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NONLINEAR SIMULATION ANALYSIS OF TAPERED REINFORCED CONCRETE COLUMN (SOLID AND HOLLOW) BEHAVIOR UNDER AXIAL LOAD

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ABSTRACT: Tapered columns are a type of column that is used for different purposes, including architectural purposes or structural needs to take into account the changes that occur to moments along with the height of the column. For example, in highway bridges, tapered columns are used to reduce the number of moments transmitted to the base of the columns and from there to the foundation. This research studied the analysis of short reinforced concrete columns with variable cross-sections along the column in a linear manner by using the ANSYS V.15 software package. The variables that were studied included the type of section, solid or hollow, the ratio of longitudinal and transverse reinforcement, the ratio of the hollowness, and the comparison of numerical results with those obtained from the previous study. The results we obtained from the simulation of the numerical analysis of the models showed a very good agreement with the results of the experimental studies for them. This agreement can also be observed through statistical analysis using the arithmetic mean and standard deviation when compared. Thus, the proposed model by numerical analysis and hypotheses is suitable for formulating the behavior of these reinforced concrete tapered column models under the effect of axially applied load and other variables. The behavior of column models is based on applied loads, load-displacement curves, crack patterns, and failure modes. The results showed that increasing the ratio of longitudinal and transverse reinforcement increases the resistance of the R.C. column models and the ductility index with a decrease in the corresponding lateral displacement. This behavior is observed when changing the section from hollow to solid. Finally cracks pattern is represented in the concrete crushing and concrete spalling out of some parts at the end of the tapered and diagonal cracks in different places, especially at the end of the tapered.

Keywords: Numerical Analysis, Tapered Columns, Solid, Hollow, Reinforced Concrete, ANSYS, Longitudinal, Ties, Recess Ratios, Compressive Strength.

1. INTRODUCTION

The design of structures, in general, depends on economy and safety, so we see most designs depend on the standard sections of the parts of the structure, including the columns because they are inexpensive or easy to obtain when implementing, but with that, the characteristics of the section are used or changed, I mean a tapered section, which gives efficiency to the structure and is economically too.

Therefore, this type of section can be used in complex facilities or that contain a special classification, as well as that, contain large spaces, where the optimum exploitation is made in terms of the efficiency of the origin when using these tapered sections by reducing the sizes and quantities of materials required at construction while enhancing their resistance [1-4].

The basis of engineering design is to achieve a balance between cost and performance, and this is achieved by the use of hollow structural members, which are widely used in bridge supports and heavy spaces. Therefore, there is a necessary need to study and evaluate the integrity of the structure under different loads when making changes to the cross-section [5-8].

Columns are defined as the pressure members whose height ratio is more than three times the other dimensions, i.e., lateral if they are considered as a rule [9,10].

Columns, in general, are the parts of the structure that bears the loads imposed on them from the other parts at vertical orientation and are in a state of compression in the first place and often bear the movement of bending around one or all the axes of the cross-section, which results in the tensile forces over that section. However, the columns are considered compression members due to the behavior of the dominant by compression forces. [11,12].

The main goal when designing is to obtain columns with high resistance and safety at the same time, that is, the necessary precautions must be taken to maintain this goal when changing the use of the structure or lifting some structural parts or when damage to the column occurs during the life of the structure, therefore, the required resistance column gain is the appropriate solution [13].

Generally, the design of concrete structures mainly includes two specific conditions that must be achieved, namely, the strength and durability of the structure. The first case of determination includes ensuring that the structure remains safe under the effect of different or various loads.

While the other limiting condition is the ability to bear loads, taking into account the cracks and deformations accompanying that [14, 15]

Concrete columns of all kinds and shapes are an important part of the facilities in civil engineering and its applications therefore, knowing its behavior under the influence of loads, including the axial load applied to it, is of paramount importance. This study included the numerical analysis of a type of tapered columns variable cross-sectioned along its linearly to investigate their behavior under the applied axial load. Most of the basic assumptions were taken into consideration in this numerical analysis to formulate models that are compatible with the actual behavior of the columns that were experimental studied in previous investigations [16].

1.1 Slenderness Ratio

The ACI-318M code [11] allows the columns to be designed as short if the secondary moment does not affect the resistance reduction by any more than 5 %. This results from determining the transition from short columns (failure due to materials) to long columns whose failure is the result of buckling, as defined by the ratio of the effective length $(kl_u)$to the inertia radius (r).

The length of the unbraced part of the column is called (lu). The coefficient of attributions for the ends of the column is called (k). The slenderness (klu/r) ratio must be less than or equal to 22.

For example, in the case of an unsupported column, a short column is classified according to the requirements of the ACI code [11], on the other hand, it can be defined as a long column if the condition does not apply.

In this study, it was confirmed that all the columns models have the effective length is (*lu=900 mm), (k = 1) as* simple support, and the radius was taken for the critical section i.e. (150x 200 mm), and as a result, the slenderness ratio is equal to ($klu/$=15.58) [16], which is less than 22, so it was considered the columns are short when studied numerically and compared with the study of the previous experimental results[16].

1.2 Tapered Columns

Structures that contain different members when bending moment occurs can be made economically proportional by used members reducing their cross-section along length i.e., used tapered members. That is, the use of a larger cross-section when the bending moment is high, and the opposite, i.e., a smaller cross-section is used when the bending moment is low [17].

Taper members when they are fully adjusted laterally, the calculation of the change in bending moments is more efficient, and when lateral restraint is not available, it is economically appropriate to use tapered members, but a load of flexural-torsional buckling must be determined for the non-prismatic member. Therefore, if the restraints are not sufficiently stiff, the failure of the tapered member may be caused by buckling with elastic restraints [18].

This research aims to formulate a theoretical model using the ANSYS software package V.15 [19] to study the behavior of tapered columns with solid and hollow sections with the effect of other variables such as the ratio of longitudinal and transverse reinforcing, type of section, and the ratio of the hollow part of the total section in the core of the column and compare it with the results of the experimental results from the previous study [16]. Also, the structural response for comparison purposes adopted load capacity, failure modes, and crack pattern distribution for all models for evaluation and discussion purposes.

1.3 Literature Review

This paragraph included a review of previous studies on reinforced concrete columns square or tapered (solid or hollow sections) etc. Where most of the available research on the effect of the applied axial load, the ratio of longitudinal and transverse steel reinforcement, the effect of the type of section, and the ratio of cavities on the behavior of concrete columns to benefit from them, when comparing on this basis between the numerical and experimental study of the research subject of the study was conducted.

There is little research on this case, which represents the use of solid and hollow tapered reinforced concrete columns, where there are research studies on the behavior of prismatic reinforced concrete columns, whether they are solid or hollow under the influence of axial loads.

When designing, tapered elements are not considered in the first place, because the structural analysis is rather difficult and cumbersome, and design standards do not exist in practice and implementation is expensive [20].

The analysis of non-prismatic columns was limited to stationary cases before the development of numerical analysis methods, which included equations of closed form using the tools of mechanical analysis. Thus, the tapered columns are with fixing conditions so that they do not allow the solution of the closed columns when designing by the general steps followed Where these methods were used in the early design of the prismatic members so that it is equivalent to the tapered columns so that its cross-section depends on the cross-section in that specific part of the tapered columns, for example, the cross-section at a distance of 1/2 and 2/3 of the length to the smaller end base [21].

The analysis study for most of the unbraced laterally frames structures shows that there is a benefit from the tapered columns as well as the beams. This results in providing more space for the joints of the sill with the column to resist moments and shear and also reduces the lateral displacements that occur between members [21].

