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Seismic Performance Evaluation of MultistoriedRCC Building with Oblique Column

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Abstract: Exploring innovative structural solutions to enhance seismic resilience in buildings is critical in advancing the field of modern structural engineering. This research contributes to this endeavor by analyzing the role of inclined columns within frame systems and their potential to strengthen the earthquake resistance of structures. This study assesses how variations in column inclination, configuration, and quantity affect seismicbehaviour. This research utilized response spectrum analysis and evaluated key seismic performance indicators, including story displacement, inter-story drift, base shear. These results high light the effectiveness of inclined columns in mitigating seismic risks, underscoring the need for careful consideration of their configuration to optimize structural resilience and their potential as a retrofitting measure.When viewed from the outside, buildings that make a certain angle to the ground and whose floor plans are horizontally offset could be defined as inclined-form buildings. Although these buildings present unique design opportunities, they present considerable challenges. This research contributes to advancing structural engineering practices by offering insights into the integration of inclined columns for seismic design, suggesting a promising direction for future building standards and construction methodologies, and retrofitting alternatives.
Keywords: Seismic resilience · Inclined columns · Structural analysis .

I. INTRODUCTION

In the modern architectural and engineering landscape, the progression of construction techniques, structural systems, and analysis methodologies has led to the rise of complex by each household. Plastic in different forms is found to be almost 5% in municipal solid, which is toxic in nature.Consequently, to counteract the threat posed by earthquake forces to structural integrity, the industry has turned towards the implementation of sophisticated and often expensive passive energy dissipation mechanismslike viscous dampers, friction dampers, tuned mass dampers, base isolatorsas critical safeguards for building system.The inclination of the columns can be taken as a strong alternative to the ones listed above.Inclined or slanted columns are the columns that are lean ing at an angle away from perfect verticality (90 degrees to the horizontal).

This includes determining the column type based on effective length and end conditions, as well as detailing reinforcement based on the maximum value of the moment. As the center of load application in the column section is shifted, inclined columns are subjected to second-order bending moments as eccentricity increases in comparison to vertical columns. The applied load is also resolved to the horizontal component due to inclination.The same phenomenon can be advantageous in the case of lateral loading (earthquake and wind loads) as with inclination, columns take some lateral forces too and result in a shorter earth quake load transfer path.Inclined columns also lead to a more uniform distribution of inter-story drift across the height of the building, potentially reducing damage to non-structural elements during seismic events.The structural system with inclined columns has better energy dissipation compared to the traditional moment-resisting frame (MRF).the implementation of inclined columns and their impact on seismic resilience is not well-documented in existing literature and the research remains relatively untapped within the domain of structural engineering.Current building codes lack specific provisions for the design and construction of structures with inclined columns. This research seeks to explore various configurations of inclined columns, examining their role in seismic force dissipation and in altering the load transfer paths within a building.

In a regular building, the nominal length of the structure is the vertical distance between the ground and the building's highest point, defined as building height. However, the nominal length will be greater than the height of an inclined building.As the inclination angle of the building increases, the nominal length of the building increases for the same height. Although the rate of increase might seem low in percentage, with an increase in the building height and inclination angle, the magnitude of the change could reach significant values. In this study, geometric characteristics and architectural and structural features of inclined buildings are comprehensively examined, and the favorable and unfavorable effects of the inclined form are investigated.

Diverse types of structural systems with case studies on inclined buildings worldwide, the challenges that are countered during the design and construction of these buildings, and solutions that are proposed and applied by designers are explored and discussed thoroughly.

II. NEED OF STUDY

1) Comparing the lateral stability of building with conventional buildings.
2) Checking the ability of slanted columns to sustain overturning moments.
3) Effect of inclination of column on high rise buildings.
4) This study will ignite an interest on the use of oblique column in lateral load resistant design of high-rise structures.

III. OBJECTIVES

1) To study the performance of symmetric structure subjected to a seismic force with normal column.
2) To study the performance of symmetric structure subjected to a seismic force with oblique column.

IV. METHODOLOGY

The proposed methodology outlines a structured process to evaluate the performance of Normal column and Oblique column by using ETABS Software. It begins with a literature study to gather relevant research insights.

In the first section,The G+12 Normal Structure Model is prepared in ETABS and results are verified for normal column. We get Story displacement, Story shear and Story drift for each floor. Once the model is ready with all results, the graphs are prepared which determines graphical representation of parameteric study of model of normal column. We have also validate the results manual for G+1 model . Hence, we have got good results for it.

In the second section,The G+12 Oblique Structure Model is prepared in ETABS and results are verified for oblique column. We prepared structure of 80°,84°,86° and 88° in software .We get Story displacement, Story shear and Story drift for each floor. Once the model is ready with all results, the graphs are prepared which determines graphical representation of parameteric study of model of normal column. We have also validate the results manual for G+1 model . Hence, we have got good results for it.

In the final stage it involves Response Spectrum Analysis method in study. The result shows the comparison of normal and oblique column. It also compares parameters, graphs. This stepwise methodologyensures a comprehensive evaluation of the seismic performance of each configuration. This methodology is broken down into the following phases:

