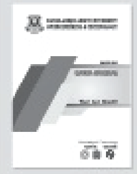

BAUET JOURNAL
Published by
Bangladesh Army University of Engineering & Technology
Journal Homepage: http://journal.bauet.ac.bd/

Optimal Reinforcement Pattern for Reinforced Concrete Jacketing of Reinforced Concrete Columns

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Abstract: Reinforced Concrete Jacketing (RC jacketing) of an existing concrete structure is a need-based concept aimed to improve the performance of any structures in Bangladesh context. The need for RC jacketing of structures arises due to preserve of historical, artistic, social and human links and also to comply with more recent code requirements. In this study, a numerical analysis on reinforcement pattern for widely practiced RC jacketing of a rectangular RC column was performed using powerful finite element based software ANSYS 2011 owing to its capabilities to predict and pictorially represent the response of RC columns in post-elastic range to the ultimate strength. Comparisons were done among four different reinforcement patterns for RC jacketing to find out the optimal pattern on lateral and axial deformation response and crack formation. One rectangular RC column without retrofitting was analyzed and then retrofitted keeping the ultimate capacity of retrofitted members theoretically unaltered in four distinct ways: retrofitted with (i) one reinforcing bar at each corner; (ii) two reinforcing bars at each corner; (iii) three reinforcing bars at each corner with diagonal confinement bar at corners; and (iv) four reinforcing bars at each corner having two layers of additional tie bars. After the analysis of results, it was found that the reinforcement pattern (iii) is the most efficient for jacketing of RC columns.

Keywords: *ANSYS; Finite element analysis; RC jacketing; Ultimate capacity; RC jacketing*

Introduction: Reinforced concrete members are often damaged due to natural disasters, notably earthquakes, overloading, changes in building usage and so on [5]. Damage may take place in almost all parts of a structure, namely slabs, beams, columns, walls etc. Column failure causes the most significant failures of reinforced concrete structures. To prevent the column failure mechanism during earthquakes, column should never be the weaker components in the whole structure [9]. Reparation is needed after the damage has taken place to bring the damaged member to the strength previously existed [4,12]. Re-strengthening is also carried out when the purpose of an existing structure changes, predicted load increases or environmental load increases than that was taken into account when designed. Practical methods available for strengthening of existing RC columns are steel jacketing, reinforced concrete (RC) jacketing, fiber reinforced polymer composite jacketing, external pre-stressing wires, strands or belts and jacketing with high tension materials like carbon fiber, glass fiber etc. [2]. Among them RC jacketing is most widely used method for strengthening of building columns [4] (in Bangladesh perspective). The aims of this study are to find the lateral and axial deformation responses, such as strain at different stages of incremental loading and to find the stresses in different elements at different stages of incremental loading, to find the optimal reinforcement pattern for the improvement of compressive load carrying capacity and to restore or improve structural integrity, appearance, durability and functional performance steel collars.

Article history:
Received 12 November 2017,
Received in revised form 12 December 2017
Accepted 28 December 2017,
Available online 30 March 2018

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Materials & Method:

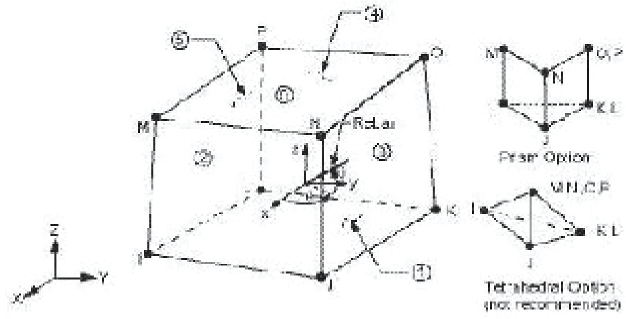
RC Jacketing of Column: RC jacketing (Section Enlargement) of column consists of adding concrete with longitudinal and transverse reinforcement around the existing columns. Additional concrete and reinforcement contributes to the increase in strength. Reinforced concrete jacketing can be employed as a repair or strengthening scheme [1]. RC jacketing increases the member size significantly, also increases the member's stiffness and is useful where deformations are to be controlled. Shear and axial load carrying capacity of the structural members can be enhanced by this method [10]. This method provides better solution for avoiding buckling problem, if the column in building is found to be slender. The resulting cured member not only strengthens the reinforced concrete member but also acts as an excellent barrier to the corrosion agents, which are detrimental to concrete and the reinforcement. In addition, the original function of the building can be maintained, as there are no major changes in the geometry of the building with this technique. In most cases, the enlargement must be bonded to the existing concrete to create a monolithic member for additional shear or flexural capacity [7,14]. Jacketing restores the section of an existing member by encasement in a new concrete [1,11]. This technique is applicable for protecting the member against further deterioration as well as for strengthening. Strengthening of existing columns is needed when (a) Load carried by the column is increased due to either increasing the number of floors or due to mistakes in the design. (b) The compressive strength of the concrete or the percentage and type of the reinforcement is not according to the codes requirement [1,14].

Materials Properties: The properties of concrete and reinforcing steel are given in the Table 1 below-

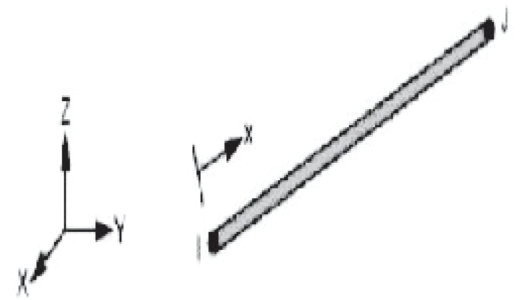
Table 1. Material Properties

Concrete Properties		Reinforcing Steel Properties	
Property	Value	Property	Value
Modulus of Elasticity	3.605E+006 psi	Modulus of Elasticity	2.9E+007 psi
Poisson's Ratio	0.18	Poisson's Ratio	0.3
Uniaxial Cracking Stress	474.34 psi	Yield Strength	60000 psi
Open shear transfer coefficient	0.3	Tang Modulus	2900 psi
Closed shear transfer coefficient	1		

An 8-node solid element, SOLID65, having 3 degrees of freedom at each node (translation in the nodal x, y and z direction) was used to model the concrete whereas a LINK8 element with 2 nodes, having 3 degrees of freedom at each node (translation in the nodal x, y and z direction) was used to model the reinforcements. TARGE170 and CONTA174 were also utilized to model the interface surface between old and new concrete.



SOLID65



LINK8

Fig. 1: Geometry of Materials

Reinforcement Pattern: In this study, one rectangular column was jacketed by RC jacketing method in four different combination of reinforcement keeping the retrofitted dimensions, main reinforcement, shear reinforcement and material properties same in each of the four models. A. Teran & J. Ruiz (1992) illustrated four major reinforcement patterns for RC jacketing of RC columns. These patterns are given below [8]-

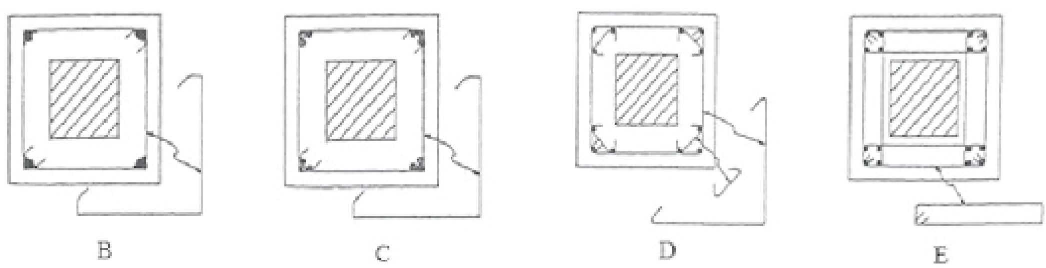


Fig. 2: Reinforcement Pattern for RC jacketing of RC columns

Modeling in ANSYS: Finite element method (FEM) models were developed to simulate the behavior of five full-size rectangular reinforced concrete columns from linear through nonlinear response and up to failure using the ANSYS program (ANSYS 2011). Comparisons were made for load-deflection plots at selected locations on the columns and cracking loads. The five full-size columns were modeled in ANSYS multi-physics software conforming the dimensions, reinforcing steel area and steel distribution patterns.