The openings and cavities that work in the reinforced concrete columns whose purpose is to pass various services such as water transmission lines, energy, communications, etc. It may be imposed by the architectural designers to maintain the external appearance of the buildings, for example, without affecting the implementation of passing services outside them [22].

The researchers Priestley and Park [23] studied hollow section reinforced concrete short columns under the influence of compound loads and bending moments. When viewing the results of the examination, it was found that the critical section is located directly above the base. Also, these columns are longitudinal steel reinforcement in the inner and outer part of their cross-section and contain transverse reinforcing in the form of a tight collar around the longitudinal steel reinforcement, as well as a circumferential collar to confine the concrete core between these layers of reinforcement. Various variables such as the level of axial load as well as the amount of tangential iron were also studied.

Mo et al. [24], made resections on the hollow rectangular columns under the bending load as a basis. The models are designed with lateral reinforcement to comply with the requirements of the code to avoid shearing failure and to achieve a spacing of fewer than six times the diameter of the longitudinal reinforcing bars. They showed that the maximum lateral forces are greater than normal when the models have a high compressive strength of concrete. This resulted in an increase in displacement and a decrease in the ductility factor of displacement

The displacement factors of ductility depend on the yield of steel reinforcement, as well as the greatest axial force resulting in great lateral forces that cause these greatest displacements and a decrease in the ductility factor.

Yeh et al. [25], tested prototypes and scale models of the hollow section concrete columns under the applied axial load as well as the bending as they studied the effect of volume size. The results of the study showed that the prototypes models have a higher ductility factor than the realistic ones. The failure mode represents the rupture of longitudinal steel reinforcement for all models while preventing shear failure and buckling by fixing and bonding appropriate braces. The results showed that models with high axial strength have lower ductility than those with lower axial strength. Also, the transverse reinforcing ratio when it is reduced to half of the specified percentage according to the ACI318 code [11] results in a failure mode, flexure – shear, or shear.

Yen [26] proposed a numerical model to represent the short columns, analyze them and design them using computers and manual calculations under the influence of axial or decentralized loads. The main longitudinal reinforcement areas have been improved. The basis of the theoretical analysis resulted in the steps of the solution according to which the applied load must be less than or equal to the force resulting from the section that includes the proportion of the fitted rebar as well as the location of the tie axis

Numerical analysis using finite elements is one of the available methods that are widely used for analysis purposes. It is considered the most complex tool for solving engineering problems that contain more complex shapes that traditional methods fail to solve accurately or that are uneconomic and require long periods. The finite element method is used to analyze any shape, genus, or structure with the various materials contained in those structural or structural parts, and this is what distinguishes it from other methods [27].

Ismail [28] has analyzed reinforced concrete columns strengthened by CFRP by 3D modeling of the columns using finite elements equipped by ANSYS. Where he studied the effect of the compressive strength of concrete, the thickness of the CFRP layer, the ratio of the dimensions of the cross-section i.e aspect ratio, as well as the elastic modulus of CFRP. Element 65 was used for concrete, and Link 180 element for steel reinforcement. As for CFRP, the shell 99 element was used to represent it. All these elements are three-dimensional.

Muhammad [29] used non-linear finite elements to analyze confined concrete columns. A three-dimensional element containing 20 nodes was used to represent the confined part of the column and the outer part of it was represented by an element containing 8 nodes in the binary sheath. The degrees of freedom in these nodes were 3 in each of them, to represent them consistently. The purpose of modeling is to achieve compatibility with the overall structural behavior and the bearing capacity of the columns.

2. MODELS GEOMETRY

Characteristics of simulated numerical models are taken from previously tested models [16]. These characteristics include geometry, End conditions (top and bottom), hollow location, loads, and support conditions. The dimensions of all models were of constant length 1000, tapered bases i.e. (top base 150 mm, bottom base 200 mm, and the beneath space of 200 mm).

These characteristics of the models can be observed in Table 1, while Figs.1,2 shows the structural details, dimensions, and specifications of the reinforced concrete column models (solid and hollow) in terms of the longitudinal and transverse cross-sections and the front views. Hence, from this, it is shown that there are two groups, one of which contains models of solid R.C Tapered columns and the other contains models of hollow section. The main variables for comparison between all models were the ratio of longitudinal reinforcing as well as transverse reinforcing i.e. (ties).

Table 1 Models Characteristics [16]

Symbols	As Ø10	Av Ø 8mm	*Type Section*	*Recess Ratio%*
C1	4	100	Solid	---
C2	4	120	Solid	---
C3	6	100	Solid	---
C4	6	120	Solid	---
C5	4	100	Hollow	16
C6	4	100	Hollow	41
C7	6	100	Hollow	16
C8	6	100	Hollow	41

C: Column; As Main Reinforcing; Av: Ties Reinforcing

2.1 Materials Properties

The mechanical properties of the materials that make up these models (concrete and steel reinforcement) are mentioned in Tables 2 and 3 respectively to simulate these materials in the Numerical analysis by ANSYS.

The dimensions details and layout geometry of R.C. models for each specimen (solid and hollow section) [16] were shown in Figs. 1 and 2. While Fig.3 shows Moulds, reinforcing, and Layout Recess locations for all models [16].

Table 2 Mechanical properties of concrete [16]

Mix No.	f_c` MPa	f_t MPa	f_r MPa	E_c MPa	*VC*
1	28	3.12	3.66	25094	0.2

f_c`: cylinder compressive strength of concrete
f_t: tensile strength of concrete
f_r: modulus rupture of concrete
E_c : elastic modulus of concrete
v_c: passion ratio of concrete

Table 3 Mechanical properties of rebars reinforcing [16]

d_b (mm)	f_y MPa	f_u MPa	E_s MPa	v_s
8	380	475	205000	0.3
10	420	525		

d_b: Bar diameter of steel reinforcing.
f_y: yield stress of steel reinforcing
f_u: ultimate stress of steel reinforcing
E_s: elastic modulus of steel reinforcing
v_s: passion ratio of steel reinforcing.

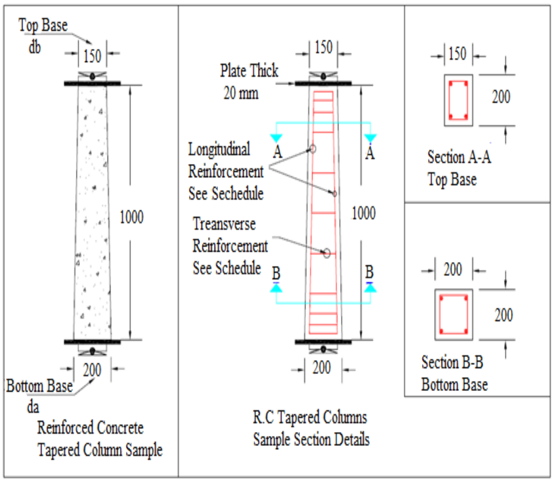


Fig.1 Dimension and Details of R.C. Tapered Columns (Solid Section) [16].

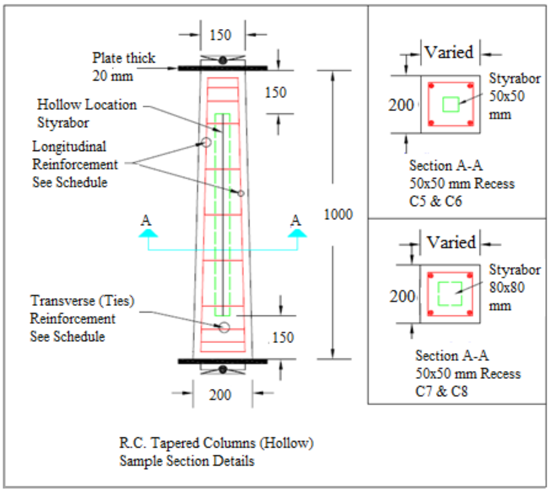


Fig.2 Dimension and Details of R.C. Tapered Columns (Hollow Section) [16].

