SEISMIC RESPONSE OF MULTI-STOREY BUILDING WITH OBLIQUE COLUMNS

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Abstract - *In recent decades there are more complex structures that are challenging earthquake theories. The earthquake involves generating seismic waves which passes through earth crest and causes massive damage to the existing structures. The densely populated area in which the buildings are not perfectly modeled can be called as earthquake prone area where the small earthquake causes a disastrous effect. The columns where they are neither parallel to each other nor they are exactly vertical are known as oblique columns. The specialty of these oblique columns is that the angle which is greater than 90 degree will have increase in its plan as we move to higher floors whereas the angle of column which is less than 90 degree will have its plan decreased as we move to higher floors. The oblique restraint causes coupling action on the principal axes.*

In this present study it involves the study of oblique column effect on a model which has 30 floors in which Height of each floor is 3.2m. The width of each bay at base is 7m. The columns are inclined at an angle of 80°, 82.5°, 85°, 87.5°, 92.5^{o}. Here linear static and dynamic analysis are done and results are obtained.

***Key Words*: ETABS, Oblique Columns, Storey shear, Storey drift, Storey Displacements, Overturning Moment.**

1. INTRODUCTION

The country economic and technical growth will be indicated by level of high-rise structures. Fewer countries have made such advancement in their design and have achieved the high standards of living. The appearance of high-rise buildings are more due to various free style of architecture features. The Pacific seismic belt and Europe Asia seismic zone are present in China country which is developing with densely populated area and has low seismic capacity building. It has most dangerous seismic area in which the building has to be designed by considering earthquake intensity.

There has been adoption of a kind of columns called oblique columns in case of multi-storied structure instead of normal columns for seismic resistance in a building. It is a type of column where it is not constructed exactly vertical. It can be adopted in medium, high and low rise structures. Oblique columns are unique because of its arrangement and angle at which it is inclined. If the angle of oblique column varies, there is change in its performance. One of the characters that changes in case if we adopt oblique column is that there will be decrease in plan when the angle is below 90 degree and there will be increase in plan if the angle is above 90 deg. The seismic performance of the oblique column needs to investigated for it adoption in a high rise structure. If the performance of this type of columns has advantages then it can be adopted in construction engineering for yielding better results. The earthquake forces are evaluated by calculating the structural response of the building. There are various methods of seismic analysis like Pushover method of analysis, static method of analysis, response spectrum of analysis and time history method are done for both linear and non-linear type of analysis. In our study we follow **Response Spectrum Method** which is a dynamic method for analyzing a building. The structure is analyzed by building a model in conceptual and these results can be obtained. In a structure minimum 3 modes should be obtained where in second or third mode will be negligible.

For the design and analysis of a structure ETABS software can be used for both simple and for complicated models. It consists of codes which are inbuilt. There is a common data base in which procedures and codes are being used. In this we can recover the material properties, column data and about member forces. According to the design codes it consists of load combinations that are inbuilt with the database.

2. LITERATURE REVIEW

Rohan Singh, Vikas Prabhakar [22](Study of Multistoried buildings with oblique columns) (2020).Analyzing the behavior of oblique columns was that the main purpose of this study. Since the Oblique columns are not conventionally parallel or at right angles to a specified line therefore, they are rotated or inclined at an angle, resulting in decrease of plan dimensions for oblique column below 90° and for above 90°, there'll be increase in plan dimensions as we reach upper floors. It affects the lateral stiffness of building and oblique columns below 90° have lesser storey shear values. Therefore, analysis is carried out by considering columns of 80°, 82°, 84°, 86°, 88° and 90° degrees. The structure is analyzed for both dynamic and for static loading. Ground motion performance of oblique columns are analyzed by Response spectrum method. The analysis of the buildings is done by using ETABS software and the performance is analyzed by same building with oblique columns replaced with normal vertical columns. The analyzed results prove that oblique columns are more seismic resistant than conventional columns since optimized oblique columns show 67% lesser story drift than normal columns. The multistoried buildings with oblique columns show 69% lesser maximum story displacement and 28% lesser story shear up to certain degree of inclination. Structure provides more resistance in the oblique column building, which makes the structural system more effective.

Navaneeth Krishna, Abhishek C. V[20](Seismic behavior of multistoried building with oblique column and its height optimization)(2020).In this study, a multistoried building is analyzed by considering oblique columns. Oblique columns are neither parallel nor at right angles to a specified line means, they are slanted or Rotated at an angle. Oblique columns are columns at an angle to the specified line, they are provided up to various height of the building. The analysis is carried out in ETABS16.0.2. by considering parameters like storey drift, storey displacement and earthquake load.

