Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

9th International Conference
on Civil and Architecture
Engineering
ICCAE-9-2012

Finite Element Model for Reinforced Concrete Column with Different Connected Sections

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Abstract

Based on architecture design, engineering designer may face a conflict to design the same column with various cross section shapes. The variation of cross section for the same column is highlighted to study axial load carried by the reinforced concrete (RC) column based on different connection heights and different vertical spacing between horizontal reinforcements.

In the present study, finite element model is proposed to model the performance of the same RC column with various cross section shapes. 2-D finite element analysis (FEA) is used to analyze performance of the RC column. However, the results obtained by the experimental study are used to verify the proposed finite element model.

The performance of the same RC column with different cross sections is expressed as load-displacement curves. Two different cross sections of the same RC column are square shape for lower part and rectangular shape for the upper part. The parametric study is conducted to calculate the axial load carried by the same RC column with various cross section shapes. The load- displacement curves of the RC column are analyzed and presented in the present study to discuss effect of cross section variation for the same RC column.

Keywords: Reinforced concrete column; vertical reinforcement; horizontal reinforcements; numerical modeling and analysis; vertical displacement; axial load; connection height.

1. Introduction

This paper presents a proposed finite element model to model the same RC column with various cross section shapes. However, Pam et al. (2003) studied post-elastic behavior of low-axially loaded high-strength reinforced concrete (HSRC) columns. Yalcin (2007)

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developed computer software for inelastic analysis of reinforced concrete columns under combined axial compression and monotonically increasing lateral loads. The software incorporated effects of concrete, steel strain hardening, reinforcement buckling, and secondary deformations due to load- displacement effect. The finite element analyses were used by many researchers to model the RC columns under different load cases (Bittar, 2006; Mostafa et al., 2008; Sayed et al., 2005; Sayed, 2010; Valdimar, 2010).
In the present study, the same RC column with various cross section shapes is made of concrete with cement content of 350 kg/m^3, coarse aggregate of 0.8 m^3/m^3, fine aggregate of 0.4 m^3/m^3, and water cement ratio (W/C) of 0.4. The vertical and horizontal reinforcements are used in the RC column, as shown in Fig. 1. The vertical reinforcement is high grade steel (36/52) and the horizontal reinforcements are normal mild steel (24/35). The lower cross section of the RC column is square section with cross section of 20 cm X 20 cm, as shown in Fig. 1. The upper cross section of the RC column is rectangular section with cross section of 10 cm X 40 cm, as shown in Fig. 1.
Fig. 1 shows the detailed vertical and horizontal reinforcements for different three reinforced concrete models (CO1, CO2, and CO3). The connection heights of the CO1 model, the CO2 model, and the CO3 are 5 cm, 10 cm, and 15 cm, respectively, as shown in Fig. 2. Fig. 3 shows the detailed vertical and horizontal reinforcements for reinforced concrete model (CO4). The connection height of the CO1 model is 10 cm, as shown in Fig. 3.
Finite element analysis is used to investigate performance of the RC column with different connection heights and different vertical spacing between horizontal reinforcements. Four RC column models are studied and analyzed based on different vertical spacing between horizontal reinforcements and different connection heights.

2. Reinforced Concrete Modeling

The finite element program COSMOS/M is used to model the same RC column with various cross section shapes. The finite element model takes into account the effects of axial load, connection heights, vertical reinforcements, and horizontal reinforcements.
The mechanical properties for concrete and steel reinforcement are presented in Table 1. The concrete block and the steel reinforcements are simulated using appropriate finite elements. In addition, the compatibility and equilibrium condition between concrete and reinforcement system are idealized in the numerical model. The linear finite element analysis (FEA) is adopted in the present study.
2-D plan stress element is used to model concrete block media and 2-D bar element is used to model vertical reinforcement and horizontal reinforcements (stirrups). The proposed short RC column used in this study is shown in Fig. 4. The lower cross section part for the RC column is 20 cm width, 20 cm length, and 55 cm height. The cross section of the upper part for the RC column is 10 cm width, 40 cm length, and 75 cm height.
The connection height for the same RC column is varied from 5 cm, 10 cm, to 15 cm. These RC columns are tested under increasing axial loads. The square column has 6 vertical bars of 12 mm diameter and the horizontal reinforcement has closed stirrups of 6 mm diameter spaced at 100 mm in vertical direction. The rectangular column has 8