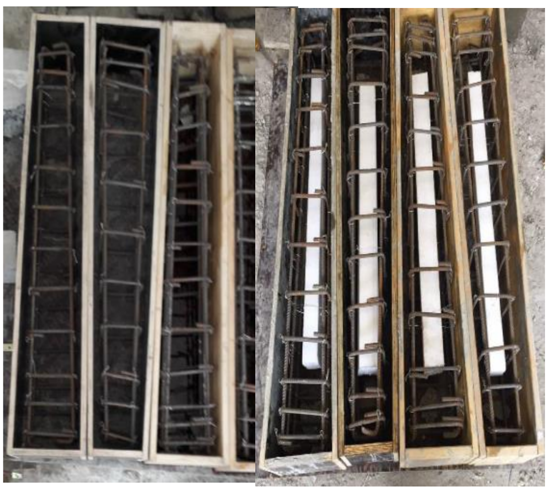


Fig.3 The Moulds, reinforcing, and Layout Recess locations for all models [16].

2.2 Assumptions

The assumption that was adopted in this study for the numerical analysis of R.C. Tapered concrete columns on the basis that the concrete and steel reinforcing materials are homogeneous and isotropic, just as the reinforcing steel surrounded by concrete has the same nodes when bonding and without fracture (reinforcements simulated as discrete). Also, the assumption of the plane remains plan and the stress-strain assumed an elastic-plastic for reinforcements.

It was used to predict the nonlinear behavior of a concrete by represent of a multilinear isotropic model. As this model accepts stress and strain at multiple points in the plastic range depend on mechanical properties of concrete.

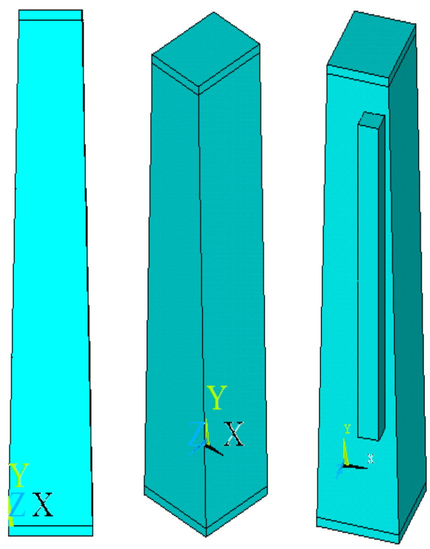
While the point of no plastic strain and yield stress is at the first point of the curve, i.e. the yield point. The stress with the strain values increases with that because the plasticity model prevents any point or curve with a slope less than zero, which is not accepted.

The following assumptions were taken for the purposes of modeling concrete that contains steel reinforcing in its composition. It was used to predict the nonlinear behavior of steel reinforcing by represent of a bilinear isotropic model. The bilinear isotropic behavior is defined also by the mechanical properties of steel reinforcing i.e by yield stress f_y for different diameter of its. These parameters which are defined in the ANSYS software package [19], and the other of the parameters are within the information program i.e (ANSYS [19] in built).

3. FINITE ELEMENTS MODELLING

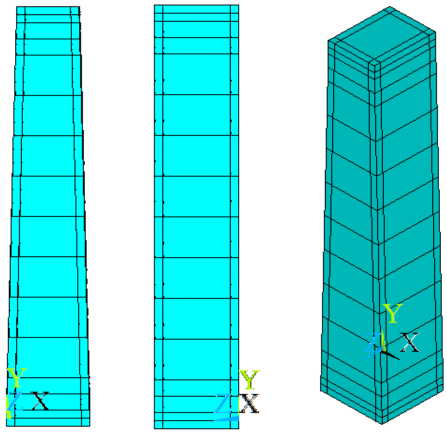
Numerical analysis involving the finite element approach was done by using ANSYS software [15] to simulate the conducted models. In the modeling process, the available elements were chosen to simulate the actual behaviors of the model's materials, supporting conditions, and the applied loading. These materials include concrete, plate support, plate under loads, main reinforcements, and stirrups. SOLID65 element was selected for concrete material, which has three degrees of freedom at each node. LINK180 element was chosen to model all-steel reinforcements. SOLID185 was adopted to represent the steel plates, which are underneath the applied loads and supports [16].

Also, each model is usually divided into small elements, i.e., each element size of 25 mm in all directions by meshing. Besides, the connection between reinforcement nodes is similar to that of concrete solid nodes, in which the concrete and steel reinforcement nodes are merged. Typically, this technique can provide a perfect bond between the simulated materials i.e. the steel reinforcing elements are assumed full bond with concrete elements. The tolerance value of 0.05 is used, in which the displacement controls during the nonlinear solution for convergence. The average load capacity of the simulated models is checked with that experimentally obtained from the previous study [16]. The whole behavior of the controlled model of normal strength concrete and those of high strength concrete subjected to eccentric distributed line load is compared with those of the experimental ones. The open and close coefficients for concrete cracks are 0.2 and 0.7, respectively. The behavior of materials for steel rebars and concrete is anelastic–full plastic. This behavior for concrete is linear up to $0.3f'_c$, an elastic up to 0.85 f_c, and full plastic up to 0.003 of the maximum value of concrete strain. The main assumptions of the numerical analysis are the plane section remaining a plane before and after applied loads, the homogeneity of concrete, full bonds between concrete and reinforcements, and ignoring the self-weight of the columns. Fig. 4 shows the wireframe for whole reinforced concrete tapered columns models components such as dimensions, longitudinal and ties reinforcing locations details, steel plate parts condition as a simply supported models and location of hollow recess parts at longitudinal center line of tapered model.

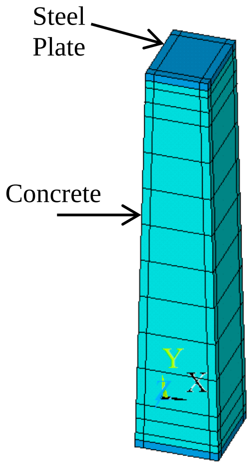


1- Area 2- Solid 3- Hollow

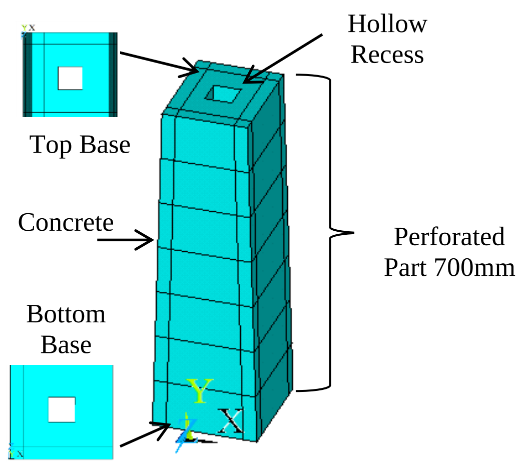
Fig.4 Modeling steps by Finite element procedures for a typical Tapered R.C. columns model



4- Front 5- Side 6- 3D views



7- 3D views for whole model solid or hollow sections



8- 3D view for typical hollow Column model

Fig.4 Continue.

