BEHAVIOURAL STUDY OF DYNAMIC PROPERTIES OF STEP BACK BUILDINGS WITH AND WITHOUT COREWALLS SITUATED ON SLOPING GROUND

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ABSTRACT - Rapid industrialization and urbanization have propelled large scale construction of multistoreyed structures irrespective of terrain, site conditions and seismic zones. Multi-storeyed Reinforced Concrete framed structures are also getting popular in hilly areas due to various obligatory circumstances. Buildings located in and along the hill slopes, in seismic areas in particular, are susceptible to damages caused due to external excitations. Hence an extra care and attention is required in the analysis and design of these structures constructed in hill slopes, because in those regions only, the structure is more susceptible to damage due to high storey displacement, storey drift, and base shear. Step back buildings are one among the building structures constructed in hilly/sloped areas which are more sensible and vulnerable to seismic excitations. In this research an attempt has been made considering this point and the damage indices for the G+4 and G+15 structures are determined. The analysis has been done adopting shell and membrane elements, on different sloping angle grounds as well and the damage indices have been studied for the structures with and without core walls. ETABS tools were used in this analysis, response spectrum method of analysis is adopted in the tool corresponding to code IS: 1893-2002 part 1. Important conclusions are drawn from the comparison of results on the influence of ground slope, core wall and height of the building with respect to the variation in the top storey displacement and base shear.

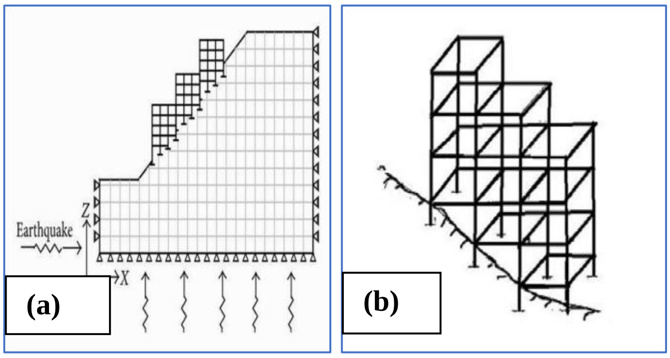
Index Terms – sloping ground, seismic analysis, core wall

I INTRODUCTION

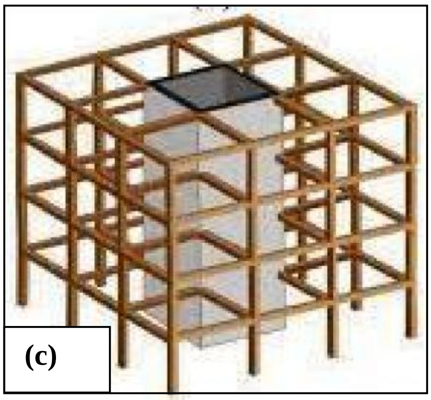
Normally earthquake stand out amongst the most devastating and inconsistent wonder of the nature. When Concrete structures are subjected to seismic drives it causes damage to the structures because concrete has low tensile strength property. With changing socio-economic pattern the space for the construction is getting constricted in urban hilly areas mostly and multistoreyed structures are adopted in these regions. But they are structurally to be more stable and there is a need of bringing forth the seismic resistance elements into the structure. Various such elements are core walls, shear walls, bracings, out triggers & dampers.

Structures constructed in hilly areas have peculiar structural configurations. Successive floors of such buildings step back towards the hill slope and sometimes, the buildings also set back, as shown in the Figure 1. The stepping back of building towards hill slope results in unequal column heights in the same story, which causes severe stiffness irregularities in along and across-slope directions.

When subjected to lateral loads in cross-slope direction, even the buildings with symmetric rectangular configurations are subjected to significant torsional coupling due to the varying lateral stiffness of uphill and downhill side frames. The torsional behaviour of these buildings is much more complex than that of the buildings on flat ground due to shifting of the centre of stiffness and centre of mass with floor level. Thus, many of the structures in earthquake prone areas are suffering from seismic hazards. The structures in the hilly areas should have adequate strength to avoid the failure during earthquakes. Reinforced Concrete core walls usually comprise of connected shear walls forming a rectangular section with opening that may be partially closed by beams or floor slabs. The moment of inertia of reinforced concrete core walls are large, hence it is adequate to carry the entire horizontal forces or lateral load. Furthermore, the location of core walls in a building is said to considerably affect its effectiveness hence the same needs to be addressed. In this research various sloping angles and one position of the core wall are taken based on the literature survey.



