

CHAPTER 5

FINITE ELEMENT MODELLING

5.1 GENERAL

Reinforced concrete structures are largely employed in engineering practice in a variety of situations and applications. In most cases these structures are designed following simplified procedures based on experimental data. Although traditional empirical methods remain adequate for ordinary design of reinforced concrete members, the development of the finite element method have provided means for analysis of much more complex systems in a much more realistic way. The main obstacle to finite element analysis of reinforced concrete structures is the difficulty in characterizing the material properties. Much effort has been spent in search of a realistic model to predict the behaviour of reinforced concrete structures. Due to the complexity of the composite nature of material, proper modeling of such structures is a challenging task.

This chapter discusses the finite element modeling of the columns with Reinforced Concrete jacketing to validate their experimental performance. The finite element software package ANSYS 10 is used to create the models of the tested specimens of columns. Using these models, the load deformation behaviour of concrete columns under cyclic loading are compared with the experimental results.

5.2 ELEMENTS USED

The elements used in ANSYS 10 to develop the model were SOLID65, SOLID45 and LINK8. The SOLID65 was used to model the concrete and SOLID45 to model the hinge support at the base of the tested specimens of beam-column joints and LINK8 was used to model the reinforcement.

5.2.1 SOLID65 Element

ANSYS provides a three-dimensional eight noded solid isoparametric element, SOLID65, to model the concrete. This element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y and z directions. This element is capable of plastic deformation, cracking in three orthogonal directions and crushing. A schematic diagram of the element is shown in Figure 5.1.

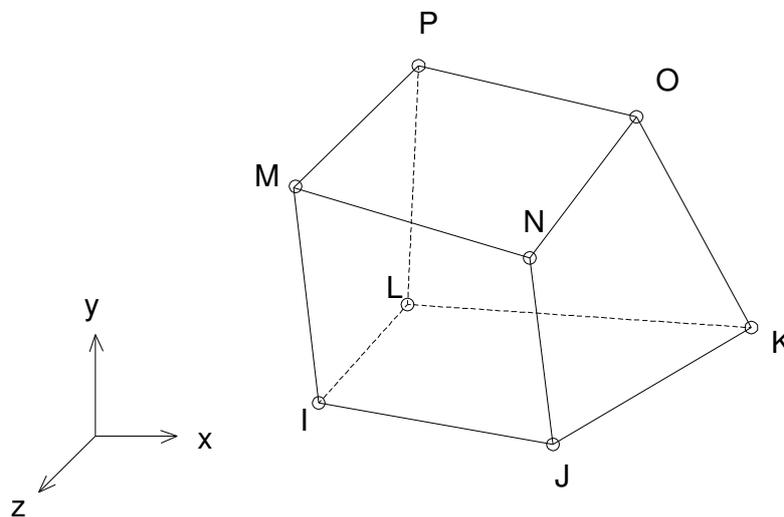


Figure 5.1 SOLID65 element

5.2.2 SOLID45 Element

This element has eight nodes with three degrees of freedom at each node - translations in the nodal x, y and z directions. The geometry and node locations for this element are shown in Figure 5.2.

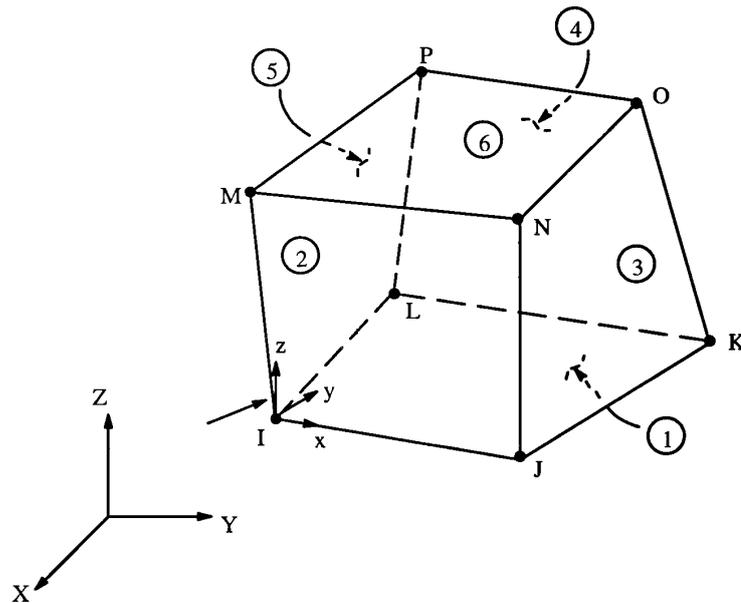


Figure 5.2 SOLID45 element

5.2.3 LINK8 Element

Depending upon the application, this element may be thought of as a truss element, a cable element, a link element, a spring element, etc. The three-dimensional spar element is a uniaxial tension-compression element with three degrees of freedom at each node – translations in the nodal x, y and z directions. As in a pin-jointed structure, no bending of the element is considered. Plasticity, creep, swelling, stress stiffening and large deflection capabilities are included. A schematic diagram of the element is shown in Figure 5.3.

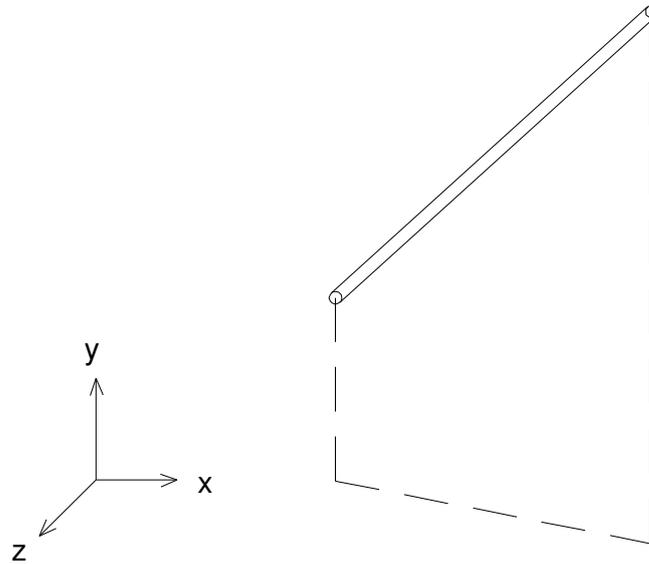


Figure 5.3 LINK8 element

5.3 SECTIONAL PROPERTIES (REAL CONSTANTS)

The real constants considered for SOLID65 element were volume ratio and orientation angles (in X and Y direction). In the present study, since there is no rebar data (smeared reinforcement), the real constants (volume ratio and orientation angle) were set to zero. No real constant sets exist for SOLID45 element. The parameters considered for LINK8 element were cross sectional area and initial strain. The real constant values for LINK8 element used for modeling column specimens are as given in the Table 5.1.