The results after analysis of structure with oblique column of angles 80°, 82°,85° and structure with normal column, comparing the above two, structure with oblique column shows higher reduction in storey displacement and storey drift compared to structure with normal columns. Hence, oblique column improves the performance of the building by resisting the seismic forces and reduces the effect of seismic forces of inner column. Column inclination and structural symmetry plays an important role in structural design.

Geethu Krishna K V and Lakshmi L [10](Study on seismic performance of multi-storeyed building with oblique columns) (2019). In this study they have experimented on oblique columns. In order to increase the seismic performance of the building the new construction technique of oblique columns is in use. Oblique columns are the columns at an angle to the specified line. The experiments have been conducted to study the performance of oblique columns to compare different parameters using response spectrum analysis by ETABS software. Here total they have used 9 models for their study. It consists of G+19 (high rise building), G+9 (mid-rise building) and G+3 (low-rise building). These three models have been used and oblique columns are at an angle of 80, 85 and 90 degrees. The results have concluded that the storey displacement for 80-degree column is 40% lesser. The storey drift will be increased when angle of oblique column increases. The storey shear is less when there are 90 degree columns. The stiffness increases if the angle of column is decreases.

Girish Kumar G. M and S.M Maheshwarappa [11] (Seismic performance study of multi-storied buildings with oblique columns by using ETABS) (2018).Here the study has been conducted on oblique columns with different angles in a high-rise structure. The response spectrum analysis has been carried out. The results of storey drift, displacement, shear are observed and compared with a regular building. The oblique columns are neither at right angles nor parallel to each other and they are slanted with an angle. Here the columns have been slanted in a degree of 80, 84, 88, 92, 96 and for 100 degrees. Both dynamic and static analysis has been conducted on the RCC structure considered. Earthquake analysis is done by response spectrum method. The size regular column considered is 750mmx750mm and for oblique column it is considered as 350mmx650mm.The analysis results show that the oblique columns with and angle 80,84 and 88 degrees has 41% less top storey displacement and 28% less storey shear when compared with normal columns. In case of 92, 96 and 100 degree oblique column has 30% less storey displacement. The oblique column has 38% lesser storey drift when compared with normal columns. By over all means the oblique columns have more seismic resistant than normal columns.

Muhammad Mostafijur Rahman et.al [19] (Seismic performance of reinforce concrete buildings designed according to codes in Bangladesh, India and U.S.)(2018).

This paper focuses on the comparison of seismic design provisions in Bangladesh (BNBC-1993), India (IS-1893), and the U.S. (ASCE 7-10) in relation to analysis, design, and seismic performance of reinforced concrete buildings on the basis of the type of allowable analysis procedures, zoning system, site classification, fundamental vibration period of the structure, response reduction factor, importance factor, minimum design lateral force, allowable story drifts, and design response spectra Three geometrically similar commercial reinforced concrete buildings in high seismic regions of Bangladesh, India, and U.S. were designed and detailed per the respective codes. Three-dimensional nonlinear dynamic analyses of the designed structures were conducted. Each structure was subjected to a pair of orthogonally applied artificial ground motions compatible with the design response spectrum for each building code. The structural performance of each building was compared in terms of roof displacements, inter-story drifts, load carrying capacity of beams and columns, and overall energy dissipation characteristics. The comparisons allowed an in-depth evaluation of the differences in the seismic performance of buildings designed according to ASCE 7-10, BNBC-1993, and IS-1893 codes. The Indian code performed better when subjected to the ground motion that is intended to represent the Indian design response spectrum.

3. OBJECTIVE OF STUDY

- To study the effect on ordinary moment resisting frame building for seismic loading in terms of storey displacement, storey shear, overturning moment and storey drift.
- To study the effect on buildings with oblique columns of 80, 82.5, 85, 87.5 and 92.5 degree for seismic loading in terms of storey displacement, storey shear, overturning moment and storey drift.

4. METHODOLOGY

4.1 Modeling

ETABS is a complex structural analysis package. It can be used for the analysis and design of buildings and its components. No need of text commands, because it has powerful GUI- graphical user interface system. Buildings can easily modeled by using available components. It is capable of handling the most complex structures which includes the effect of wide range of non-linear behavior. The updated version of ETABS provides 3D object based modeling and visualization tools, fast linear and non-linear analytical power, sophisticated and comprehensive design capabilities for a wide range of materials and insightful graphic displays, reports and schematic drawings that allow users to quickly and easily decipher and understand analysis and design results.

