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NONLINEAR 3D FINITE ELEMENT MODEL FOR ECCENTRICALLY LOADED CONCRETE ENCASED STEEL COMPOSITE COLUMNS

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ABSTRACT: Concrete encased steel composite columns have been extensively used in construction owing to that they utilize the most favorable properties of both of constituent materials, ductility, large energy-absorption capacity, and good structural fire behavior. This paper presents a nonlinear 3-D finite element by numerical simulations using ABAQUS software model for eccentrically loaded concrete encased steel composite columns .The model accounted for the interface between the steel section and concrete. It different column dimensions, different structural steel sizes, different concrete strengths, and different structural steel yield stresses by columns with were investigated in a this study.

KEYWORDS: Concrete encased steel column; Eccentrically load, Nonlinear, FEM.

1 INTRODUCTION

The philosophy of using composite material is that weakness of an element is compensated by another object in order to have optimum use from this set. But in recent years, another idea has been added which expresses confinement in addition to the above purpose. Confined structures have more flexibility rather than concrete structures and yet they are stiffer and in conclusion, they have less capacity for buckling than steel structures. Many experiments have been conducted on concrete columns with embedded steel that most of them were analyzed for off-center loading or centralized loading for slenderness ratio of steel and concrete sections. Although many theoretical researches were carried out on the behavior of these structures' frames, doing these experiments is costly and time-consuming. For this reason, numerical methods based on finite element can be one of the most effective methods to estimate the behavior of these structures. Finite element methods for nonlinear analysis of these structures can be planned into two methods of “present finite element software or beam-column developed models”. When using the present software, concrete and steel elements are modeled separately and then they will connect to each other by some elements. The most important defect of this method is the complexity and time consuming calculations of analysis of these structures which can be removed by numerical method.

In this paper, it is attempted that the most effective nonlinear finite element model be investigated for evaluation of concrete columns’ behavior with embedded steel under off-center loading with two joint head supporting conditions, in which the nonlinear behavior of steel and concrete, longitudinal and transverse rebar, contact surfaces/brush between steel and concrete and concrete confinement have been considered and the strength of sections have been calculated by America Steel Code, AISC, and Europa Code, Euro code [1].The obtained results from Abaqus software will be validated by the test results of Al-Shahri and et.al and Morino [4,5].

In Al-Shahri’s experiment, 7 types of sections with square shape (BC1 to BC7) with the following features have been used [4].its line equals 230 millimeter, varied length equals 2000 to 3000 millimeter, concrete strength equals 13.7 to 28.2 MPa, steel yield stress is 307 to 337 MPa, and proportion of eccentricity to section depth is 0.17 to 0.3 and in Morino’s experiment, 3 square sections (BC8 to BC10) have been used with these properties: line equals 160 millimeter, varied length is 960, 2400 and 3600 millimeter, concrete strength equals ½ to 23.4 MPa and steel yield stress is 345 MPa. In table 1, the features of Al-Shahri’s test is given and properties of Morino’s test is indicated in table 2.[4,5].

Table 1. Properties of Al-Shahri’s experiment and et.al

section	Effective length of column (mm)	$\frac{e}{D}$	Steel yield stress (MPa)
BC1	2000	0.3	337
BC2	2000	0.3	337
BC3	2000	0.3	307
BC4	2000	0.3	307
BC5	3000	0.3	307
BC6	3000	0.17	337
BC7	3000	0.17	337

Table 2. Properties of Morino's experiment and et. al

section	Effective length of column (mm)	$\frac{e}{D}$	Steel yield stress (MPa)
BC8	960	0.25	345
BC9	2400	0.25	345
BC10	3600	0.25	345

2 PROPERTIES OF MATERIALS

For all used sections in this paper, yield stress (f_y) equals 350 N/mm^2, elasticity modulus (E_s) is 21×10^4 N/mm^2, compressive strength (f_c) is 30 N/mm^2, and strain has been considered 0.0025. The stress-strain curve of steel has been drawn based on BS 1993-1-2 code [6] and for concrete based on BS 1994-1-2 code [2].