(a), (b) Step back Buildings



(c) Core wall structure

Fig.1: Building configurations

1.1 SEISMIC DAMAGE ASSESSMENT

Assessment of multi-storeyed buildings refers to the quantification of damage in components and as well as in the whole building using certain damage indices for an analytical structural model of the building. There are various softwares for assessing seismic damage of the building. Some of these softwares are ETABS, STAAD.PRO and ANSYS.

The importance of core wall, its ability for seismic resistance to the seismic vibrations is projected in this paper by taking two building models G+4 and G+15 on different sloping ground angles like 0, 20, 27 and 40 degrees. Analysis is done using the membrane and shell elements separately with bare frame and frame with core wall at its centre. The point in taking the core wall in the centre is that the core wall is resisting more vibrations at this point, because of its Centre of gravity. Drawing the comparison between the two, retrofit measures can be suggested easily and effectively. The dynamic response of the structure with different storeys and different sloping angles are also observed. Indices like the top storey displacement, base shear are calculated using ETABS and conclusions are drawn for step back buildings.

II. METHODOLOGY

In this research to analyze both the models G+4 and G+15 at different sloping angles linear elastic dynamic analysis is adopted. Response of the models for the given ground excitations are analyzed hence the name response spectrum analysis. The code followed in here is IS:1893-2002 part 2. Through response spectrum analysis we have computed base shear and top storey displacement. Analysis has been done in both X & Y directions considering shell and membrane concepts. The seismic zone considered in this study is zone V in India. For the present study, medium soil condition is considered.

2.1 Building description

In this study, the building is a 3-dimensional structure and is analyzed as special moment resisting frame. For displaying and investigation of the building ETABS programming bundle is used.

The G+15 & G+4 storeyed buildings have been modelled at different sloping angle ground with and without core walls. The model created using ETABS is as depicted in the figures. Buildings are subjected to analysis in accordance to the Indian code practice for design of seismic resistance buildings.

The length and width of the building is 25mx25m size and each bay is 5mx5m. The story height of the building is assumed to be constant including ground storey. Building is considered to be located in zone V and Modal damping of 5% has been considered. The fundamental criteria for using this program is straight forward. We have to set up the grid lines, characterize material property and basic properties, place structural objects in with respect to grid lines utilizing point, line and protest devices. Different types of loads can be defined in load pattern and assigned to respective structural components. The properties like mass source, complete number of mode shapes and its bearings for element investigation can be characterized. After the analysis has been done the outcomes are created in graphical or tabular form which can later be printed to a record for use in other system.

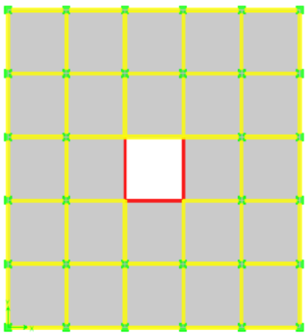
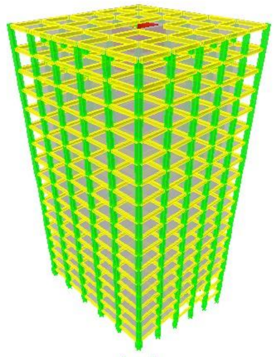



Fig.2: Project model plan and 3D view

2.2 MODEL DESCRIPTION:

The buildings as mentioned earlier were analyzed using two types of elements i) membrane and ii) shell. Buildings are subjected to analysis according to the Indian code practice. The buildings considered are assumed to be fixed at the base and floors acts as a rigid diaphragm. For the modeling and analysis purpose ETABS is used.

Configuration 1: In this configuration G+15 storey and G+4 storey buildings are considered at a sloping angle of 0^0 i.e., plain ground. Elevation of G+4 storey and G+15 storey buildings are as shown in figure 3.

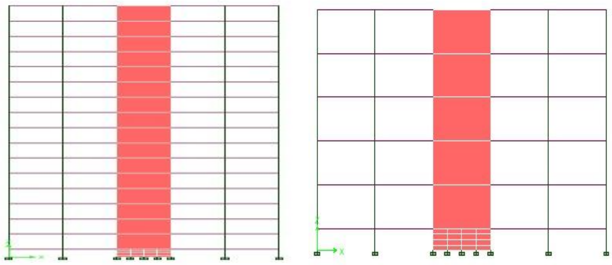


Fig 3: G+15 and G+4 storey building, 0^0 slope

Configuration 2: In this configuration G+15 storey and G+4 storey buildings are considered at a sloping angle of 20^0 i.e., plain ground. Elevation of G+4 storey and G+15 storey buildings are as shown in figure 4.

