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Research Article

Investigation of different column shapes model under lateral forces

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flexural test,
modal analysis.

Abstract:

Columns in structures are an indispensable issue. However, the challenge is how can specify a suitable shape of column that can bear the highest weight under simplest conditions. This study investigates a set of column shapes for building structure that can be practically applied in different sizes to discover their properties. The ANSYS program is used to discover these properties, which included two basic stages in the testing processes. The first stage is to find the amount of displacement in each type of column under the lateral forces, and the second stage is to find the column's behaviour under vibrations which is called the Mode. The results observed that the traditional reinforced concrete columns can be improved in performance by using specially designed columns that operate as a succedaneum. The special-shaped concrete column (featuring L-shaped or T-shaped column sections) performs exceptionally well. Also, Modal analysis, or mode-superposition methodology, presented a unique individual response of special-shaped concrete column that characterizes displacement designs by assessing and superimposing mode forms.

1. Introduction

Columns are the most crucial structural elements, and their failure can have severe consequences for the entire building. Consequently, they receive significant attention [1]. The shape of a column can indeed affect its efficiency [2]. Different shapes can impact the column's load-bearing capacity, stability, and resistance to buckling. For example, a slender column with a larger cross-sectional area may be more efficient in carrying a load compared to a shorter, thicker column. The nature of capacity curve also indicates that the structure almost remains in the elastic range up to the performance point [3,4]. Within reinforced concrete buildings, the columns serve as the primary load-bearing components responsible for withstanding axial compressive stresses, moments, and the transmission of the entire load from the upper structure to the lower structure. Columns can assume various shapes and structures. Less popular but more spacious column designs, such as T-, L-, and plus (+)-shaped columns, provide greater interior space compared to commonly utilized varieties as in Fig.1. Common shapes for columns include round, rectangular, and square. Columns with unconventional shapes can optimize the utilization of a room's square area by eliminating uncomfortable corners [5,6].

During an earthquake, the Earth's surface undergoes multidirectional displacement. Buildings are most commonly damaged by motions perpendicular to the ground, as columns are primarily built to bear vertical gravity loads [7]. Several buildings possess inherent vertical strength, and the standard safety factor for vertical loading usually considers the vertical impact of an earthquake [8-10]. Furthermore, the vertical vibrations that occur at all sites will be quite similar as most of their horizontal dimensions are significantly smaller than the wavelength of ground motion during an earthquake. Consequently, there will be minimal or no accumulation of stress as the structures will experience negligible or no movement. Consequently, there is a scarcity of specific standards about the vertical force accompanying the horizontal force of an earthquake. During specific instances, numbers serve as a representation of ground acceleration. In order to faithfully represent the highly disparate fluctuations in acceleration throughout time, it is necessary for these temporal points to be in close proximity to each other [11,12].

Civil engineers are responsible for implementing innovative strategies to improve safety in buildings by replacing conventional methods. This allows for the construction of commercial areas in limited spaces, enhancing living conditions. Buildings, designed for office, institutional, or commercial purposes, are driven by rapid urban population growth and need to enhance structural resilience against lateral forces and minimize vibrations [13,14]. Based on the results, calculations are drawn showing the effectiveness of different shapes of the column under the effect of seismic loads [15-17]. Shruti R. Sarage et al, in 2021 also study the square columns, circular columns and combination of column cross sections such as L, T and plus (+) shaped as shown in Fig. 2.

The presence of a certain lateral load can cause a column's design to be impacted, leading to failure, displacements, and internal forces. Various types of pressures, such as axial load, can cause columns of different geometries or, more precisely, different types of column materials—to exhibit distinct vibrations when exposed to the force of gravity. An essential research field within the study of deformable solids focuses on investigating nonlinear internal stresses in structural columns. The column may experience vibrations and ultimately collapse due to this. This work finds two main concerns: the concrete material and the relationship between the column's geometry and its modal qualities. The effectiveness of concrete can be determined by considering its cross-sectional thickness, density, Young's moduli, and form types. The challenge at hand pertains to the efficacy of current methodologies in generating viable solutions for constructing concrete columns, while considering their behaviour under lateral forces. The main contributions of this work can be stated as follows:

a- Investigate the modal modes of different structural forms using traditional, readily available column structural concrete.

b- Analyze the reaction of the current column structure to an increase in column height and compare it with an elevated column.

The work is organized as follows: Section 2 describes the research methodology, including material properties, properties of concrete mixture, and production samples, the test for concrete mixture, and building the modes. Section 3 comprehensively presents the results, followed by a discussion of the findings in detail. The key conclusions that have been derived from this work are finally summarized in Section 4.

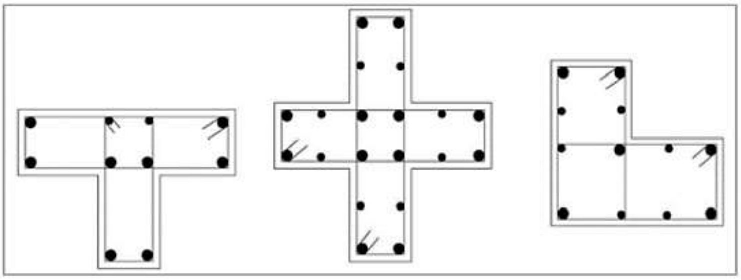


Figure 1. *Specially shaped (T, +, L) columns with longitudinal and lateral reinforcement.*

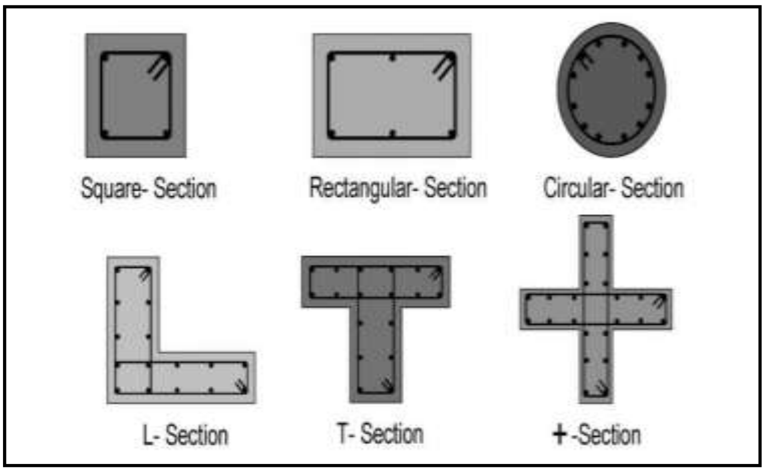


Figure 2. *Columns with lateral and longitudinal reinforcement [19].*

***Table 1.**. Mixing design*

Material	Quantity (kg)
Cement (kg)	310
River sand (kg)	605
Gravel (kg)	1220
Water in liters (W/C: 0/55%)	0.55