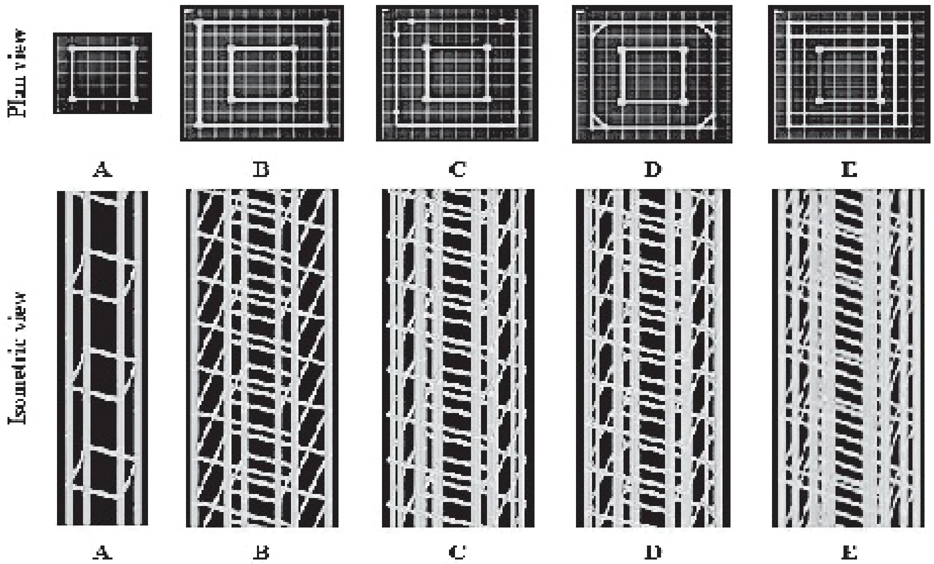
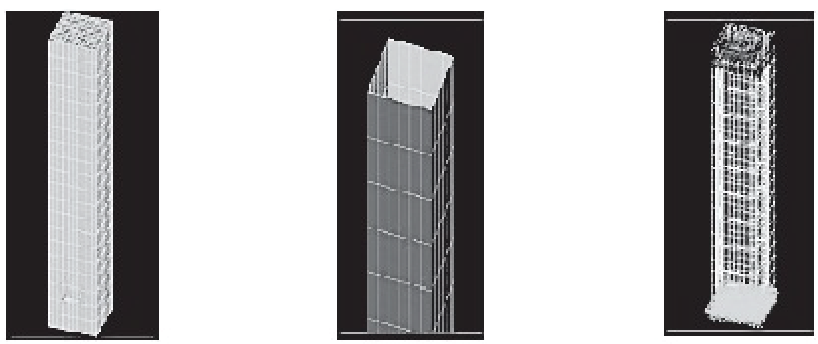


Fig. 3: ANSYS Models of Columns (Plan and Isometric View)

Meshing of Element and Boundary Conditions: After modeling and inputting all the data the models were meshed. The original column (A) was subdivided into 6x6x20 = 720 elements whereas the retrofitted columns (B, C, D and E) were subdivided into 10x10x20 = 2000 elements. Each element sizes 2"x2"x6". The mesh size was kept the same in contact surface i.e., 2"x6". Number of elements in contact surface was 6x20x4 = 480. CONTA174 and TARGE170 were used in the interface surface creation. For 3D modeling, the surface of old concrete was taken as contact surface and the surface of new concrete was taken as target surface by default. Then a contact pair was created using standard contact behavior. Default values of normal penalty stiffness and penetration tolerance were allowed for the surface to surface contact creation. Maximum friction stress was taken to be $1x10^{20}$ psi.