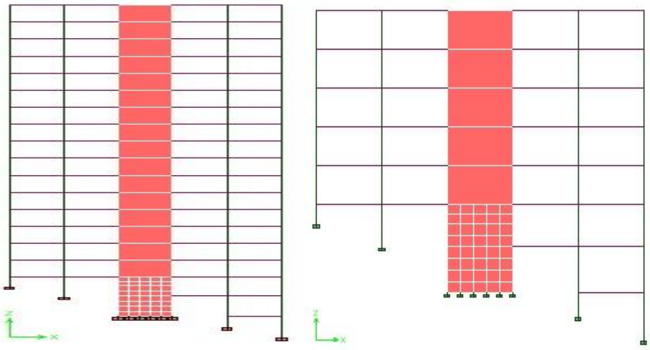


Fig 4: G+15 and G+4 storey buildings, 20^0 Ground slope

Configuration 3: In this configuration G+15 storey and G+4 storey buildings are considered at a sloping angle of 27^0. Elevation of G+4 storey and G+15 storey buildings are as shown in figure 5.

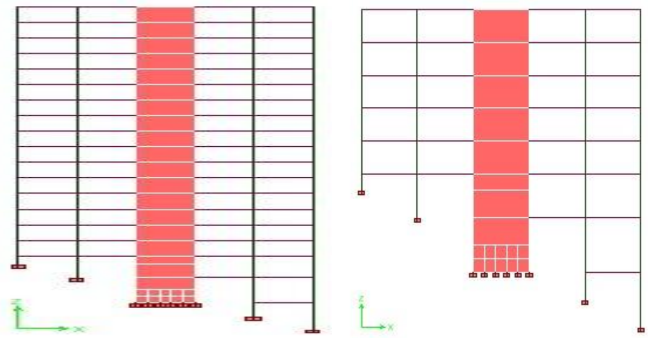


Fig 5: G+15 and G+4 Storey Building, 27^0 Ground slope

Configuration 4: In this configuration G+15 storey and G+4 storey buildings are considered at a sloping angle of 40^0. Elevation of G+4 storey and G+15 storey buildings are as shown in figure 6.

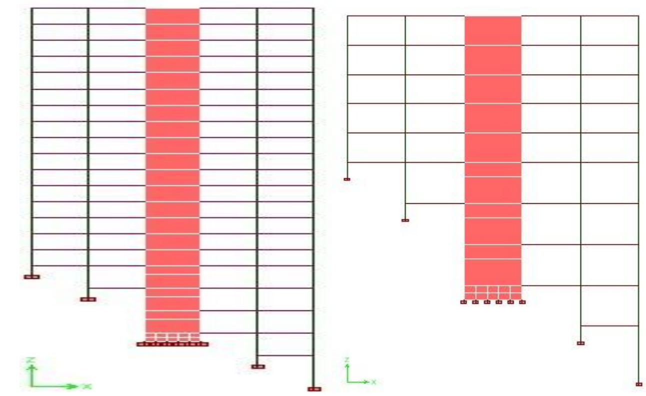


Fig 6: G+15 and G+4 Storey building, 40^0 Ground slop3.

RESULTS AND DISCUSSION

3.1 COMPARISON OF DYNAMIC PROPERTIES FOR G+15 AND G+4 STOREY BUILDINGS

3.1.1 Top Storey Displacement for G+15 storey building in spec x and spec y directions: Top storey displacement is the lateral shift of the top storey of the building due to the effect dynamic loadings and it should not be more than height of the structure by 500.

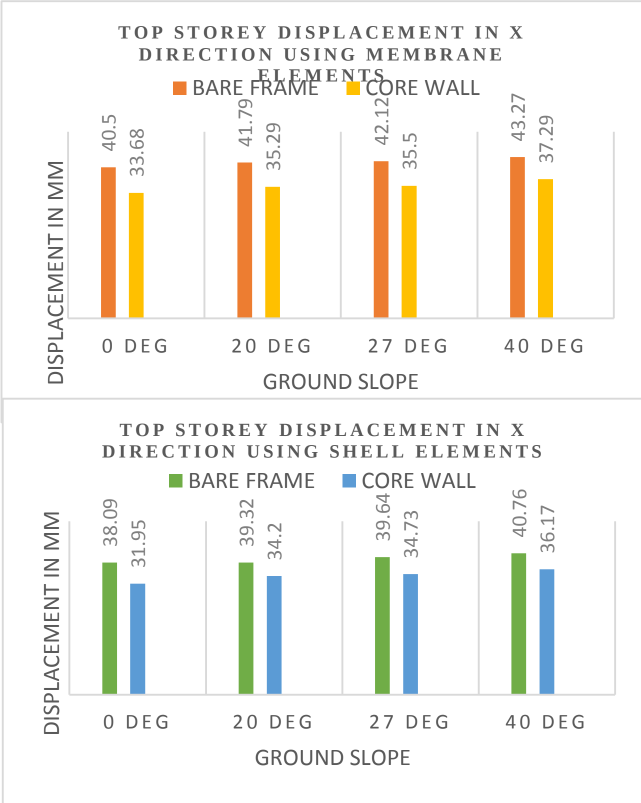


Fig 7: Top storey displacement in X direction (G+15)

