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Seismic Performance of Multistorey Building Founded on Slopes With Water Tank

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Abstract: The most effective shape of water tank is rectangular and corner position is best suited for building on plain ground. The best suitable position of water tank on top of the structure with different sloping ground is still a matter of concern. This paper analyzed various models on STAAD Pro using static method of seismic analysis. Structure with G+4 building having two bay and four bay frame were analyzed which were founded on different slopes i.e. 0^0, 10^0, 20^0. Each model was analyzed for different positions of water tank on top of the building. It was observed that the position of overhead water tank on 2-bay and 4-bay structure founded on sloping ground affects the performance of structure. After analysis, a corner 1 position which is at the shorter column of the structure was found to be best for 2 bay structure with 0^0, 10^0, 20^0 slopes while for 4 bay structure center position was found to be best for plain ground i.e. 0^0 and corner 1 position for 10^0 and 20^0 slopes. Hence, it is recommended that for every building with water tank on slopes must be analyzed for better location so that its position will be detrimental to structure.

***Keywords* — seismic design; water tank; building on slopes, location of water tank, bending moment, shear force.**

I. INTRODUCTION

The hilly area is more prone to seismic activity e.g. northeast region of India. All the buildings in hilly area are constructed on slopes. The residential buildings and commercial building in hilly area leads to economic growth of the region. It leads to dense population in the urban hilly area. Also there is scarcity of plane ground in hilly regions so reinforced cement concrete buildings such as hospital buildings, residential buildings are constructed in the sloping areas, hence the construction of multi-storey R.C. Frame buildings on hill slope is the only feasible choice to accommodate increasing demand of residential & commercial activities. Since, the behavior of buildings during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings. The presence of such typical constructions in seismically prone areas makes them exposed to greater shears and torsion as compared to conventional construction[1].

A seismic design of high rise buildings has assumed considerable importance in recent times. In traditional methods adopted based on fundamental mode of the structure and distribution of earthquake forces as static forces at various stories may be adequate for structures of small height subjected to earthquake of very low intensity but as the number of stories increases the seismic design demands more rigorous. During past earthquakes, 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. Two examples of buildings with short columns in buildings on a sloping ground and buildings with a mezzanine floor as shown in the Fig.1 [2].

The water tank position of such building become challenge due to earthquake forces. The building on slope make it more complex. Hence, this paper focuses on study of seismic performance of high rise building with water tank on slope.

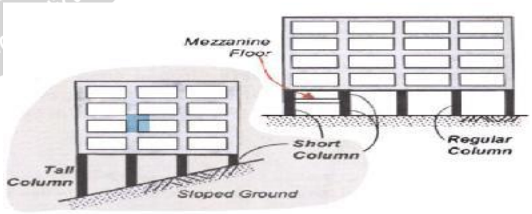

Figure1: Building Frame with Short Column

II. LITERATURE REVIEW

The seismic analysis of buildings resting on sloping ground with varying number of bays and hill slopes with the variation of time period, base shear and top storey displacement with respect to variation in number of bays along slope direction and hill slope angle had been carried out [1]. It was observed that, in all configurations, base shear increases with increase in number of storey, increases with increase in number of bay and decreases from lower angle to higher angle of slope. When compared between different configurations, base shear of step back building was found to be higher than step set back building. It was observed that the time period increases with increase in number of storey in all configurations, in step back building

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time period increases with increase in number of bays, which was a reverse case in step back set back building in which time period decreases with increase in number of bay and in all configurations time period decreases with increase in hill slope.