Here 6 models are analyzed. It consists of 30 storey building. The models are generated by considering column angle 80 degree, 82.5 degree, 85 degree, 87.5 degree, 90 degree and 92.5 degree. Height of each floor considered is 3.2m. The plan is rectangular in nature. Spacing maintained between the columns is 7m. Here live load considered is 2kN/m² and Floor load will be 1.1KN/m².

4.2 Building Information

Table -1: Concrete Property M25

Properties	Values
Weight/unit volume	24.99KN/m³
Mass/unit volume	2548.53Kg/m³
Modulus of Elasticity	25000Mpa
Poison's ratio	0.2
Strength (compressive)	25Mpa

Table -2: Concrete Property M30

Properties	Values
Weight/unit volume	24.99KN/m³
Mass/unit volume	2548.53 Kg/m³
Modulus of Elasticity	27386.12Mpa
Poison's ratio	0.2
Strength (compressive)	30Mpa

Table -3: HYSD 500 Properties

Properties	Values
Weight per unit volume	76.97 KN/m³
Elastic modulus	200000Mpa
Mass per unit volume	7849.04Kg/m³
Minimum tensile strength	545Mpa
Minimum yield strength	500Mpa

Table -4: Structural Elements Property

Elements	Material	
	Concrete	Rebar
Beam	M25	HYSD 500
Column	M30	HYSD 500
Slab	M25	HYSD 500

4.3 LOADS:

4.3.1 Dead Loads:

- IS 875-1987 (Part -1) is used
- Floor finish considered is 1.1KN/m².
- The material properties are considered according to IS875-1987 (Part-1)

4.3.2 Live Loads:

- IS 875-1987 (Part-2) is used
  Live load considered is 2 KN/m^2
- The model is considered as commercial and values are taken from IS875-1987 (Part-2)

4.3.3 Earthquake Loads:

- IS 1893-2002 (Part-1) is used
- The loads will not occur frequently
- The Time History is matched for 1940 El Centro Earthquake, North South Component (Peknold Version)

Table -5: Parameters considered for earthquake analysis

Parameters	Consideration
Response reduction factor	3
Zone factor	0.36
Importance factor	1
Soil Type	Medium soil
Damping	5%

Table -6: Load combinations considered for the Analysis and Design

Combination of Loads	Load Combination Details
Combo 1	1.5DL
Combo 2	1.5DL+1.5LL
Combo 3	1.2DL+1.2LL+1.2EQX
Combo 4	1.2DL+1.2LL-1.2EQX
Combo 5	1.2DL+1.2LL+1.2EQY
Combo 6	1.2DL+1.2LL-1.2EQY
Combo 7	1.5DL+1.5EQX
Combo 8	1.5DL-1.5EQX
Combo 9	1.5DL+1.5EQY
Combo 10	1.5DL-1.5EQY
Combo 11	0.9DL+1.5EQX
Combo 12	0.9DL-1.5EQX
Combo 13	0.9DL-1.5EQY
Combo 14	0.9DL+1.5EQY