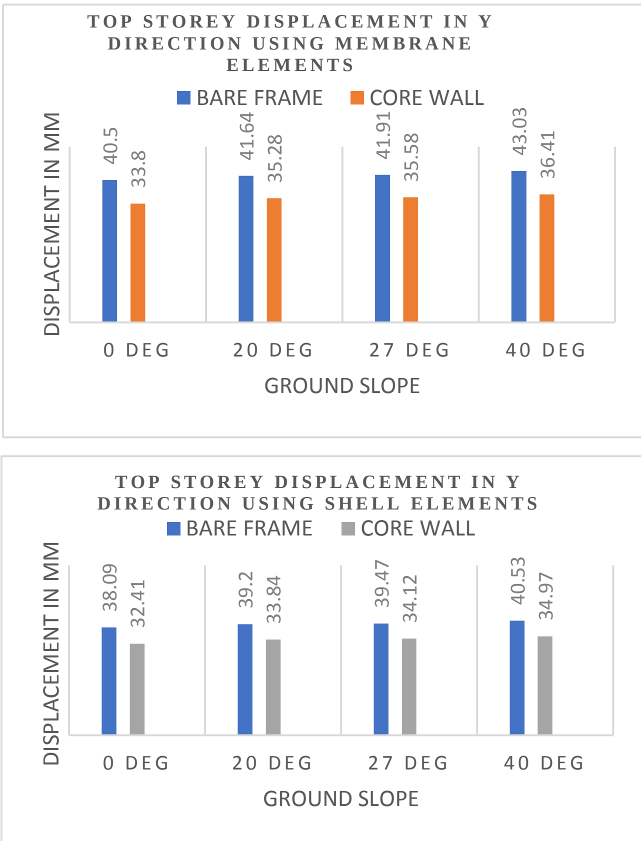


Fig 8: Top storey displacement in Y direction (G+15)

Table 1: Top storey displacements in X direction

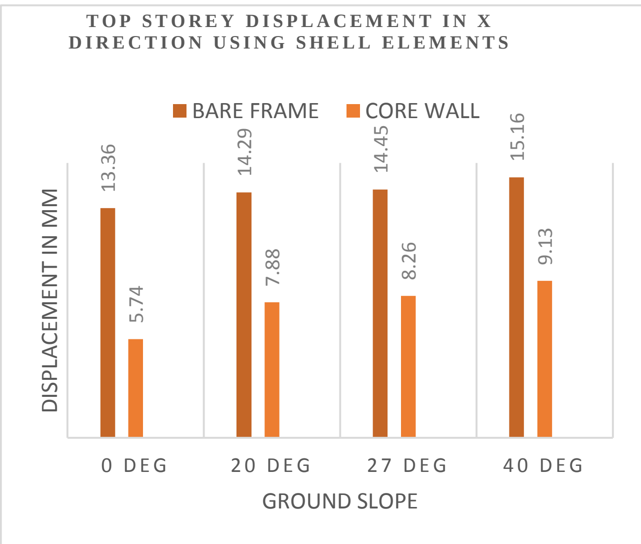
	G+15 Building –X Direction (displacements in mm)							
	Membrane Element				Shell Element			
	0^0	20^0	27^0	40^0	0^0	20^0	27^0	40^0
Bare frame	40.5	41.79	42.12	43.27	38.09	39.32	39.64	40.76
Core wall	33.68	35.29	35.85	37.29	31.95	34.2	34.73	36.17
%reduction	16.83	15.55	14.88	13.82	16.11	13.02	12.38	11.26