The top storey displacement decreases with increase in hill slope showing lower value for higher slope. It was concluded that the step back frames produce higher base shear, higher value of time period and higher value of top storey displacement as compared to step back set back frames The performance of elevated water tanks in framed building subjected to dynamic loading, considering the effect of sloshing provide certain design recommendations for elevated water tank in framed building to avoid negative damping and resonance. Linear static and non-linear dynamic analysis (Time history analysis) was conducted to estimate the earthquake response of the system. The seismic response of the building models with varying tank geometries were presented. The analysis of elevated water tank in framed building was carried out using SAP 2000 software and the results were compared to obtain an economic design strategy. This study help on all aspects to be considered while deciding on the tank shape, whether circular or rectangular whether placed at corner or near to centre position in a framed building. It was observed that rectangular water tank placed near corner position in framed building performed better than another one [3].

G+ 10 storeys RCC building and the ground slope varying from 10^0 to 30^0 had been considered for the analysis[A comparison had been made with the building resting on level ground. The modelling and analysis of the building had been done by using structure analysis tool ETAB 2015, to study the effect of varying height of the column in bottom storey at different position during the earthquake. The seismic analysis was done by the response spectrum analyses have been carried out as per IS:1893 (part 1): 2002. The results were obtained in the form of top storey displacement, Storey Acceleration, Base shear and Mode period. It was observed that short column is affected more during the earthquake [4].

G+ 12 storeys RCC building and the ground slope for 20^0,30^0 & 40^0 had been considered for the analysis. The modeling and analysis of the building had been done by using structure analysis tool ETAB. The seismic analysis was done by linear static analysis and the response spectrum analyses had been carried out as per IS: 1893 (part 1): 2002. The results were obtained in the form of top storey displacement, drift, base shear and time period. It was observed that short column was affected more during the earthquake. The analyses showed that for construction of the building on sloppy ground the stepback setback building configuration was suitable [5].

The Step back Set back building and Set back building were analyzed. 3 –D analysis including torsional effect had been carried out by using response spectrum method. The dynamic response properties i.e. fundamental time period, top storey displacement and, the base shear action induced in columns had been studied with reference to the suitability of a building configuration on sloping ground. It was observed that Step back Set back buildings were found to be more suitable on sloping ground [6].

The structure without and with tuned liquid damper buildings of G+10, G+20, and G+30 storey height structural models were considered. The vulnerability of without and with tuned liquid damper structures under various load conditions were studied and for the analysis seismic region 3 with different water depths were considered. Analysis was carried out for different heights to study the seismic behavior of structure without and with tuned liquid damper building analysis was for different heights to see what changes going to take place if the height of both structural systems varies. The characteristics of the seismic behavior of both structural systems suggests the additional measures for guiding the conception and design of these structures in seismic regions and also to improve the performance of these structural systems under seismic loading. The parameters lateral displacement, storey drift, base shear influences the performance [7].

The literature review shows that building constructed on slopes subjected to seismic loads shows varying behavior. Also water tank located on high rise buildings, its location influences development of base shear and bending moments during earthquake. The high rise building with water tank on its top and resting on subjected to seismic forces slopes are not studied in detailed. Hence an attempt had been made to study various parameters affecting the performance of buildings with water tank resting on slope.

III. STAADPro

STAAD Pro. Software was used for the seismic analysis of multistory building founded on slopes having water tank on its top. It was used for 3D model generation, analysis and multi material design. The four storey building was modeled and analyzed on slopes of 0^o to 20^o. The water tanks were placed at different location on top of the buildings. The results obtained were studied for various parameters.

IV. OBJECTIVE OF WORK

In order to study the performance of building with water tank on slope, a systematic approach was designed. The work comprises of seismic analysis of (G+4) R.C. building having water tank on its top having two bay and four bay frame. The location of water tank on roof top was at different place. The analysis was carried out for the following aspects considering that the structure should withstand the moderate earthquakes, which may be expected to occur during the service life of structure with damage within acceptable limits. Such earthquakes are

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characterized as Design Basis Earthquakes (DBE). The objectives for the study were considered as;

1. To determine the suitable position of water tank on the buildings resting on slope.
2. To study the variation of various parameters with respect to variation in hill slope angle for different configurations of buildings frames. These parameters were as follows
   i) Base Shear
   ii) Bending Moment
   iii) Shear Force
   iv) Beam Displacement
   v) Node Displacement
   vi) Torsion

V. *METHODOLOGY*

In the present work, the focus was made to study the seismic behavior of multi-storey building resting on sloping ground with different positions of water tank on top of the building. The results were compared for structure on plane ground and on sloping ground for various parameters. For analyzing different models STAADPro software had been used.