vertical bars of 10 mm diameter and the horizontal reinforcement has closed stirrups of 6 mm diameter spaced at 100 mm. The concrete cover of the RC column is 25 mm.
The four RC columns are subjected to axial loads. To better modeling, the bond strength between the concrete media and the steel reinforcement should be considered and idealized in the FEA. To provide perfect bonding, the bar elements for the vertical reinforcements and the vertical reinforcements are connected to the nodes of each adjacent concrete element, so the two materials shared the same nodes.
The finite element model is considered to be fixed supported in the bottom end of the column and subjected to loading at the top**.** The vertical boundaries of the 2-D finite elements model are free to move so as to simulate a free surface. The movement at the upper horizontal plane is free to simulate a free surface, as shown in Fig. 4. The 2-D finite element mesh is shown in Fig. 4.

3. Column Model Verification

The proposed finite element model is verified based on the experiment results conduct by Bittar (2006). The proposed RC column (CO model) tested by Bittar (2006) is made of concrete with cement content of 350 kg/m^3, coarse aggregate of 0.8 m^3/m^3, fine aggregate of 0.4 m^3/m^3, and water cement ratio (W/C) of 0.4. The vertical reinforcements and the horizontal reinforcements are used in the CO model, as shown in Fig. 5. The vertical reinforcements are high grade steel (36/52) and the horizontal reinforcement are normal mild steel (24/35). The cross section of the CO model is square section with cross section of 20 cm X 20 cm, as shown in Fig. 5. The height of the CO model is 150 cm.
The results obtained by the finite element analysis are compared with those obtained by the experimental study. Fig 6 shows the applied axial load against vertical displacement based on the results obtained by both the FEA and the experimental test. The results show that there is a good agreement between the readings obtained by both the finite element analysis and the experimental test.

4. Performance of RC Column Based on Different Connection Heights

A parametric study is conducted using the proposed finite element model to investigate the effect of various parameters on the performance of the same RC column with various cross section shapes. Compressive strength of concrete media, the height of the RC column, the thickness of the concrete cover, and the properties of materials are kept constant for all column models.
For connection height of 5 cm, the CO1 model is subjected to different axial loads. Figs. 1 and 2 show the longitudinal section RC column model (CO1). Fig. 7 shows variation of axial load against vertical displacement of CO1 model. Fig. 8 shows the vertical displacement profile of the CO1 model using the 2-D finite element analysis.
For connection height of 10 cm, the CO2 model is subjected to different axial loads. Figs. 1 and 2 also show the longitudinal section RC column model (CO2). Fig. 7 also shows variation of axial load against vertical displacement of CO2 model.
For connection height of 15 cm, the CO3 model is subjected to different axial loads. Figs. 1 and 2 again show the longitudinal section RC column model (CO3). Fig. 7 shows variation of axial load against vertical displacement of CO3 model.

The results show that the vertical displacement for the CO3 model is the smallest readings with respect to those for both the CO1 model and the CO2 model. The results also indicate that the connection heights of the RC column have a little impact on the performance of variable connected sections for the same reinforced concrete column.

5. Performance of RC Column Based on Different Stirrup Spacing

A reinforced concrete column with variable cross section shapes under axial load is modeled based on different stirrup spacing. The 2-D finite element analysis is used to model the RC column. To investigate the effect of vertical spacing between the horizontal reinforcements (stirrup), the vertical spacing between the stirrups is chosen to be 50 mm and 100 mm.

The stirrups spacing of the CO2 model is considered to be 100 mm, as shown in Fig. 1. The connection height of the CO2 model is 10 cm. The stirrups spacing of the CO4 model is considered to be 50 mm, as shown in Fig. 3. The connection height of the CO4 model is also 10 cm. The concrete cross section of the CO2 model is the same as that of the CO4 model. The vertical reinforcements at the CO2 model are the same as these at the CO4 model. However, the only difference between the CO2 model and the CO4 model lies on the different stirrup spacing. Fig. 9 shows variation of axial load against vertical displacement for the CO2 model and the CO4 model.