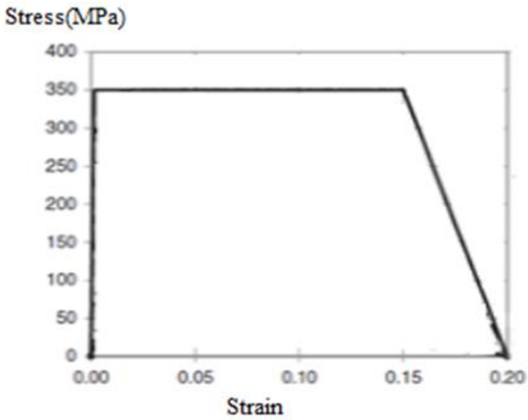

Figure 1. Steel stress-strain curve

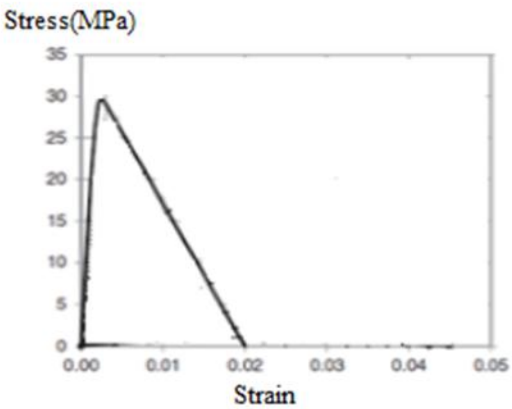

Figure 2. Concrete stress-strain curve

For simulation by Abaqus software [3], steel will be modelled by real stress-strain relation which is obtained from equations below:

$$\sigma_{true} = \sigma_{nom}(1 + \varepsilon_{nom})$$

$$\varepsilon_{true} = ln\,(1 + \varepsilon_{nom})$$

In which ε_{nom} and σ_{nom} are nominal strain and nominal stress of section, respectively. The values of real stress and strain of steel has given in table 3.

Table 3. The values of real stress and strain of steel

Real stress (MPa)	Plastic strain
300	0.000
350	0.025
375	0.100
394	0.200
400	0.350

For modelling concrete in plastic region and examination of deterioration in it, plastic damage model of concrete has been used. The values of stress, strain and concrete plastic destruction in tension and compression has been given in tables 4 and 5.

The analysis method was Newton-Rofson software and due to the touching elements between concrete and steel and considering the friction of brush, asymmetric Newton-Rofson method has been applied. For modelling the behavior of materials, Von Misez yield criterion and isotropic stiffening law has been used.

The concrete core is defined with six-sided, eight node element and with three transitive degree of freedom in each node by using C3D8R model. The material is of concrete type with the capability of fraction in three orthogonal directions in effect of tension and failure under the effect of compressive stresses and plastic deformations too. As it is observed in figure3, concrete confinement has high influence in stress-strain curve, therefore, the effect of concrete confinement has been considered in this model.

Steel wall has been defined through C3D8I element which like C3D8R is described with eight nodes and three degree of freedom in each node and it has a good adaptability with other used elements in model. Also, friction and slip between steel and concrete core by surface to surface connecting element are modelled in addition to the effect of stiff connect for applying connecting stress between all components and surface in contact to each other. This element is able to transfer compression in normal direction and transfer shear in the direction tangent to the surface.