Table 5.1 Real constants for reinforcement in column models

Real Constant Set No	Details of LINK8 element	Real constant values	
		Area(mm ²)	Initial strain
1	Main bars of original column with 8mm diameter longitudinal reinforcement	50.265	0
2	Lateral ties for original column with 8mm diameter longitudinal reinforcement	28.27	0
4	Main bars of jacketed column with 0.18% longitudinal reinforcement	28.27	0
4	Main bars of jacketed column with 0.32% longitudinal reinforcement	50.26	0
4	Main bars of jacketed column with 0.50% longitudinal reinforcement	78.5	0
4	Main bars of jacketed column with 0.72% longitudinal reinforcement	113	0
4	Lateral Ties for jacketed column with 0.18% longitudinal reinforcement	28.27	0
5	Lateral Ties for jacketed column with 0.32%,0.50% and 0.72% longitudinal reinforcement	50.26	0
1	Main bars of beam with 8mm diameter longitudinal reinforcement	50.26	0
2	Lateral ties for beam with 8mm diameter longitudinal reinforcement	28.27	0

5.4 MATERIAL PROPERTIES

The material properties defined in the column models are given in Table 5.2. The present study assumed that the concrete is a homogeneous and isotropic. Poisson ratio is taken as 0.2 and the shear transfer coefficient is assumed to be 0.2. E_X is the modulus of elasticity of the material and PR_{XY} is the Poisson's ratio. The yield stress and tangent modulus of reinforcement bars were obtained from laboratory tests.

Table 5.2 Material properties used in jacketed column models

Material Model No.	Element Type	Material Properties	
1	Link 8	Linear Isotropic	
		EX	$2.1 \times 10^{11} \text{ N/m}^2$
		PRXY	0.3
		Bilinear Kinematic	
		Yield Stress	$432 \times 10^6 \text{ N/m}^2$
		Tangent Modulus	$847 \times 10^6 \text{ N/m}^2$
2	Solid 65	Linear Isotropic	
		EX	$32517 \times 10^6 \text{ N/m}^2$
		PRXY	0.15
		Concrete	
		Shear transfer coefficients for an open crack	0.2
		Shear transfer coefficients for a closed crack	0.9
		Uniaxial tensile cracking stress	$3.71 \times 10^6 \text{ N/m}^2$
		Uniaxial crushing stress	$35.376 \times 10^6 \text{ N/m}^2$
		Biaxial crushing stress	0
		Ambient Hydrostatic stress state	0
		Biaxial crushing stress under ambient hydrostatic stress state	0
		Uniaxial crushing stress under ambient hydrostatic stress state	0
		Stiffness multiplier for cracked tensile condition	0

The concrete cube compressive strength f_{ck} determined from the experimental result were taken. The relationship of cylinder strength (f'_c) and cube strength (f_{ck}) given by the ACI 318:2002 as ($f'_c = 0.8f_{ck}$). The uniaxial tensile cracking stress of concrete (f_t) was determined using Equation (4.1).

$$f_t = 0.623 \sqrt{f'_c} \quad (4.1)$$

5.4.1 Compressive Uniaxial Stress-Strain Relationship for Concrete

The ANSYS program requires the uniaxial stress-strain relationship for concrete in compression (Figure 5.4). The uniaxial stress-strain curve for concrete developed by Desayi and Krishnan (1964), which is given by Equation (4.2), was adopted for modelling concrete.

$$f = \frac{E \varepsilon}{1 + \left(\frac{\varepsilon}{\varepsilon_0} \right)^2} \quad (4.2)$$

where,

f = stress at any strain, ε

ε_0 = strain at the ultimate compressive strength f'_c

$$\varepsilon_0 = \frac{2 f_{ck}}{E_c}$$

E = a constant (same as initial tangent modulus) such that $E = \frac{2 f'_c}{\varepsilon_0}$

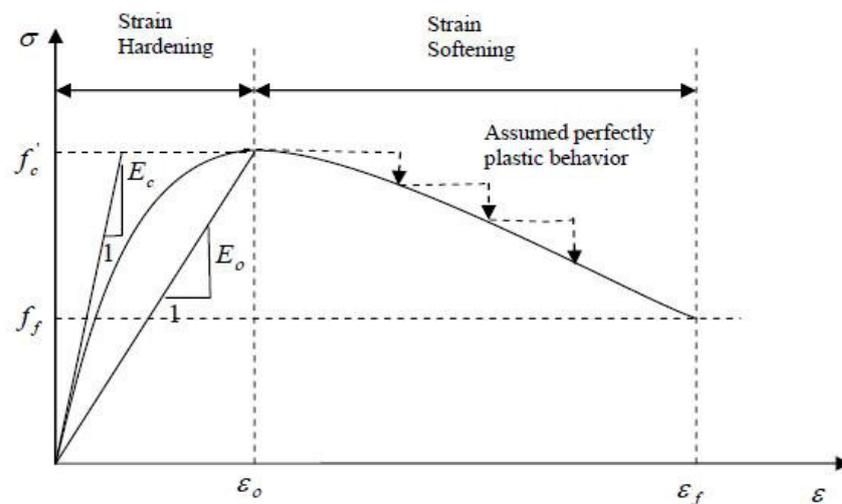


Figure 5.4 Uniaxial stress –strain curve of concrete

Until the crack, initial tangent modulus E_c is used to find the maximum positive (tensile) stress. The cracked concrete can still carry some tensile stress perpendicular to the crack, which is termed tension stiffening. In this study, a simple descending line is used to model this tension stiffening phenomenon as shown in Figure 5.5 (Hoque 2006). The default value of the strain ε^* at which the tension stiffening stress reduced to zero is $\varepsilon^* = 0.001$. In Figure 3.13, E_c and E_t are the modulus of elasticity of tensile concrete between zero to fracture strain and fracture strain to ε^* respectively.

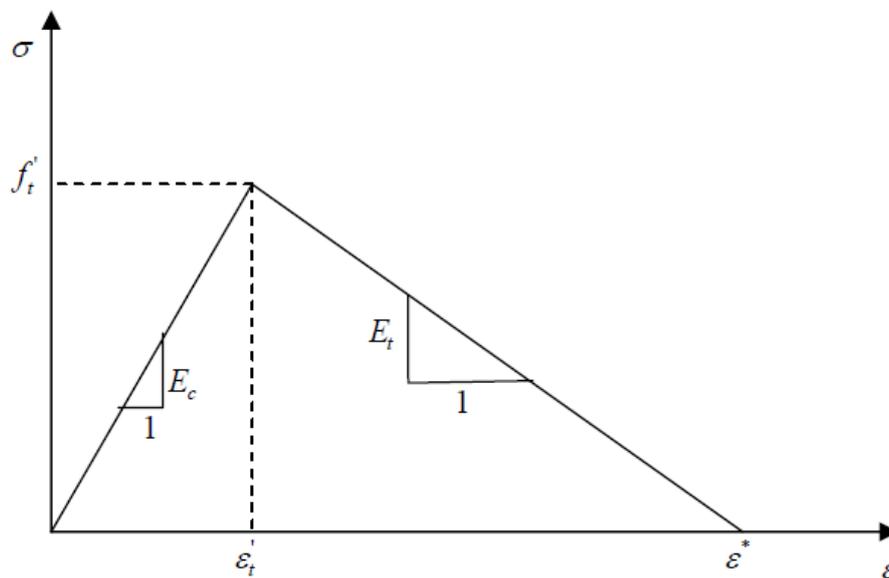


Figure 5.5 Tension stiffening model

5.4.2 Stress-Strain Curve for Steel Reinforcing Bars

The stress-strain curve of the reinforcing bar is assumed to be elastic up to the steel yield stress f_y followed by linear hardening up to the steel ultimate strength (f_u) as shown in Figure 5.6 (Hoque 2006). The dowel action of the reinforcing steel is neglected and the bond between steel and concrete is assumed to remain perfect.