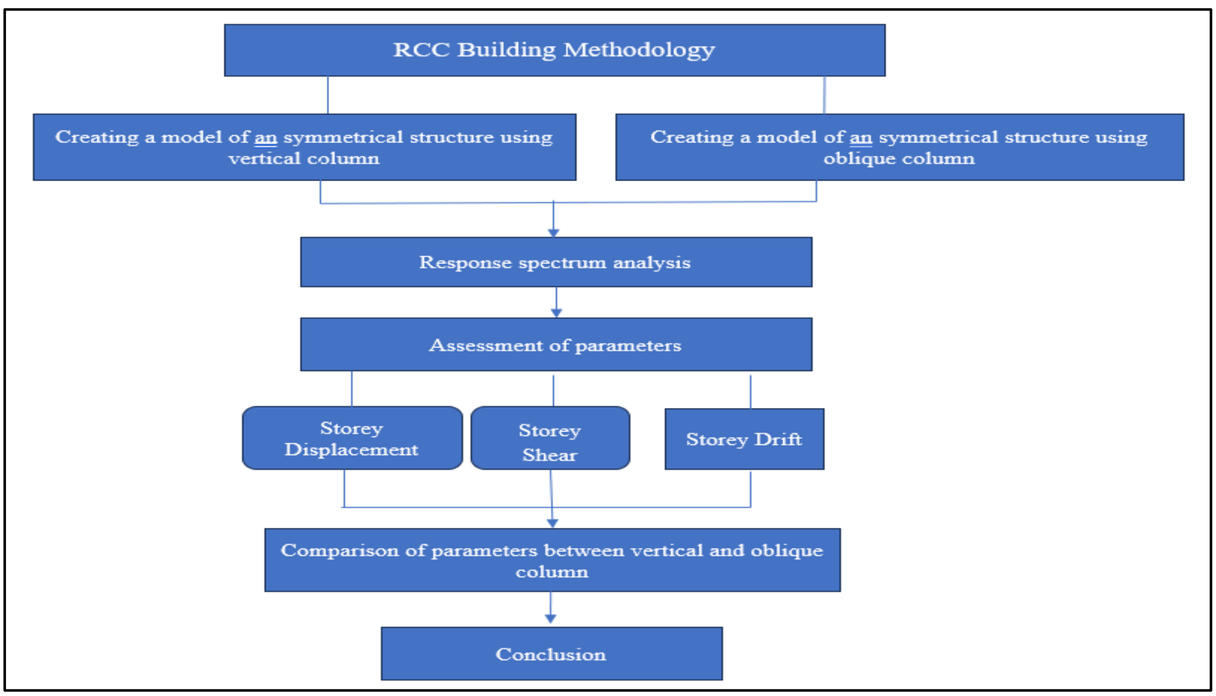

Fig.1FlowchartShowingProcedureofProjectWork

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1) ProblemDefinition :-

Table I :- Problem Definition

Description	Conventional column	Oblique column
BuildingStatus	New	New
StoreyHeight(m)	3	3
Noofstories	G+12	G+12
GradeofConcrete	M25	M25
GradeofSteel	Fe500	Fe500
Size ofBeam(mm)	300x450mm	300x450mm
Size ofColumn(mm)	550x750mm	550x750mm
ThicknessofSlab(mm)	150	150
SoilConditions	Medium	Medium
ResponseReductionFactor	5	5
ImportanceFactor	1	1
LiveLoadonfloors(kn/m^2)	2	2
FloorFinish(kn/m^2)	1	1
Wallload(kn/m^2)	11	11
Seismic zone	V	V
Seismic zone factor (Z)	0.36	0.36

2) For 90 degrees

The plan view presented in Fig.3 illustrates a structural layout of a multistory building, designed on a uniformly spaced grid system. The configuration consists of 5 bays along both the horizontal and vertical directions, resulting in a 5x5 grid. Each bay spans 5 meters in both directions, establishing a square grid with consistent spacing throughout. This regular spacing contributes to the structural symmetry, ensuring uniform load distribution and enhanced seismic performance.

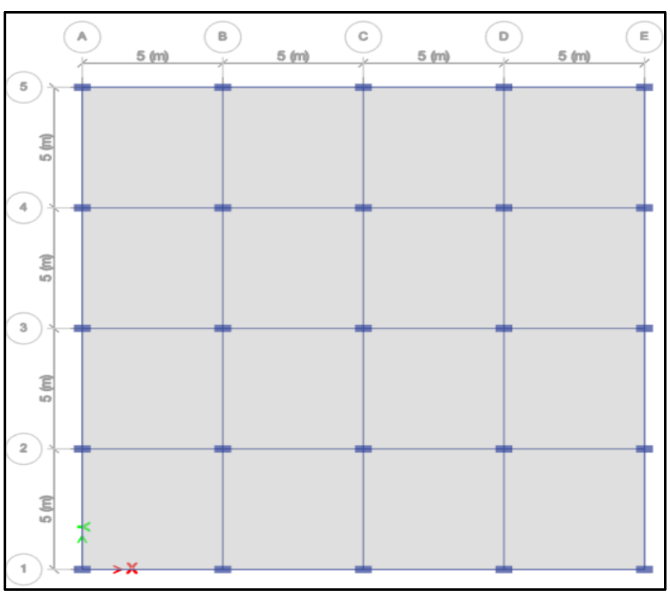

Fig. 3: Plan View

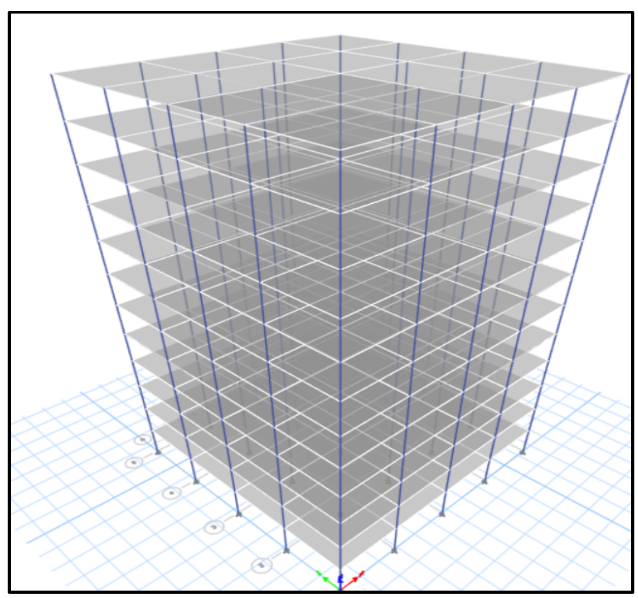

Fig. 4: 3D View

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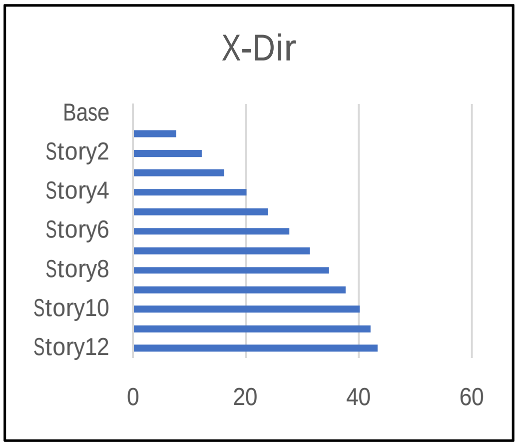

Fig.5:Story displacement in X direction

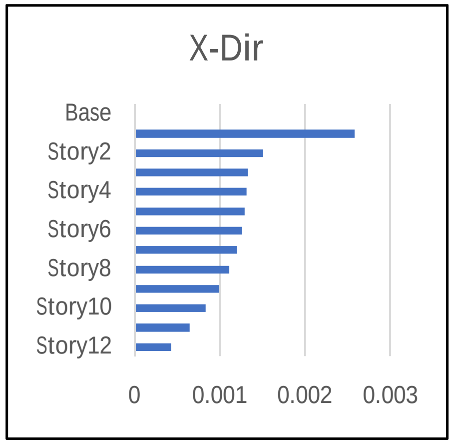

Fig.6:Story drift in X direction

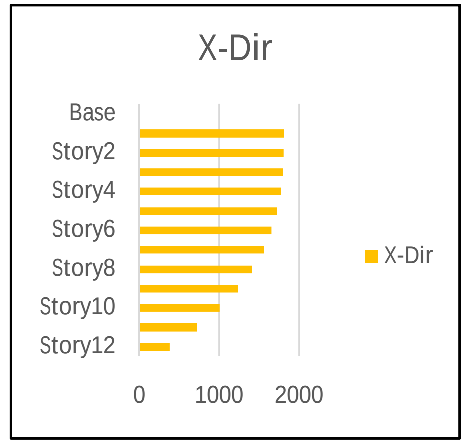

Fig.7:Story shear in X direction

X direction represents different stories of a building, from the base (lowest story) to story 12 (highest story).The first story has a displacement of 7.74 mm and story 12 shows 43.40 mm the highest displacement. The first story has a driftof 0.00258 mm and story 12 shows 0.000427. The first story has a shear force of 1814.5905 KN. The top story has shear force382.4999 KN.