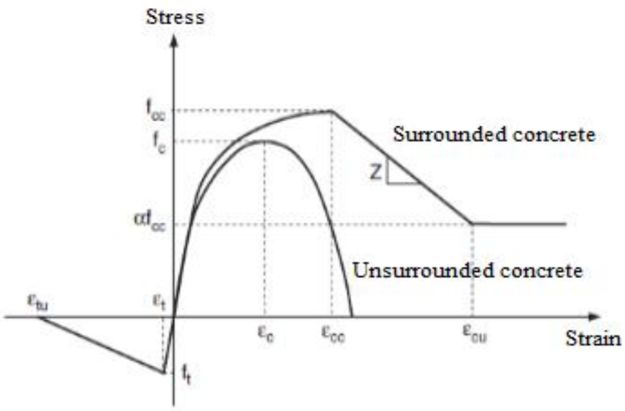

Figure 3. Effect of confinement in concrete stress-strain curve

Moreover, in order to examine the behavior of column after buckling and passing critical point such that it leads to bearing capacity reduction without divergence in problem solving, arc length method has been used to solve nonlinear equations.

Table 4. The values of stress, strain and plastic destruction of concrete in tension

Tensile strength (MPa)	Fraction strain	Destruction parameter in tension
5.3	0	0.00
5.31	0.000176	0.25
0.58	0.001539	0.99

Table 5. Values of stress, strain and plastic destruction of concrete in compression

Compressive strength (MPa)	Fraction strain	Destruction parameter in compresion
17.5	0.000000	0.000
25.7	0.00038	0.112
34.9	0.00189	0.429
35	0.00218	0.466
28	0.00456	0.701

3 NUMERICAL SIMULATION BY ABAQUS SOFTWARE

The general scheme of concrete sections with embedded steel has been represented in figure 4.Three dimensional model of finite element of concrete columns with embedded steel under the effect of eccentric loads is observed in figure 5, which has been divided into 3 parts of totally confined, trivial confined and unconfined. Also, the whole scheme of column under the effect of eccentric load was given in figure 6.

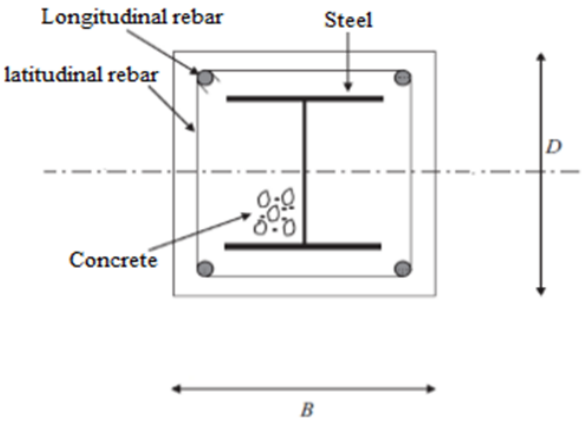

Figure 4. General scheme of concrete column with embedded steel

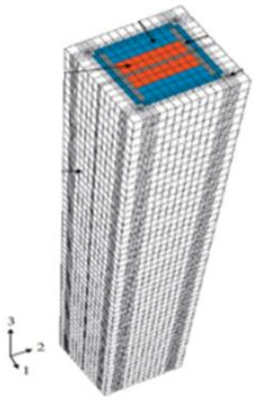

Figure 5. Three dimensional model of finite element

Concrete confinement has been modelled by concrete strength and plastic response of stress-strain and maximum tensile stress is evaluated by linear relation between failure and crack width. When the fracture energy is divided with crack in section, its value can be calculated by the area under the stress plastic diagram in stress-strain curve, which here equals 0.12 Newton per millimeter. Longitudinal and transverse bars will be modelled by the forenamed dimensions and elasticity modulus 200 Giga Pascal and Poisson coefficient 0.3. Also, in modelling the contact surface between concrete and steel is considered by Abaqus software and friction coefficient of 0.25.

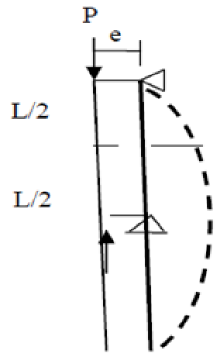

Figure 6. General scheme of column under eccentric load

3.1 Comparison of finite element results and experimental results

As it was given in table 6, by numerical simulations of this kind of sections it can be observed that the obtained results from finite element have high accordance with the experimental results.