After completing the drawing of the areas and generating the volumes of the model parts by the ANSYS software package [19], the process of dividing into small parts begins with the command “Mesh tool” from the program, and as shown in

Fig.5 where the front, side and three-dimension views of the tapered model can be observed and the distribution of the finite elements into small elements at each side. The length of each element in different directions is 25 mm.

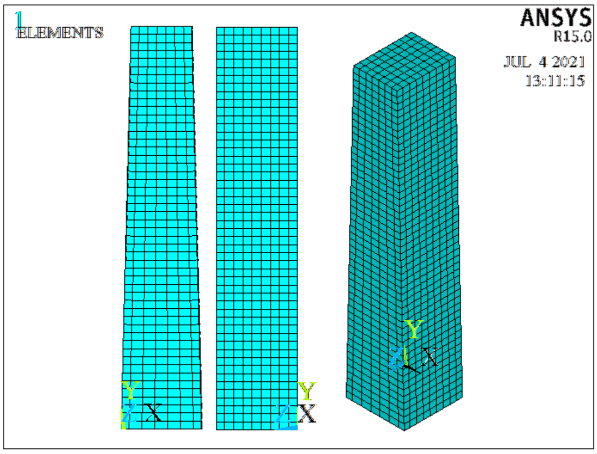


Fig.5 Front, side and 3D views of typical Tapered Column model mesh.

Fig. 6 shows the different parts of the model with its representation by the elements available in the ANSYS environment, as the concrete was represented by element Solid65, the longitudinal and transverse reinforcing, as by the element Link180, and finally, the steel plate that serves as a support for the model was represented by the element Solid185.

The support of the upper base is a roller with restrictions in the horizontal direction and the support of the lower base is a pin with restrictions in the vertical and horizontal directions which are shown in Fig. 7. While the modeling of applied loads as shown in Fig.8, the loads were axial and perpendicular to the upper base on the intermediate nodes of its.

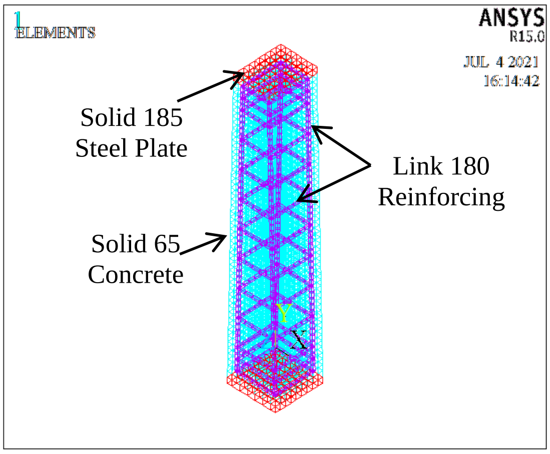


Fig.6 3D views for the Elements details (Steel plate, concrete and steel reinforcing for a typical model.

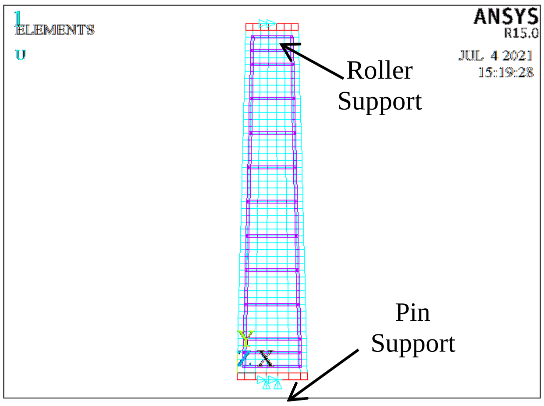
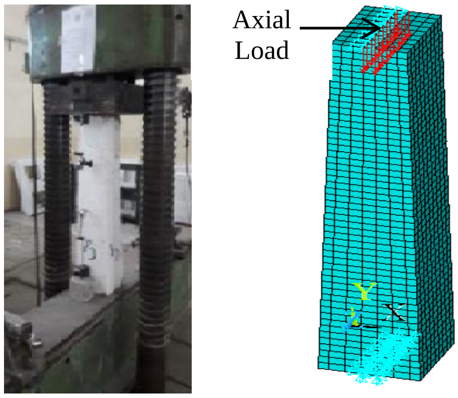


Fig.7 Supports modeling of base Ends for typical model



a- Experimental [16] b- Numerical

Fig.8 Loads Modeling for typical Tapered Columns Model.

3.1 Results and Discussions

The finite element model was analyzed by ANSYS software package [19] for eight models of tapered columns, which were simulated in terms of the mechanical properties of the materials constituting the model, as well as the applied load and the different support conditions that were taken from the study of the previous experimental tests [16]. This section shows the basic relationships of the models that were analyzed by simulating them using ANSYS software [19] will be listed by studying the effect of the type of section i.e., when used (solid or hollow section), as well as the effect of the longitudinal and ties transverse steel reinforcing ratio on the structural behavior of reinforced concrete Tapered columns under axial load and show the enhancement on load-carrying capacity based on these variables.

Based on the results of the analysis, all the models failed due to concrete peeling off and some fragments spalling out in different location parts as well as cracking of concrete.

Fig. 9 shows that the failure of the hydrostatic stress pressure of the typical model of the solid and hollow column, where can be observed that the stresses are diagonal and are concentrated at the supports and up to the towards parts in the direction of the applied load and this stress increases according to the type of section, that is, the hollow section have higher stress than the solid section of the same applied load by about (22-37%) [14,15]. Also, the ratio of longitudinal and transverse steel reinforcement affects this stress, as it decreases as the percentage of steel reinforcing increases by (50%).

while the Von-misses stress and strain of the controlled typical columns as shown in Figs. 10 and 11, respectively. these figures show that the stresses were high and concentrated at the supports, hollows (recess), and side of Tapered edges at top and bottom bases of columns models. This behavior is related due to the distributions of stresses are result from the mechanism of loading transfer in the tapered columns [16].

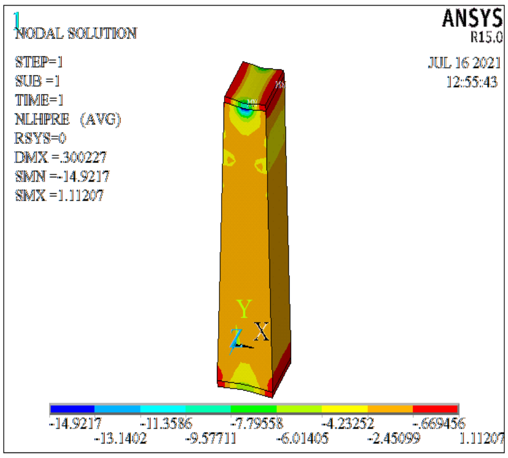


Fig.9 3D- views for Hydrostatic stress of the Typical controlled Tapered columns C1(Solid).