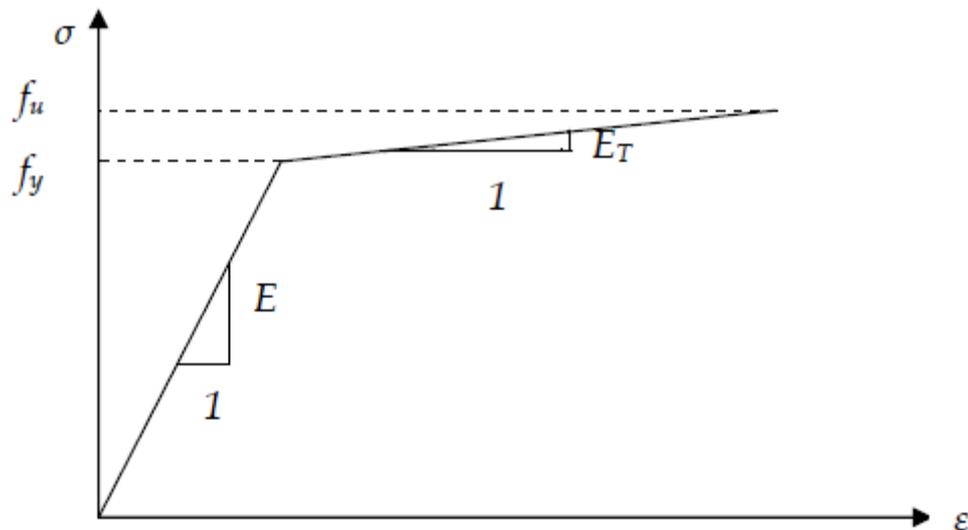
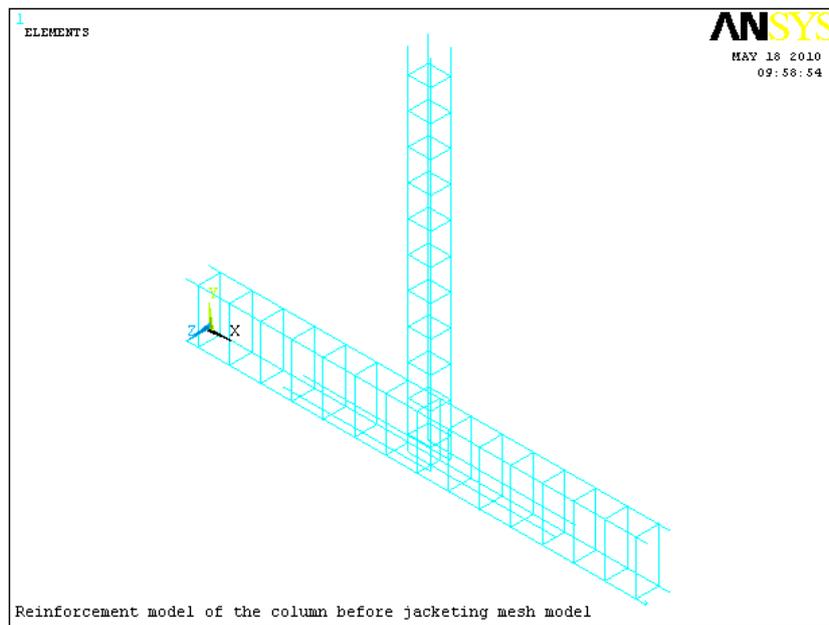


Figure 5.6 Uniaxial stress – strain relation for steel

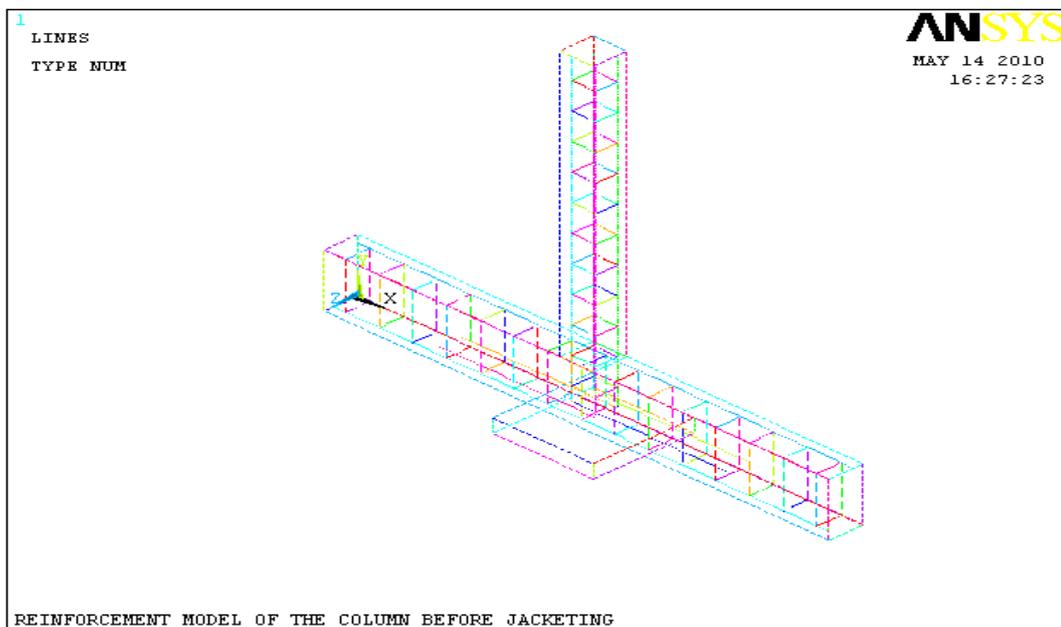
5.5 MODELLING OF SPECIMENS

5.5.1 Unretrofitted Columns

Columns having 2.01% of longitudinal reinforcement is considered for the analytical study. The column specimens modeled is analogous to the column specimen C8A tested in the laboratory. The column was modeled in ANSYS 10 software using the element types and the material properties mentioned in sections 4.4. The axial load of 10 kN was applied on the top of the column with a lateral load at a distance of 30 mm from top of column. The modeling details are shown in the Figure 5.7 (a) and (b)