Meshing Interface Surface Modeling Boundary Conditions

Fig. 4: Meshing of Element, Boundary Conditions and Load Application

To ensure that the model acts the same way as the experimental columns specimens, boundary conditions need to be applied where the supports and loadings exist. For concentric columns model, the displacement of all nodes at bottom base of column in x, y and z. directions held zero (Ux = 0, Uz = 0 and Uy = 0). To apply the axial load on the top of the concentric column specimens, loads were applied on each node at the top of the columns.

Design of Re-Strengthened Columns: A 12"x12" column was taken to be re-strengthened by RC jacketing. The dimensions of jacket for all four patterns were also kept unaltered (4 inch at each side). The design was done in such a way that the design compressive strength of the four models after re-strengthening is equal. The modeling of interface surface was done in the same way for four models. These conditions conform that the change in compressive load carrying capacity will be controlled only by reinforcement pattern. The dimensions and reinforcement details of re-strengthened columns are shown in Table 2.

Table 2. Dimensions and Reinforcement Details of Re-Strengthened Columns

<table>
<tr><td rowspan="2">Before Retrofitting</td><td>Model Name</td><td>Dimension before retrofitting</td><td>Dimension after retrofitting</td><td>Main Reinforcement</td><td>Shear reinforcement</td></tr>
<tr><td>A</td><td>12"x12"</td><td>N/A</td><td>4#8φ</td><td>#3φ @12″c/c</td></tr>
<tr><td rowspan="5">After Retrofitting</td><td>Model Name</td><td>Dimension before retrofitting</td><td>Dimension after retrofitting</td><td>Main reinforcement in jacket</td><td>Shear reinforcement in jacket</td></tr>
<tr><td>B</td><td>12″x12″</td><td>20″x20″</td><td>4#8φ, one at each corner</td><td>#3φ @6″c/c</td></tr>
<tr><td>C</td><td>12″x12″</td><td>20″x20″</td><td>8 nos. of 0.3923935 in^2 area bars, two at each corner</td><td>#3φ @6″c/c</td></tr>
<tr><td>D</td><td>12″x12″</td><td>20″x20″</td><td>12 nos. of 0.26159 in^2 area bars, three at each corner</td><td>#3φ @6″c/c with corner confinement</td></tr>
<tr><td>E</td><td>12″x12″</td><td>20″x20″</td><td>16 nos. of 0.19619675 in^2 area bars, four at each corner</td><td>0.0551805 in^2 area bar tie @6″c/c (in two layers)</td></tr>
</table>

Results and Discussion:

The most important property of concrete is the compressive strength. The quality of concrete is judged largely on the strength of that concrete. Obviously, the strength of any structure, or part of a structure, is important, the degree of importance depending on the location of the structural element under consideration. Strength is usually the basis for acceptance or rejection of the concrete in the structure. The only engineering property of concrete that is routinely specified is the characteristic compressive strength. It is used as an input in all concrete design procedures. The design compressive strength of rectangular reinforced concrete column was calculated by the following equation [3,6,13]-

$$P_u = 0.80\ \Phi\ (.85A_c f_c' + A_s f_y) \qquad \text{Eq. 1}$$

Where, Φ = 0.65 for rectangular tied column, P_u= Design compressive strength (kips), A_c= x-sectional area of concrete (in^2), f_c'= Uniaxial compressive strength of concrete (ksi), A_s= x-sectional area of steel (in^2), f_y= Yield strength of steel (ksi)

In case of perfectly bonded concrete to concrete connection, this formula remains valid. The calculated design compressive strength and nominal compressive strength of the column models are shown in Table 3.