The results show that the vertical displacements for the CO2 model are the same as those for the CO4 model. The results also illustrate that the different stirrup spacing of the RC column (CO2 and CO4) have a little impact on the performance of variable connected sections for the same reinforced concrete column.

6. Conclusions

A 2-D linear finite element analysis is used to study the same reinforced concrete column with various cross section shapes. The following conclusions can be drawn as follows:

1. A 2-D numerical model is applicable to analyze and predict the detailed performance of the reinforced concrete model based on the experimental test.

2- The 2-D finite element analysis is adopted to predict the performance of the same reinforced concrete column with various cross section shapes based on different connection heights and different stirrups spacing.

3. The impact of the connection heights for the RC column has a little impact on the performance of the same reinforced concrete column with various cross section shapes.

4. The stirrups spacing of the RC column has a little impact on the performance of the same reinforced concrete column with various cross section shapes.

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Table 1: Mechanical properties for concrete model and steel reinforcement

Material properties	Elastic Modulus	Poisson's ratio
Concrete	210 t/cm^2	0.18
Steel reinforcement	2100 t/cm^2	0.3

40 cm

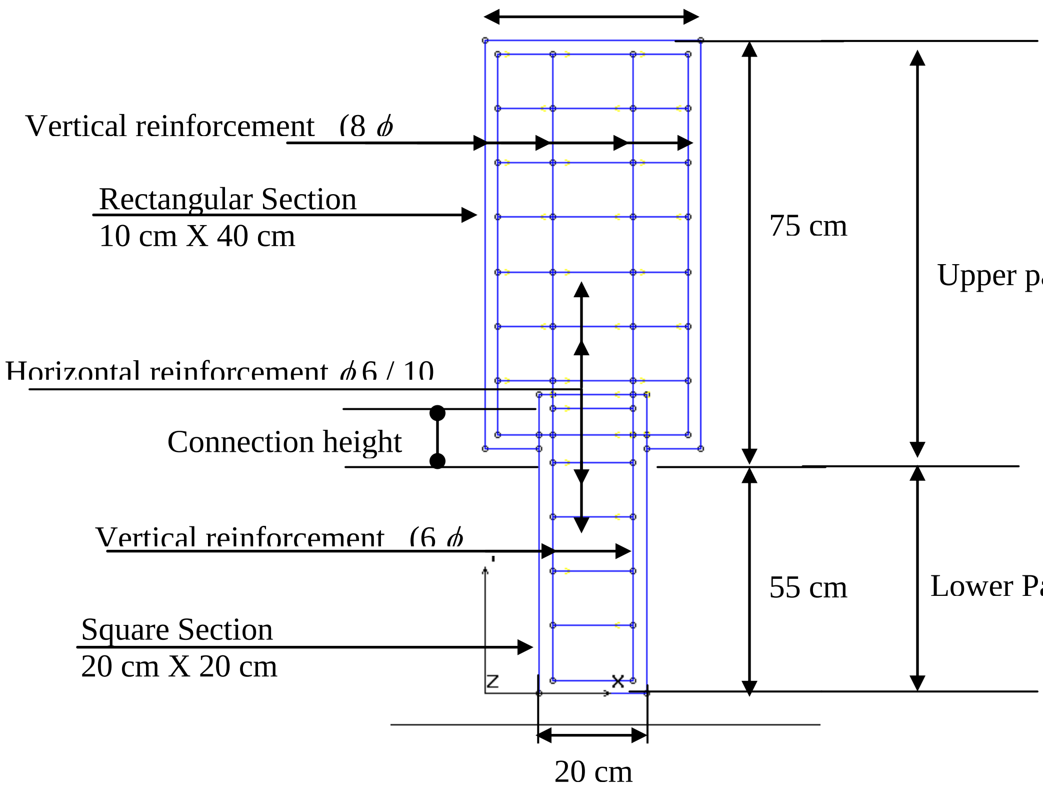
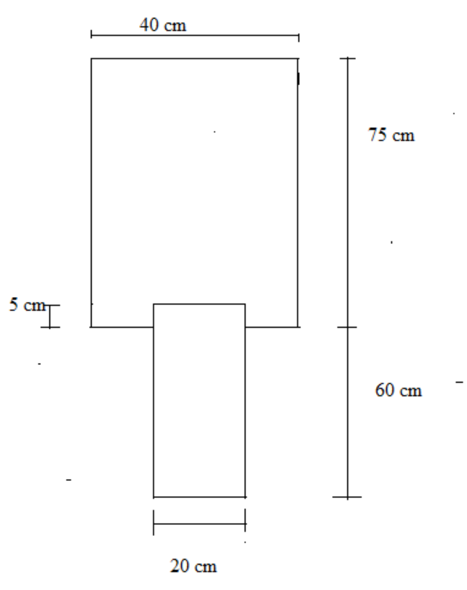
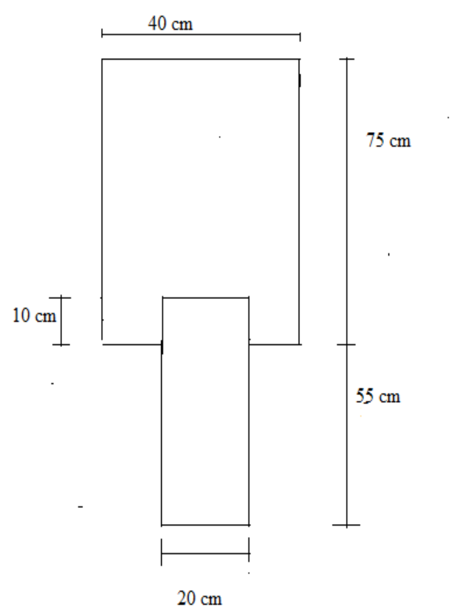