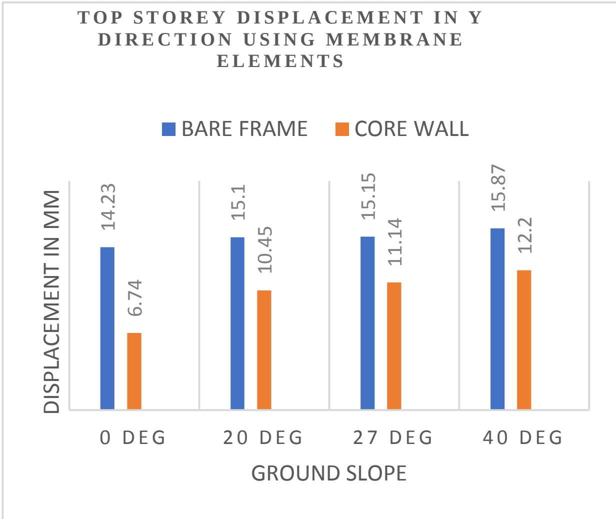
Table 2: Top storey displacement in Y direction

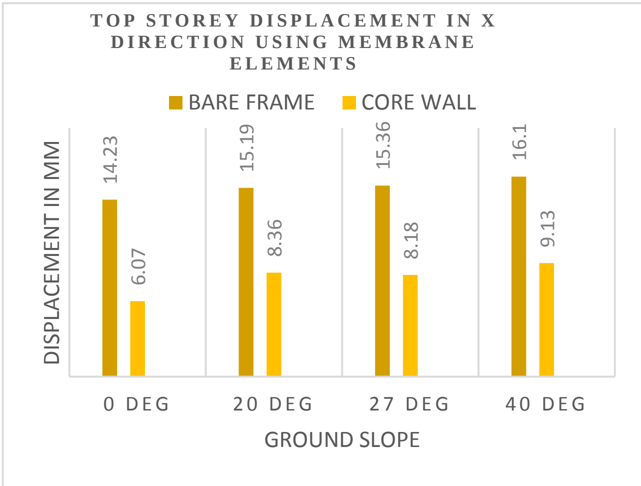
	G+15 Building – Y Direction (displacements in mm)							
	Membrane Element				Shell Element			
	0^0	20^0	27^0	40^0	0^0	20^0	27^0	40^0
bare frame	40.5	41.64	41.91	43.03	38.09	39.20	39.47	40.53
Core wall	33.8	35.28	35.58	36.41	32.41	33.84	34.12	34.97
%reduction	16.5	15.27	15.10	15.38	14.91	13.67	13.55	13.71

From fig.7 and 8 it is observed that in G+15 storey building top storey displacement both in X and Y direction increases with increase in the slope of ground. This displacement reduces by 17% and 11% on the introduction of core wall at the centre at 0^0 ground slope and 40^0 ground slope respectively. Compared to the analysis using membrane elements the analysis using shell elements have yielded 5 to 8 % lesser values of displacements.

3.1.2 Top Story Displacement for G+4 storey building in spec x and spec y directions:







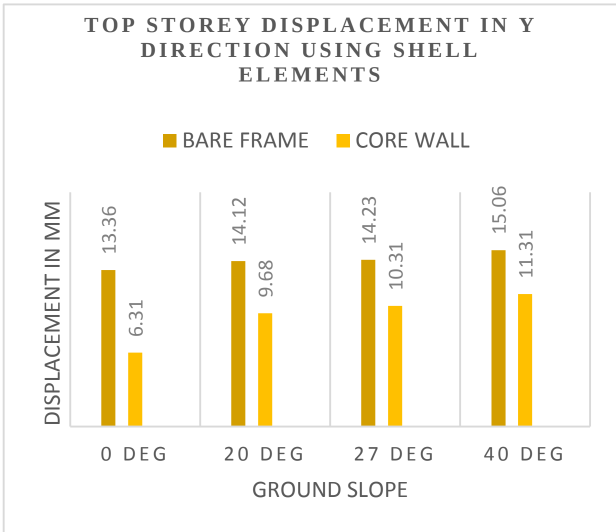


Fig 9: Displacement of G+4 building in X & Y direction (G+4)