Table 6. Comparison of results of finite element and experimental model

Sections	experimental ultimate load (KN)	Finite element ultimate load (KN)	Proportion of P_{FEM}/p_{test}
BC1	654	601	0.92
BC2	558	511	0.92
BC3	962	827	0.86
BC4	949	946	1
BC5	900	822	0.91
BC6	813	684	0.84
BC7	704	583	0.83
BC8	740	660	0.89
BC9	504	530	1.05
BC10	412	406	0.99

In addition, in figure 7 the results of finite element failure mode have been compared with the experimental failure mode for BC5 model.

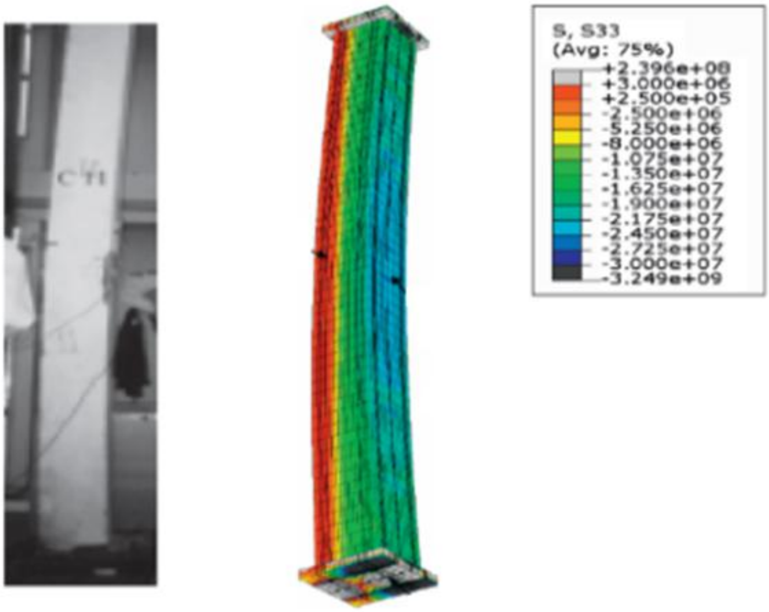

Figure 7. Comparison of finite element failure mode with experimental failure mode of BC5 sample

3.2 Introduction of used sections' characteristics and investigation of results

Now we examine some new sections, these new sections are classified into 6 groups that the first 3 groups are square sections with a line equals 230 millimeter and proportion of eccentricity to section depth equals 0.125, 0.25 and 0.375 and the second three groups are rectangular sections with dimensions of 165×177 millimeter and eccentricity ratio equals 0.125, 0.25 and 0.375, and the length of all sections equals 3000 millimeter, compressive strength of concrete for all sections is 30 MPa and steel yield stress is 350 MPa.

Then we compare the results obtained from finite element with results from Euro code 4. In Euro code, the method of designing concrete columns with embedded steel under the effect of eccentric loads is calculated on the basis of section area and the relation between axial force and bending moment. The comparison of obtained results of sextet groups from finite element method and Euro code has been shown in figures 8 and 9.