***Figure 3.** Project samples.*

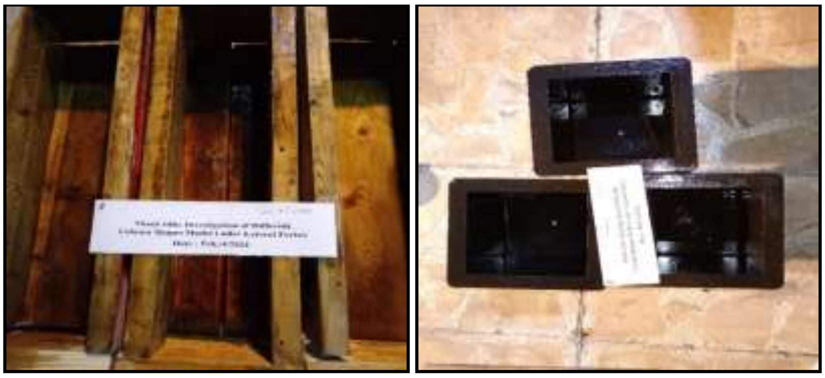


***Figure 4.** Oiling the melds.*

***Figure 5.** Casting process*

2. Research Methodology

In this work, fine aggregate uses medium size sand from Euphrates river with a modulus of fineness = 2.20; normal grading with the silt content 0.8%, specific gravity 2.677. Coarse aggregate, crush gravel with a size of 5-20 mm and normal continuous grading is used. The crushing index d"6% and the specific gravity 2.738. For the used water, the quantity of water in concrete determines its workability, compressive strengths, permeability and water tightness, durability and weathering, drying shrinkage and potential cracking. Concrete's high compressive strength allows it to withstand compression without breaking. Mix design incorporates desirable attributes like workability, durability, setting time, strength, and impermeability. C30 concrete, with an average strength of 30 MPa, is commonly used in floors, driveways, and commercial constructions. The experiment uses C30 concrete to construct a column with the specified elements. It is meant to incorporate the elements indicated in Table1.

The water-to-cement ratio in both combinations was calculated to be 0.55%, based on the characteristics of the ingredients. The choice of cement type depends on the task and performance. Kubaisa cement, sourced from Iraq, was used in the project. The strength of concrete depends on the concentration of cement and the cement-to-water ratio. Decreased water content can lead to a loss in strength and increased capillary porosity, while also decreasing the water-to-cement ratio [18]. The production of liquid mortar involves the combination of Portland cement, water, and aggregate, resulting in a highly malleable and formable material [19]. The mixture is strengthened by the addition of reinforcing materials, such as reinforcing bars, to enhance its tensile strength. This technology facilitates the production of reinforced concrete. The samples selected for the model, as shown in Fig. 3, consist of cubes of dimensions 15 cm × 15 cm × 15 cm, cylinders of dimensions 200 cm × 100 cm, and blocks of dimensions 100 cm × 100 cm × 500 cm.

Figure 6. *Compressive test machine.*

Figure 7. *Splitting test machine.*

Figure 8. *Flexural test machine*

Figure 9. *Results of flexural samples test*

To initiate the process, the dehydrated constituents, namely sand, gravel, cement, and additives, are subjected to rotation within a mixer until they are fully integrated. The fusion of all the elements resulted in the formation of a solid mass. The casting slurry is prepared by carefully including water into the mixture, which is subsequently followed by the addition of fibers. In order to mitigate the adhesion and separation of the concrete sample, a substantial amount of oil was applied to the mold as explain in Fig. 4. The process of blending sand and cement to create high-quality concrete involves ensuring the correct proportions of sediment, sand, and cement. This ensures the consistency of the mixture, preventing bleeding and segregation. The quantity of each component is crucial for achieving a homogeneous aggregate. The panel is created by compressing the slurry into a mold, leveling the spaces between layers, and using vibrations to remove air bubbles. In Fig. 5, three samples are produced for each scenario to measure the material's modulus of elasticity, tensile strength, and compressive strength [20]. This subsection includes a compressive strength test, splitting test, and flexural test machine. The compressive strengths of the cube specimens were determined at 7 and 28 days, using the guidelines given in BS 1881: Part 103: 1983. These procedures are used to accurately measure the compressive capacities of concrete cylinders. After the specimen has been prepared and placed in the central position of the apparatus, it is subsequently subjected to an axial compressive force until it ruptures. The compressive test machine is explained in Fig. 6.

The split tensile test is a complex procedure that involves a radial force on a cylindrical object to induce a vertical fracture. Concrete's compressive strength significantly influences fracture probability, and its fragility makes it susceptible to strain. Fracture occurs when applied tensile stresses exceed the material's tensile strength. This test is based on the ASTM C496 standard and IS 5816 1999. In Fig. 7, the split test is shown.

The flexural test revealed that concrete under compression zone pulverization led to flexural cracks, causing columns to fail. Copper slag-reinforced concrete demonstrated improved resistance to external forces. Energy absorption was evaluated, showing columns with copper slag enhanced energy absorption capabilities. The study suggests ductility may be responsible for this increase in energy absorption. The flexural test machine and the result of flexural samples test are explained in Fig. 8, and 9, respectively. Additional information regarding fracture patterns and failure modes was gathered once the machine had reached its maximum capacity, prior to the machine being deactivated and the crane being removed. After the radius of failure has been calculated and the sample has been photographed, a fresh sample is introduced into the testing apparatus.

