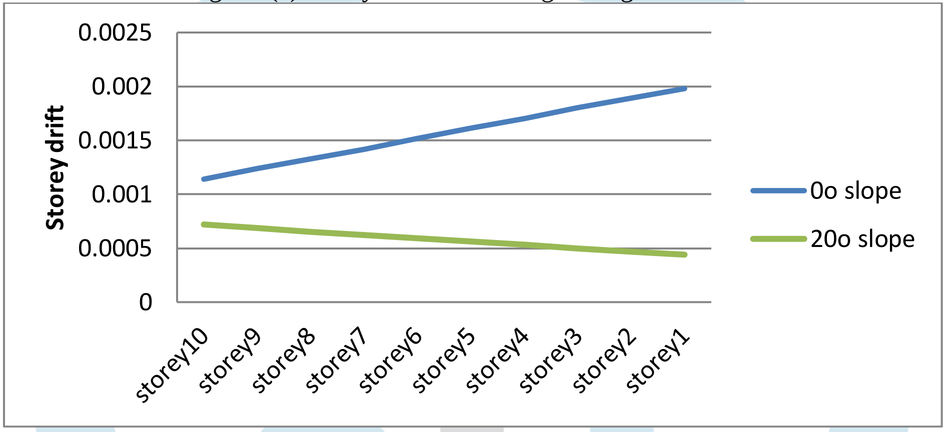


Fig 5.5 (b) Storey drift for building resting on medium soil

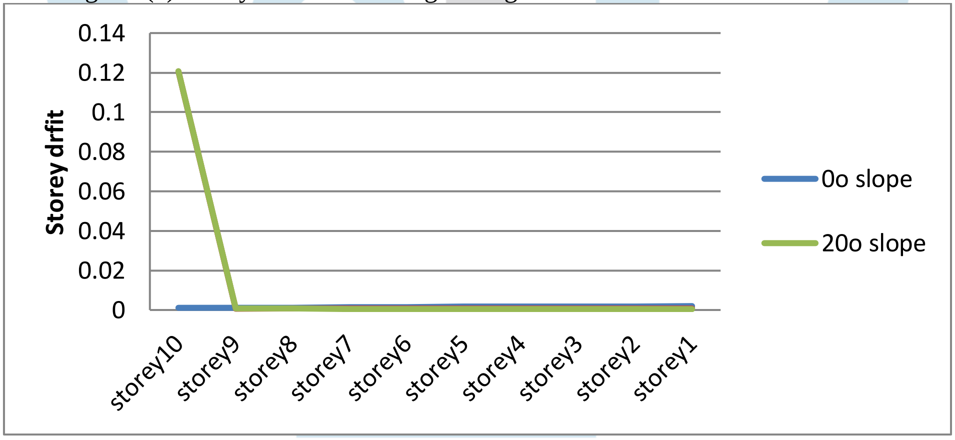


Fig 5.5 (c) Storey drift for building resting on hard soil

9.6 STORY DISPLACEMENT

Figure 5.6(a), 5.6(b) and 5.6(c) shows the storey displacement (mm) for building resting on soft, medium and hard soil having an inclination of 0° and 20°. As the inclination of ground increases storey displacement increases and it observed maximum at the top storey.

