Finite Element Modelling of Normal and High Strength Reinforced Concrete Square Columns

Yaarub Gatia Abtan1, Hayder A. Mahdi1 and Hassan Falah Hassan1
1 Assist Prof., Civil Engineering Department, Al-Mustansiriayah University, Baghdad, Iraq.
yarubabtan@yahoo.com/ yarubabtan@uomustansiryah.edu.iq/mobile 07902504475

Abstract:
This paper deals with a numerical simulation of reinforced concrete square columns. The behavior of reinforced square columns of normal and high strength concrete was studied, and special attention paid to the concrete strength, ratio of longitudinal steel reinforcement, as well as reinforcement steel grade of this type of columns. In the present study, ABAQUS program was utilized to represent the response of this type of columns. The numerical model of finite element employs the approach of damaged plasticity for concrete. For effectiveness, a column of reinforced concrete was represented that had been comparison with experimental results that presented from the other researchers. In this research the numerical results were done for three types of loading, columns subjected to pure compressive force only (compression failure is done), columns undergo bending moment only (tension failure is done), and finally columns under axial load as well as bending moment such that the tension and compression failure is done at same moment. An interaction equation was derived in this research and can be applicable for any section of columns. The present equation was appeared a very good results when compare its interaction diagram with interaction diagram driven from previous works.

Keywords: ABAQUS, Behavior, Columns, High-Strength Concrete, Reinforced Concrete.

1. Introduction
Concrete with reinforcement is considered a complex material to be modeled using finite element programs. An appropriate material represent using finite element model should necessarily qualify for demonstrating the elastic as well as plastic behavior of material in compression and tension. However, in addition to that, the complete compressive behavior should include strain softening regimes. There are actually many models of numerical material obtainable previous searches with the possibility to find typical relations of stress-strain for concrete to compression and tension individually dependent on the tests of experimental works. At this research, ABAQUS software [1] is utilized to represent the behavior of column. The numerical model employs the approach of damaged plasticity for concrete; this process cans assistance to emphasize the theoretical approaches and to give a worthy complement to the experimental works of behavior. The term for concrete of high-strength varies with several states and time. At 1992, ACI Committee 363 described it for a concrete capacity of (41 MPa). While, in the FIP/CEB (1990), this type of concrete is regarded beyond (60 MPa).
2. Literature review
For normal concrete strength, Mander, et al. [2,3], reported the results of experimental work deals with columns had varied section such as square, circular as well as rectangular subjected to loading of low and high rates. They sophisticated an analytical model utilizing the connotation of effectively restricted area of core, suggested previously by Sheikh and Uzumeri [4]. Saatcioglu and Razvi [5,6] found an analytical model for tied concrete useful to the columns of different section; circular, square, or rectangular. For high strength concrete, Martinez, et al. [7,8], restraint of concrete was estimated by experimentation of varied size of concrete cylinders, concrete strength varied between (20.7 and 69) Mpa. Yong, et al. [9], columns of square section with concrete strength between 83.5 and 94 Mpa, were investigated to examine the response of confined column of high-strength concrete. Results from these tests referred to that the relationship between stress-strain of concrete with high-strength was enhanced when utilizing lateral steel ties as reinforcement for confinement. It was recommended that the transverse steel spacing must be less than the lateral dimensions of column. Also, many experimental works had been conducted on columns under monotonic axial compression load [10-12].

3. Scopes of Work and Modelling
In this study a square column had section of (400x400) mm with height (3.35)m are used in the numerical simulation by using nonlinear finite element modeling for reinforced concrete in ABAQUS software [13]. The Model of Concrete Damaged Plasticity is done in the present investigation. Stress-strain relation in compressive and tension can be noticed in the figures 1 and 2. Till initial yield, the compressive behavior is elastic, then, was described by stress of hardening then by strain softening beyond the final point. When the beginning of micro-cracking (failure stress at failure) the reaction is softened, making strain localizations in the concrete element. Similar to the earlier two models, post-cracking response can be considered by designating a post stress-strain relationship or by using a criterion of fracture energy. In both relations of stress-strain for tensile and compressive, the unloading stage is designated as undermining of the material as well as elastic stiffness degradation. These situations can be defined as parameters of particular damage. Furthermore, ABAQUS gives the user to appoint stiffness recapture factors.

![Figure 1: Damage plasticity uniaxial of concrete compressive behavior by ABAQUS](image)
Figure 2: ABAQUS Damage plasticity tension response of concrete [1].

Rebar can be specified in membrane as smeared layers also as elements of shell, or surface, see figure 3. In continuum elements by instill “rebar defined” surface as well as rebar can also be included as membrane elements. On the other hand, element based rebar can be utilized for other type of elements such as; membrane, shell, surface, continuum or beam. Also, rebar can be represented discretely in elements of beam as well as column.

Figure 3: Rebar representation as shell, membrane, or surface element by ABAQUS [1].