3) For 80 degree

The plan view has a consistent 5x5 bay grid, with each bay measuring 5 meters x 5 meters. The layout maintains the typical orthogonal alignment, with columns placed at the grid intersections. The labeling from A to E (horizontal) and 1 to 5 (vertical) facilitates precise column positioning. The plan reflects a regular and symmetric foundation for the vertical development of the structure.

The 3D representation reveals a multi-story (10-story) structural frame with vertical elements (columns) noticeably tilted inward, converging toward the top. The column inclination in this model is increased to 80 degrees from the base, representing a significant deviation from vertical.

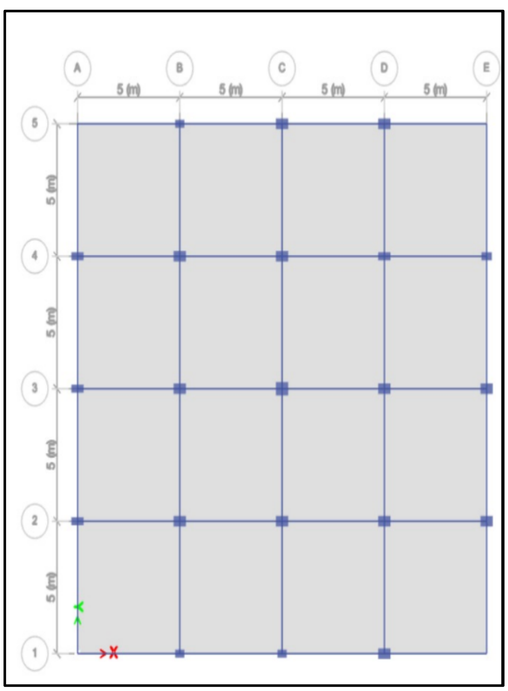

Fig. 8: Plan View

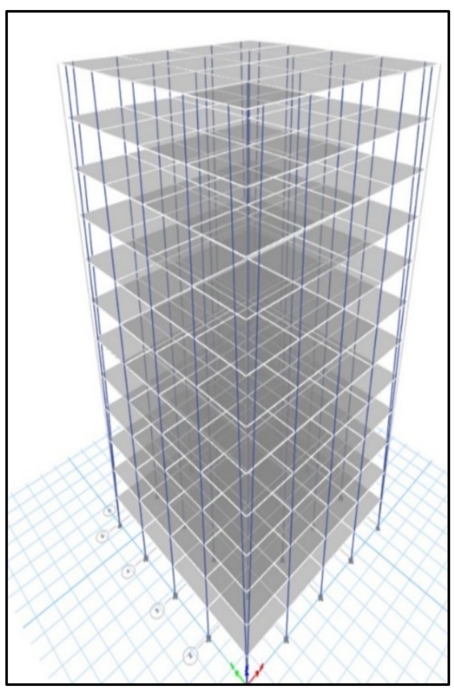

Fig. 9: 3DView

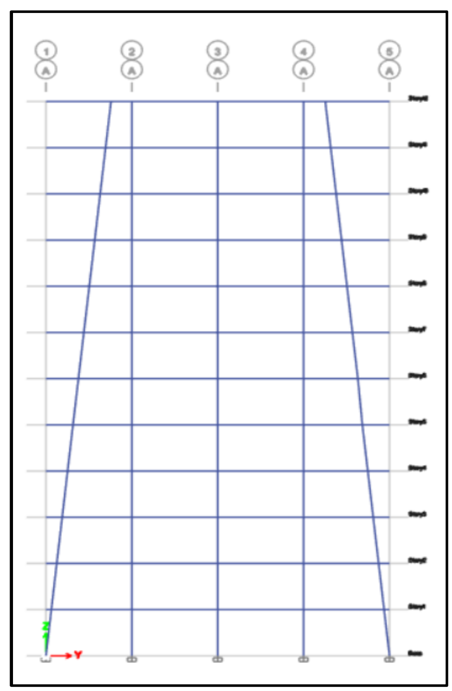

Fig. 10: Elevation View

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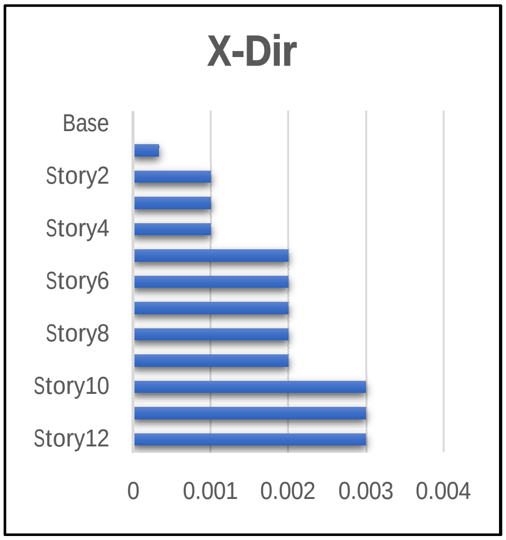

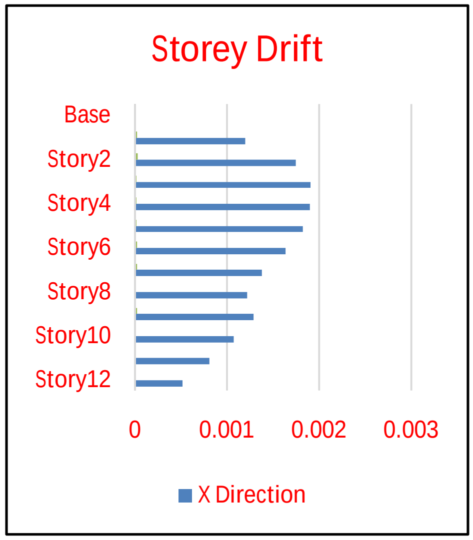

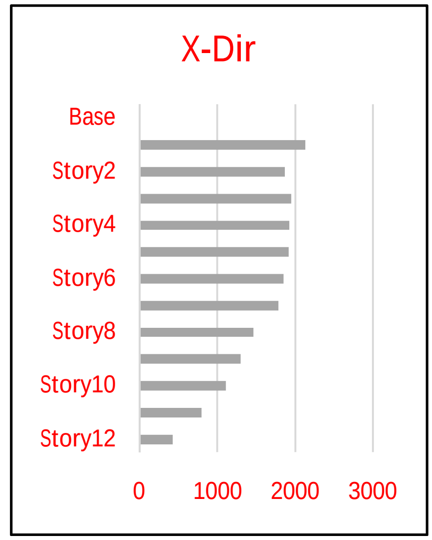

Fig.11:Story displacement in Xdirection Fig. 12:Story drift in Xdirection Fig.13:Storyshear in Xdirection

X direction represents different stories of a building, from the base (lowest story) to Story 12 (highest story).The first story has adisplacement of 0.000332mm and story 12 shows 0.003 mm the highest displacement. The first story has a drift of 0.003 and story 12 shows 0.0027. The first story has a shear force of 2135.39KN. The top story has shear force426.894 KN.