Table 3. Design Compressive Strength and Nominal Compressive Strength of the Column Models

Column ID	A_c (in^2)	f_c' (ksi)	A_s (in^2)	f_y (ksi)	P_u (kips)	P_n (kips)	Remarks
A	140.9	4	3.142	60	433.8	667.4	Before re-strengthening
B-E	393.7	4	6.283	60	1115.2	1715.6	After re-strengthening

Comparison of First Cracking Loads: The values of loading at which first cracks occur in concrete were also compared for five models since cracks play an important role in structural failure of reinforced concrete members. The failure of well-designed reinforced concrete members are often preceded by formation of cracks. In this study, comparisons were done based on the axial and lateral deformation response such as strain with the increment of loading and the first cracking load. Comparisons of first cracking loads are shown in the Table 4 and Figure 5.

Table 4. Comparison of First Cracking Loads

Model	A	B	C	D	E	Preferable
First Cracking Load (Kips)	230.6	648.6	619.9	652.1	648.3	D
Increment (compared to A), %	0.00	181.27	168.82	182.78	181.14	

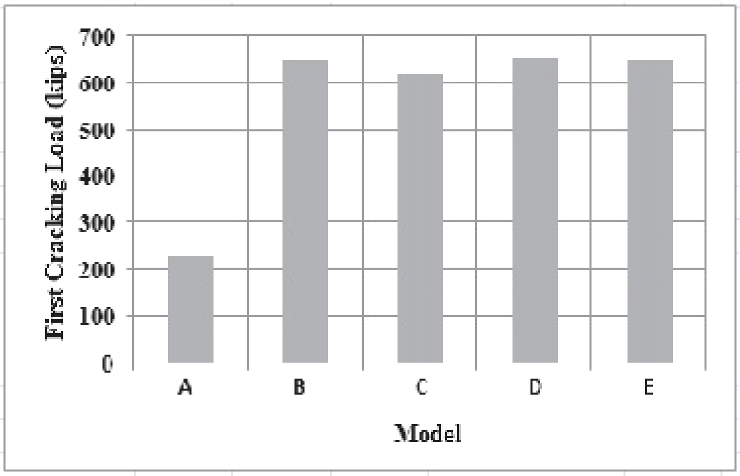
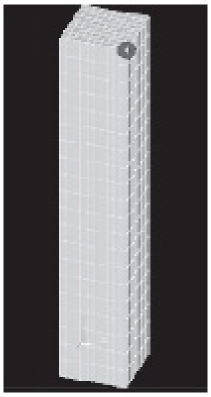
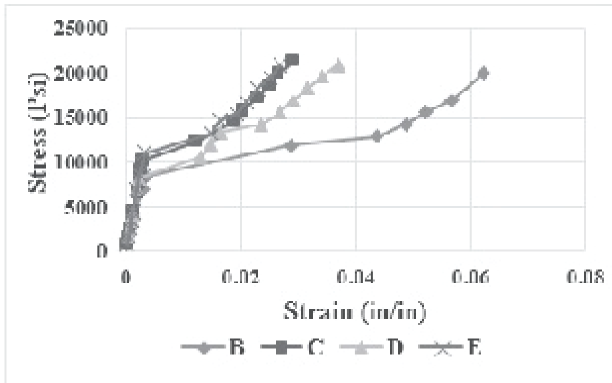


Fig. 5: Comparison of First Cracking Loads

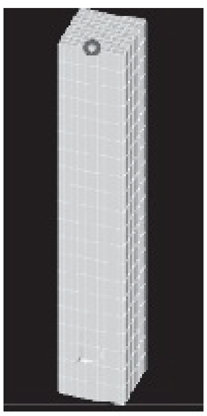
Figure 5 represents the comparison of first cracking loads for model A (Before RC Jacketing), B, C, D and E (After RC Jacketing). From the analysis it was found that model A shows very little cracking load (230.6 kips) while model B, C, D and E shows cracking loads approximately 2.69 times greater than that of model A. Model D shows maximum cracking load (652.1 kips) at which the first crack of the column element is occurred. So model D is the best reinforcement pattern for RC jacketing of RC columns based on cracking load.