Generally, typical models for material which used with rebar are metal plasticity. ABAQUS program gives many types of such models. Represented models for material behavior can be combined in ABAQUS to model certain behavior. To model the steel reinforcement, a combination between elastic behavior and plastic behavior can be used, as well as strain hardening, to represent the pre and post- yielding action for this material. On the other hand in ABAQU, bond between concrete and reinforcement bar is represented almost through insert tension stiffening for the concrete to “simulate load transfer across cracks through the rebar”. In the present investigation, the variables were; concrete compressive strength ranging between 20Mpa and 140Mpa, reinforcement steel ratio was taken 0.01, 0.03, and 0.06 and finally the yielding strength of steel was taken 275Mpa, 400Mpa, and 500Mpa. Geometry and section details of columns can be seen in figure 4.
Three types of load failure were studied, the first were columns subjected to pure compression force only and compression failure was done in this stage, the second were columns subjected to pure bending moment and tension failure was done in this stage, the final stage was columns are subjected to concentrated force and bending moment such that the tension and compression failure were done at same time. Figure 5 show the finite element mesh, deformation, and rebar reinforcement of column.
4. Results and Discussions

From figures 6-15, the relation between concrete strength (in compression) and forces or moments for three stages of failure is linear except the relation between compressive strength and maximum deflection is nonlinear. It can be seen, the capacity load for columns is increased as concrete strength was increased for all stages of failure, while the brittleness of concrete is decreased. The results show the capacity load of column is increased when reinforcement ratio is increased. Also, increasing in the yielding strength of reinforcement, the ultimate load of columns was increased too. But the influence of steel is more than the effect of yielding strength of steel reinforcement into the capacity of column load.

![Figure 6: Force-concrete strength relationship.](image1)

![Figure 7: Force-concrete strength relation.](image2)
Relationship Between Pure Bending Moment and Compressive Strength of Concrete for Different Steel Ratio

Figure 8: Moment-concrete strength relation.

Relationship Between Pure Bending Moment and Compressive Strength of Concrete for Different Yielding Strength of Steel

Figure 9: Moment-concrete strength relation.

Relationship Between Concentrated Force and Compressive Strength of Concrete for Different Steel Ratio When Compression and Tension Failure is Done at Same Time

Figure 10: Force-concrete strength relation.

Relationship Between Concentrated Force and Compressive Strength of Concrete for Different Yielding Strength of Steel When Compression and Tension Failure is Done at Same Time

Figure 11: Force-concrete strength relation.
From the above results we can have derived the following equation of interaction diagrams of column by using several methods in the mathematics and statistic, this equation can be applied of any column section if we know the failure load of columns in compression, tension, and both compression and tension of columns section.
The equation is as follows:

\[
\tan^{-1} \frac{P}{M} = \frac{\tan^{-1} \frac{P_2}{M_2} + \frac{\pi \sqrt{M_2^2 + P_2^2}}{2(P_2^2 - M_1 P_1)} (M_1 - \sqrt{M_2^2 + P_2^2})}{\left(1 - \frac{\sqrt{M_2^2 + P_2^2}}{M_1}\right) + \left(\frac{P_1}{M_1} - 1\right) \sqrt{M_2^2 + P_2^2}} (M_1 + \sqrt{M_2^2 + P_2^2}) - \tan^{-1} \frac{P_2}{M_2} + \frac{\pi \sqrt{M_2^2 + P_2^2}}{2(P_2^2 - M_1 P_1)} (M_1 - \sqrt{M_2^2 + P_2^2}) \left(1 - \frac{\sqrt{M_2^2 + P_2^2}}{M_1}\right) + \left(\frac{P_1}{M_1} - 1\right) \sqrt{M_2^2 + P_2^2} M_1 + \frac{\pi}{2(P_2^2 - M_1 P_1)} (M_2^2 + P_2^2) + \frac{\tan^{-1} \frac{P_2}{M_2}}{2(P_2^2 - M_1 P_1)} \left(\frac{P_1}{M_1} - 1\right) \sqrt{M_2^2 + P_2^2} \left(1 - \frac{\sqrt{M_2^2 + P_2^2}}{M_1}\right) + \left(\frac{P_1}{M_1} - 1\right) \sqrt{M_2^2 + P_2^2} M_1 + \frac{\pi}{2(P_2^2 - M_1 P_1)} (M_2^2 + P_2^2)}.
\]

Where:

- \(P_1\) = maximum concentrated load of column at pure compression failure only.
- \(P_2\) = maximum concentrated load of column at both compression and tension failure in the same time.
- \(M_1\) = maximum bending moment of column at pure tension failure only.
- \(M_2\) = maximum bending moment of column at both compression and tension failure in the same time.

Hany, et al. [12], studied reinforced columns of high strength concrete subjected to eccentric load. A comparison between its results interaction diagrams and ACI interaction diagrams with above equation is represented in figure 16. It can be noticed from this figure appropriate relation between the proposed interaction and others researches.
5. Conclusion
In the final we can conclude the following points:

- The capacity of columns loadings are increased as increasing the strength of concrete, yielding as well as ratios for steel rebar.
- Britteness of columns of high strength concrete is increased when increasing the compressive capacity for concrete.
- Linear relation between compressive strength of concrete and column capacity (concentrated load, moment) is noticed for all variables, but the relation between concrete strength (in term of compressive) and deflection was nonlinear.
- An interaction equation that derived in this research can be applicable for any section of columns and shown good agreement with other researches.

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