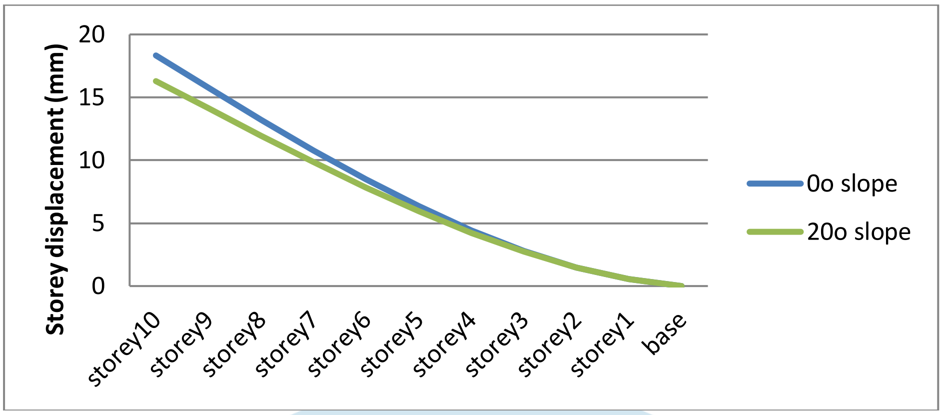


Fig 5.6 (a) Storey displacement for building resting on soft soil

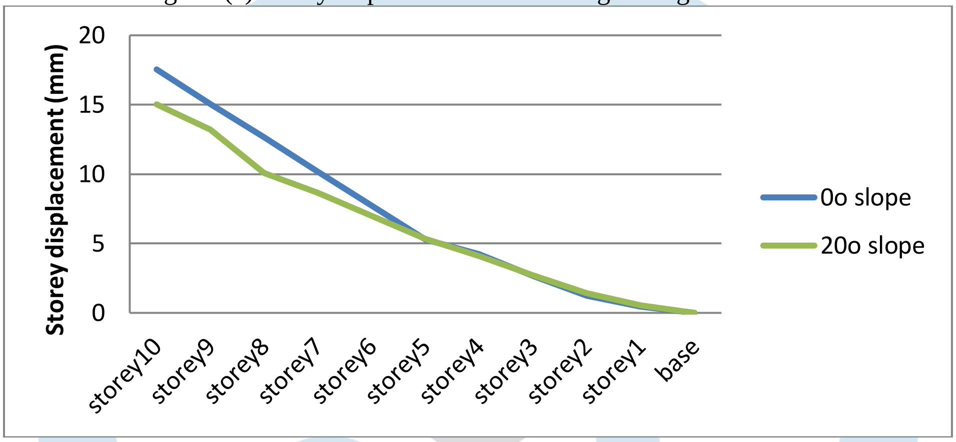


Fig 5.6 (b) Storey displacement for building resting on medium soil

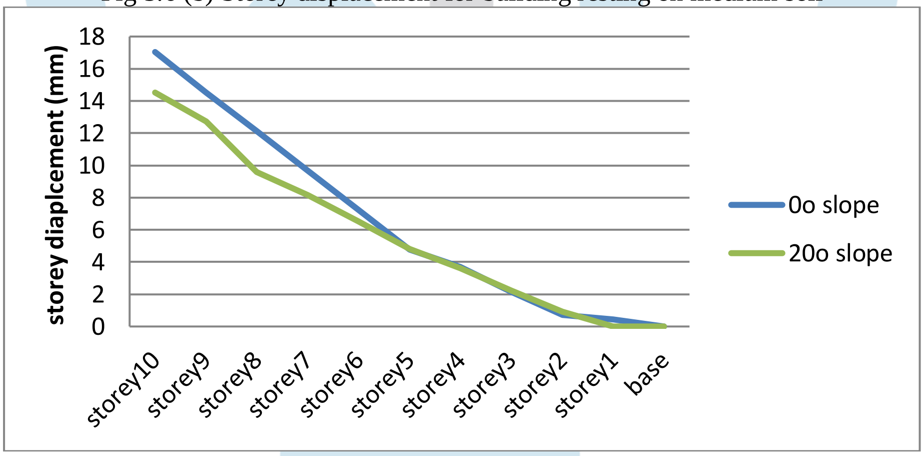


Fig 5.6 (c) Storey displacement for building resting on hard soil

10. COST ANALYSIS

The cost analysis of buildings is carried in order to check the quantity of filling required for construction of building on sloping ground. The rates considered are as per Public Works Department (PWD) schedule of rates (S.O.R) September 2017 including 12% GST.

10.1 COST ANALYSIS FOR 0° SLOPE

Table 5.6 gives the detailed cost analysis of building on 0 degree on soft, medium and hard soil conditions. It can be observed that the cost of building is more in the case of soft soil condition as response values are more in this case and also the reinforcement required is more.

Table 5.6 Cost Analysis for 0 degree

DESCRIPTION	CONCRETE (cum.)			REBAR (Newton)		
Type of soil	Soft	medium	hard	soft	medium	hard
Quantity	461.38	443.87	376.26	1695.45	1587.87	1494.97
Rate	1153450	1109675	940650	1446218.9	1354453.1	1275209.4

10.2 COST ANALYSIS FOR 20^{O} SLOPE

Table 5.7 gives the detailed coast analysis of building on 20 degree on soft, medium and hard soil conditions. It can be observed that the cost of building is more in the case of soft soil condition as response values are more in this case and also the reinforcement required is more.

Table 5.7 Cost Analysis for 20 degree

DESCRIPTION	CONCRETE (cum.)			REBAR (Newton)		
type of Soil	soft	medium	hard	soft	medium	Hard
QUANTITY	495.09	479.8	440.83	1892.8	1792.87	1797.7
RATE	1237725	1199500	1102075	1614558.4	1529318.11	1533438.1
% increase	7.30	8.10	17.16	11.64	12.91	20.25

From Tables 5.6 and 5.7 it is seen that the cost of building is more in case of 20 degree inclination and also more for soft soil conditions. Therefore while designing the building in the sloping ground the seismic analysis and cost of the building are the measure factors to be considered. The cost of building increases by about 20.25% in case of 20 degree inclined ground as compared to building constructed on plain ground.

11. CONCLUSIONS

The seismic responses of the above buildings as horizontal displacement, bending moment, shear force, torsion and storey drift in order to study its seismic behaviour are investigated. The cost analysis of these buildings is also carried out. The seismic analysis of the multi-storied building is carried out using Etabs software.

The following conclusions are drawn from the present study:

1. As the inclination of ground increases the bending moment developed in the building increases. It is also observed that for soft soil the bending moment is more as compared to medium and hard soil conditions. The bending moment increases with higher slope, hence requires more reinforcement.
2. The inclination of ground increases the torsion also increases. It is also observed that for soft soil the torsion increases as compared to medium and hard soil conditions. The torsion is observed maximum in the initial storey's of the building.
3. The base shear is observed maximum at 20° inclined slope. The base shear is maximum at the base of the buildings.
4. As the inclination of ground increase the time period of building decreases. The time period is maximum at top storey and decrease towards the bottom stories of the building.
5. The storey drift is maximum in zero degree ground almost a plain ground.
6. As the inclination of ground increases storey displacement also increases and it observed maximum at the top storey.
7. It can be observed that the cost of building is more in the case of soft soil condition as response values are more in this case and also the reinforcement required is more. The cost of building increases by about 20.25% in case of 20 degree inclined ground as compared to building constructed on plain ground.

From the present study, it can be concluded that hard soil, plain ground is effective and best. In case of different inclination of ground (0^o and 20^o) among all 0^o is best, as it provide better stability due to plain ground and also reduces the effect of short columns and variation in stiffness.

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DATA AVAILABILITY STATEMENT

Some or all data, models, or codes that support the findings of this study are available from the corresponding author , IS Code and upon reasonable request.

DECLARATION OF COMPLETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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