The ANSYS program uses geometric primitives like volumes, areas, and lines to construct models. It can integrate bottom-up and top-down methodologies, with a focus on higher primitive elements. Differentiating between bottom-up techniques and geometric primitives is crucial. Balancing coordinate systems with operational planes is also possible. The issue statement or the problem description should explicitly indicate that the decision is an integral component of the problem. Based on the model presented in table2,

In the subsequent step, the data acquired during the initial phase will be imported using one of the various import tools offered by the SolidWorks software. The successful completion of the current project necessitates the execution of two crucial procedures: inputting the precise measurements of the panel component into the SolidWorks program. The correlations among the various components of the section exhibit a proportional relationship with the magnitude of the curve. The first phase of the modeling process involves examining the panel's reaction to various forces by employing its constituent elements, which are determined from its geometric properties. The responses will be analysed using modelling software. after the conclusion of the calculation, it is imperative to save the file with the IGS extension appended. Table 2 presents a comprehensive summary of the transmission coefficients, compressive values, and tensile stresses pertaining to several solid panel materials. Within this particular framework, variables encompass transmission parameters, tension stress, and compressive values, among various other elements.

3. Results and Discussions

The solution of improving the building structure that described in the problem statement was found. concrete constructions with slender non-rectangular columns. These structures demonstrated structural integrity, since all analytical results fell within permissible parameters. This building method effectively fulfills the spatial requirements of corners and intersections, ensuring that there are no visible edges or columns in the constructions. The usable floor area is expanded, enabling the inclusion of extra furniture within the buildings. Frame constructions with specially designed columns provide several advantages for various sorts of buildings, such as villas and multi-story complexes.

Simulation models are increasingly used for problem-solving and decision-making. All parties involved in building and using these models, as well as those who rely on the models' outputs and are affected by their judgments, must ensure the models' accuracy and conclusions. We use model validation to address this issue. Validation is needed to prove your model's accuracy for its intended usage. As a representation, a simulation model will never properly predict the behavior of the item or system it represents, regardless of its quality. Thus, models must be tested and validated only as needed for their applications. After training, more steps are needed to test a model and fix the issue. To validate a model, one must first evaluate its assumptions, structure, logic, and causal connections, compare and contrast the model and system's behavior in various experimental situations, and evaluate the theories that influenced its creation. To choose a genuine model, several are created during model development. This method can use many validation tools. No consistent process or strategy exists for choosing validation methodologies. Most of their subjective or objective use depends on the model, system, and present circumstances. The simulation findings compare autonomous numerical results to ANSYS testing under the same conditions. Common deformations include center displacement. The column's core may have the lowest inertia due to its curvature. A rectangular building with 51-foot Y and 50-foot X dimensions is studied. We study a single structure using four ANSYS models: 6, 10, 15, and 20 storeys. Each model has L and T-shaped columns. Next, we calculate economically feasible column dimensions.

The results show that central stiffness affects load. Column mass and model load are affected by the same variables. The model shows a second bending mode that can bear more force while preserving one or more nodes around the item. The change was most noticeable from above. Bends emerge in the node-based model when stiffness increases in one direction. Figures 10 and 11 demonstrate the current study's simulation test results and the prior study's experimental test findings. To build model confidence, the model's expected behavior is compared to the system's actual performance under multiple experimental settings. This requires access to the system's and model's input-output data in the experimental settings. To evaluate the model's accuracy, an appropriate range of accuracy must be defined to compare its output behaviors to the system's. No scientific method has yielded such precision, according to the author. Model validation rarely establishes an accurate range.

The columns next to the loading criterion have different labels. The sets and labels were used in various stories for analysis. The wind load was defined in ANSYS, and the center and corner columns provided axial forces. This was followed by a comparison and contrast.

The statistics show a strong relationship between building height and displacement, with wind-load combinations having the largest impact on structural displacement.The term "special-shaped column structure" refers to a construction having L- or T-shaped columns. It can carry more weight and bend more than L- and T-shaped columns due to its unique form. Adding specially constructed substitute columns improves standard reinforced concrete column performance. The concrete skyscraper performs well despite its unusual appearance.

A "special-shaped column structure" has L or T-shaped column components. Due to its dramatically different form from the L-shaped and T-shaped columns, the shaped column has a much lower carrying capacity and is less flexible than the three special-shaped columns we just covered. A succedaneum, a special column, can strengthen reinforced concrete columns. Excellent efficiency and height characterize the unusual concrete skyscraper. The results indicate that the most significant structural displacement is caused by wind-load combinations, which is a clear indication that displacement is directly correlated with building height.

Special-shaped columns have L- or T-shaped segments. Its carrying capacity and ductility varies substantially from the special-shaped columns with the three shapes stated above due to its major form variance from L and T shaped columns. As succedaneums, uniquely formed columns strengthen reinforced concrete columns. Uniquely designed concrete columns work well.

L- or T-shaped column sections make up a "special-shaped column structure." The shaped column has a far better carrying capacity and ductility than the other three special-shaped columns because of its dramatically different shape from L- and T-shaped columns. Using sucedaneum-type reinforced concrete columns improves performance. The unique concrete column works well.

Modal analysis examines dynamic processes in deforming areas. Showing structural elements' movement under dynamic loading conditions, including electrostatic actuators, helps determine a mechanical system's vibrational characteristics. It shows the basic mechanism of a mechanical device. Building a structure to manage dynamic loads requires consideration of modal form centers. The linear mode analysis method describes displacement patterns by evaluating and combining numerous mode forms. Mode-superposition is another name for it. Mode analysis means mode-analysis technique. Mode forms are a structure's natural configurations. The majority of responders worry about a left or right shift. Each structure with n degrees of freedom should have a maximum of n form modes. Magnifying and combining displacement patterns creates new patterns. Analyzing electric system behavior using mode shapes. A system's components move continuously and sinusoidally. By studying natural frequencies and mode shapes, modal analysis determines structures' linear behavior under dynamic loads. Modal analysis breaks down a structure's vibrational response into modes. Modes are defined by frequency and form. Slope-based building models have more forms, and the time period is the opposite. Modal analysis analyzes recurrent connections across frames. The mode states of a mechanical design or component can be determined by exhibiting how structural elements change under high stacking conditions such lateral stress. Regular mode forms restrict dynamic stacking design concepts. Mode-superposition methodology, or modal analysis, directly assesses and mixes mode forms to define displacement designs. In pattern recognition, mode forms show the most common starting points. Widely accepted, parallel elimination processes are needed. Having N outcomes means having N modes. Each mode form represents a distinct and standardized uprooting approach; by expanding and merging them, one can create a final relocation plan. The fundamental distortion is seen in modal space. When stimulated at certain frequencies, structures become mode forms, or distortions. All modes are used to create a tough combination under operational settings. Modal analysis divides a complex structure into numerous frames that represent diverse possibilities on a single level.