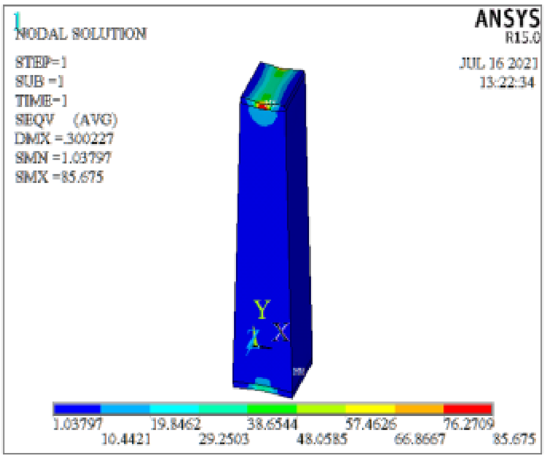


Fig.10 Von-Misses stress of the controlled tapered column model C1 (3D view)

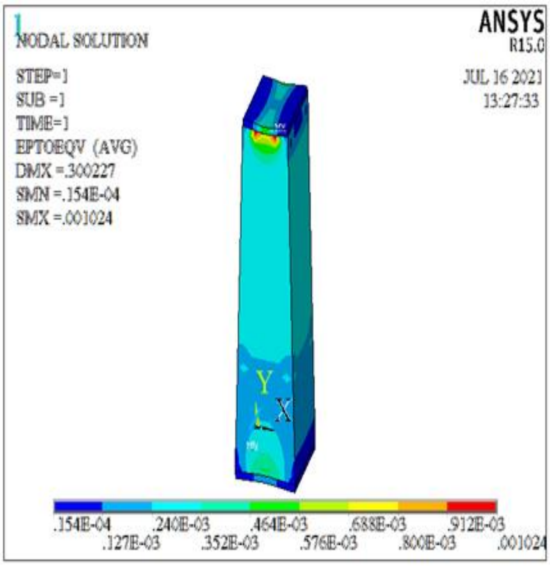


Fig.11 Von-Misses strain of the controlled wall tapered column model C1 (3D view)

Figs. 12 and 13 show the three-dimension views contour at the failure stages of displacement. From this figure can observe that the RC tapered columns behavior shows that the maximum displacement occurs at the top ends of tapered dimensions of the models due to the varied dimension i.e the top base length less than the dimension of other parts this trend produced critical failure lies near top base not the middle of models, this behavior give safe against buckling failure [6,14,15]. The middle and top-end displacements represent a cumulative displacement that was recorded varied range quantity but symmetric about a center line of models i.e (at tension and compression sides of all tapered columns).

However, the displacement values are higher in the hollow sections compared with other solid sections of tapered columns models due to the hollow recess ratio gives less loading capacity and increased displacement.

Also, when increasing the longitudinal and ties reinforcing ratios gives more enhancement response for load carrying capacity and reduces the corresponding displacement of models.

In general, for sections that contain recess (hollow) when the ratio of their longitudinal and transverse reinforcement is increased, this increase gives an improvement in the load capacity of the models, so that it compensates for the decrease in the resistance as a result of the work of these recess in the models [14,18].

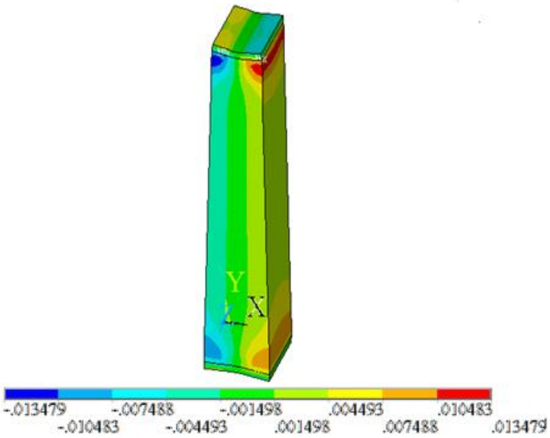


Fig.12 A 3D view contour for the displacement failure of the column model C1(Solid)

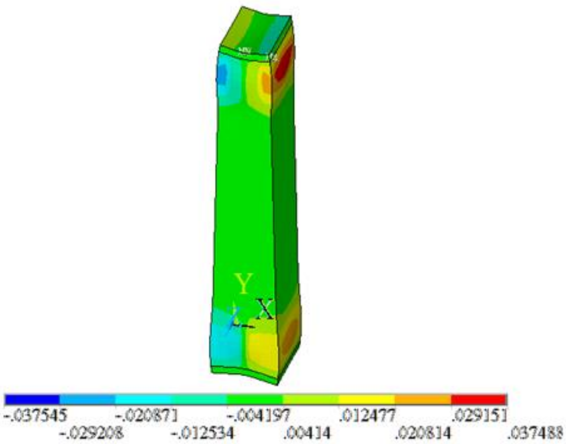
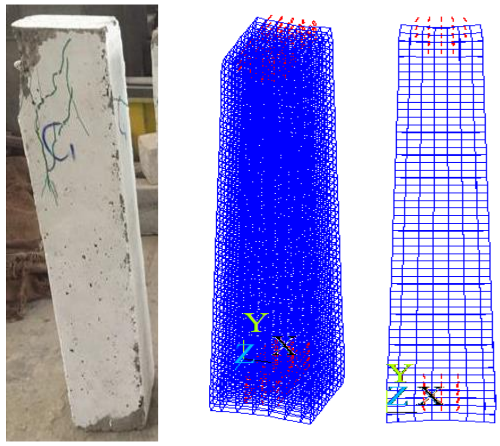


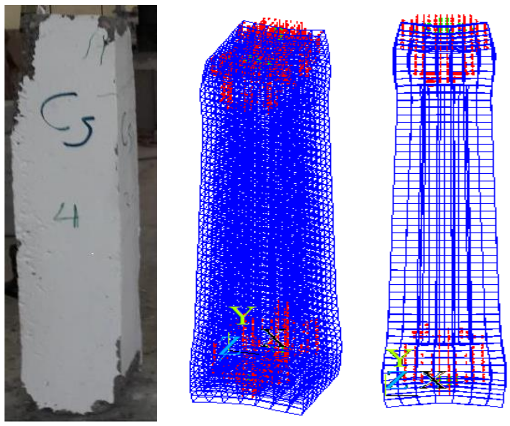
Fig.13 A 3D view contour for the displacement failure of the column model C5 (Hollow)

The two Figs. 14 and 15 show a comparison of the cracks pattern distribution at failure stage between experiential test result [16] and analytical results numerically by ANSYS software package [19], for the controlled tapered columns model solid and other hollow section respectively. These figures showed the cracking of the models obtained from the finite elements by a compatible matching program when compared with the failure patterns of experimental results. These cracks appear and develop to reflect the failure pattern of the tapered columns (solid or hollow) sections. Since the finite elements when representing the model is an accurate prediction of the failure of the model. Also, these cracks were concentrated at the ends, especially at the upper end as a result of stress concentration, then these cracks vanish towards the inner part of the model a long length. Finally, when comparing the solid and hollow section models, the ones that contain recess have a higher number of cracks than others.



C1, Exp. [16] C1, Numerical

Fig.14 Cracks pattern and failure mode for controlled solid model C1(Solid).



C5, Exp. [16] C5 Numerical.

Fig.15 Cracks pattern and failure mode for controlled Hollow model C2 (Hollow)

As for the loads that were taken in the analysis, it is the same loads that we obtained from the experimental test results [16] for all models, with a gradual increase of load by 10 KN. As for the position of the displacement dial gauge the experimental test study [16], it is fixed in the middle part and a quarter of the length i.e. (500mm and 250 mm at distance from top base respectively) of the tapered column model, as shown in Fig. 16

Fig.16 Dial gauges Positions [16]

Figs. 17 to 26 show a comparative study of the experimental and numerical analysis results of displacement with the applied load at the upper end of the column and for cases of variable loads according to the strength capacity of the comparative tapered column model.

These figures show the effect of a different variable on the behavior of R.C. tapered column models (varied linearly cross-section along the length).