(a) Mesh model of the reinforcement configuration of untrofitted column

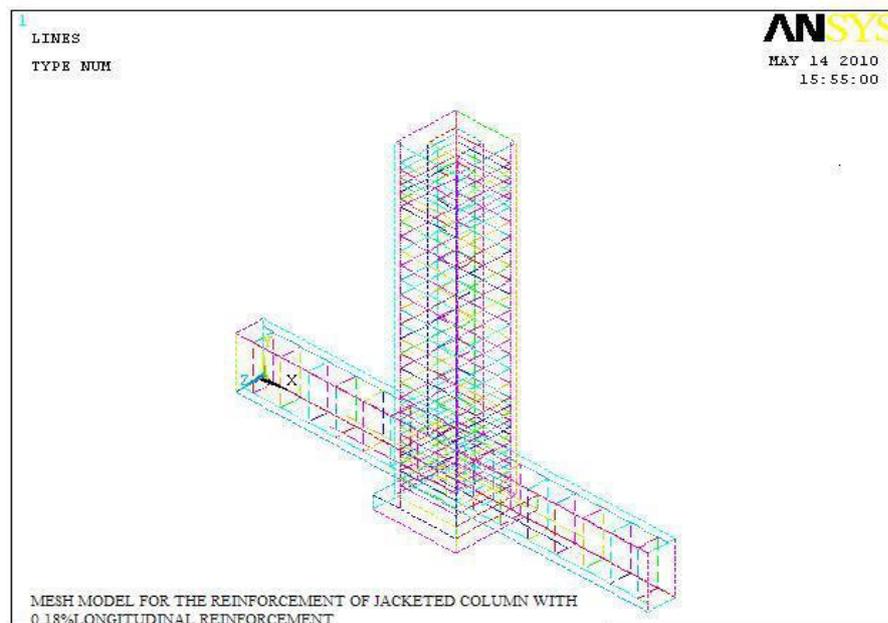


(b) Reinforcement configuration of the untrofitted column with slab

Figure 5.7 Modeling details of columns before jacketing

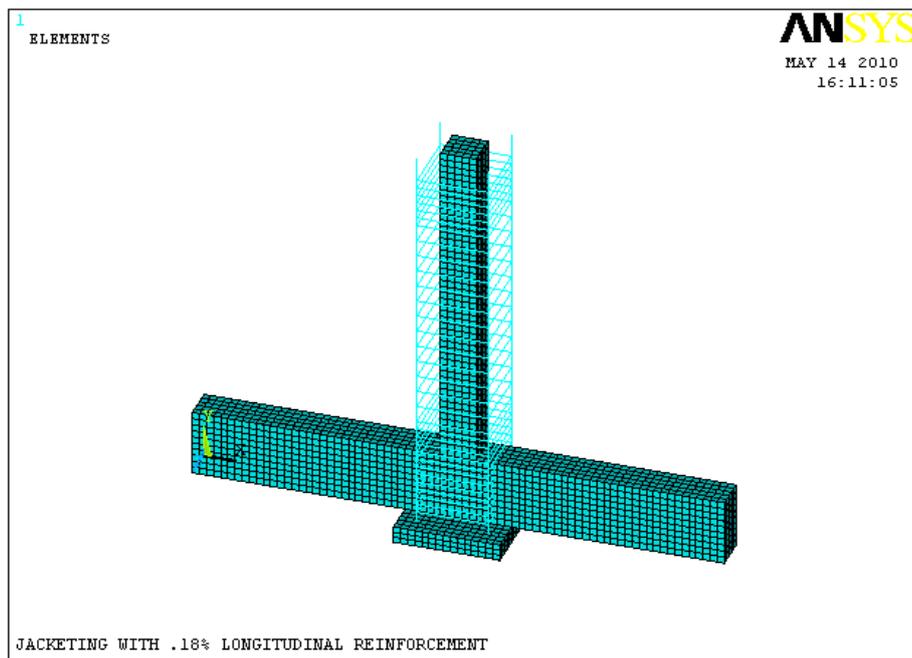
5.5.2 Retrofitted Columns with Reinforced Concrete (RC) Jacketing

In order to validate the experimental test performance of the RC jacketed columns, the specimens were modeled and analysed using ANSYS software. The column specimens modeled were analogous to the column specimens RCJ1, RCJ2, RCJ3 and RCJ4 tested in the laboratory. The column specimens RCJ1, RCJ2, RCJ3 and RCJ4 have an additional reinforcement of 0.18%, 0.32%, and 0.50% and 0.72% respectively. The column was modeled in ANSYS 10 software using the element types and the material properties mentioned in sections 4.4. The axial load of 10 kN was applied on the top of the column with a lateral load at a distance of 30 mm from top of column. The modeling details are shown in the Figure 5.8 (a) to (j).

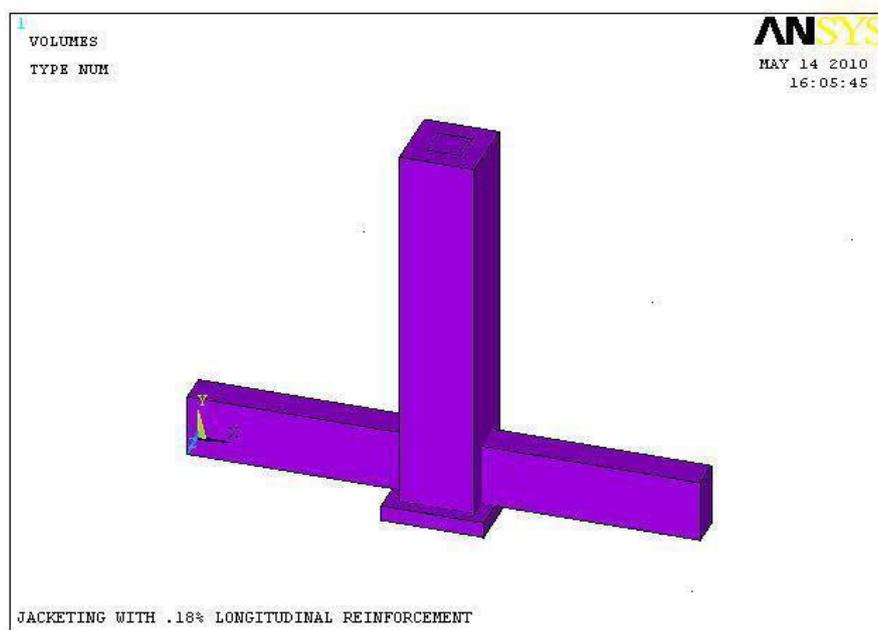


(a) Reinforcement Configuration with an additional reinforcement of 0.18% (Specimen RCJ1)