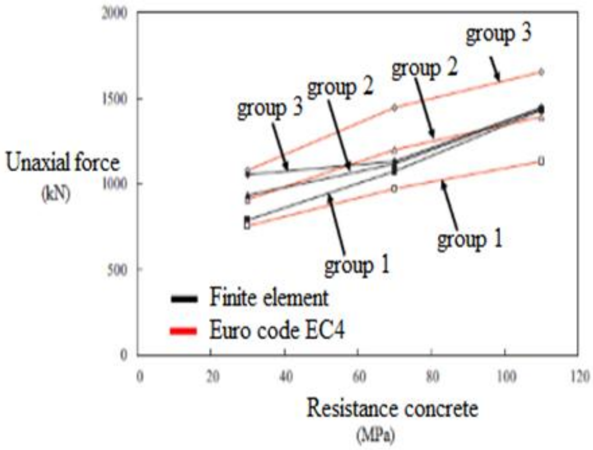

Figure 8. Comparison of finite element results and EC4 code for groups 1 to 3

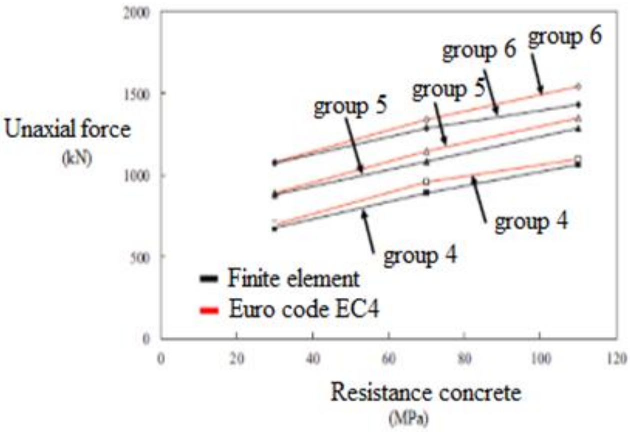

Figure 9. Comparison of finite element results and EC4 code for groups 4 to 6

As it is observed in the following figures, the results of Euro code EC4 have desirable agreement with the results of finite element for concrete with low and high strength and also with low and high yield stress of steel, although there is negligible difference in figure 8.

Moreover, the effect of increasing eccentricity on the displacement value of sections under the effect of applied load has been demonstrated in figures 10 and 11.

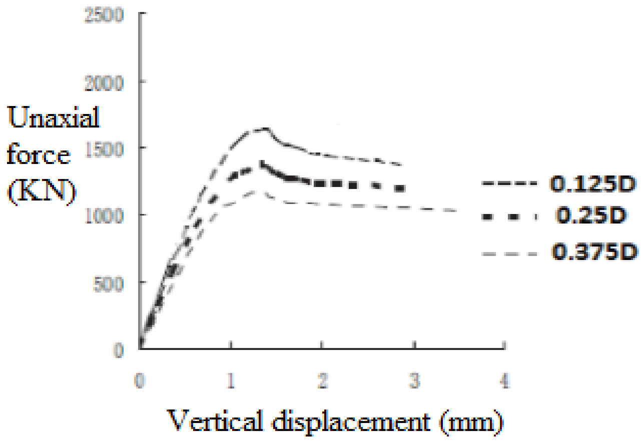

Figure 10. The effect of increasing eccentricity on bearing capacity and displacement of rectangular section

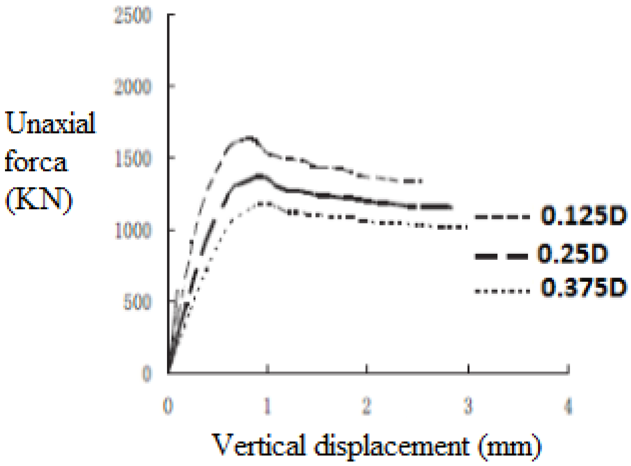

Figure 11. The effect of increasing eccentricity on bearing capacity and displacement of square section

As it is observed, by increasing eccentricity in both sections, the bearing capacity will decrease. Besides, by increasing eccentricity the rate of displacement resulted from maximum eccentric load in square section is less than displacement in rectangular section. In addition, figures 12 and 13 have displayed the displacement diagram of sections under the effect of applied load according to slenderness coefficient of column L/D.