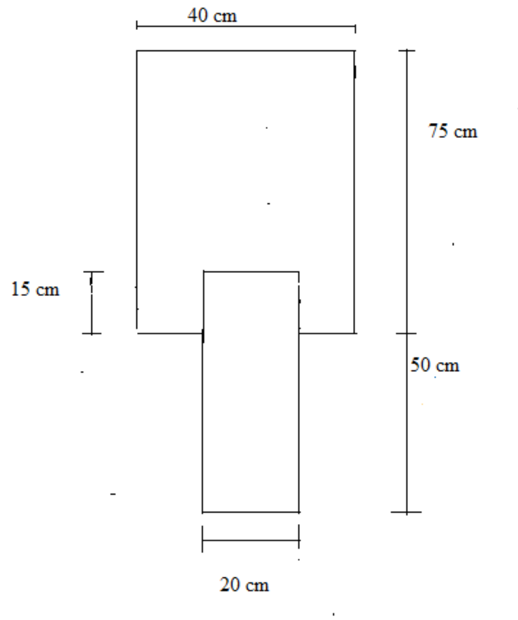
Fig. 1: Longitudinal section for the proposed tested reinforced concrete columns (CO1, CO2, CO3)



CO1 model



CO2 model



CO3 model

Fig. 2: longitudinal section for different reinforced concrete models (CO1, CO2, and CO3)