4) For 84degree

The plan view displays a typical 5x5 grid layout, with each bay measuring 5 meters by 5 meters, indicating a modular and symmetric design. The horizontal axis is labeled A to E, while the vertical axis is labeled 1 to 5, allowing for precise identification of each grid intersection where vertical structural elements (columns) are located. The uniform bay spacing ensures consistency in load distribution and structural behavior across the plan.

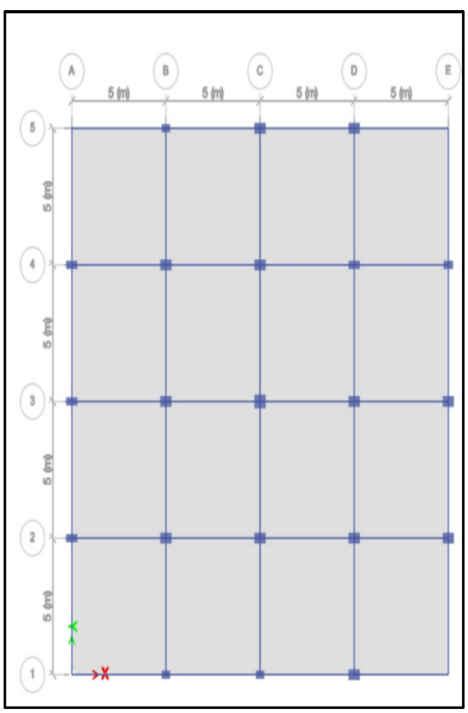

Fig. 14: Plan View

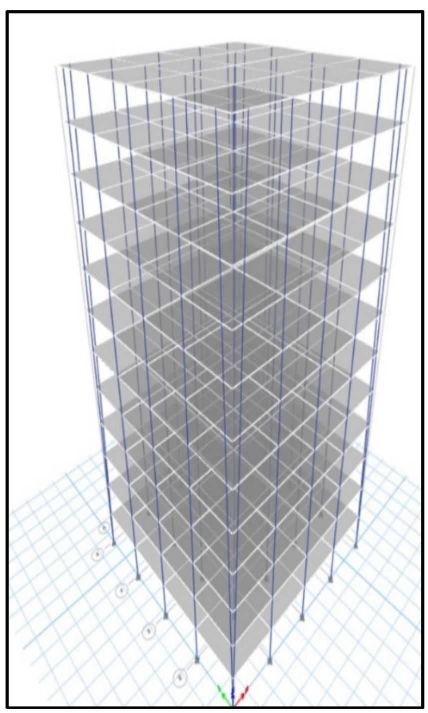

Fig. 15: 3D View

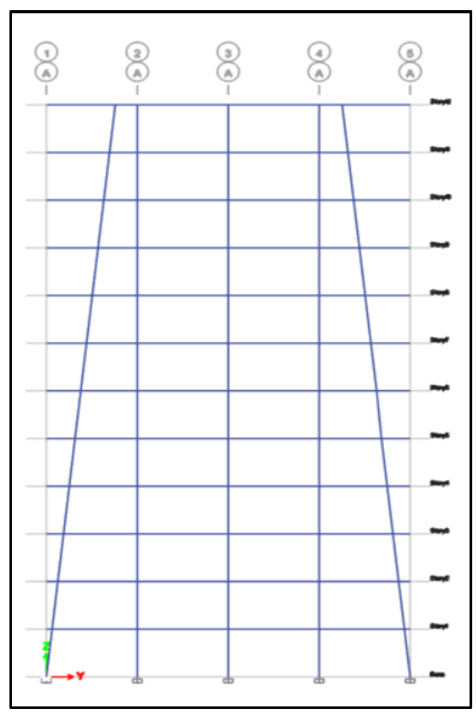

Fig. 16: Plan View

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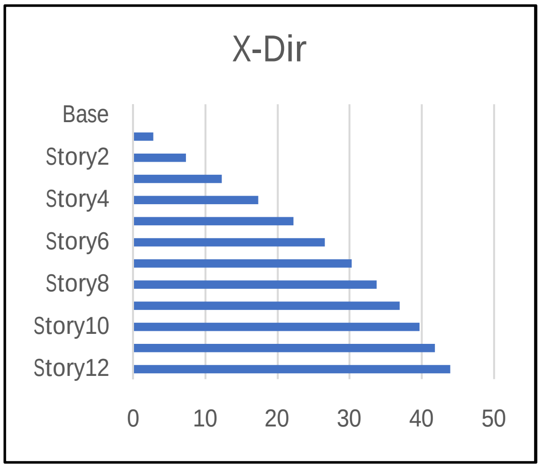

Fig.17: Story displacement in X direction

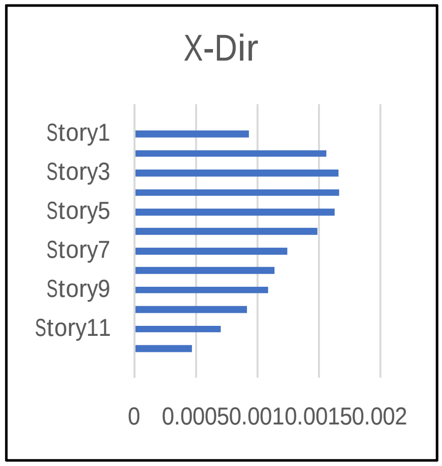

Fig. 18: Story drift in X direction

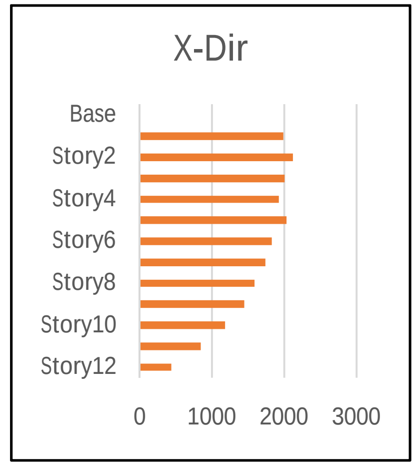

Fig.19 :Story shear in X direction

X direction represents different stories of a building, from the base (lowest story) to Story 12 (highest story).The first story has a displacement of 2.8mm and story 12 shows 43.95 mm the highest displacement. The first story has a drift of 0.00093 and story 12 shows 0.00046. The first story has a shear force of 1989.9 KN. The top story has shear force440.96 KN.