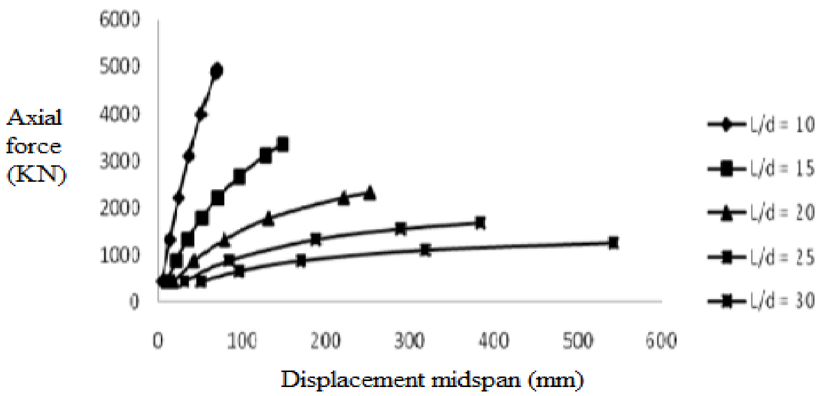

Figure 12. The effect of increasing slenderness coefficient of column on bearing capacity and displacement of square section

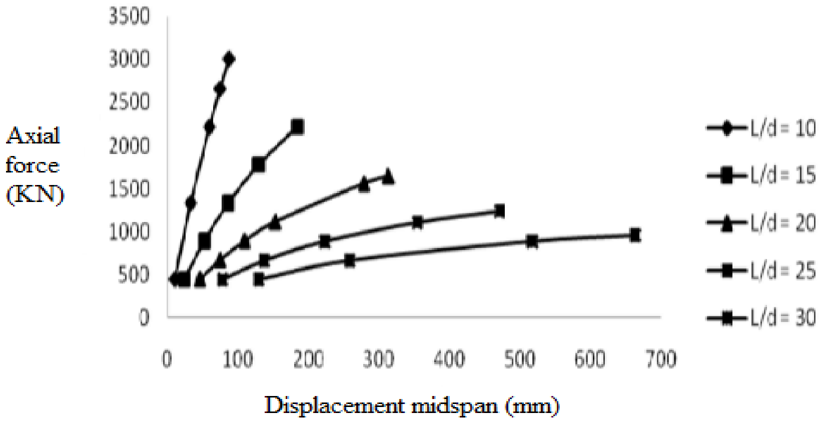

Figure 13. The effect of increasing slenderness coefficient of column on bearing capacity and displacement of rectangular section

As it is seen, in both sections by increasing the slenderness coefficient of columns, the bearing capacity of section will decrease and this is while by increasing the slenderness coefficient of column the bearing capacity of square section gets more than that of rectangular section. In addition to this, by increasing the slenderness coefficient of column the displacement of square section is less than rectangular section. Also the diagram of moment-axial force interactions for groups 1, 3, 4 and 6 has shown in figures 14, 15, 16 and 17. The location of geometric fracture of columns has been displayed with a black rectangular for all groups in diagram.