Figure 5.8 Modeling details of the jacketed columns

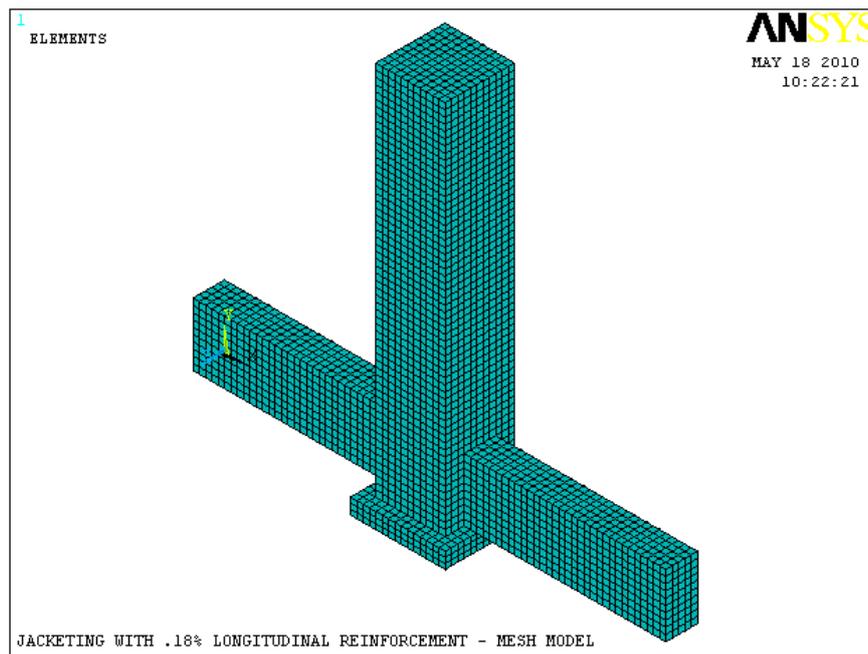


(b) Jacketing reinforcement

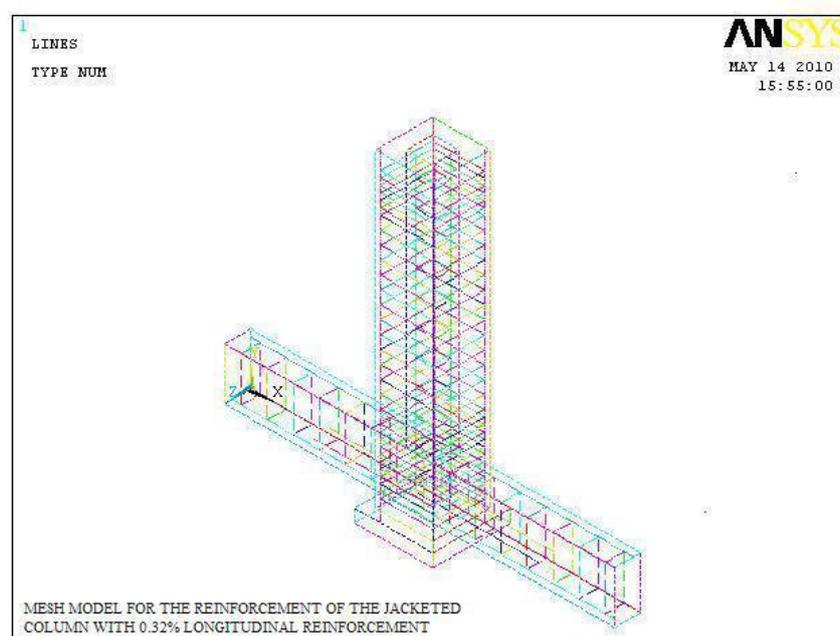


(c) Solid model of the jacketed column

Figure 5.8 (Continued)

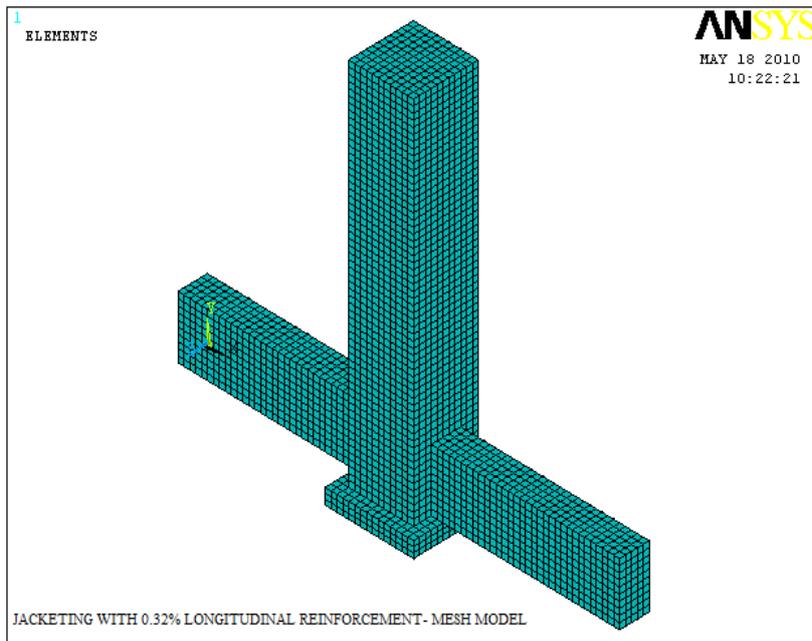


(d) Mesh of Concrete with an additional reinforcement of 0.18%

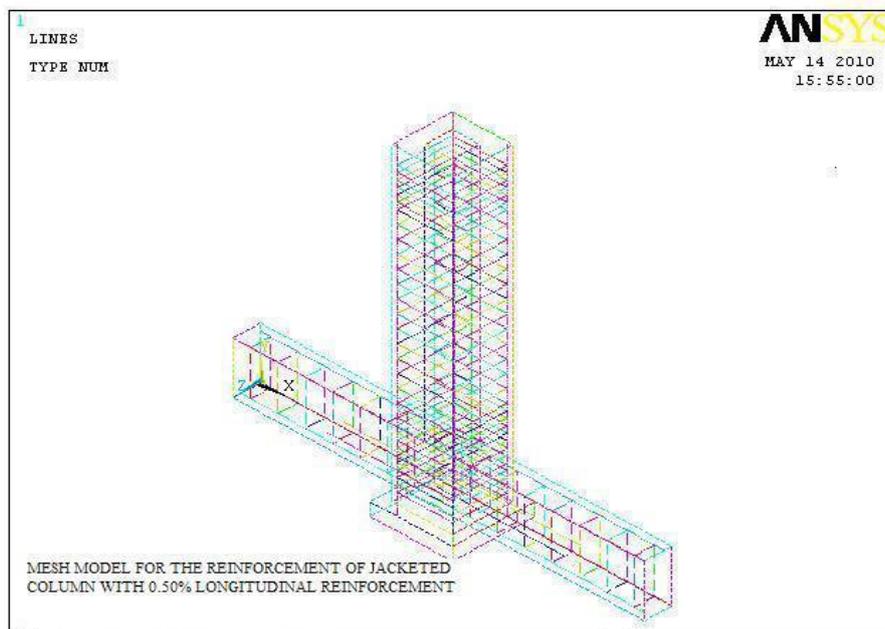


(e) Reinforcement Configuration with an additional reinforcement of 0.32 % (Specimen RCJ2)

Figure 5.8 (Continued)