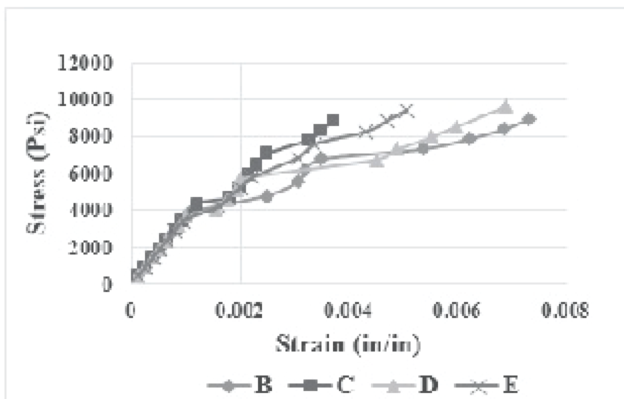
Comparison of Stress-Strain Diagram: Stress-strain curves are an extremely important graphical measure of a material's mechanical properties. The engineering measures of stress and strain were determined from the measured load and deflection using the original specimen cross-sectional area and length. The stress strain diagram for both corner nodes and middle nodes on column surface (top to bottom) are shown in Figure 6 and Figure 7.





Isometric view **Fig. 6:** Stress-strain diagram for corner nodes on column surface (top to bottom)





Isometric view **Fig. 7:** Stress-strain diagram for middle nodes on column surface (top to bottom)

From the stress-strain diagram as shown in Figure 6 and Figure 7, it was established that all the four models act almost the same up to the proportional limit and beyond proportional limit, the model C shows a steeper stress-strain diagram. The model E shows almost same behavior as model C. The stress-strain diagram for model B is flatter than that of the model D. The model B shows maximum strain at the same stress level as the model D but the curve ends before reaching the maximum stress level reached by the model D. So model D is the best reinforcement pattern for RC jacketing of RC columns based on the stress-strain characteristics of the modeled columns.

Comparison of Displacements: Lateral displacement of a reinforced concrete frame building under lateral loading is a critical parameter for structural evaluation or design. Lateral displacement is important when structures are subjected to lateral loads like earthquake and wind loads. The performance of the modeled columns was evaluated in terms of lateral displacement using structural analysis software ANSYS. In this study effort has been made to investigate the reinforcement pattern based on the lateral displacement of the structural element. Comparisons of displacements (side nodes and corner nodes) of the elements are shown in Figure 8 and Figure 9 for model B, C, D and E.

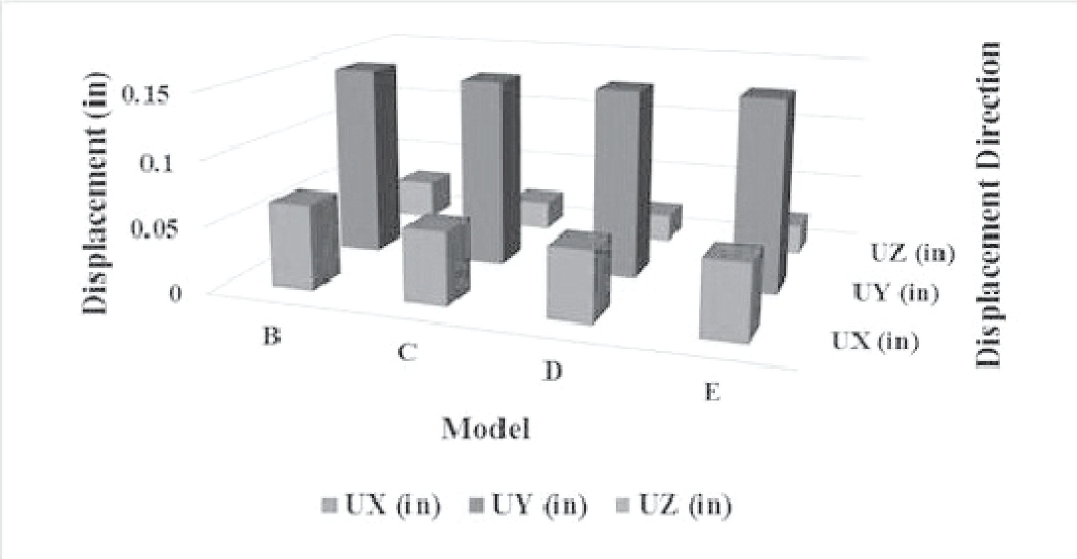


Fig. 8: Comparison of Displacements (side nodes, on top of the column), in.