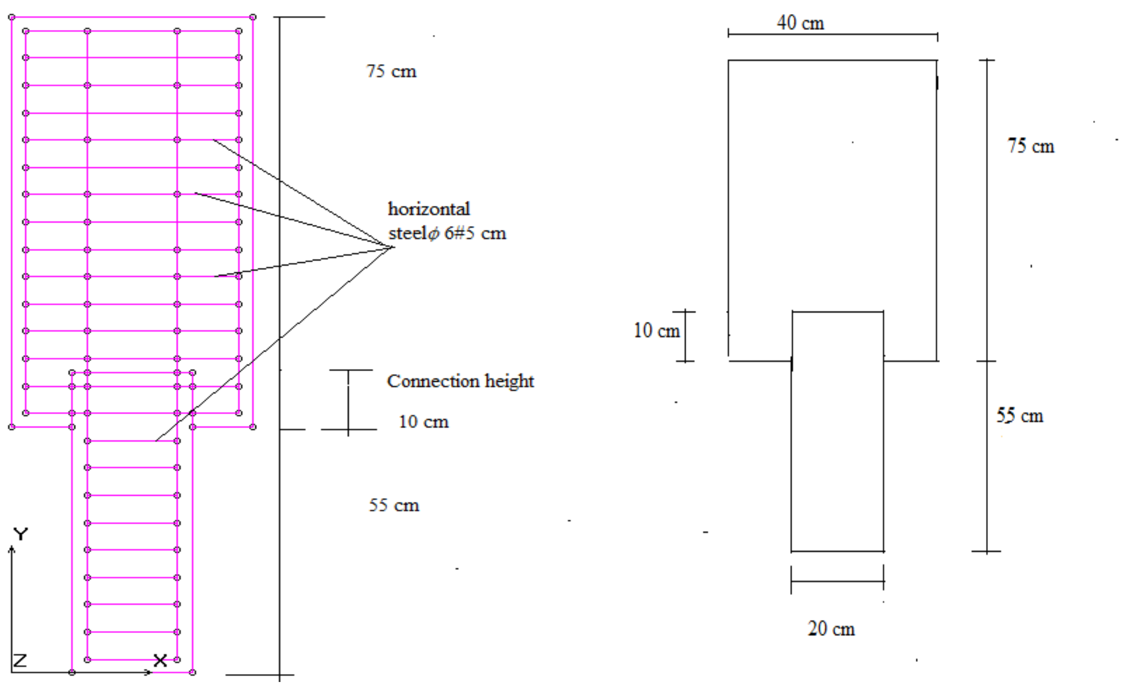


Fig. 3: Longitudinal section for the reinforced concrete model CO4

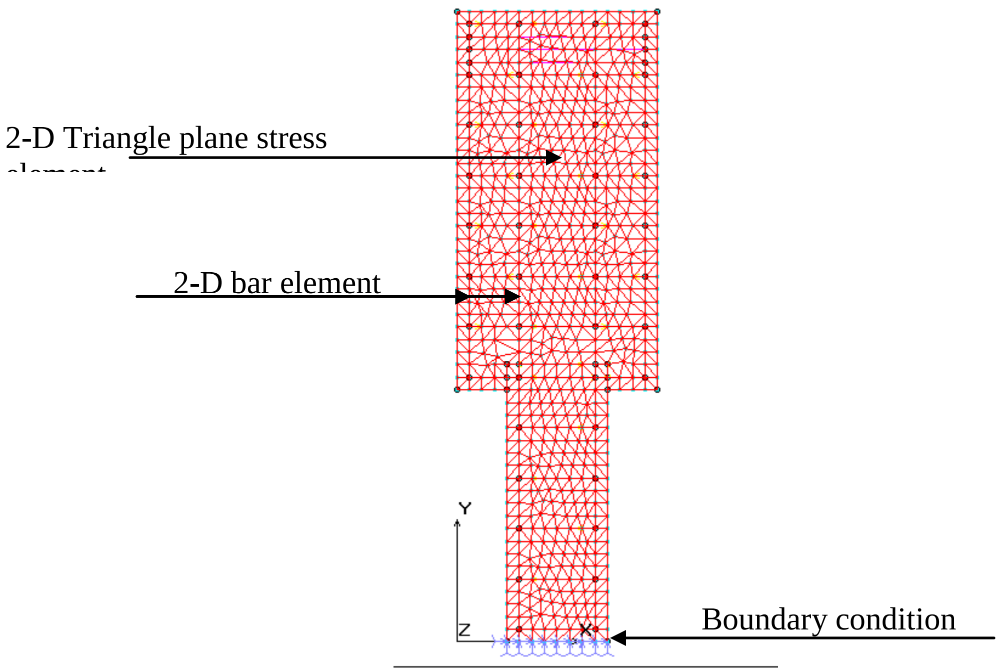


Fig. 4: 2-D finite element model

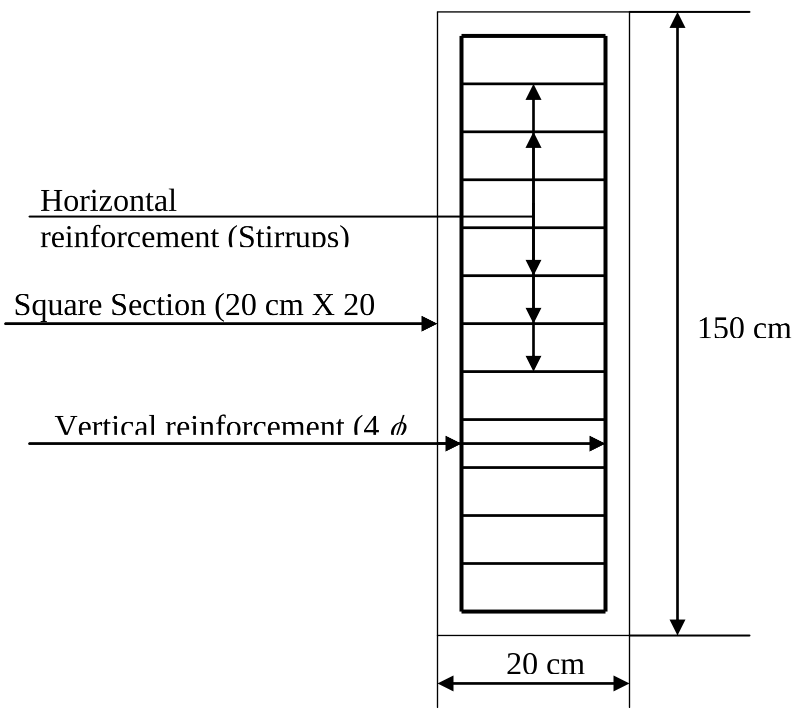