Mode shapes define electric system behavior. An even, sinusoidal motion pattern for system components. Modal analysis determines linear response to dynamic loads by determining natural frequencies and mode shapes. Modal analysis breaks down a structure's response into vibrational modes. Frequency and shape characterize modes. For different mode forms, slope-based construction models are more frequent and have the inverse response time. Modal analysis examines the unique traits of cross-frame connections. It shows how structural elements change under extreme mounting conditions, including lateral stress, to help determine the component's mechanical design or mode states. Regular mode forms limit dynamic layering design principles. The direct, individual response method of mode-superposition analysis analyzes displacement designs by assessing and superimposing mode forms. Pattern recognition usually begins with mode forms. Many agree that simultaneous eradication efforts are essential. If N outcomes are possible, so are N modes. Each mode form represents a standardized uprooting technique and can be amplified and stacked to create a relocation plan. One way is to examine the distortion in modal space. When triggered at their characteristic frequencies, structures form mode forms or distortions. The usual activity parameters cover all complex mix production options. Modal analysis also simplifies complex structures by breaking them into frameworks that reflect different possibilities at one level.

Table 2. *Column models used in the present research*

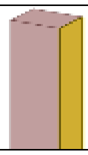
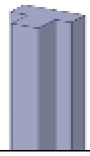
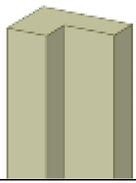
Column Model		Dimensions	
Model 1	Rectangular column	13'',16''	
Model 2	Special column shape type T	21'',26'',5''	
Model 3	Special column shape type L	23'',24'',5''	

Table 2*. The input representation of ANSYS data.*

Mechanical Properties	**Symbol**	**Steel**
Young's modulus (GPa)	E	207.0
Shear modulus (GPa)	G	80.0
Poisson's ratio	N	0.3
Density (kg/m3)	P	7600
Yield strength (MPa)	S_y	370
Shear strength (MPa)	S_x	370

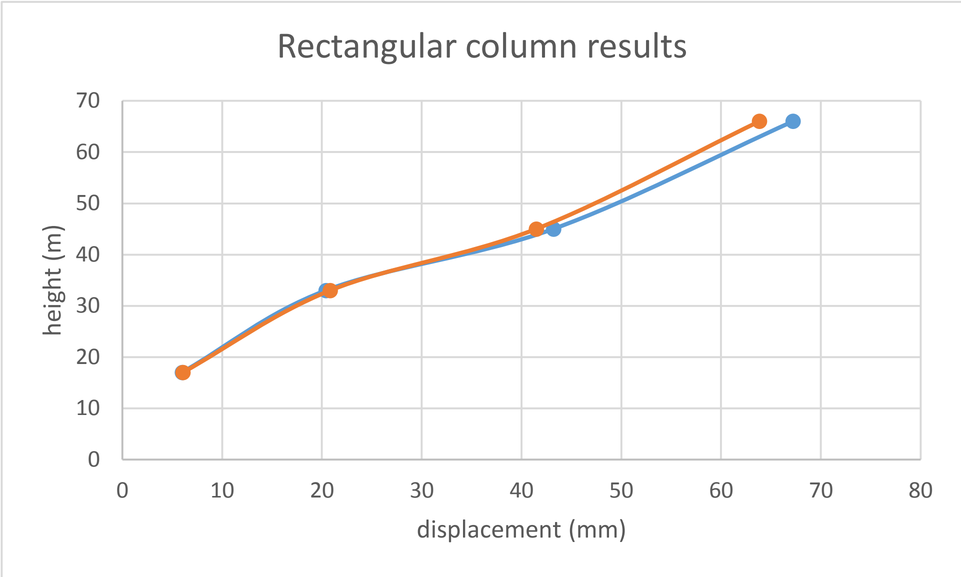


Figure 10. *Comparison of rectangular column results*

Table 3. *Deviation rate of rectangular column results*

Rectangular column results			
recent study	previous study	height (m)	error
displacement (mm)	displacement (mm)		
6.07	6	17	1%
20.83	20.4	33	2%
41.47	43.2	45	4%
63.84	67.2	66	5%

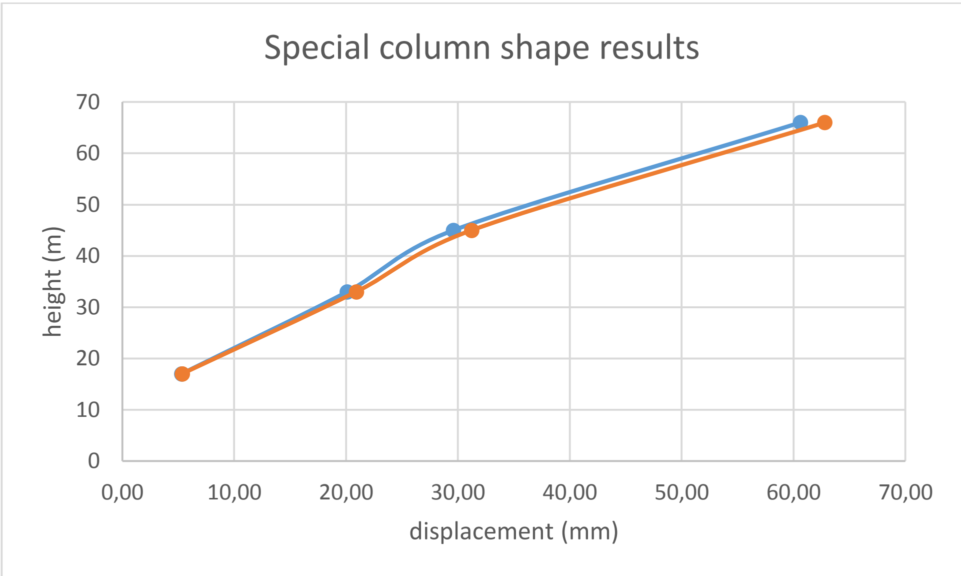


Figure 11. *Comparison of special column shape results*

Table 4. *Deviation rate of special column shape results*

Special column shape results			
recent study	previous study	height (m)	error
displacement (mm)	displacement (mm)		
5.35	5.30	17	1%
20.92	20.10	33	4%
31.22	29.60	45	5%
62.78	60.60	66	4%