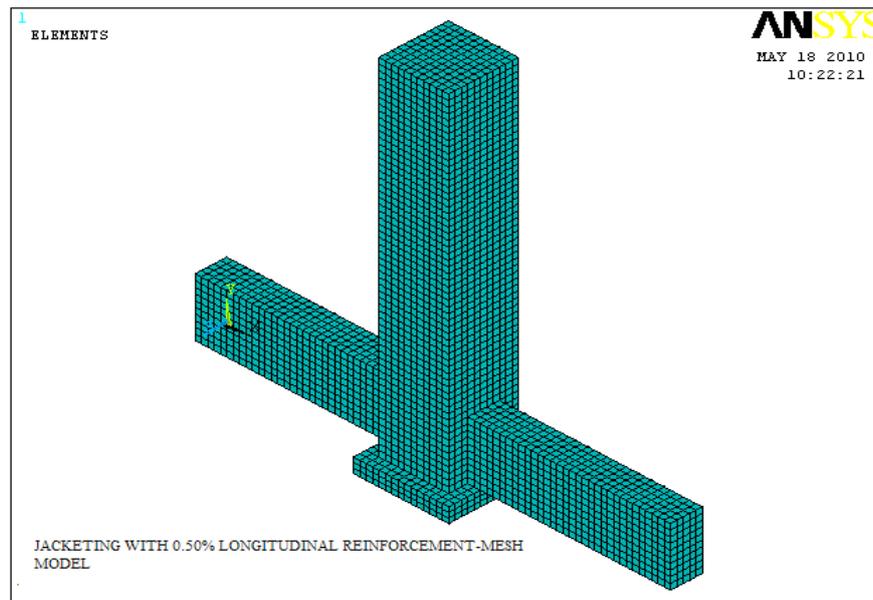


(f) Mesh of Concrete with an additional reinforcement of 0.32 %

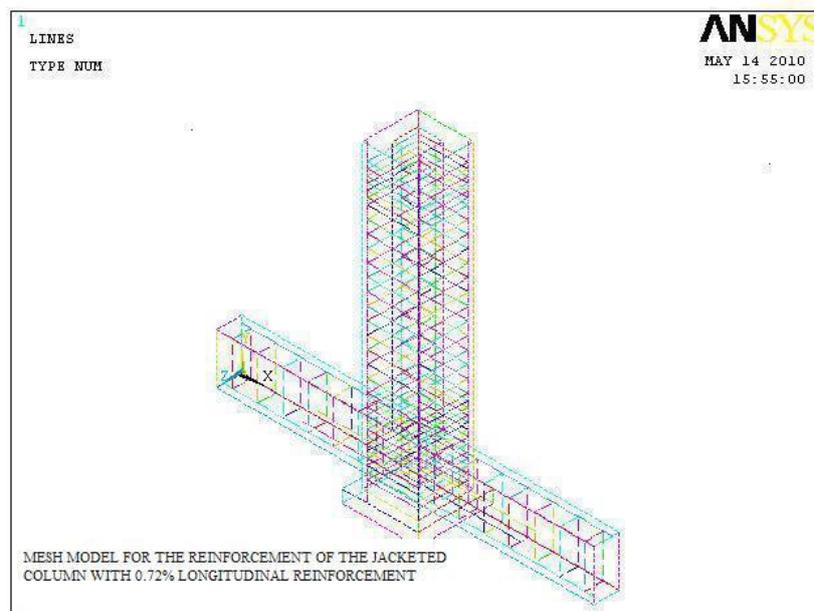


(g) Reinforcement Configuration with an additional reinforcement of 0.5 % (Specimen RCJ3)

Figure 5.8 (Continued)

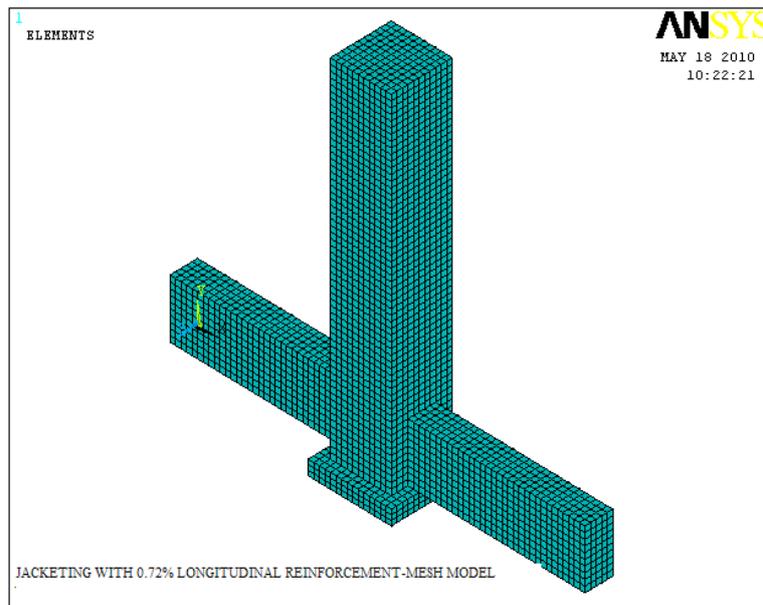


(h) Mesh of Concrete with an additional reinforcement of 0.50 %



(i) Reinforcement Configuration with an additional reinforcement of 0.72 % (Specimen RCJ4)

Figure 5.8 (Continued)



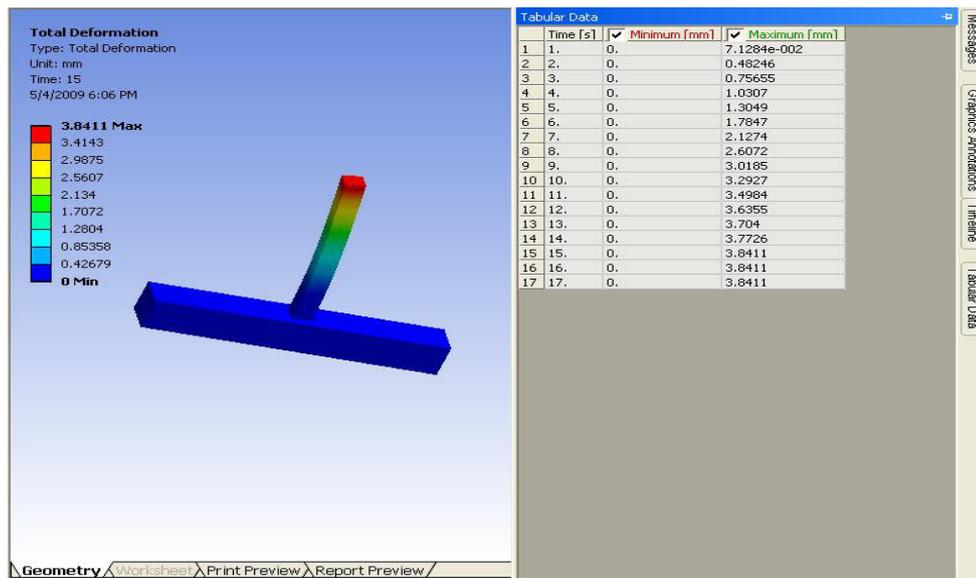
(j) Mesh of Concrete with an additional reinforcement of 0.72 %

Figure 5.8 (Continued)

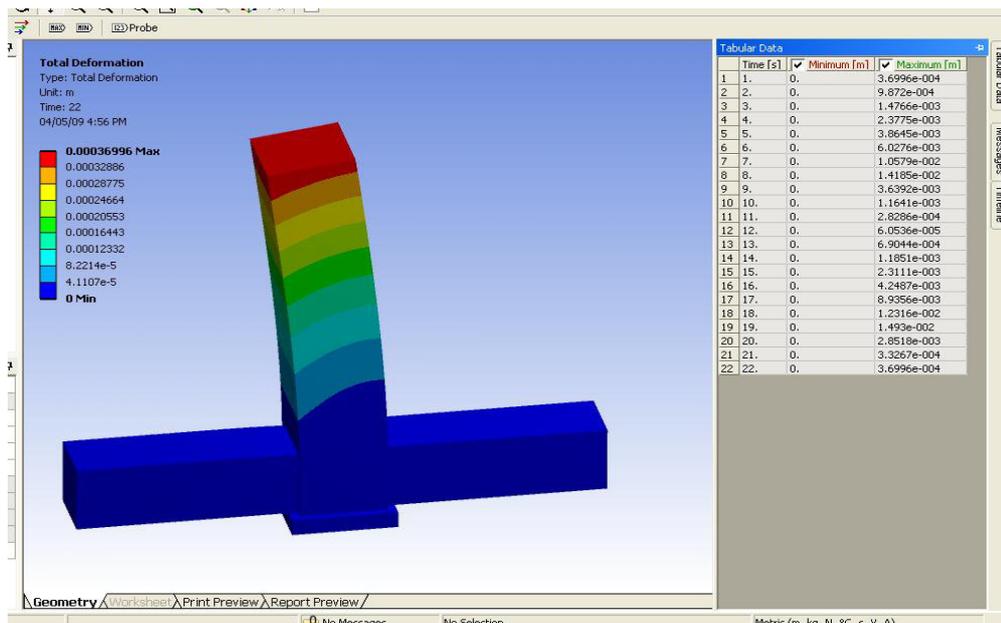
5.6 OBSERVATIONS

5.6.1 Deflected Shape

The control specimen RC0 and the RC jacketed columns RCJ1, RCJ2, RCJ3 and RCJ4 were modeled in ANSYS. The deflected shapes of the specimens are shown in Figure 5.9 (a) to (e). It is observed that specimen jacketed with 0.32% additional longitudinal reinforcement has the maximum deflection when compared with other specimens.