Fig. 5: Longitudinal section for the CO model

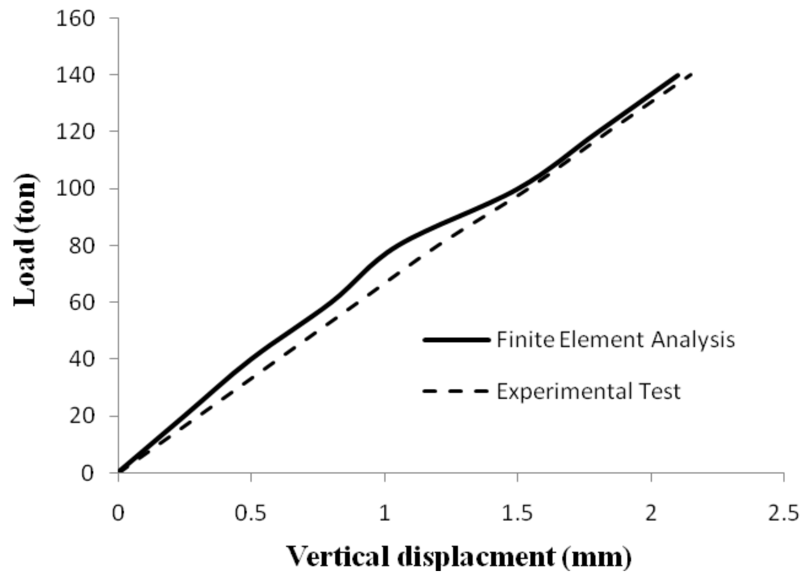


Fig. 6: Variation of axial load with vertical displacement of concrete column
(Model verification)