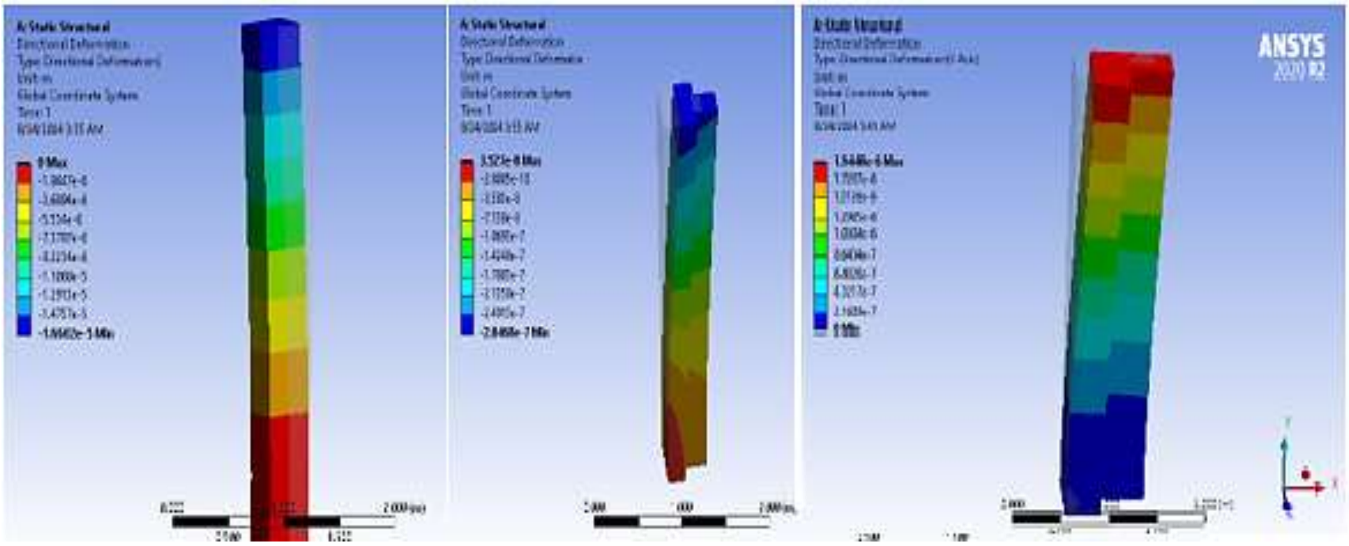


Figure 12. *Models,1,2 and 3 from ANSYS results*

Table 5. *Models considered for variation in column shape*

Column Model	Dimensions	Wind velocity	Concrete grade
Model 1	13’ 16’	96	C30
Model 2	21’’ 26’’ 5’’	96	C30
Model 3	23’’ 24’’ 5’’	96	C30
Model 1	13’ 16’	96	C40
Model 2	21’’ 26’’ 5’’	96	C40
Model 3	23’’ 24’’ 5’’	96	C40
Model 1	13’ 16’	110	C50
Model 2	21’’ 26’’ 5’’	110	C50
Model 3	23’’ 24’’ 5’’	110	C50