4.4. MODELS CONSIDERED FOR STUDY:

Model 1: Oblique column with angle 80 degree

Model 2: Oblique column with angle 82.5 degree

Model 3: Oblique column with angle 85 degree

Model 4: Oblique column with angle 87.5 degree

Model 5: Oblique column with angle 90 degree

Model 6: Oblique column with angle 92.5 degree

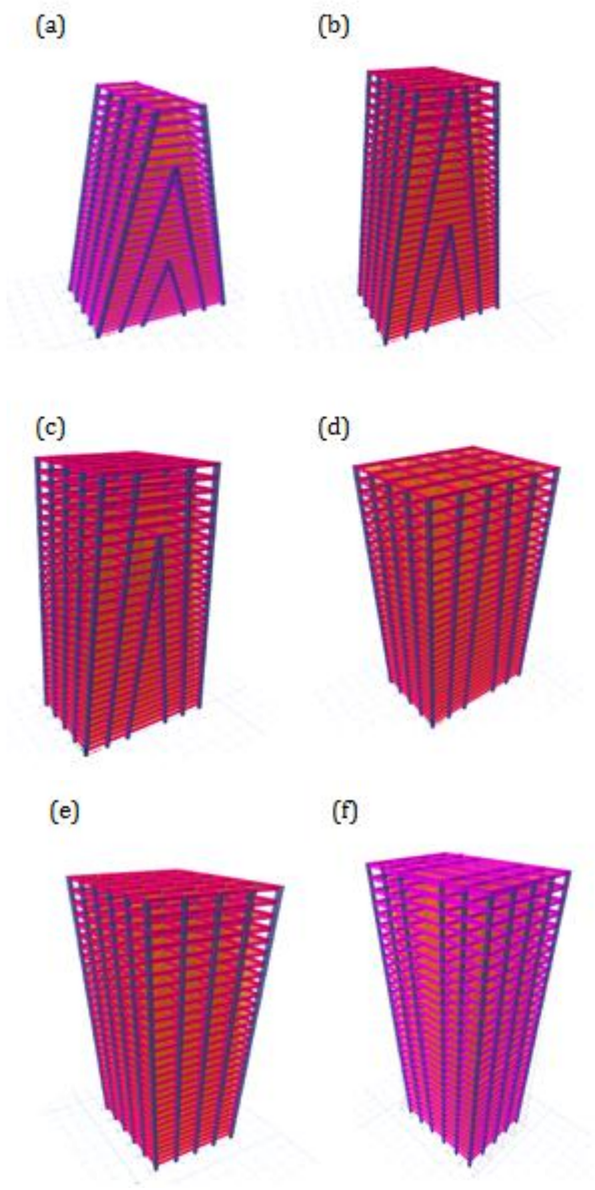

Figure 1 (a, b, c, d, e and f) 3D view of E-TABS model of Multistoried buildings with oblique column of 80, 82.5, 85, 87.5, 90 and 92.5 degrees respectively

5. RESULTS AND DISCUSSION

Table -7: Maximum Storey displacement for all buildings

Inclination of Column	Maximum Storey Displacement(mm)			
	EQX	EQY	Time X	Time Y
80°	40.16	81.33	96	62.387
82.5°	42.329	77.74	29.391	50.428
85°	44.977	69.43	41.726	47.445
87.5°	62.984	76.384	43.438	163.048
90°	73.157	69.62	52.03	49.29
92.5°	95.287	74.599	95.287	103.996