The methodology of the project was divided into two different parts:

1. Analysis of (G+4) RC building having 2-bay frame structure.
2. Analysis of (G+4) RC building having 4-bay frame structure.

The different positions of water tank on top of building for 2-bay frame and 4-bay frame are shown in Fig.2 and Fig.3 respectively. Each color box in figure shows the location of water tank under different circumstances.

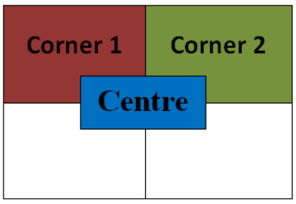

Figure 2: Different Positions of Water Tank in 2-Bay Frame

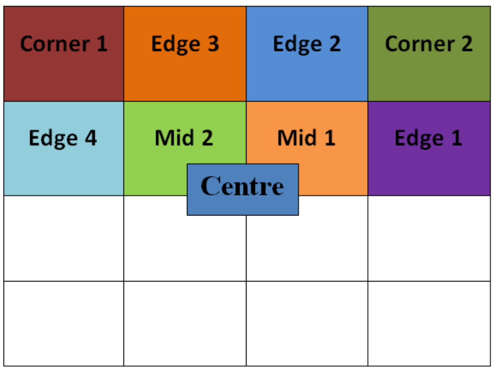

Figure 3: Different Positions of Water Tank in 4-Bay Frame

VI. GENERAL SPECIFICATIONS AND LOAD CASE DETAILS

The general specifications used in the work were as follows,

i) Earthquake Zone- III (Z= 0.16)
ii) Ordinary Moment Resisting frame (RF= 3)
iii) Importance factor = 1
iv) Soil type soft
v) RC frame
vi) Slopes, 0^0, 10^0, 20^0
vii) Damping ratio= 0.5%
viii) Beam Size = 0.45 m * 0.5 m
ix) Column Size = 0.45 m * 0.6 m
x) Plate thickness = 0.15 m.
xi) Slab thickness = 0.15 m.
xii) Floor to Floor height =3m
xiii) Dead Load Calculation from IS 875 Part I
xiv) Live Load Calculation from IS 875 Part II
xv) Seismic load calculation from IS 1893-2005

A. *DEAD LOAD*

Following dead loads were considered while analysing the frames;

1. Self-weight of the structure
2. Self-weight of slab = 0.15 * 1 * 25 = 3.75 kN
3. Weight of External wall = 0.35 * 2.65 * 20 + 1.9 = 20.45 kN
4. Weight of partition wall = 0.20 * 2.65 * 20 + 1.9 = 12.50kN
5. Weight of parapet wall = 0.20 * 1.5 * 20 + 1.9 = 7.9kN
6. Weight of water

B. *LIVE LOAD*

The live load on each floor except the roof floor was considered as 4 kN/m^2. For roof, live load was considered as 2 kN/m^2.

C. *SEISMIC LOAD*

Basically three methods are there for seismic analysis of the structure. These methods are as follows:

1. Equivalent static method
2. Lumped mass model method
3. Response spectrum method

Out of these methods, equivalent static method for analysis was used for different models of the study.

Following are the different parameters considered for seismic analysis:

1. Zone Factor
   Zone III = 0.16
2. Importance factor = 1
3. Response reduction factor = 3
4. Soil type = soft

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5. Seismic weight of building = IS 1893 clause 6.3 recommends that for live load less than 3 kN/m^3 seismic weight of building is taken as DL+25% of LL. For live load more than 3 kN/m^3 seismic weight of building is taken as DL+50% of LL. We had considered DL+50% of LL as our LL is more than 3 kN/m^3.