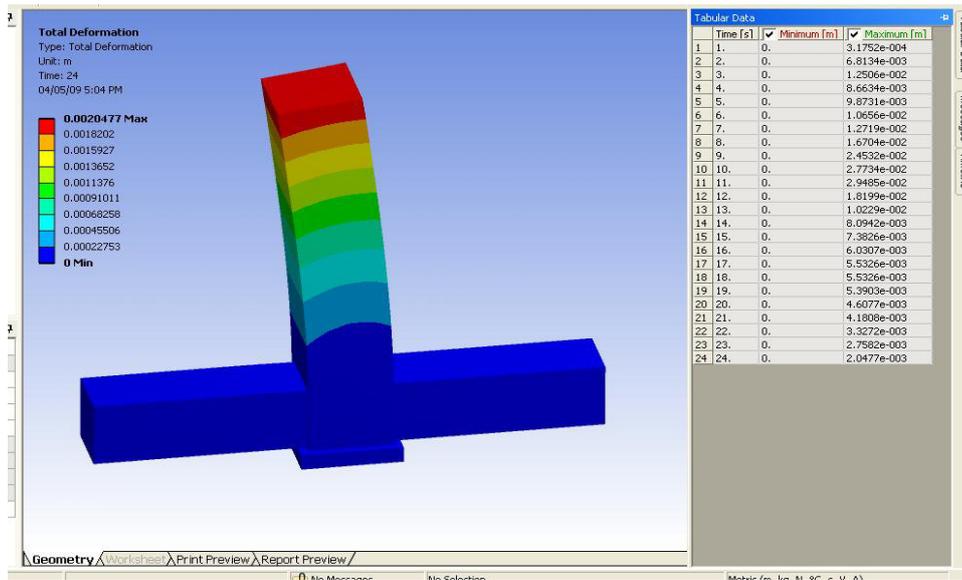


(a) Specimen without jacking

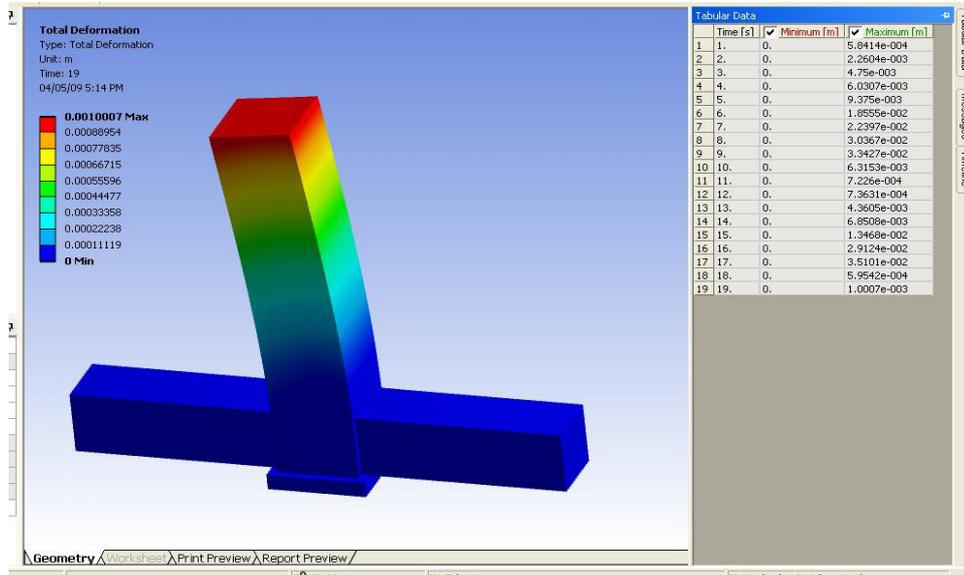


(b) Specimens with 0.18 % longitudinal reinforcement(RCJ1)

Figure 5.9 Deflected shapes of the specimens

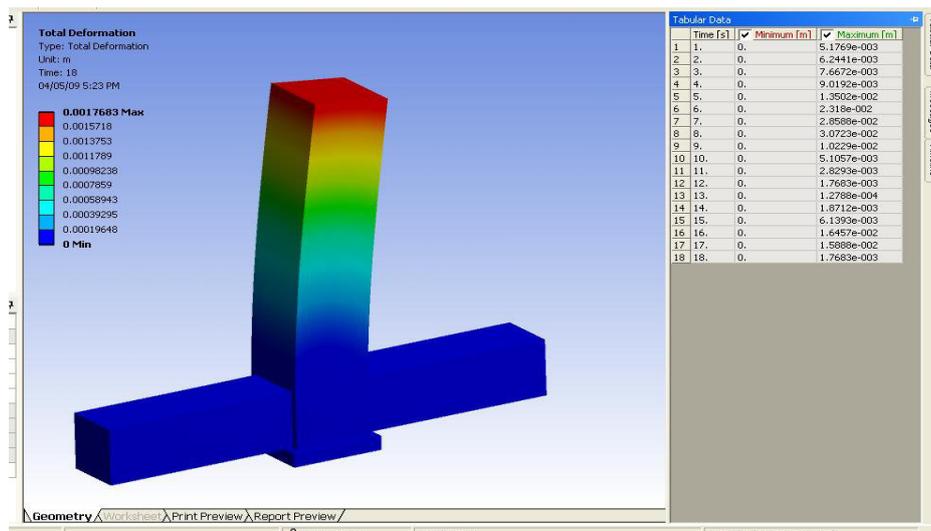


(c) Specimens with 0.32 % longitudinal reinforcement (RCJ2)



(d) Specimens with 0.50 % longitudinal reinforcement (RCJ3)

Figure 5.9 (Continued)

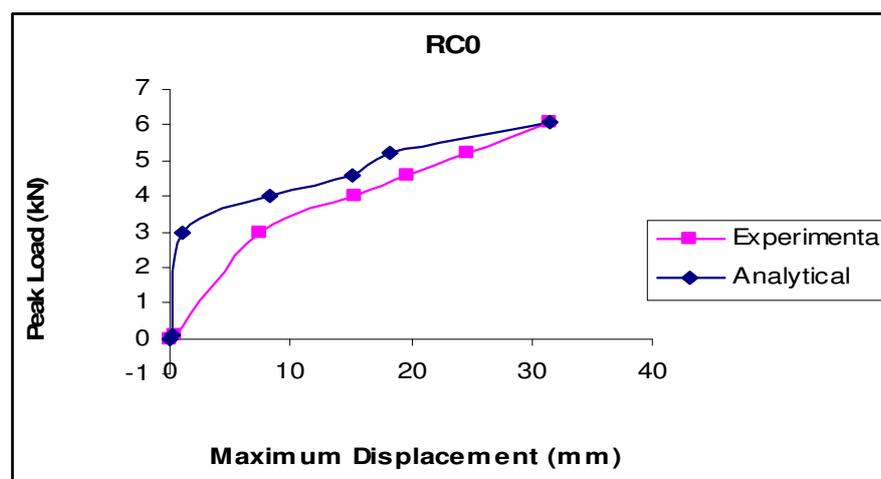


(e) Specimens with 072% longitudinal reinforcement (RCJ4)

Figure 5.9 (Continued)