5) For 86 degree

The plan view symmetric structural layout arranged in a 5x5 grid, where each bay measures 5 meters in both horizontal directions, resulting in a total plan area of 25 grid intersections. The grid lines are labeled A to E horizontally and 1 to 5 vertically, aiding in precise identification of column locations. This regular and evenly spaced configuration provides geometric simplicity and structural efficiency, especially under typical vertical loading conditions.

The 3D view illustrates the overall form of a 10-story building frame, composed of vertical columns and horizontal floor slabs. This tilt could simulate behavior under extreme lateral forces, such as wind or seismic effects, or be part of a parametric study on stability and deflection. The elevation view further emphasizes the angular deviation of the structural frame. The columns lean noticeably, confirming the building’s inclination at 86 degrees.

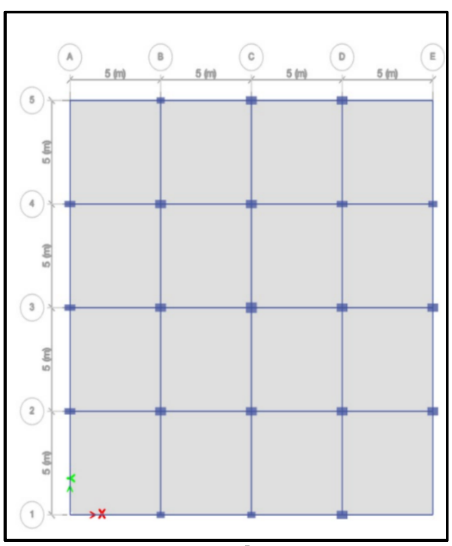

Fig. 20 : Plan View

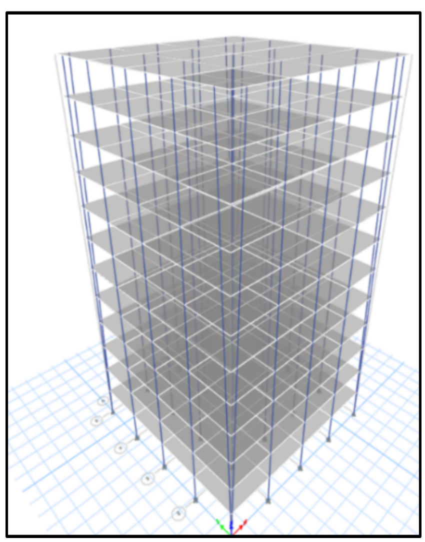

Fig. 21: 3D View

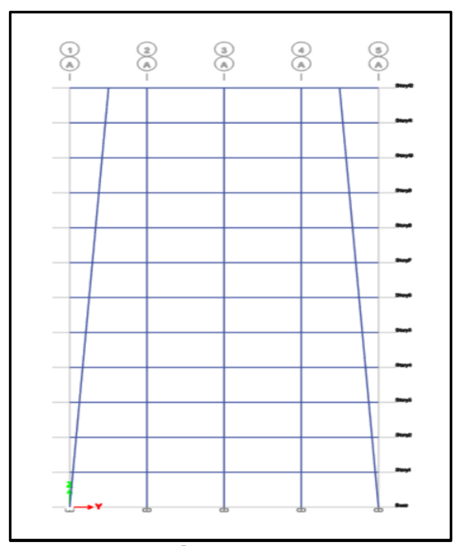

Fig. 22: Elevation View

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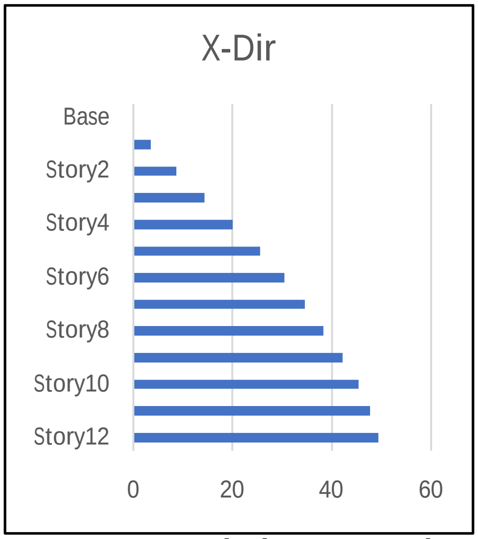

Fig.23: Story displacement in X direction

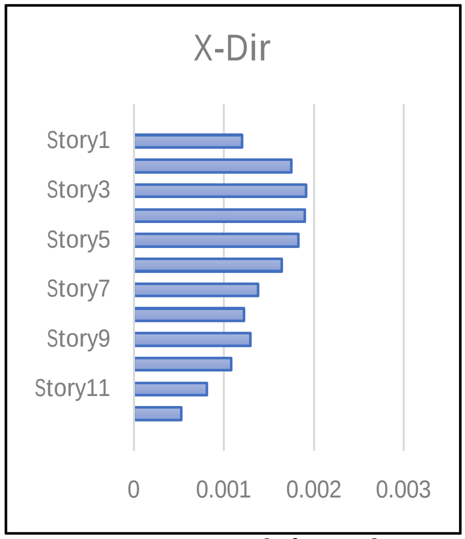

Fig. 24 : Story drift in X direction

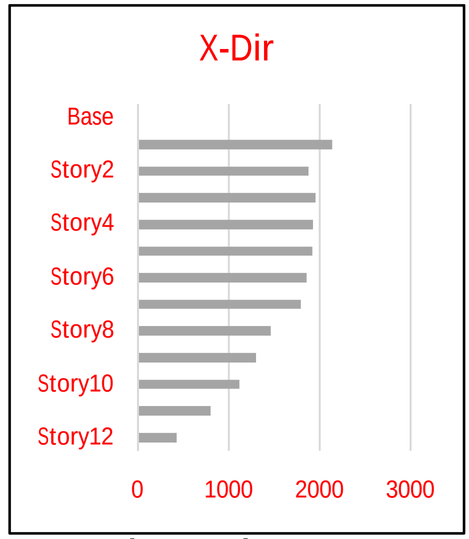

Fig.25 :Story shear in X direction

X direction represents different stories of a building, from the base (lowest story) to Story 12 (highest story).The first story has a displacement of 3.59mm and story 12 shows 49.31mm the highest displacement. The first story has a drift of 0.00119and story 12 shows 0.00523. The first story has a shear force of 2135.39KN. The top story has shear force 426.89KN.