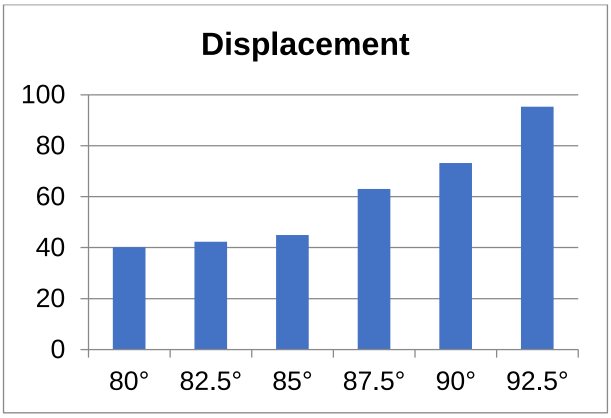

Chart -1: Maximum Storey Displacements (mm) of 30- Storey Buildings for EQX

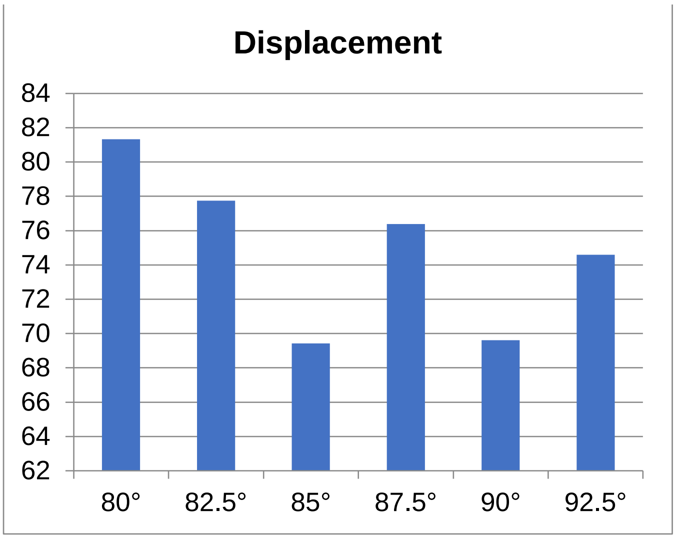

Chart -2: Maximum Storey Displacements (mm) of 30- Storey Buildings for EQY

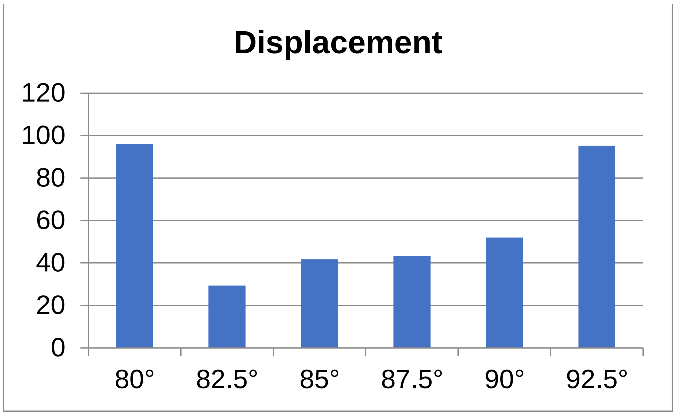

Chart -3: Maximum Storey Displacements (mm) of 30- Storey Buildings for Time X

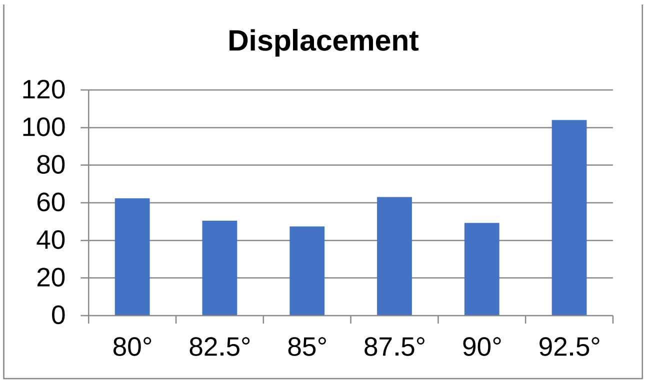

Chart-4: Maximum Storey Displacements (mm) of 30- Storey Buildings for Time Y

Table -8: Maximum Storey drifts for all buildings

Inclination of Column	Maximum Storey Drift			
	EQX	EQY	Time X	Time Y
80°	0.001096	0.001139	0.000881	0.000879
82.5°	0.000954	0.001252	0.00112	0.001222
85°	0.000668	0.000915	0.000727	0.000773
87.5°	0.001299	0.0035	0.00139	0.00131
90°	0.000937	0.0009	0.0008	0.00076
92.5°	0.000864	0.001085	0.00136	0.001556