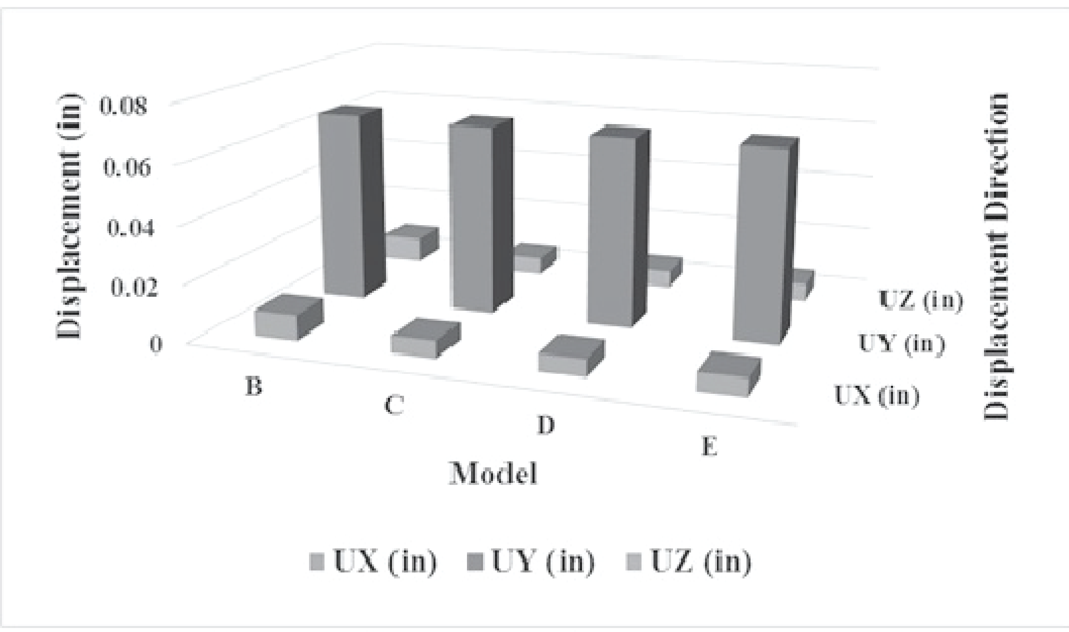


Fig. 9: Comparison of Displacements (corner nodes, top to bottom), in.

The analysis results revealed that the lateral displacements of model B, C and E were higher than that of model D considering all the three directions. The stiffness of the element decreases with the increase of lateral displacements and vice versa. Since the model D shows the minimum lateral displacements compared to the other three, it is the best reinforcement pattern for RC jacketing of RC columns.

Conclusions: Based on the above results on the comparison of the four different models, conclusion may be stated as: (1) The axial and lateral deformation responses of model B, C, D and E are similar at low stage of loading. Model E performed best with the increment of load. With further increment of load, model D performed better than the other three. (2) From the stress-strain diagrams (Figure 6 and Figure 7) model D showed more ductile behavior than model B, C and E. (3) Model D showed minimum lateral displacement (Figure 8 & Figure 9) considering all nodes than the other three. So model D is the optimal reinforcement pattern for RC jacketing of RC columns based on axial and lateral deformation responses, such as strain at different stages of incremental loading, stresses at different points and cracking load.

Acknowledgements: The authors are grateful for the technical support from the Department of Civil Engineering, Chittagong University of Engineering & Technology (CUET), Chittagong-4349, Bangladesh.

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