6) For 88degree

The plan view represents a regular grid structure comprising 5 bays in both directions, with each bay spanning 5 meters, creatingsquare grid layout of 25 structural frames. The grid system is labeled using alphabets A to E along the horizontal axis and numbers 1 to 5 along the vertical axis, which helps in identifying column positions precisely. The uniformity in spacing and layout reflects a symmetrical floor plan, which is beneficial for distributing lateral and vertical loads effectively.

The 3D view provides a perspective of the complete multi-story structural frame.

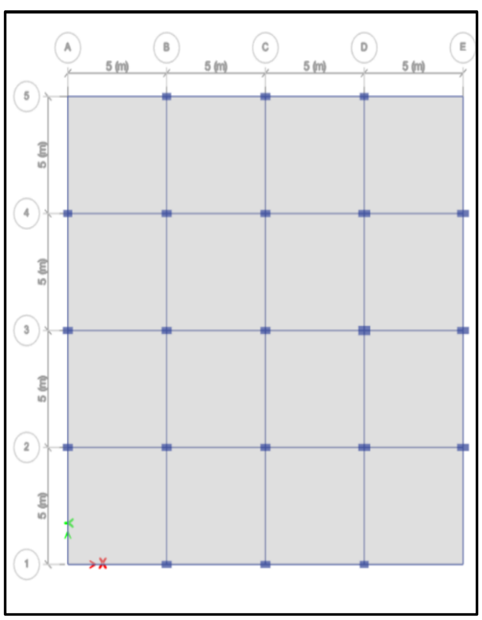

Fig. 26 : Plan View

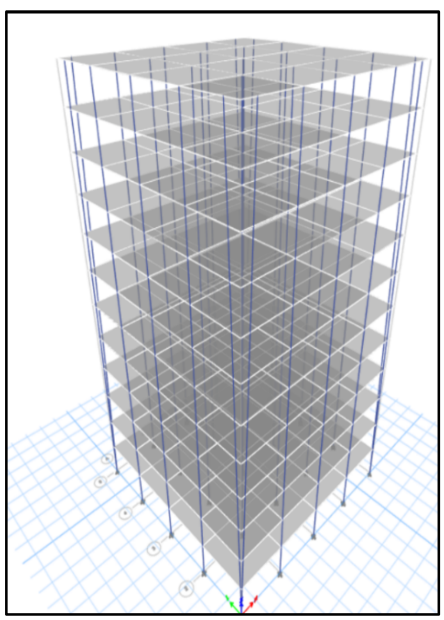
Fig. 27: 3D View

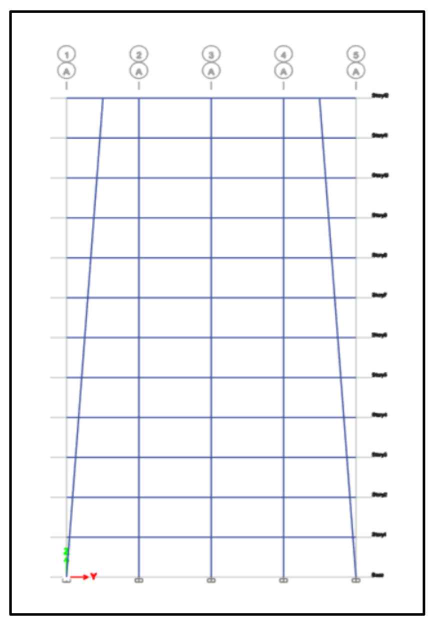
Fig. 28 : Elevation View

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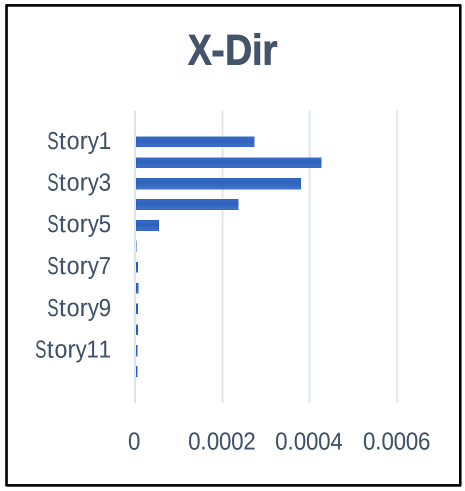

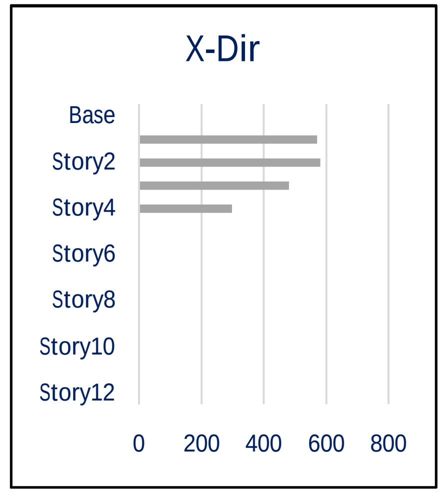

Fig.29: Story displacement in X direction Fig. 30 : Story drift in X direction Fig. 31: Story shear in X direction

X direction represents different stories of a building, from the base (lowest story) to Story 12 (highest story).The first story has a displacement of 0.816mm and story 12 shows 3.96 mm the highest displacement. The first story has a drift of 0.815 and story 12 shows 3.98. The first story has a shear force of 5740.46 KN. The top story has shear force 0.011KN.

V. RESULTS

A. Comparative study

1) Story Displacement

TableII:StoryDisplacement

	90°	88°	86°	84°	80°
Story12	43.406	3.984	49.391	43.953	0.003
Story11	42.127	3.99	47.831	41.847	0.003
Story10	40.197	3.991	45.403	39.738	0.003
Story9	37.69	4.024	42.174	36.982	0.002
Story8	34.718	4.024	38.308	33.734	0.002
Story7	31.385	4.042	34.646	30.345	0.002
Story6	27.789	4.06	30.528	26.629	0.002
Story5	24.015	4.055	25.608	22.224	0.002
Story4	20.136	3.9	20.126	17.349	0.001
Story3	16.209	3.194	14.425	12.348	0.001
Story2	12.239	2.063	8.709	7.372	0.001
Story1	7.74	0.815	3.593	2.8	0.000332
Base	0	0	0	0	0

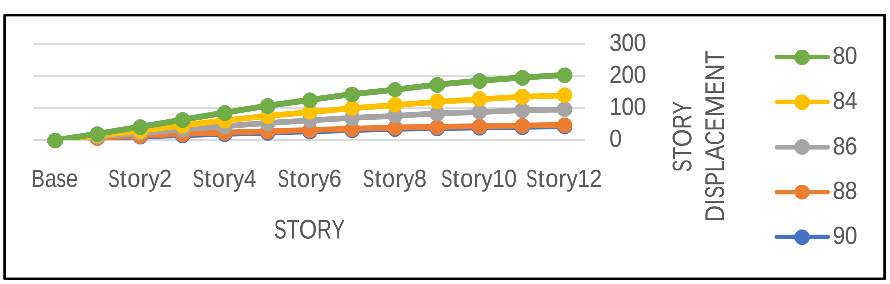

Fig.32:- Story Displacement

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Thissection presented graph illustrates the variation in story displacement of a multi-story building under multiple conditions, represented by legend values ranging from 80 to 90. The horizontal axis labels the building levels from Base to Story12, while the vertical axis represents the displacement magnitude in consistent units (e.g. mm).All curves exhibit a typical parabolic displacement profile, where the displacement increases progressively with elevation. The highest displacement occurs at Story12, reaching approximately 420 units under the most critical condition (legend value **80**). Intermediate values such as 84, 86, and 88 show displacement reductions of approximately 52%, 29%, and 40%, respectively, when compared to the maximum displacement at value **80**. This consistent decline across all stories indicates the positive effect of increasing stiffness or adjusting external parameters.