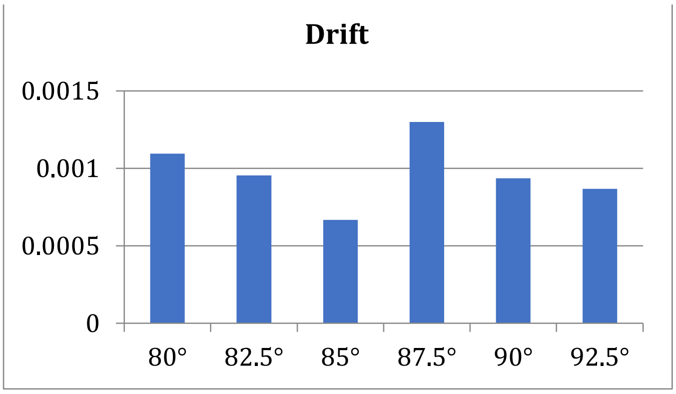

Chart -5: Maximum Storey Drift of 30- Storey Buildings for EQX

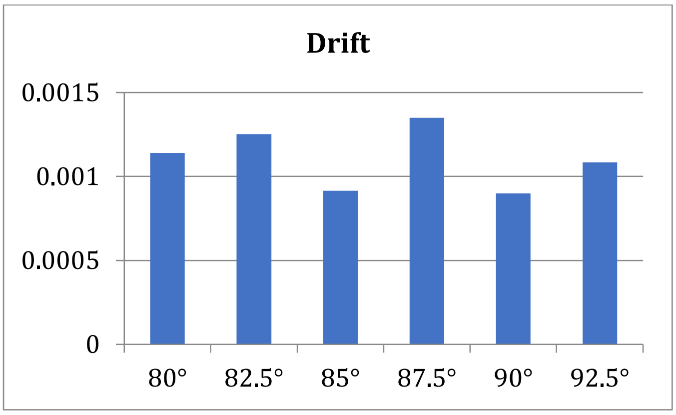

Chart -6: Maximum Storey Drift of 30-Storey Buildings for EQY

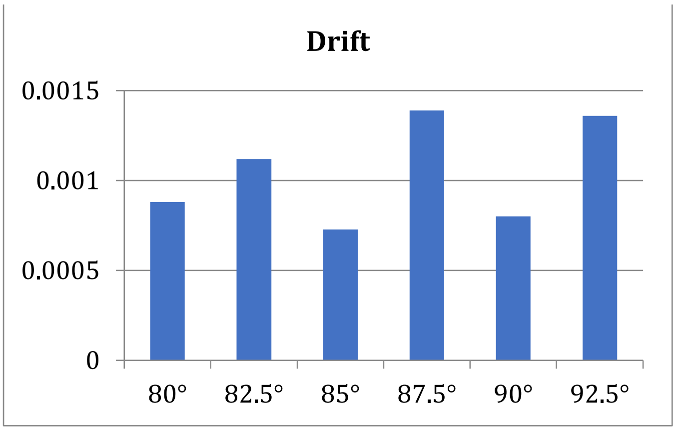

Chart -7: Maximum Storey Drift of 30-Storey Buildings for Time X

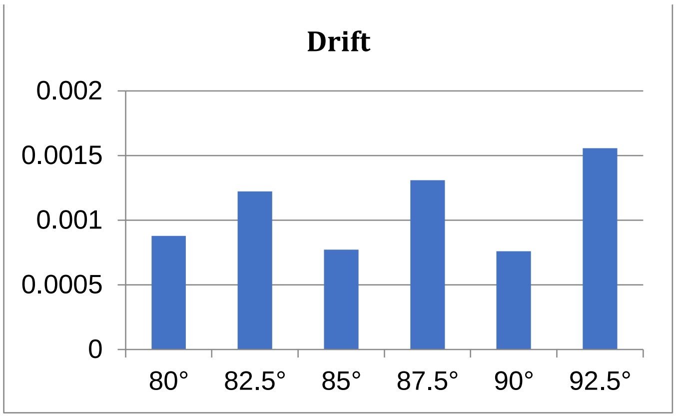

Chart -8: Maximum Storey Drift of 30-Storey Buildings for Time Y

Table -9: Maximum Overturning Moment for all buildings

Inclination of Column	Maximum Overturning Moment (KN-m)			
	EQX	EQY	Time X	Time Y
80°	611225.5	297769.7	452451.7	611225.5
82.5°	543433	323139.35	396181.5	209998.5
85°	456116	329420.6	413123.3	227651.7
87.5°	404489	368287	277842	300890
90°	373964	387124	257727	264699
92.5°	334801.9	314048	453827	415655