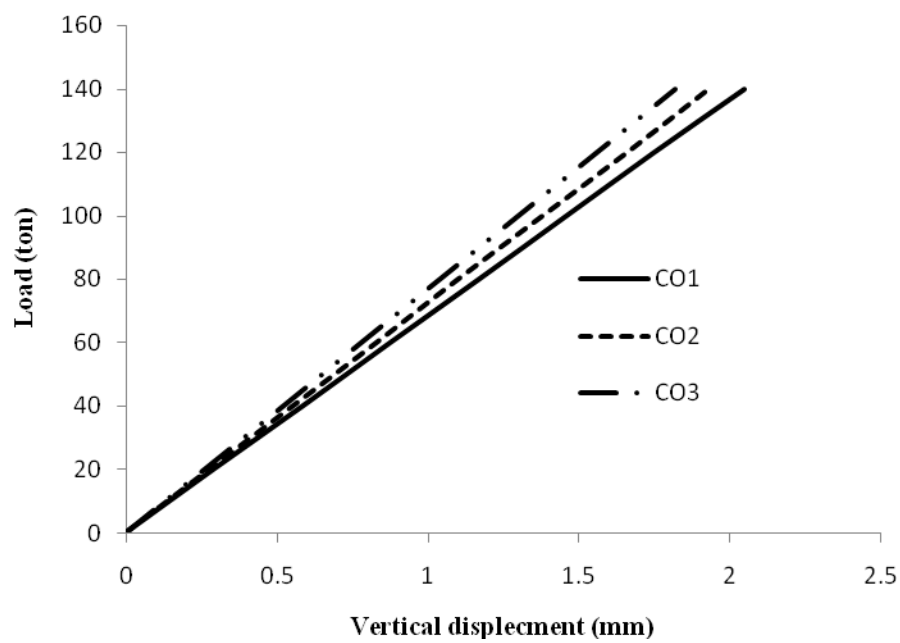


Fig. 7: Different axial loads against vertical displacement for CO1, CO2, and CO3 models

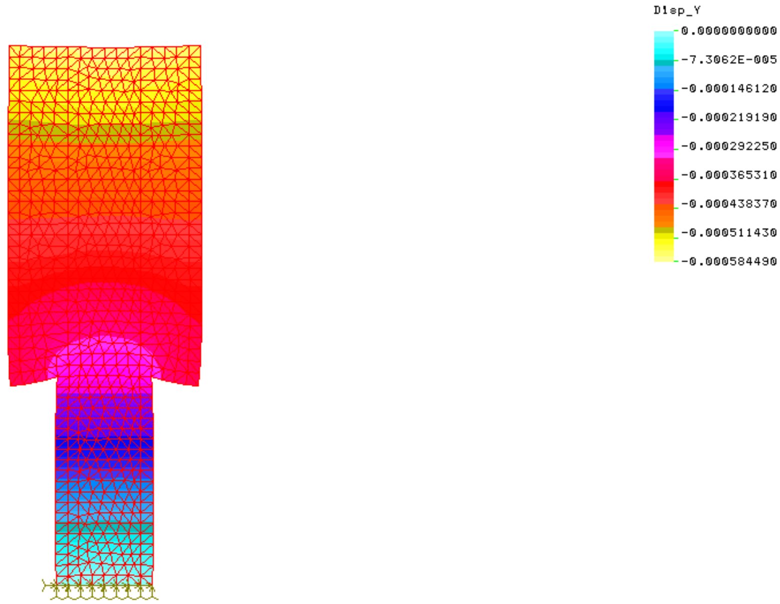


Fig. 8: Contour of vertical displacement for the CO1 model

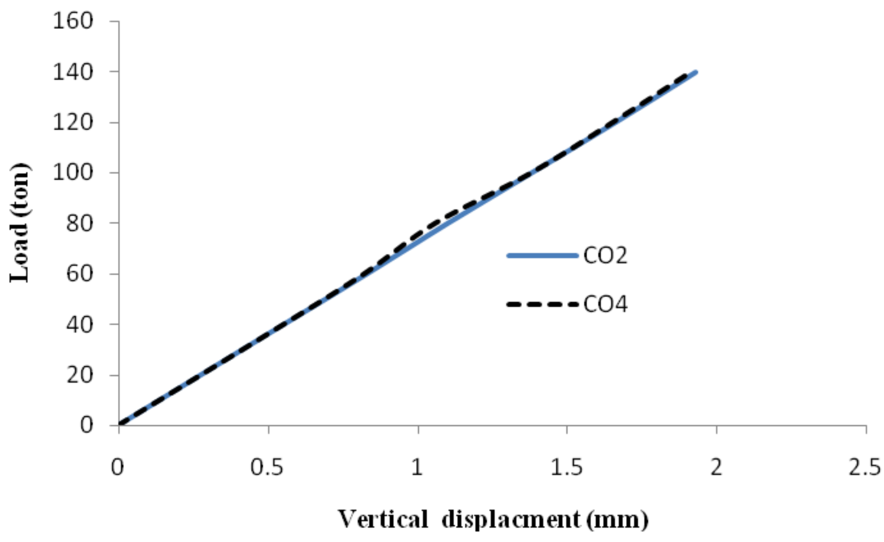


Fig 9: Variation of axial load against vertical displacement for the CO2 model and the CO4 model