2) Story drift

TableIII:StoryDisplacement

	90°	88°	86°	84°	80°
Story12	0.000427	0.000005	0.000523	0.000468	0.000523
Story11	0.000643	0.000005	0.00081	0.000703	0.00081
Story10	0.000836	0.000005	0.001077	0.000919	0.001077
Story9	0.000991	0.000005	0.001295	0.001086	0.001295
Story8	0.001111	0.000005	0.001222	0.001139	0.001222
Story7	0.001199	0.000005	0.001381	0.001244	0.001381
Story6	0.001258	0.000005	0.001641	0.001489	0.001641
Story5	0.001293	0.000005	0.001829	0.001632	0.001829
Story4	0.001309	0.000005	0.001901	0.001668	0.001901
Story3	0.001327	0.000005	0.001911	0.001661	0.001911
Story2	0.001509	0.000005	0.00175	0.001563	0.00175
Story1	0.00258	0.000005	0.001198	0.000933	0.001198
Base	0	0	0	0	0

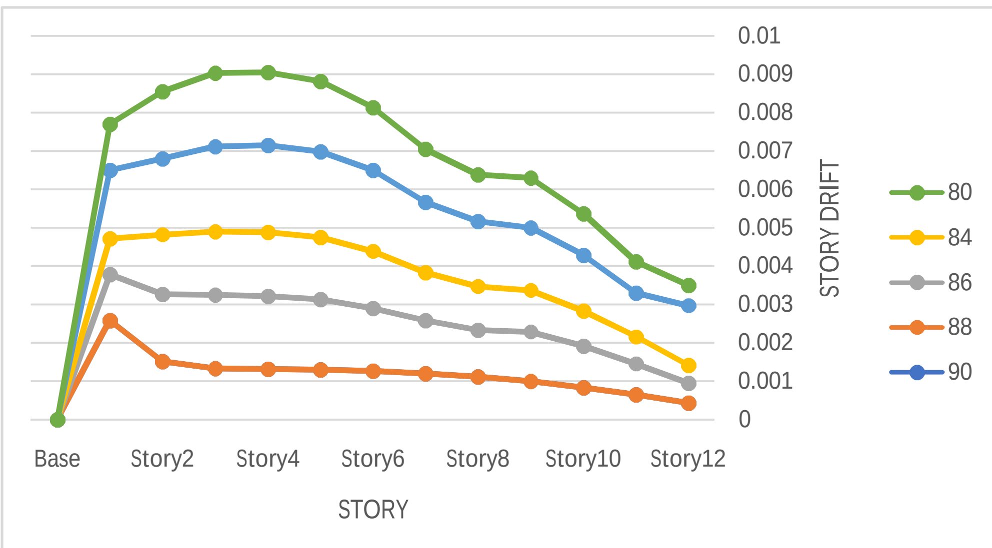

Fig.33 :- Story Drift

The graph illustrates the variation of story drift across the height of a 12-story building under five different conditions labeled as 80, 84, 86, 88, and 90. Story drift is plotted on the Y-axis, ranging from 0 to 0.008, while the building stories are shown on the X-axis from Story12 (top) to the Base. For condition 80, represented in green, the story drift starts at approximately 0.0018 at the top story and increases gradually, reaching a peak of about 0.0071 around the 4th and 5th stories before decreasing towards the base.

Under condition 84 (yellow), the drift follows a similar pattern, with values starting at approximately 0.0015 and peaking around 0.0053 at the 5th story.

The condition for 86 drift begins at around 0.0012 and reaches a maximum of roughly 0.0040, again around the 4th and 5th stories, showing a more moderate drift profile. In condition 88 the drift starts at a lower value near 0.0008 and increases slightly, with a noticeable jump at Story1, where the maximum drift of around 0.0027 occurs. For condition 90 displays zero drift across all stories, indicating either an idealized rigid structure or a condition with no lateral loads applied.

3) Story Shear

TableIV:Story Shear

	90°	88°	86°	84°	80°
Story12	0.000427	0.000005	0.000523	0.000468	0.000523
Story11	0.000643	0.000005	0.00081	0.000703	0.00081
Story10	0.000836	0.000005	0.001077	0.000919	0.001077
Story9	0.000991	0.000005	0.001295	0.001086	0.001295
Story8	0.001111	0.000005	0.001222	0.001139	0.001222
Story7	0.001199	0.000005	0.001381	0.001244	0.001381
Story6	0.001258	0.000005	0.001641	0.001489	0.001641
Story5	0.001293	0.000005	0.001829	0.001632	0.001829
Story4	0.001309	0.000005	0.001901	0.001668	0.001901
Story3	0.001327	0.000005	0.001911	0.001661	0.001911
Story2	0.001509	0.000005	0.00175	0.001563	0.00175
Story1	0.00258	0.000005	0.001198	0.000933	0.001198
Base	0	0	0	0	0