These variables included the effect of section type i.e (solid or hollow), the main longitudinal and transverse ties reinforcing ratio and the hollow ratio was carried out. Displacement at all stages of loading of the reinforced concrete column was also discussed.it can be observed that when increased steel reinforcing ratios i.e. (longitudinal or ties) led to improvement in strength capacity load by about (22-35%) and reduced the lateral displacement by about (15-20%). while the ductility of specimen's enhancement by about (8-13%) for the solid section. while the model with a hollow section (recess), these recesses led to a decrease in load capacity by about (25-38%) and increased in lateral displacement by about (11- 18%) with the same other property of specimens. also, hollow recess gives a decrease in ductility ratio by about (20-29%) compared with solid specimen's models. it can show clearly that when increased longitudinal reinforcing led to give more in strength capacity of specimens contains hollow recess.

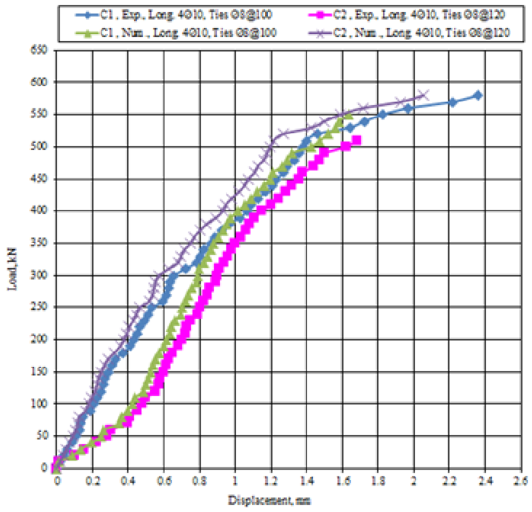


Fig.17 Comparison evaluations of Exp. and Num. for the load-lateral quarter displacement of C1 & C2 (solid)

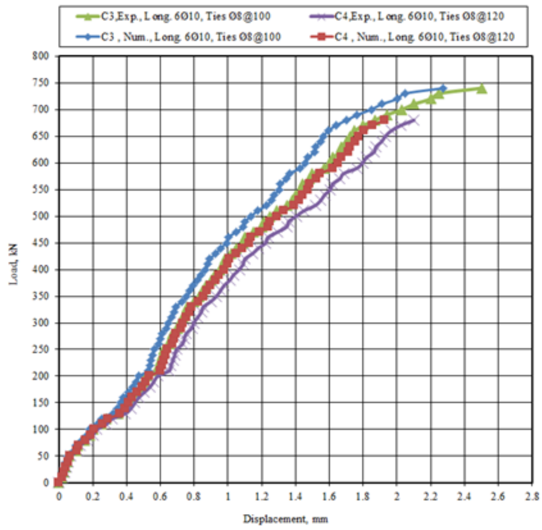


Fig.19 Comparison evaluations of Exp. and Num. for the load-lateral quarter displacement of C3 & C4 (solid)

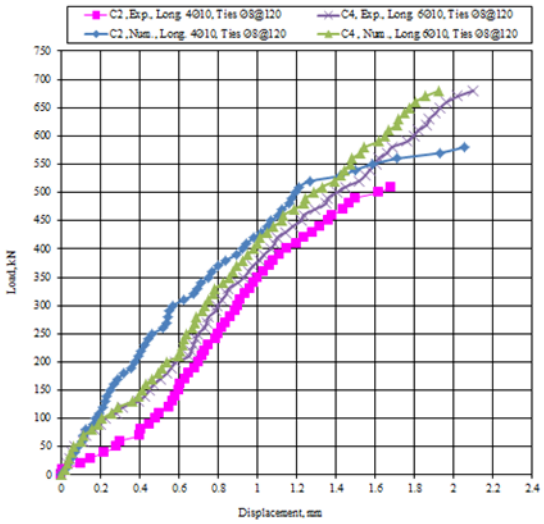


Fig.18 Comparison evaluations of Exp. and Num. for the load-lateral quarter displacement of C2 & C4 (solid)

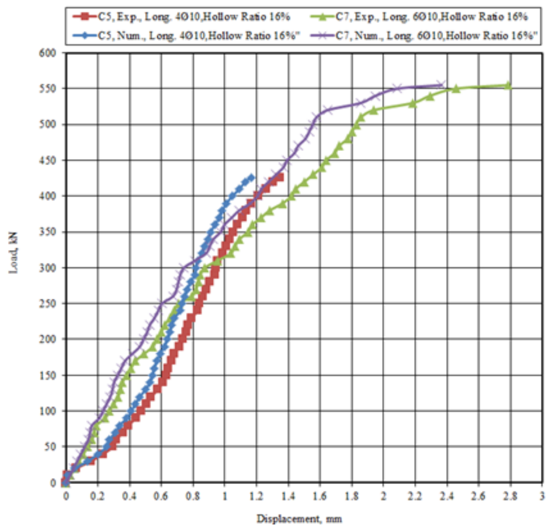


Fig.20 Comparison evaluations of Exp. and Num. for the load-lateral quarter displacement of C5 & C7 (hollow)

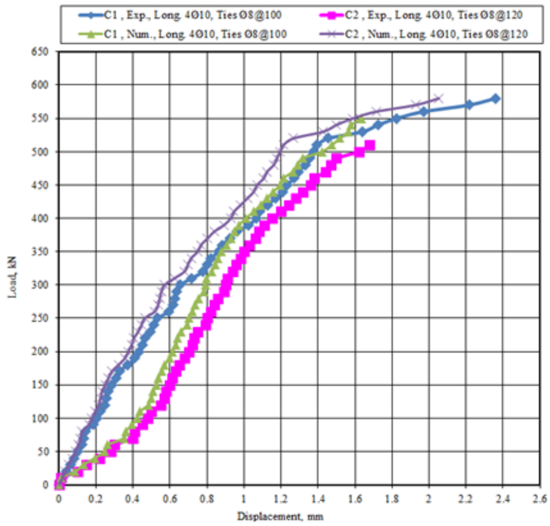


Fig.21 Comparison evaluations of Exp. and

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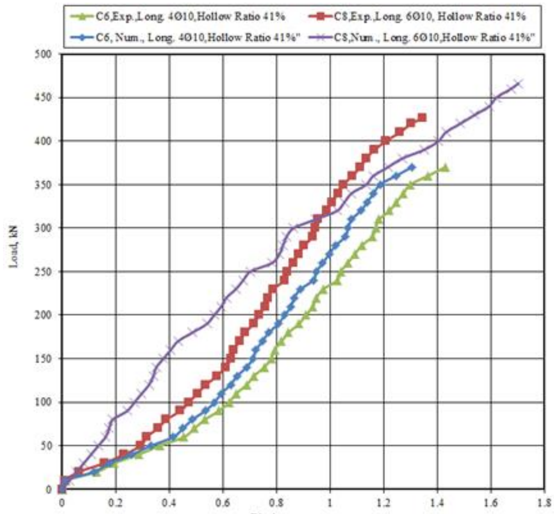

Fig.22 Comparison evaluations of Exp. and

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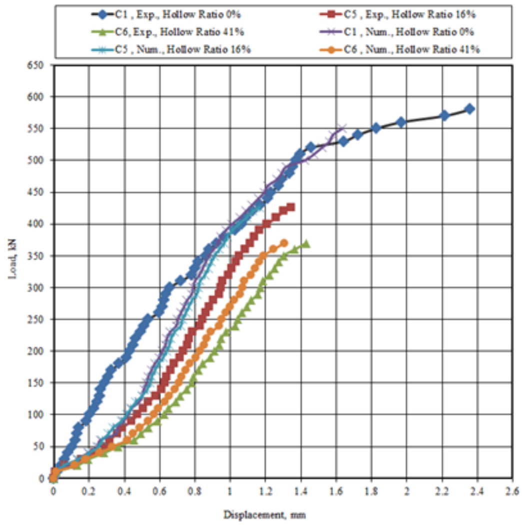