D. LOAD COMBINATIONS

Following load combinations were considered for the study;

i) 1.5(DL + LL)

ii) 1.2(DL + LL + EQX)

iii) 1.2(DL + LL + EQZ)

iv) 1.2(DL + LL - EQX)

v) 1.2(DL + LL - EQZ)

vi) 1.5(DL + EQX)

vii) 1.5(DL + EQZ)

viii) 1.5(DL - EQX)

ix) 1.5(DL – EQZ)

x) 0.9DL + EQX

xi) 0.9DL + EQZ

xii) 0.9DL – EQX

xiii) 0.9DL – EQZ

VII. RESULTS

The behavior of G+4 building with 2-bay frame structure and 4-bay frame structure was considered for the study. Both the frame structures were analyzed for three different slopes i.e. 0^0, 10^0, 20^0. Each model was further analyzed for different positions of water tank as shown in Fig. 2 and Fig. 3. The behavior of different structures was analyzed by various parameters such as Bending Moment, Shear Force, Torsion, Beam Displacement, Node Displacement and Base Shear.

The results obtained for 2-bay and 4-bay frame structure are shown in Table 1 and Table 2 respectively and the bolted values represent critical values i.e. position creating minimum values. The maximum value of base shear, bending moments and shear force in X & Z direction, torsion and nodal & beam displacement were noted for all analysis with respect to water tank location for building resting on various slopes.

VIII. CONCLUSIONS

After analyzing the results obtained, it was observed that the best suitable position of water tank on different slopes for both two bay frames and four bay frame which were as follows;

1. The base shear, bending moments and shear force in X & Z direction, torsion and nodal & beam displacement with respect to water tank location on corner 1 for building resting on various slopes is minimum for 2 bay and 4 bay structures except for 4 bay structure on plane ground.
2. Corner 1 location of water tank is best location for G+4, 4-Bay & 2 bay frame structures for all slopes except for 4 bay structure on plane ground.
3. Centre position of water tank is best position for G+4, 4-Bay frame for plane ground.
4. As the number of bay varies various parameters changes accordingly.
5. As the slope changes parameters vary along with the slopes.

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Table 1. Results of 2-Bay Frame

Slope	Parameters	Direction	Different Positions of Water Tank		
			Centre	Corner 1	Corner 2
0^0	Base Shear(KN)	X-direction	272.37	290.19	**271.70**
		Z-direction	348.79	366.47	**348.12**
	Bending Moment(KNm)	Y-direction	199.09	**150.41**	175.88
		Z-direction	232.16	**231.22**	302.19
	Torsion(KNm)		25.19	**17.67**	19.59
	Shear Force(KN)	Y-direction	187.39	**161.04**	195.01
		Z-direction	97.66	**87.65**	106.31
	Node Displacement(mm)	-	37.27	**33.12**	82.22
	Beam Displacement(mm)	-	35.71	**32.79**	81.09
10^0	Base Shear(KN)	X-direction	294.75	309.06	**293.89**
		Z-direction	368.61	384.60	**364.82**
	Bending Moment(KNm)	Y-direction	194.16	174.57	**174.15**
		Z-direction	**227.96**	236.35	230.26
	Torsion(KNm)		25.05	**11.46**	15.62
	Shear Force(KN)	Y-direction	186.15	**163.79**	167.74
		Z-direction	94.76	93.54	**89.34**
	Node Displacement(mm)	-	44.12	**39.17**	43.31
	Beam Displacement(mm)	-	42.78	**38.53**	42.78
20^0	Base Shear(KN)	X-direction	278.5	290.29	**277.15**
		Z-direction	315.63	327.51	**310.08**
	Bending Moment(KNm)	Y-direction	186.41	171.95	**169.51**
		Z-direction	220.51	223.92	**219.05**
	Torsion(KNm)		24.46	**11.13**	14.58
	Shear Force(KN)	Y-direction	183.06	**159.41**	169.91
		Z-direction	91.37	84.88	**78.12**
	Node Displacement(mm)	-	45.67	**41.17**	44.86
	Beam Displacement(mm)	-	45.67	**40.32**	44.27