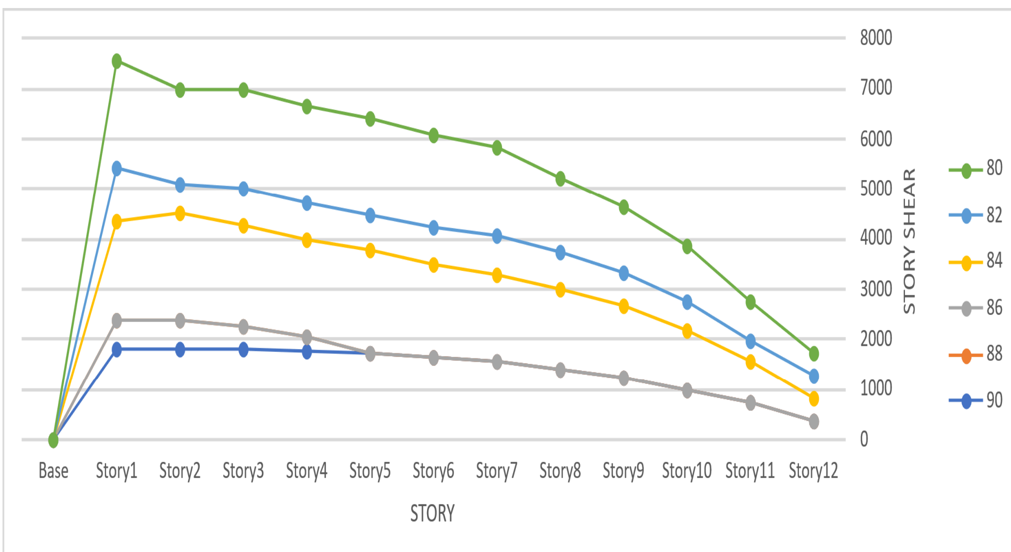

Fig.34: Story shear

The graph illustrates the story shear across the height of a 12-story building for different parameter values labeled as 80, 84, 86, 88, and 90. The x-axis represents the story levels from the base up to the 12th story, while the y-axis shows the corresponding story shear in consistent units. It is observed that the story shear is highest for the value 80 which increases significantly from the base up to Story 1, indicating a structural behavior withhigher lateral force resistance. As the parameter value increases (from 80 to 90), the magnitude of story shear decreases progressively, with the value 90 showing the lowest and most uniform shear distribution.

This suggests that higher parameter values may be associated with increased flexibility or damping in the structure, leading to reduced shear demands.

The peak shear in all cases typically occurs near the lower stories (around Story 1 or 2) and drops sharply to zero at the base, which is consistent with the cumulative transfer of lateral loads to the foundation. The smoother and flatter curves observed for higher parameter values (particularly 88 and 90) indicate a more evenly distributedlateral force, which can be beneficial in reducing local stress concentrations and improving seismic performance.

VI. CONCLUSIONS

This study confirms that Oblique columns improve seismic performance in certain configurations by redistributing forces and reducing overall base shear. The maximum story drift reduces from approximately 0.0072 at 80° and 0.0025 at 90°, representing a 65.3% reduction. The top-story displacement decreases from around 205 mm to 48 mm, showing a 76.6% reduction.Story shear alsofollows this pattern, dropping from about 6600 kN 80° and 1800 kN at 90°, which accounts for a 72.7% reduction.Maximum drift of 80° 0.0072 and minimum drift of 90° 0.0025 showing a reduction of 65.3%.Compared to 80°, drift is reduced by over 75%, and it closely approaches the performance of the 90° vertical column.Top-story displacement at 88° is approximately 75 mm, compared to 205 mm at 80°.88° strikes a balance betweenvertical load efficiency and architectural inclination.

Unlike 80° or 84°, which may cause more torsion, uneven stiffness, and stress concentrations, 88° remains close enough to vertical to avoid excessive lateral flexibility.Among the oblique column configurations, the 88° column performs the best in terms of reducing story drift, displacement, and shear, while still maintaining the architectural or structural benefits of an inclined system. It offers a good compromise between aesthetics and structural performance, and is therefore the most efficient choice for oblique column designs based on the current analysis.Base shear is consistently lower in buildings with oblique columns, indicating a reduced seismic force transfer to the foundation.

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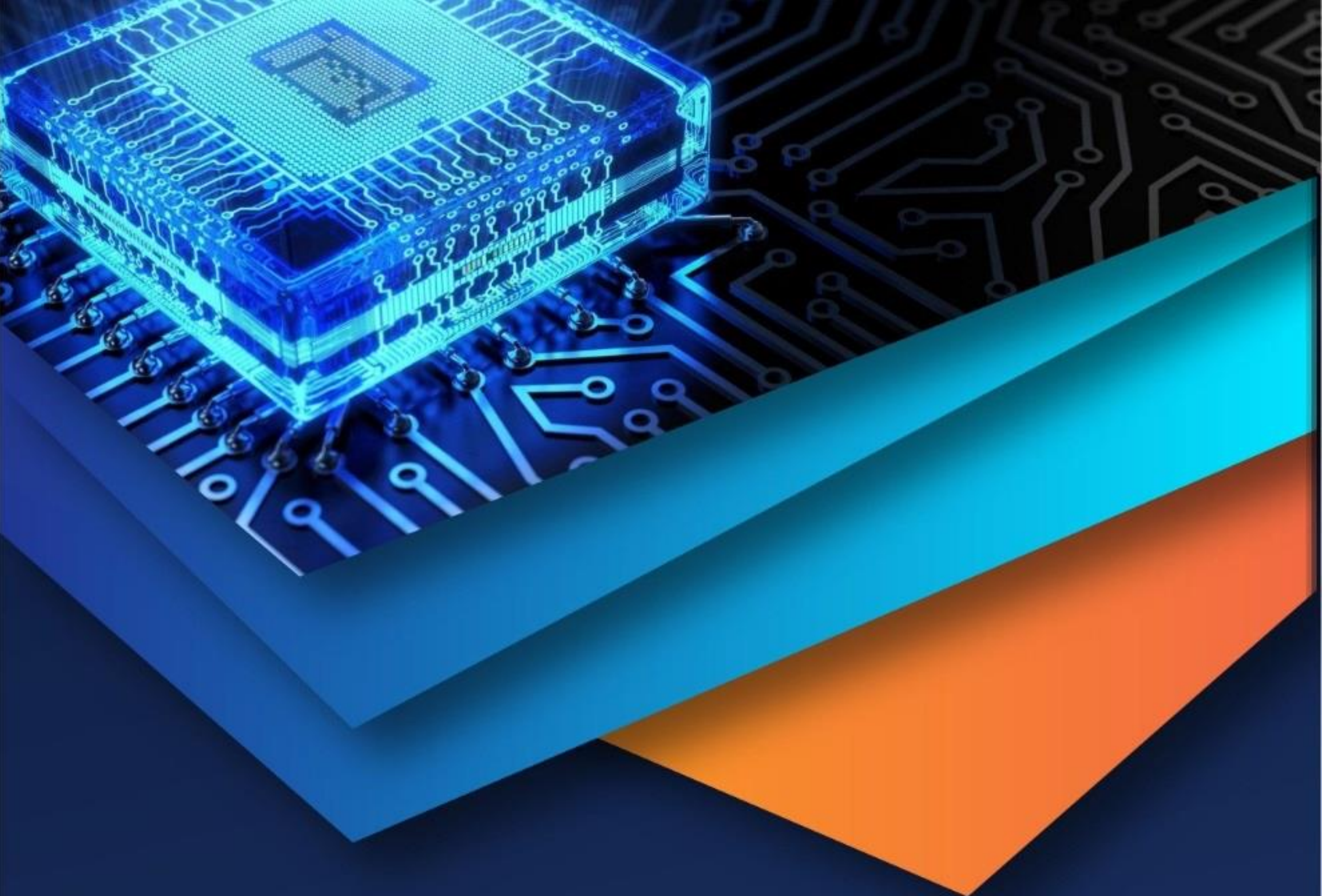

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