Fig.23 Comparison evaluations of Exp. and Num. for the load-lateral quarter displacement of C1, C5 & C6

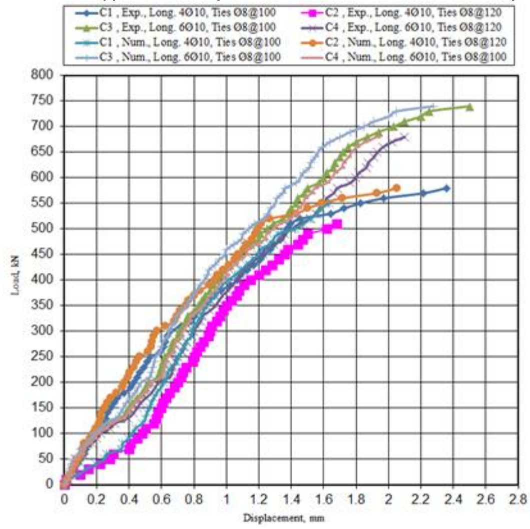

Fig.25 Comparison evaluations of Exp. and Num. for the load-lateral quarter displacement of C1, C2, C3 & C4 (solid)

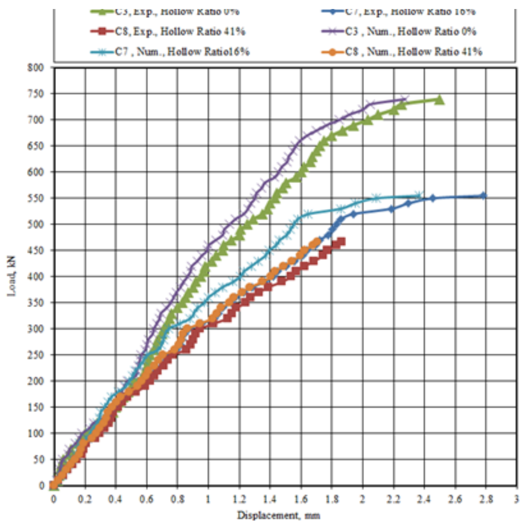

Fig.24 Comparison evaluations of Exp. and Num. for the load-lateral quarter displacement of C3, C7 & C8

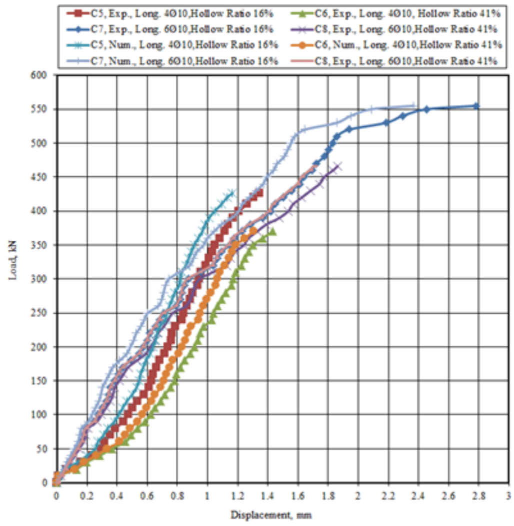

Fig.26 Comparison evaluations of Exp. and Num. for the load-lateral quarter displacement of C5, C6, C7 & C8 (hollow)

quarter-end and mid-length of the column model respectively at the stage of the appearance of the first crack and the effect of the failure load with the experimental test results of the previous study [16]. Table 6 only displays the results of the statistical analysis, which included the mean and standard deviation of the numerical to the experimental quarter displacement of column models, as through the results it was found that the deviation increases with the increase in the applied load. The presence of recess results in an increase in deviation with the application of the load increased. This is in agreement with the arithmetic mean and standard deviation of the ductility index of the comparative models in terms of numerical analysis and the results of the process, as shown in Table 6 concerning the lateral displacement in the upper quarter end of the column models, where the arithmetic mean is 0.974 for the percentages of the ductility index. It is also evident from Table 6 that the ductility index is affected by the rest of the variables, such as the ratio of longitudinal and transverse steel reinforcing, as shown when comparing the models, and this increase is due to the increase in the imposed load, i.e. (the load resistance). Finally, when comparing the values of the ductility index, there is a very good agreement for the practical and numerical results. It can be seen from Table 6. Also, the peak ratio of the decrease in the ductility index to the displacement can be observed when changing the section from solid to hollow, which amounted to approximately 98%. A simulation of the models was analyzed and formulated based on the results of the practical examination from the previous study. An analysis process was carried out by a program ANSYS [19] and compared with the practical results, where a very good convergence and agreement were found between them. This enabled us to prepare a study for other parameters based on the simulation that was carried out in the numerical program. In the future, these parameters will be addressed and studied in a practical way, to benefit from them for research or design purposes.

Table 4. Statistical Exp. and Num. lateral quarter-displacement comparison results of the tapered column models.

Model No.	Section type	Exp. & Num. loads (kN)		Exp. Displacement (mm)		Num. Displacement (mm)		Num./Exp. Displacement ratio	
		First	Failure	First	Failure	First	Failure	First	Failure
C1	solid	170	550	0.6	2.00	0.55	1.95	0.916	0.975
C 2	solid	192	510	0.55	1.35	0.53	1.30	0.963	0.97
C 3	solid	230	740	0.77	2.50	0.74	2.45	0.961	0.98
C 4	solid	210	680	0.42	1.40	0.38	1.36	0.904	0.971
C 5	hollow	164	426	0.67	2.40	0.63	2.36	0.940	0.983
C 6	hollow	155	370	0.71	2.48	0.68	2.44	0.957	0.983
C 7	hollow	183	555	0.82	2.60	0.77	2.53	0.939	0.973
C 8	hollow	145	466	0.46	1.86	0.42	1.78	0.913	0.956
							Mean	0.937	0.974
							STD	0.023	0.008

Table 5. Statistical analysis results of the ductility index comparison of the Exp. and Num. of lateral quarter displacements of tapered columns models.

Beam model	Exp. displacement (mm)		Ductility index, DI	Num. displacement (mm)		Ductility index, DI	Num./Exp. DI
	First	Failure	Exp.	First	Failure	Num.	
C1	0.6	2	3.333	0.55	1.95	3.545	1.063
C 2	0.55	1.35	2.454	0.53	1.3	2.452	0.999
C 3	0.77	2.5	3.246	0.74	2.45	3.310	1.019
C 4	0.42	1.4	3.333	0.38	1.36	3.578	1.073
C 5	0.67	2.4	3.582	0.63	2.36	3.746	1.045
C 6	0.71	2.48	3.492	0.68	2.44	3.588	1.027
C 7	0.82	2.6	3.170	0.77	2.53	3.285	1.036
C 8	0.46	1.86	4.043	0.42	1.78	4.238	1.048
						Mean	1.039
						STD	0.024

4. PARAMETRIC ANALYSIS

This study also included a parametric study consisting of modeling and analysis of sixteen models of tapered R.C. columns using the ANSYS V.15, software package [19]. In this study, the effect of the compressive strength of concrete fc`was taken into consideration as an important parameter in increasing the load capacity of tapered reinforced concrete columns, which are considered compression members. Analysis of these parametric variables is a list and presented in Table 6 and Fig.29

Two Compressive strength of 40 and 60 MPa was used as a parametric variable. Table 6 and Fig.29 showing the results of the numerical analysis showed that the maximum load at failure and the amount of lateral displacement at a quarter of the edge of the tapering from the columns models at the upper end. Whereas the increase in the compressive strength by 43% and 100% led to an increase in the maximum loading resistance of the columns by an amount ranging (22-28%) and (32%-50%), respectively, and we notice the highest increase when the columns are solid and not hollow, the reason for this is due to the increase in the compressive resistance that works to confine the concrete and prepare a resistance to bear the applied loads.