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Table 2. Results of 4-Bay Frame

Slope	Parameters	Direction	Different Positions of Water Tank								
			Centre	Corner1	Corner2	Edge1	Edge2	Edge3	Edge4	Mid1	Mid2
0^0	Base Shear(KN)	X-direction	675.72	663.68	**663.56**	667.2	663.77	663.77	667.12	667.76	667.6
		Z-direction	875.81	880.73	858.92	**858.64**	865.11	865.11	882.0	864.97	864.97
	Bending Moment(KNm)	Y-direction	**120.78**	131.75	151.76	138.57	142.24	142.24	124.15	130.12	130.12
		Z-direction	**215.64**	233.21	231.31	222.78	231.51	231.51	224.97	223.87	223.87
	Torsion(KNm)		24.17	**17.75**	195.61	18.28	31.73	31.73	17.91	18.74	18.74
	Shear Force(KN)	Y-direction	**180.85**	186.21	185.93	187.60	186.03	186.03	188.23	187.61	187.61
		Z-direction	**84.91**	102.65	97.89	95.49	89.93	89.93	94.59	88.82	88.82
	Node Displacement(mm)		**33.50**	56.75	57.51	49.56	55.23	55.23	48.49	48.08	48.08
	Beam Displacement(mm)		**31.67**	56.46	56.44	48.67	55.16	55.16	48.44	47.73	47.73
10^0	Base Shear(KN)	X-direction	796.84	796.15	796.09	795.13	796.22	796.36	795.72	678.96	**678.86**
		Z-direction	950.88	955.46	940.68	**939.97**	944.63	951.02	956.75	671.74	677.64
	Bending Moment(KNm)	Y-direction	184.82	**182.11**	186.46	186.47	185.86	185.18	182.49	186.27	184.89
		Z-direction	248.37	**247.05**	248.42	248.86	248.03	247.84	247.71	246.94	247.56
	Torsion(KNm)		27.03	11.55	12.57	11.41	11.32	11.67	11.91	**11.10**	11.45
	Shear Force(KN)	Y-direction	203.27	**190.79**	195.27	195.47	195.05	195.00	195.14	194.36	194.40
		Z-direction	90.66	**85.67**	89.44	90.16	92.51	91.81	91.39	93.16	92.46
	Node Displacement(mm)		44.87	42.49	42.54	42.79	**42.08**	42.48	42.95	45.39	42.94
	Beam Displacement(mm)		43.59	41.72	41.89	42.08	**41.35**	41.69	42.06	45.50	42.06
20^0	Base Shear(KN)	X-direction	680.86	**678.11**	678.12	678.92	678.25	678.24	678.82	678.96	678.86
		Z-direction	678.12	680.06	665.44	**665.38**	670.68	676.78	681.29	677.74	677.64
	Bending Moment(KNm)	Y-direction	161.92	**159.10**	161.21	161.73	162.89	161.89	159.48	165.28	162.74
		Z-direction	255.42	**245.87**	251.39	253.04	252.22	252.26	254.02	252.94	255.98
	Torsion(KNm)		26.23	**11.08**	11.05	11.00	11.30	11.49	11.68	11.26	11.41
	Shear Force(KN)	Y-direction	200.89	**195.22**	196.18	196.44	195.95	195.91	195.78	196.73	195.47
		Z-direction	76.14	**72.12**	72.38	72.59	73.94	76.05	80.79	73.55	74.86
	Node Displacement(mm)		44.57	44.61	47.32	45.89	44.87	44.23	**44.11**	46.63	44.71
	Beam Displacement(mm)		44.01	43.64	46.65	45.79	44.87	**43.72**	43.02	46.63	44.71

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