Table 3: Displacement of G+4 building in X & Y directions

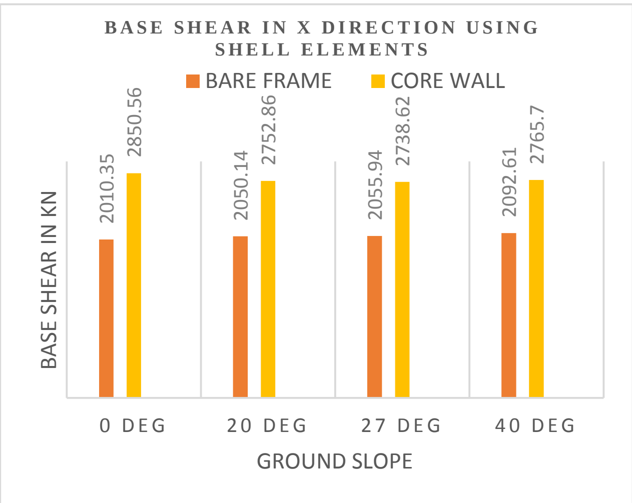
	G+4 - X DIRECTION (displacements in mm)							
	Membrane Elements				Shell Elements			
	0^0	20^0	27^0	40^0	0^0	20^0	27^0	40^0
Bare frame	14.23	15.19	15.36	16.1	13.36	14.29	14.45	15.16
Core wall	6.07	8.36	8.18	9.75	5.74	7.88	8.26	9.75
%reduction	57.34	44.96	46.74	39.44	57.03	44.85	42.83	35.68
	G+4 - Y DIRECTION (displacements in mm)							
	Membrane Elements				Shell Elements			
	0^0	20^0	27^0	40^0	0^0	20^0	27^0	40^0
Bare frame	14.23	15.1	15.15	15.87	13.36	14.12	14.23	15.06
Core wall	6.74	10.45	11.14	12.2	6.31	9.68	10.31	11.31
%reduction	52.63	30.79	26.46	23.12	52.76	31.44	27.54	24.90

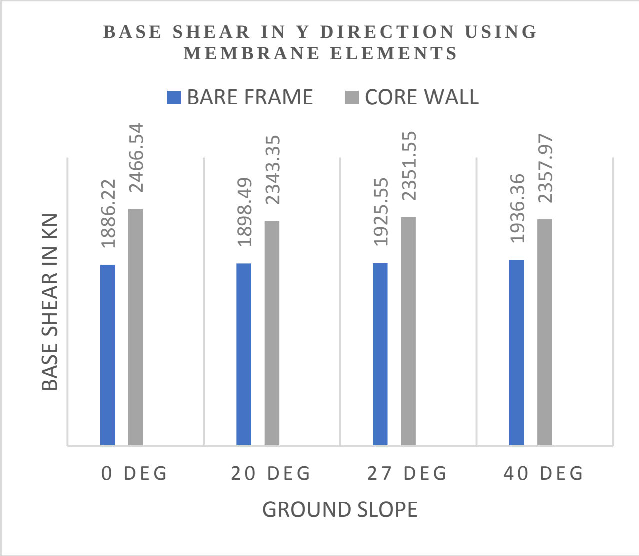
From fig.9 it is observed that in G+4 storey building top storey displacement both in X and Y direction increases with increase in the slope of ground. This displacement reduces by 52-57% and 23-25% on the introduction of core wall at the centre at 0^0 ground slope and 40^0 ground slope respectively. Compared to the analysis using membrane elements the analysis using shell elements have yielded 5 to 8 % lesser values of displacements.

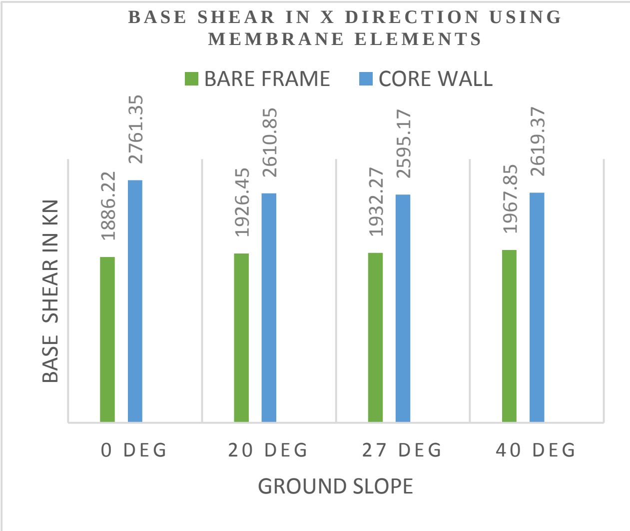
3.1.3 Base shear in spec x and spec y directions:

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. Calculations of base shear (V) depend on: soil conditions at the site, proximity to potential sources of seismic activity etc.

Base shear in spec x and spec y directions of G+15 storey building:







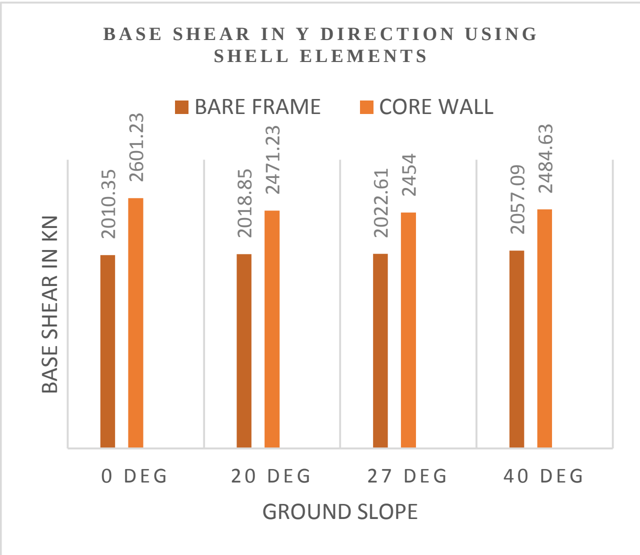


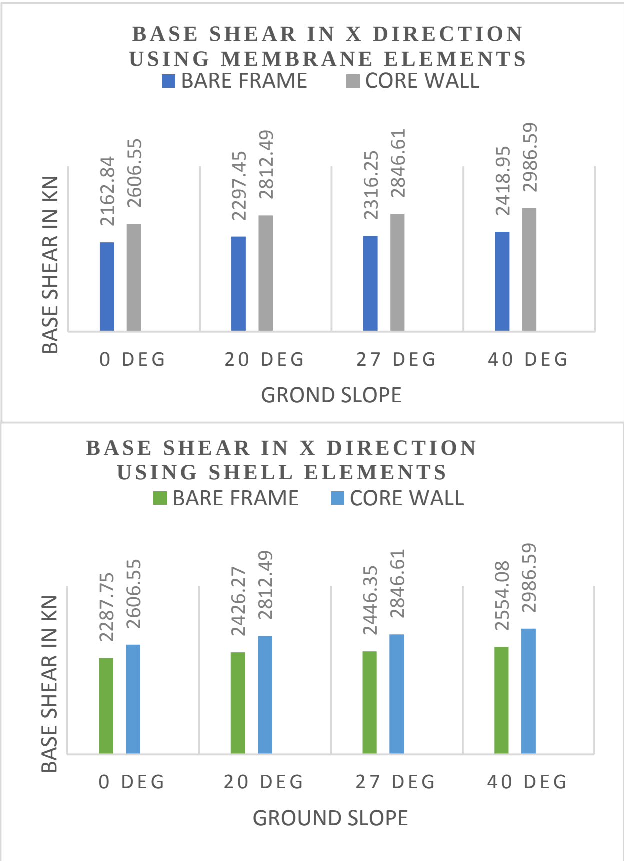
Fig 10: Base Shear of G+15 building in X & Y directions

Table 4: Base Shear of G+15 storey building in spec X & spec Y directions.

	G+15 - X DIRECTION							
	Membrane Elements				Shell Elements			
	0^0	20^0	27^0	40^0	0^0	20^0	27^0	40^0
Bare frame	1886.22	1926.45	1932.27	1967.85	2010.35	2050.14	2055.94	2092. 61
Core wall	2761.35	2610.85	2595.17	2619.37	2850.56	2752.86	2738.62	2765.7
%increase	46.39	35.52	34.30	33.10	41.79	34.27	33.20	32.16
	G+15 - Y DIRECTION							
	Membrane Elements				Shell Elements			
	0^0	20^0	27^0	40^0	0^0	20^0	27^0	40^0
Bare frame	1886.22	1898.49	1925.55	1936.36	2010.35	2018.85	2022.61	2057.09
Core wall	2466.54	2343.35	2351.55	2357.97	2601.23	2471.23	2454	2484.63
%increase	30.76	23.43	22.12	21.77	29.39	22.40	21.32	20.78

From Fig.10 it is observed that as the slope of the ground increases Base shear increases both in X and Y directions. Comparatively the Percentage increase in Base shear is more in X direction i.e., along the sloping direction. The percentage increase in Base shear is around 40-46% at 0^0 slope and reduced to around 32-33% at 40^0 slope. The increment in Base shear found less in shell elements compared to membrane elements.

Base shear in spec x and spec y directions of G+4 storey building:



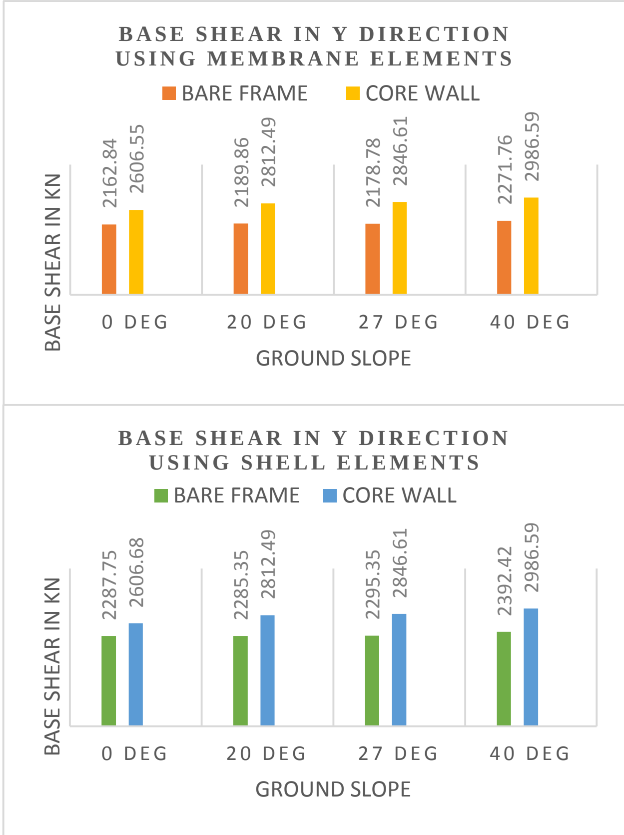


Fig 11: Base Shear of G+4 building in X & Y directions

Table 5: Base Shear of G+4 storey building in X & Y directions.

	G+4 - X DIRECTION							
	Membrane Elements				Shell Elements			
	0^0	20^0	27^0	40^0	0^0	20^0	27^0	40^0
Bare frame	2162.84	2297.45	2316.25	2418.95	2287.75	2426.27	2446.35	2554.08
Core wall	2606.55	2812.49	2846.61	2986.59	2606.55	2812.49	2846.61	2986.59
%increase	20.51	22.41	22.89	23.46	13.93	15.91	16.36	16.93
	G+4 - Y DIRECTION							
	Membrane Elements				Shell Elements			
	0^0	20^0	27^0	40^0	0^0	20^0	27^0	40^0
Bare frame	2162.84	2189.86	2178.78	2271.76	2287.75	2285.35	2295.38	2392.42
Core wall	2606.55	2812.49	2846.61	2986.59	2606.68	2812.49	2846.61	2986.59
%increase	20.51	28.43	30.65	31.46	13.94	23.06	24.01	24.83

From Fig.11 it is observed that as the slope of the ground increases Base shear increases both in X and Y directions. The percentage increase in Base shear is around 13-20% at 0^0 slope and increased to around 16-23% at 40^0 slope. The increment in Base shear found less in shell elements compared to membrane elements.

IV Conclusions:-

In this research G+4 and G+15 Buildings were analyzed with different slopes of ground 0^0,20^0,27^0 and 40^0. In all cases, same size of core wall was adopted at the centre of the building. Graphs were plotted. From the study, the following conclusions are arrived at:

1) As the slope of the ground increases top storey displacement increases, towards the increasing slope direction, maximum being at 40^0 sloping angle with horizontal.

2) Compared to buildings with bare frame, the top storey displacement in the case of buildings with core wall is uniformly less. This reduction becomes much less in the case of G+15 storey compared to G+4 storey building. As the number of storeys increases the effect of core wall in reducing the top storey displacement becomes less. Here, uniform size of core wall has been adopted for both types of buildings. The effect will be better if the size of the core wall is increased.

3) The top storey displacements obtained using shell elements gives less displacement compared to the displacements obtained using membrane elements.

4) In the case of G+15 storey building the reduction in the displacement on the use of core wall is around 17% in the case of 0^0 slope. This reduction reduces to around 11% in a case of 40^0 slope.

5) In the case of G+4 building the reduction in the displacement on the use of core wall is 52-57% in the case of 0^0 slope. This reduction reduces to 23-25% in a case of 40^0 slope. Hence the core wall is found to be much effective when the number of storeys is less.

6) Hence, as the number of storeys increases the percentage reduction in the top storey displacement decreases. This is in the case of same size of core wall for both buildings. This need further research on varying the cross sectional dimensions of the core wall.

7) As the slope of the ground increases the percentage increment in base shear reduces in both X and Y directions, maximum reduction being at 40^0 slope with Horizontal.

8) Compared to buildings with bare fame the base shear in the case of building with core wall uniformly increases. This increment become much less in the case of G+4 storey compared to G+15 storey building. As, the number of storeys increases the effect of core wall in increasing the base shear becomes more.

9) The base shear obtained using shell elements gives lesser values compared to values obtained using membrane elements.

10) In case of G+15 storey building the increase in base shear on the use of core wall is around 47% in the case of 0^0 slope. The increment reduced to around 33% in the case of 40^0 slope.

11) In the case of G+4 building the increment in the base shear on the use of core wall is 20% in the case of 0^0 slope. This increment increases to 23% in the case of 40^0 slope.

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