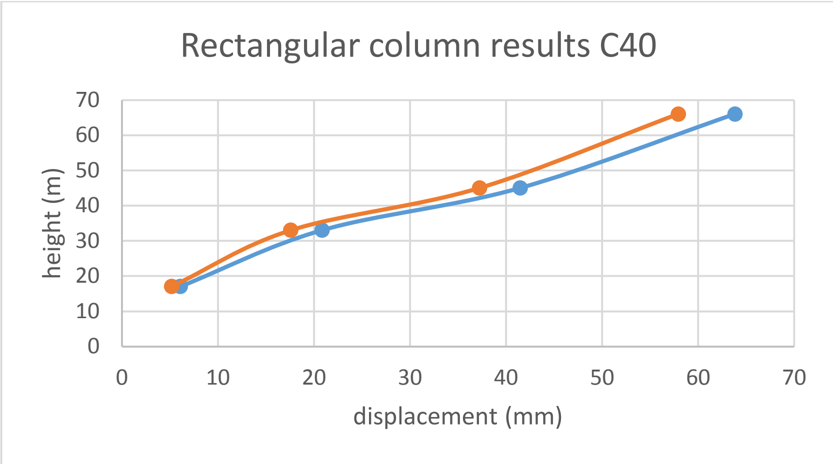


Figure 13. *Rectangular column results C40 and wind velocity 96 mph*

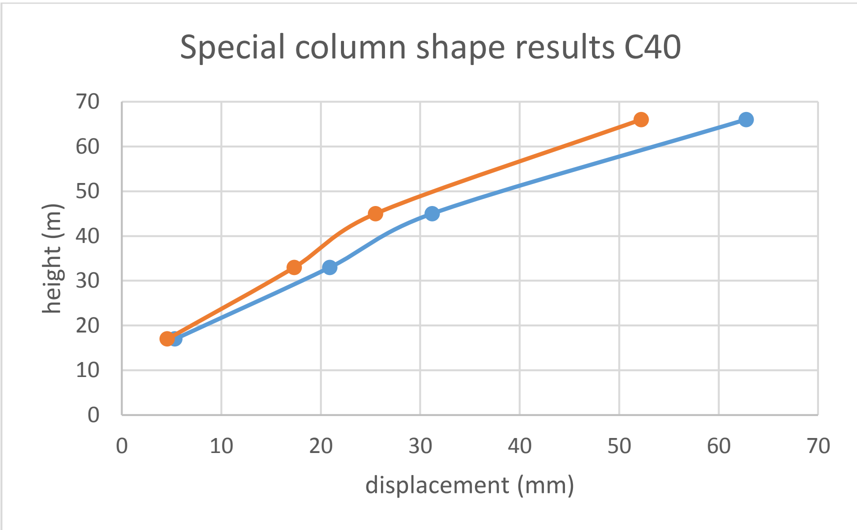


Figure 14. *Special column shape results C40 and wind velocity 96 mph*

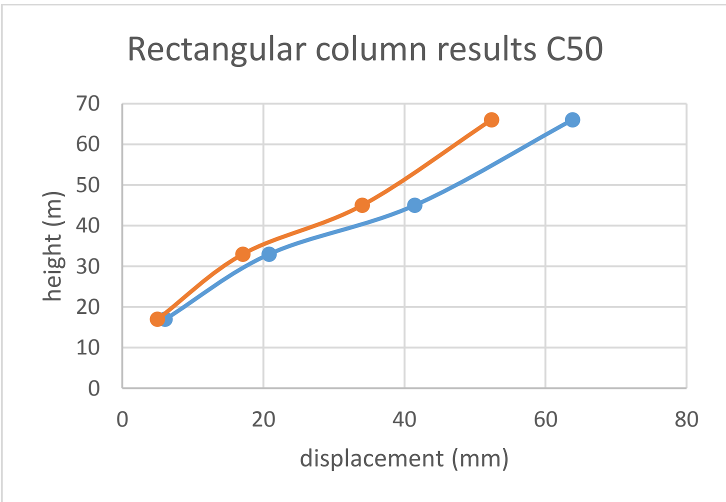


Figure 15. *Rectangular column results C50 and wind velocity 96 mph*

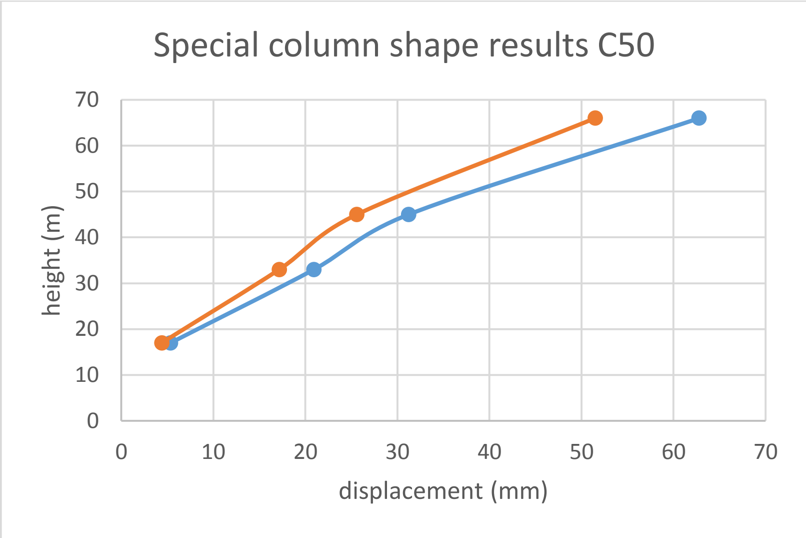


Figure 16. *Special column shape C50 and wind velocity 96 mph*

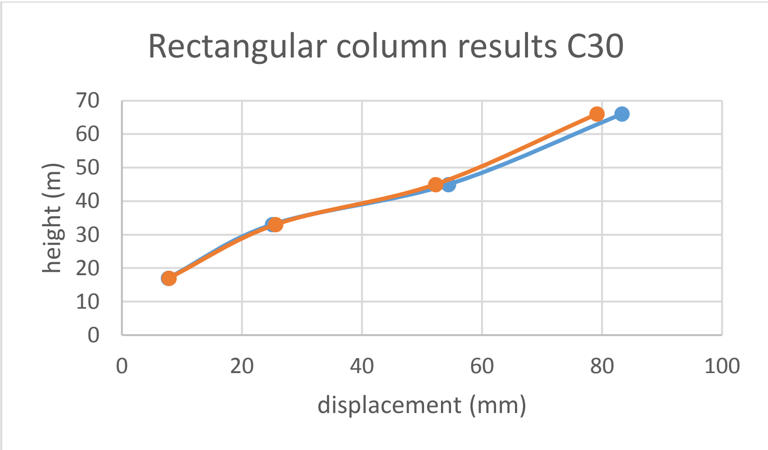


Figure 17. *Rectangular column results and wind velocity 110 mph*

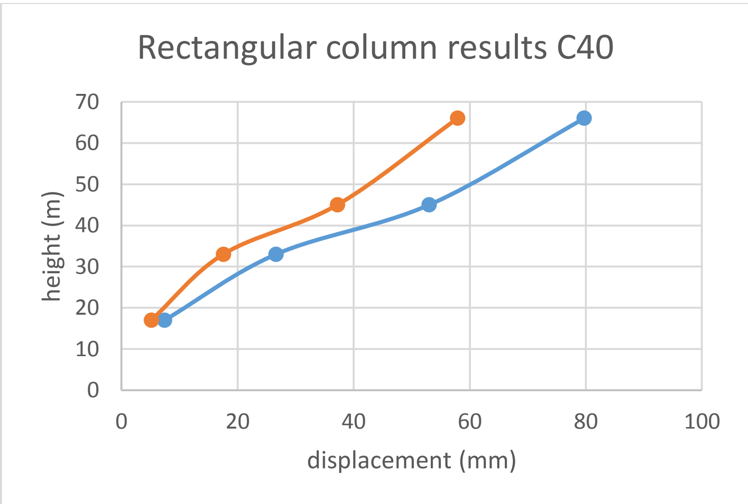