Finally, the proposed study to demonstrate the accuracy of the finite element model for other research at future works, as shown:

1- Study of the behavior of high strength R.C. hollow tapered columns.
2- Behavior of R.C. columns with tapered ends under the influence of compound load

Table 6. Effect of compressive strength of concrete fc` on failure load and lateral quarter-displacement.

Symbols	*Variable fc`*	As Ø10	Av Ø 8mm	*Type Section*	*Recess Ratio%*	*Pu, Num. kN*	*ΔNum. mm*
C1*	28	4	100	Solid	---	550	1.95
C1.1	40	4	100	Solid		705	1.88
C1.2	60	4	100	Solid		810	1.75
C2*	28	4	120	Solid	---	510	1.3
C2.1	40	4	120	Solid		642	1.26
C2.2	60	4	120	Solid		702	1.18
C3*	28	6	100	Solid	---	740	2.45
C3.1	40	6	100	Solid		960	2.39
C3.1	60	6	100	Solid		1100	2.32
C4*	28	6	120	Solid	---	680	1.36
C4.1	40	6	120	Solid		885	1.29
C4.2	60	6	120	Solid		983	1.25
C5*	28	4	100	Hollow	16	426	2.36
C5.1	40	4	100	Hollow	16	521	2.31
C5.2	60	4	100	Hollow	16	588	2.27
C6*	28	4	100	Hollow	41	370	2.44
C6.1	40	4	100	Hollow	41	460	2.38
C6.2	60	4	100	Hollow	41	510	2.33
C7*	28	6	100	Hollow	16	555	2.53
C7.1	40	6	100	Hollow	16	695	2.49
C7.2	60	6	100	Hollow	16	770	2.43
C8*	28	6	100	Hollow	41	466	1.78
C8.1	40	6	100	Hollow	41	586	1.74
C8.2	60	6	100	Hollow	41	650	1.68

* Experimental column specimen [16], represented by ANSYS [19] for comparison.

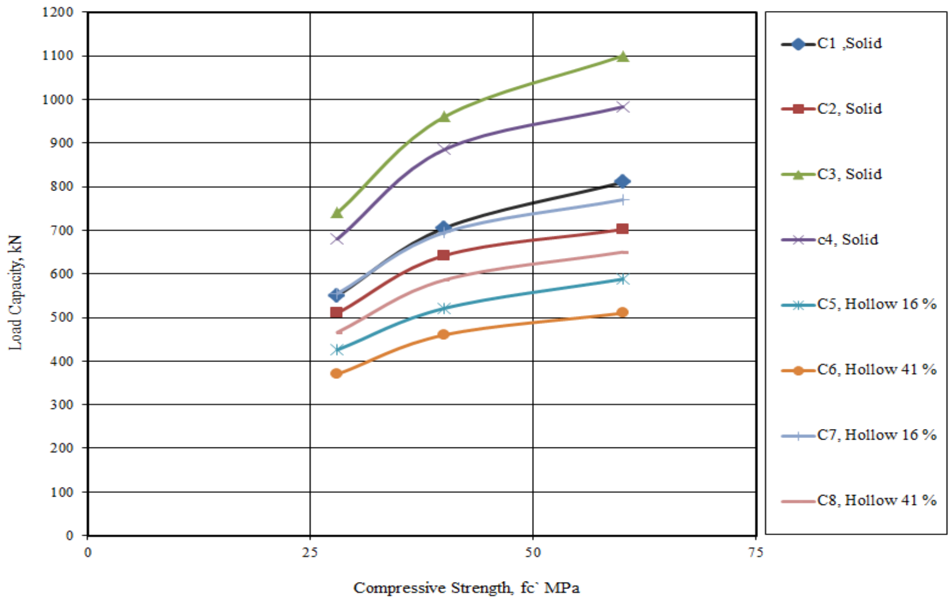

Fig.27 Effect of compressive strength of concrete f_c` failure load and lateral quarter-displacement.

5 CONCLUSIONS

This study included a numerical analysis of several tapered reinforced concrete column models by finite elements using the ANSYS software package and comparing them with the experimental test result obtained in a previous study. Based on these analyzes, the following points can be deduced:

- The numerical approach analysis showed accuracy in its results when predicting the structural behavior of the R.C. tapered column models and their different parts as a result of taking into account the appropriate assumption and the procedure steps of modeling representation of the model and conditions of supports, loading and the selection of elements that match the practical reality.
- Structural behaviors when analyzing column models numerically in terms of maximum resistance to loading, the cracking and failure patterns showed a very good agreement with the behaviors of the evaluated models when tested in the experimental results from the previous study [16]. Where this compatibility was verified by applying the statistic, e.g., mean and the standard deviation of the different models depending on the lateral displacements or the maximum strength resistance.
- The ultimate carrying capacity or loads at the failure stage of solid columns models are higher than the capacity strengths of hollow column models because of the behavior of ductile of the former models.
- The lateral displacement at the upper end is greater than the lower end by about (42-55%), and this behavior appeared compatible in both the cases of numerical analysis as well as when evaluated the experimental test results and this is because there is a varying in the section linearly along with the model and this gives a varying in the moment of inertia along the length column section.
- Cracking patterns and their evolution appear more influential in the models of columns that contain recess than those Which are the solid of the section because the hollow section leads to reduced resistance under the same loads applied.
- The upper end of the tapered column models contains a higher percentage of cracks than the lower end, as a result of changing its dimensions as well as the result of the load applied directly to it. This behavior can be seen in the numerical analysis and experimental test results.
- When a comparison between the numerical analysis and experimental results showed a good agreement with the behaviors of the models when the ratio of longitudinal reinforcement to twice, resulting in an increase in the columns' resistance and a decrease in the corresponding displacement by 25 to 28%, respectively.
- The load resistance of the column increases by 11% when the ties reinforcing ratio is increased by about 20%.
- The presence of recess in the centreline along the length of columns, i.e., hollow sections,

leads to an increase in the lateral displacement by (18-35%) and a decrease in the load capacity of all models by about (22-37%) compare with others i.e (solid section model).

- Increasing the ratio of the recess ratio to twice (16 to 41%), while keeping the other characteristics constant results in a decrease in the load capacity of the models by about (13-16%) and an increase in lateral displacement by about (10-14%). as well as an increase in cracks of these models and their concentration at the edges of the model as a result of the resistance of this part of it
- All the models failed due to concrete peeling off and some fragments spalling out in different location parts as well as cracking of concrete.
- All cases gave an increase in the ductility of the models by about (20-36%) when steel reinforcing was increased.
- The results of the statistical analysis concerning the mean and standard deviation of the ductility index values for the experimental and numerical lateral displacements in the first and failure stages showed the accuracy of the current numerical study.
- The parametric study based on concrete compressive strength has more effect on the ultimate load capacity of Reinforced concrete tapered columns also in addition to steel reinforcing ratios. These reinforcement ratios, when their amount is increased, have a decisive effect in controlling the propagation of cracks and preparing the appropriate ductility for tapered columns.

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