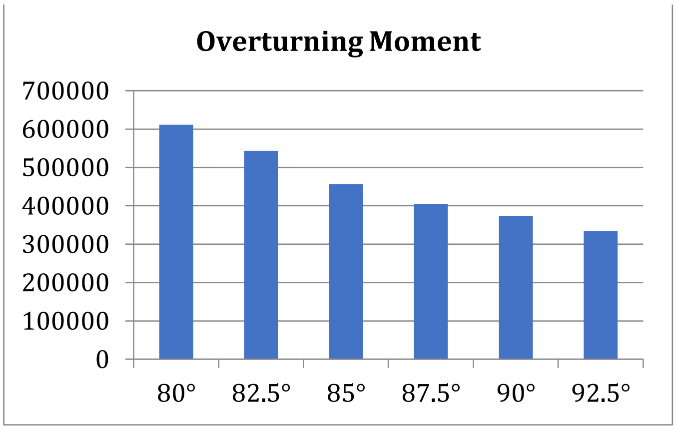

Chart -9: Maximum Overturning of 30- Storey Buildings for EQX

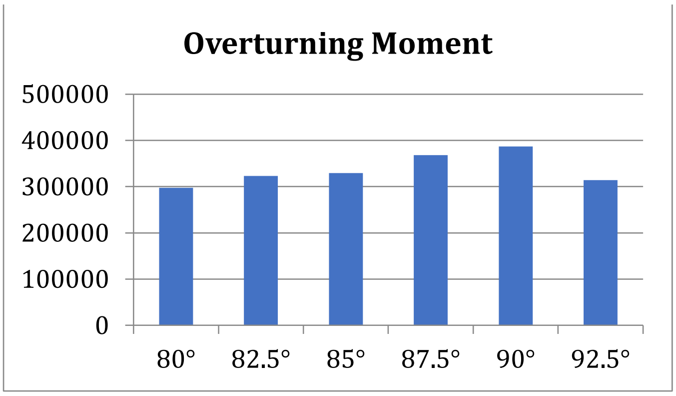

Chart -10: Maximum Overturning of 30- Storey Buildings for EQY

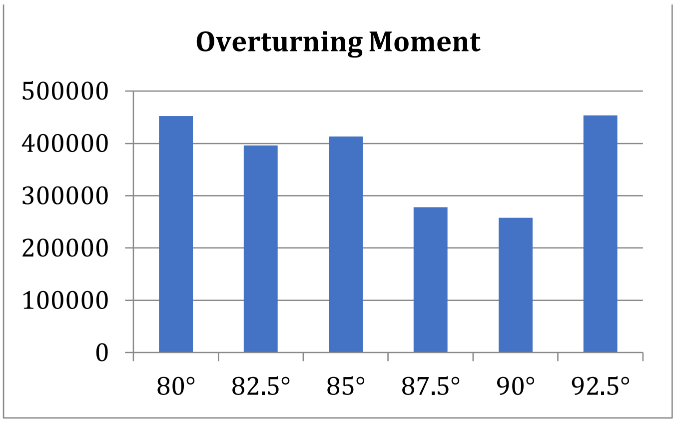

Chart -11: Maximum Overturning of 30-Storey Buildings for Time X

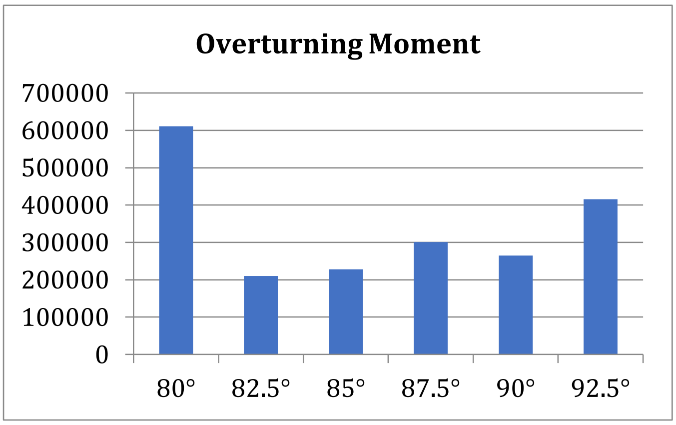

Chart -12: Maximum Overturning of 30-Storey Buildings for Time Y

Table -10: Maximum Storey Shear for all buildings

Inclination of Column	Storey Shear (KN)			
	EQX	EQY	Time X	Time Y
80°	9327.26	4589	9327.31	4588.96
82.5°	7884.2	4751.73	7883.9	4751.69
85°	6515.83	4728	6631.39	4728
87.5°	5701.38	5205.18	5701	5205
90°	5124.27	5304.59	5124	530461
92.5°	4551.85	7186.3	7535.94	7186.3