Figure 18. *Rectangular column results and wind velocity 110 mph*

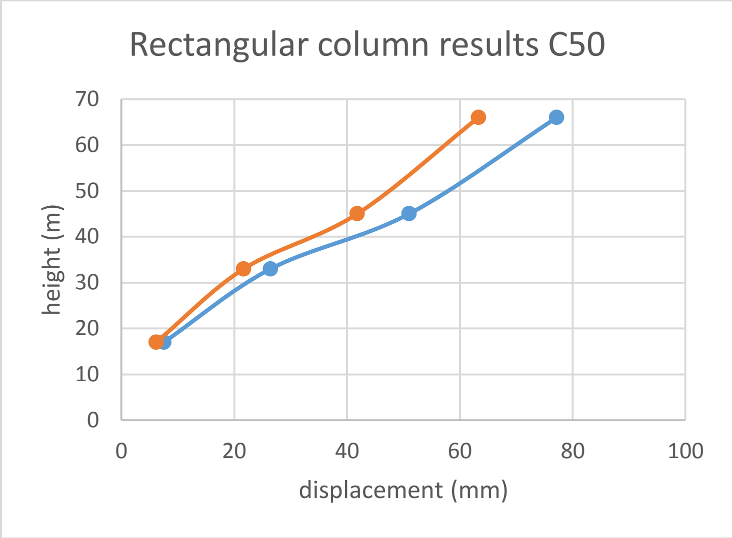


Figure 19. *Rectangular column results and wind velocity 110 mph*

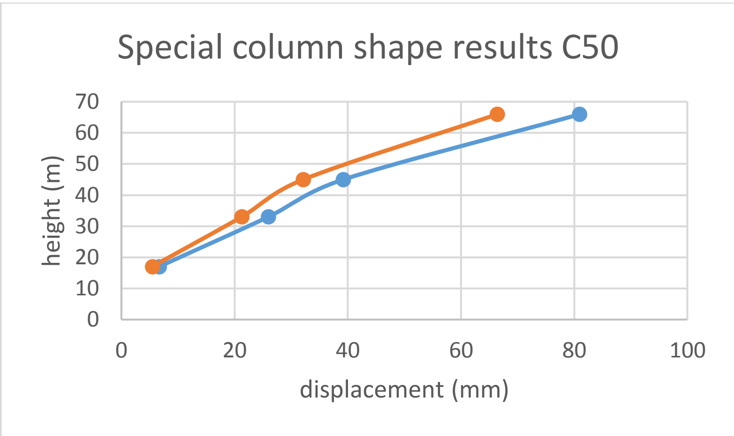


Figure 20. *Special column shape and wind velocity 110 mph*

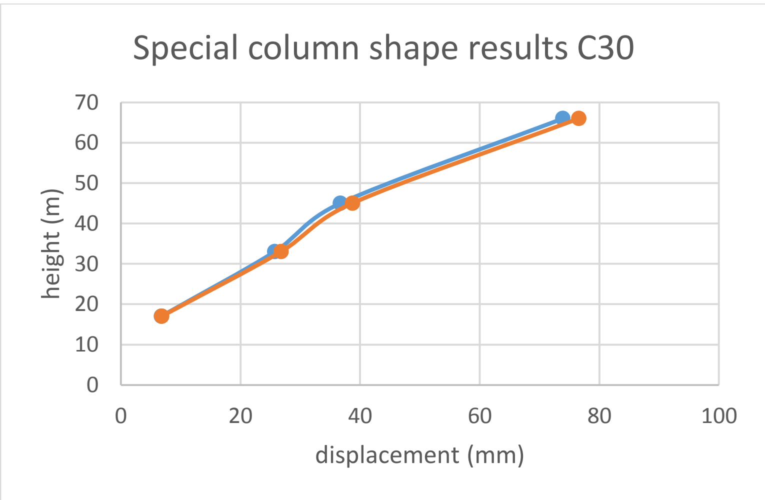


Figure 21. *Special column shape and wind velocity 110 mph*

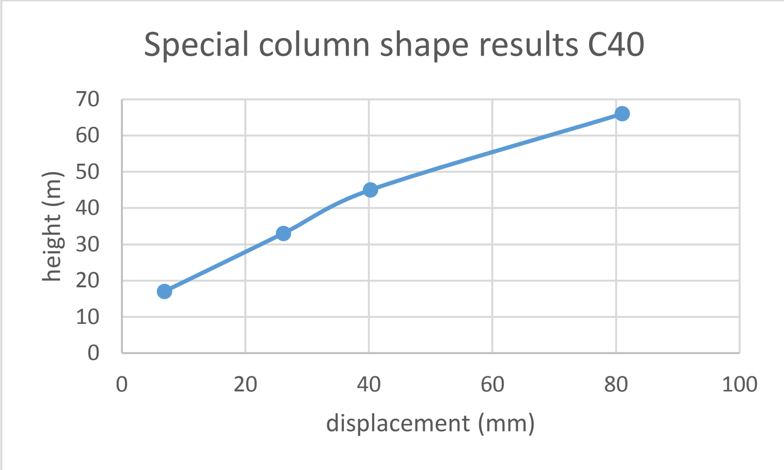
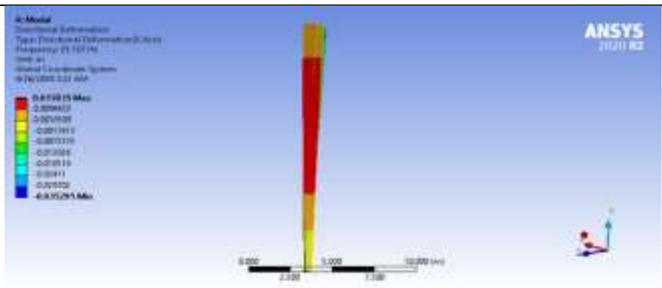
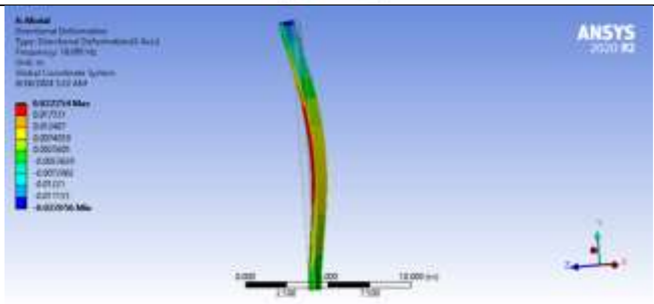
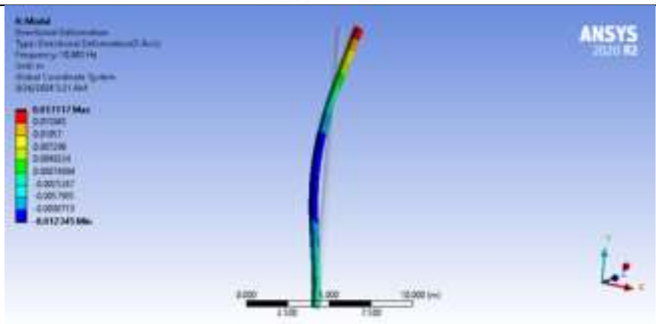
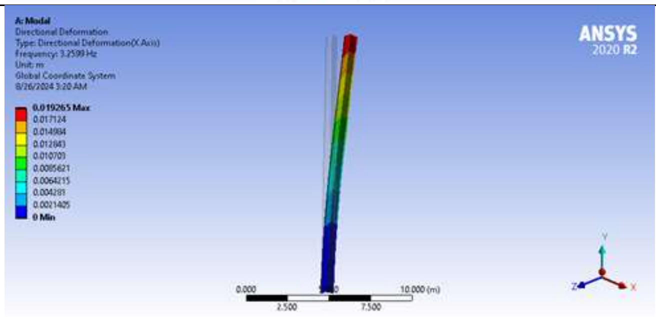