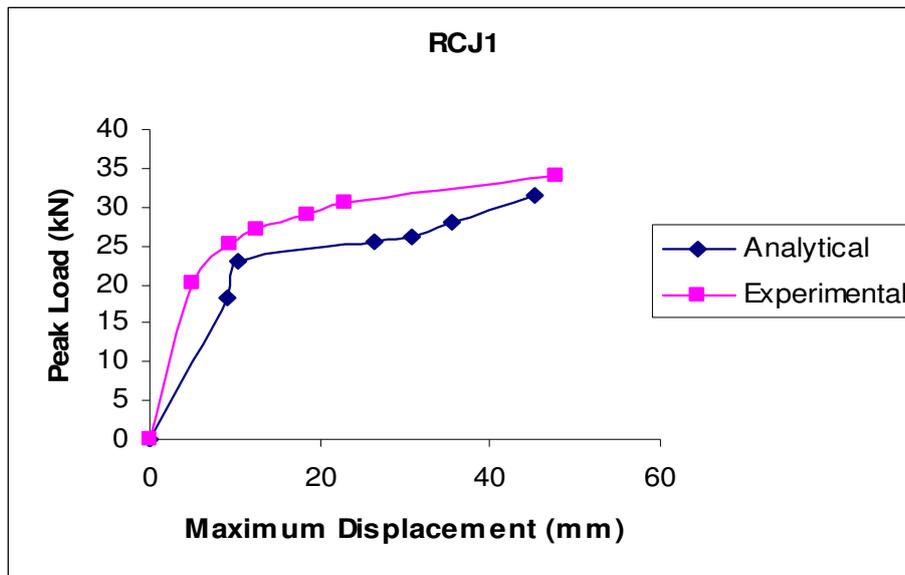
5.6.2 Validation of the Results

The load – deflection curves for each specimen were analysed and compared with the experimental results. The load displacement curves for the experimental results (Section 6.3.4.3) and analytical results are plotted and compared. The comparisons of results are shown in Figure 5.10 (a) to (e). The analytical results are in good agreement with the experimental values.

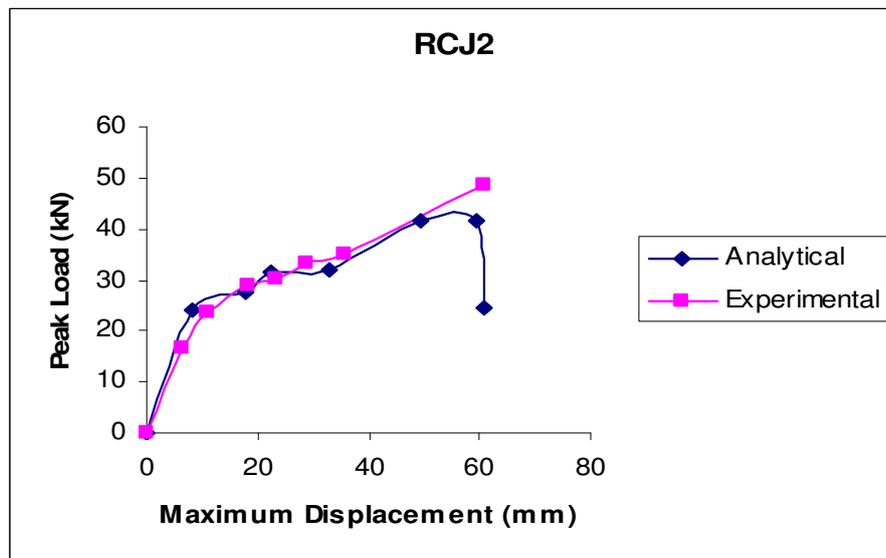


(a) Specimens without jacketing

Figure 5.10 Comparison of load-Displacement curves

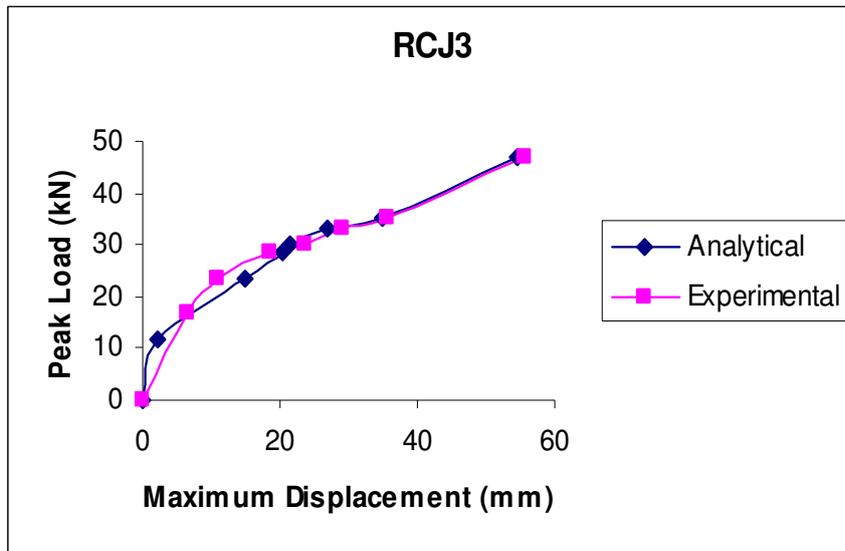


(b) Specimens with 0.18 % longitudinal reinforcement

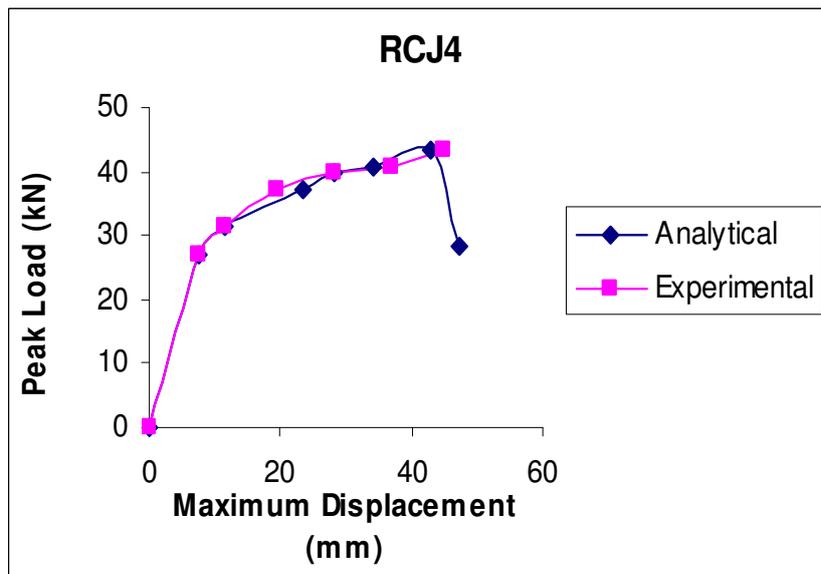


(c) Specimens with 0.32 % longitudinal reinforcement

Figure 5.10 (Continued)



(d) Specimens with 0.50 % longitudinal reinforcement



(e) Specimens with 0.72 % longitudinal reinforcement

Figure 5.10 (Continued)

5.7 SUMMARY

The control specimen RC0 and the RC jacketed columns RCJ1, RCJ2, RCJ3 and RCJ4 were modeled in ANSYS. The deflected shapes of the specimens were drawn and the load – deflection curves for each specimen were analysed and compared with the experimental results.