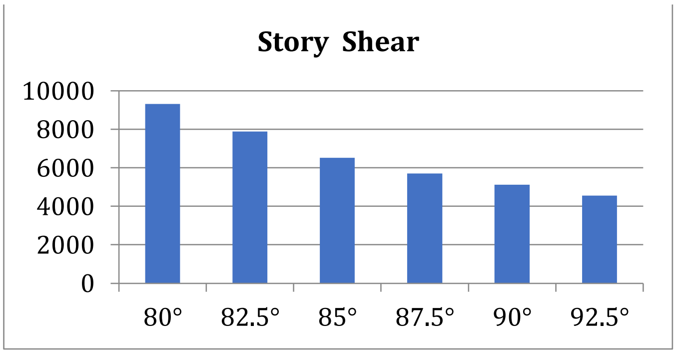

Chart-13: Maximum Storey Shear (KN) of 30- Storey Buildings for EQX

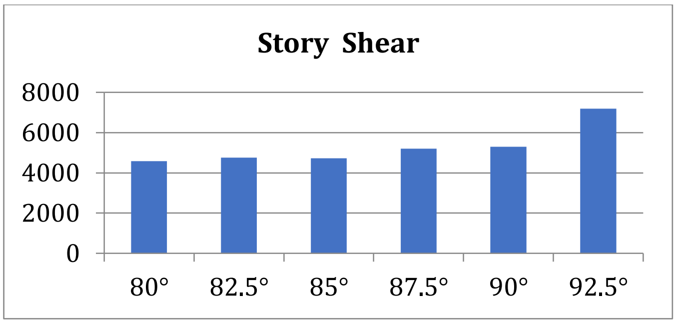

Chart -14: Maximum Storey Shear (KN) of 30- Storey Buildings for EQY

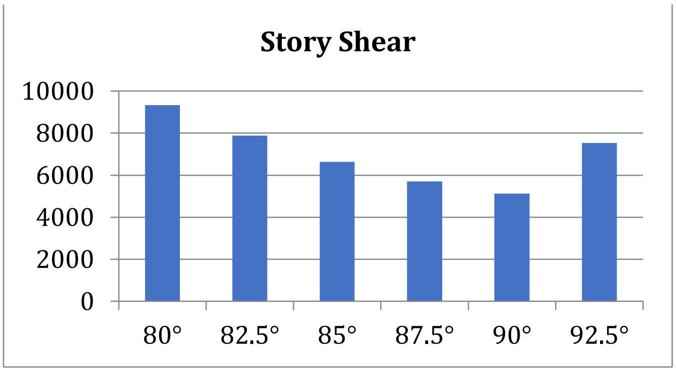

Chart- 15: Maximums Storey Shear (KN) of 30- Storey Buildings for Time X

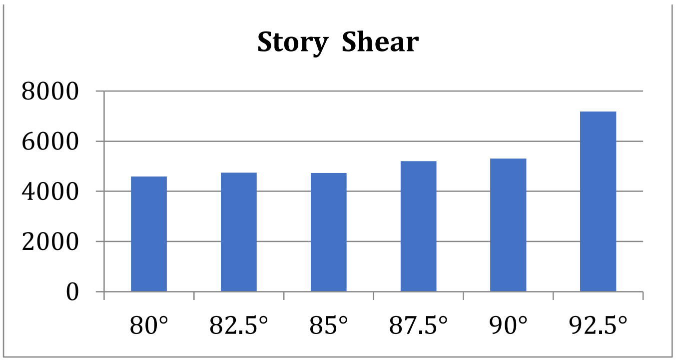

Chart -16: Maximum Storey Shear (KN) of 30- Storey Buildings for Time Y

Table -11: Time Period for all the oblique column buildings

Model	80°	82.5°	85°	87.5°	90°	92.5°
Time Period	2.20	2.52	2.58	2.92	2.77	3.19

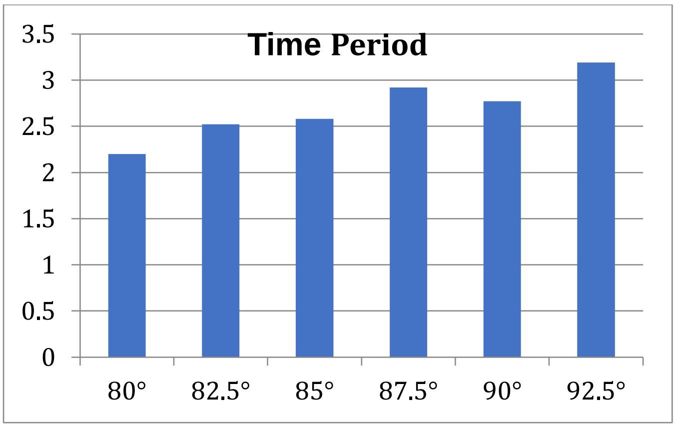

Chart -17: Time Period (sec) of 30- Storey Buildings at different oblique column angles

6. CONCLUSIONS

Numerical studies of 6 models were conducted by using ETABS software. The numerical tests were carried out for different scenarios. The main findings are listed below:

- In linear static analysis, the maximum storey displacement and minimum storey displacement are observed in columns having inclination of 92.5° is 95.28mm and column having inclination of 80° is 40.164mm whereas in linear dynamic analysis the maximum storey displacement is 103.99mm and minimum storey displacement is 62.387mm observed in the same model.
- In linear static analysis, the maximum storey drift and minimum storey drift observed in column having inclination of 87.5° by 0.001299 and column having an inclination of 90° by 0.0009 whereas in linear dynamic analysis the maximum storey drift is 0.00139 and minimum storey drift is 0.00076 observed in the same model.
- In linear static analysis, the maximum overturning moment and minimum overturning moment observed in column having inclination of 80° by 611225.48 KN-m and 314048 KN-m whereas in linear dynamic analysis the maximum overturning moment is 611225.5 KN-m and minimum overturning is 415655 KN-m observed in the same model.
- In linear static analysis, the maximum storey shear and minimum storey shear observed in column having inclination of 80° by 9327.26 KN and column having inclination of 85° by 4728 KN whereas in linear dynamic analysis the maximum storey shear is 9327.26 KN and minimum storey shear is 4728 KN observed in the same model.
- The time period is observed less in structure with oblique columns. This reflects more stiffness of the structure.
- Structure provides both gravity and lateral load more resistance in the oblique column building which makes the structural system more effective.
- The effect of earthquakes on the 80-degree building is poor compared to conventional 90-degree column building. Hence, Oblique buildings of column inclination below 90-degree structures can use in earthquake prone areas.

7. FUTURE SCOPE

- In the present study, oblique columns with angles 80° to 92.5° are considered. This work can be extended to other angles greater than 92.5°.
- In this study, all the oblique column structures showed better performance against seismic load for 30 storey height. This study can be extended for structures with higher storeys.

- In each model, all the columns have same inclination due to which the structure gets resistance to lateral load. It may increase when considering different/mixed angles of columns in every building.
- Oblique columns offer best resistance to lateral loads. Hence, it needs optimum design procedure to proceed for further studies and also for construction.

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