Figure 22. *Special column shape and wind velocity 110 mph*

Table 6. *Modal analysis L*

Modal node	ANSYS result	Frequency (Hz)
1		23.123
2		18.893
3		10.843
4		3.2599

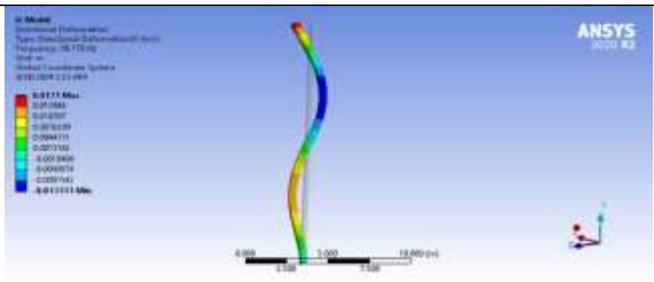
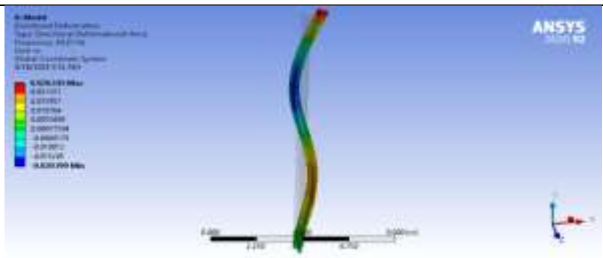
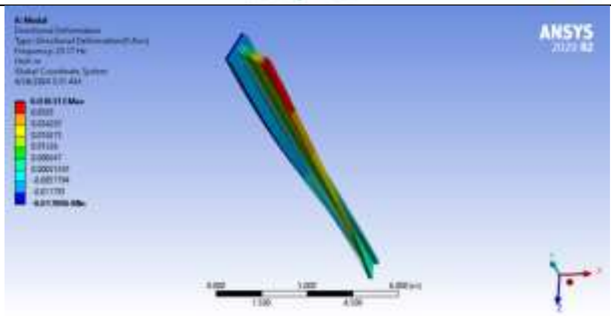
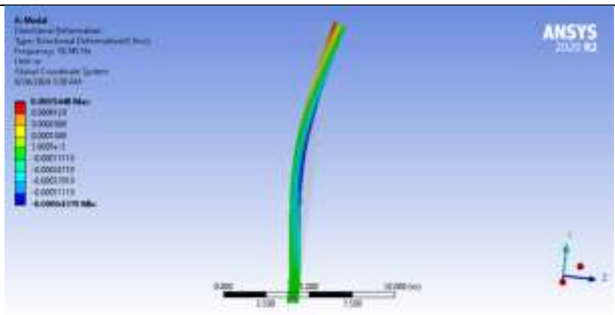
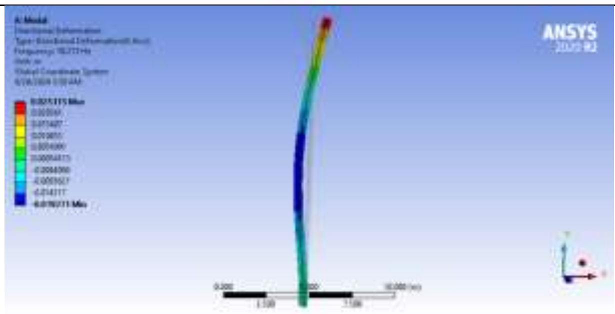
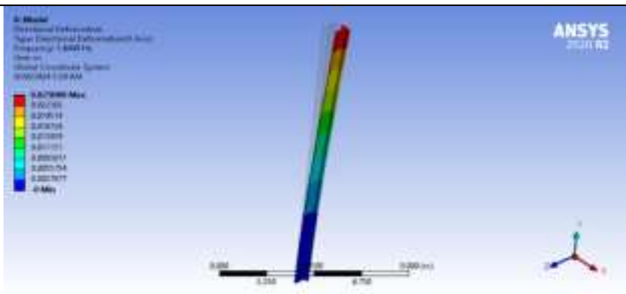
5		30.178

Table 7. *Modal analysis T*

Modal node	ANSYS result	Frequency (Hz)
1		28.25
2		23.17
3		19.745
4		10.213

5		1.6449

4. Conclusions

The sectional characteristics mostly rely on the dimensions and shape of the column. The structural serviceability is greatly influenced by the inverse relationship between the moment of inertia of an I-section and the depth raised to the third power. Recently, several types of columns have become increasingly prevalent in construction projects. Form columns provide several benefits, such as enhanced bending stiffness and ease of maintenance, a deeper section without adding weight, lower costs for maintenance and painting, and a greater strength-to-weight ratio. Column shear is taken into account while analyzing columns, and research on column attributes has been somewhat increased. Based on the data obtained in this investigation, one may reach the following conclusion. The composite moment of inertia of the castellated column section. Analyzing the axial force data facilitates the consideration of column design. The magnitude of column axial displacement is higher in the rectangular shape compared to the other forms.

The results are presented as load versus deflection responses and failure scenarios. They are based on modeling rectangular steel columns with square openings. We created the columns using SolidWorks. Both experimental and finite element investigations reveal that the FE models accurately simulate the experimental models' load-deflection behavior and breakdown processes. Modal space deformation might serve as the primary deformation in this scenario. Mode forms, which are distortions, can be utilized to illustrate the patterns being studied here. Most of the time, "building in a complicated mixture" entails utilizing all potential modes of movement. Modal analysis simplifies complex structures by breaking them down into level-one chance frameworks. This makes the structure clearer and easier to comprehend. Standard functioning conditions are required for it to function properly.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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