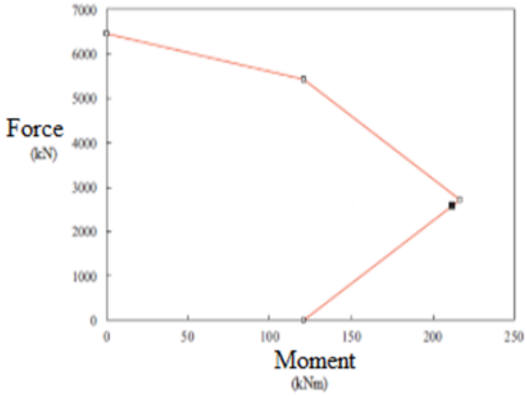

Figure 14. Axial force-bending moment diagram of group 1

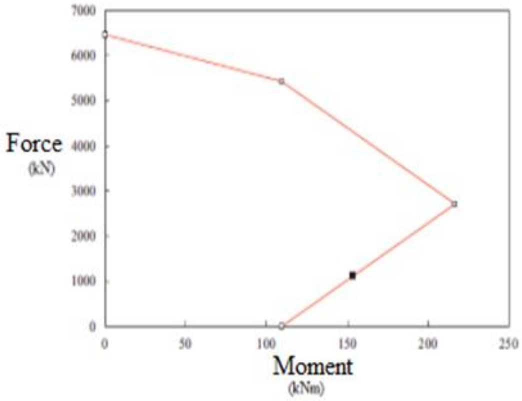

Figure 15. Axial force-bending moment diagram of group 3

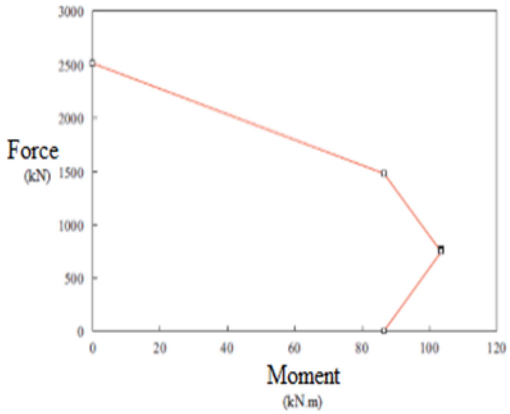

Figure 16. Axial force-bending moment diagram of group 4

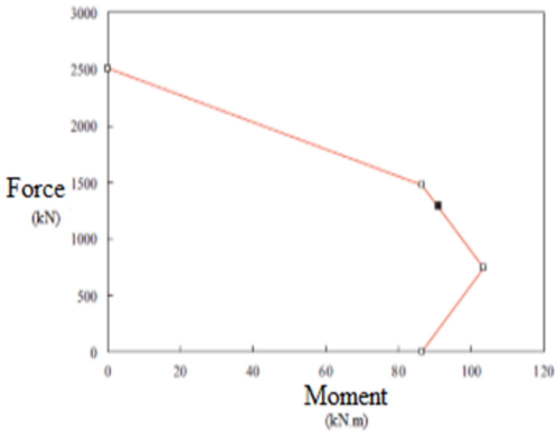

Figure 17. Axial force-bending moment diagram of group 6

As it is observed, the sustainable moment in balance mode is more in square section than in rectangular section. Moreover, increasing bending moment on confined column not only leads to the reduction of compressive bearing capacity of column due to compressive load interaction and bending moment, but also results in the decrease of confining compressive stress and consequently decrease of confined compressive strength of these columns.

4 CONCLUSIONS

Increasing concrete strength for columns with square section and high eccentricity will not have much effect on increasing ultimate load of section and conversely, in lower eccentricity increasing concrete strength will have significant effect on increasing the ultimate bearable load in section.

The less the eccentricity, the more the sustainable ultimate load of section.

With columns with rectangular sections and with more eccentricity, the bearable ultimate load will increase considerably by increasing concrete strength.

By increasing concrete strength, the tolerable moment of section in balance mode regardless of eccentric, will increase.

By increasing eccentricity in both sections, the bearing capacity will decrease, but the displacement resulted from maximum eccentric load in square section is less than the displacement in rectangular section.

Applying bending moment on confined columns have decreasing effect on the compressive strength of concrete and as a result, on the interaction of compressive load and bending moment.

By increasing the slenderness coefficient of column, the bearing capacity of column will decrease. Whereas by increasing slenderness coefficient of column, the bearing capacity of square section is ever more than that of rectangular section.

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