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Effect of Contact Surface Normal Pressure on the Structural Behavior of Non-Symmetric Concrete Column Jackets

Mohamed A.Al-Azzouny[1], HishamA.El-Arabaty[2], Ahmed A.Korashy[3], and Hany M. El-Shafie[4]

[1]*PhD Candidate, Structure Department,Faculty of Engineering,Ain Shams University, Cairo, Egypt,*
[2]*Assoc.Professor, Structure Department,Faculty of Engineering,Ain Shams University, Cairo, Egypt*
[3,4]*Professor, Structure Department,Faculty of Engineering,Ain Shams University, Cairo, Egypt*
Corresponding Author: Mohamed A.Al-Azzouny

ABSTRACT: *The main objective of this research is an in-depth investigation of the effect of contact surface normal pressure on the structural behavior of columns strengthened by non-symmetric jackets used to strengthen edge and corner understrength columns. The relation between normal pressure and the developed shear stresses at the contact surface is studied in detail. Two different analytical techniques are introduced for the simulation of the contact surface between the original column and the concrete jacket. While the first technique utilizes an normal pressure assumption for the idealization of the shear transfer mechanismat the interface surface, the second technique is based on use of multiple shear-slip relationships at the contact surface, each corresponding to a specific level of normal pressure. A highly sophisticated analytical algorithm is developed, incorporating the nonlinear behavior of the concrete material, together with accurate modeling of the shear transfer mechanism at the contact surface using the two proposed techniques. Finite element models are developed and verified, and used to conduct a parametric study on a number of actual building rectangular columns of varying dimensions, strengthened using 3-sided and 2-sided concrete jackets. The analysis results are used to explain the effect of normal pressure on the behavior of non-symmetrical column jackets, and provide insight into the behavior ofnon-symmetric concrete jackets, and to make an assessment of their efficiency in strengthening existing columns. Useful conclusions are provided to assist designers in this field.*
Key Words*: Strengthening Reinforced Concrete Columns, Non-Symmetric Concrete Jackets, Non-linear Analysis, Normal Pressure, Shear Transfer Mechanism, And Finite Element Method.*

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I. INTRODUCTION

Many researches had been carried out to study the behavior of columns strengthened by concrete jackets without modeling the surface of interface between the original column and the concrete jacket, and study its effect on the actual behavior of the composite jacketed column. Previous researches were concerned mainly on columns strengthened by full concrete jackets from 4-sides, a very few studies was concerned about non-symmetric concrete jackets. Moreover strengthening rectangular columns are more critical than strengthening square or circular columns. Assuming monolithic behavior between existing column and concrete jacket could not established in site because both original column and concrete jacket are different in loadings, material quality, shrinkage, creep....etc. In addition traditional method of analysis in analyzing the strengthened column by neglecting the existing column and consider jacket is resisting all loads as hollow section overestimates the load carrying capacity of the strengthened column because total release of loads from the existing column is very difficult in site and concrete jacket is not resisting direct vertical loads especially when strengthening columns at ground and basement floors only. Carrying out this research is very essential to have an analytical model for actual building rectangular columns of varying dimensions taking into consideration shear transfer mechanism at the contact surface between the existing column and the concrete jackets.

Lampropoulos, Tsioulou, and Dritsos,(2007)state that friction, cohesion and the thickness of the jacket are the three parameters that influence the strength at the interface. Stephanos E. Dritsos1,(2007) sounds that placing reinforced concrete jackets or layers to strengthen or repair and strengthen concrete columns is anormal construction practice but there are many unresolved issues regarding the capacity of thestrengthened elements. In the absence of any guidance, engineering judgement is often used.Herrera, Go´mez and Agranati, (2009) stated that stress transmission mechanisms of concrete jacketedcolumns are still not fully understood and appropriate design procedures are still not established.Lampropoulos, Dritsos (2011) indicate that there are many uncertainties concerning the behavior of the composite specimen, particularly at the interface between the old and new concrete. Giovanni Minaf'o, (2014) explain that the structural efficiency for the jacketed columns is related to twomain effects: – the enlargement of the transverse cross section; – the confinement action provided by the external jacket to the inner core.The main objective of this research is to study the effect of normal pressure on thestructural behavior of RC columns strengthened using non-symmetric concrete jackets taking into consideration the actual condition of the original column before the jacketing process takes place. Especially, the level of acting load since release of such load in real application is difficult to achieve.

II. ANALYTICAL ALGORITHM

In order to reflect the actual case of loading acting in the field during the strengthening process, the old core is already stressed and deformed, in addition it is very difficult to release all loads from the old core . So all loads are mainly applied on the old core. The shear slip at the interface between the old core and the jacketis taken into consideration during the analysis. The relation between the relative movement (sliding) at the interface and the total normal compression stress (confinement) applied on the shear interface is inverse proportional . Increasing the confinement at the interface, increase the shear resistance and decrease the relative slip between the existing member and new added jacket.

Thermou, Pantazopoulou, Elnashai, (2006) present an analytical model for estimating the composite action of prismatic reinforced concrete reinforced concrete members repaired/strengthened by concrete jacketing. The model considers the slip at the interface between the existing member and the jacket and establishes the mobilized to resist this action thereby supporting composite behavior.The cross-section is divided into three layers; the two external ones represent the contribution of the jacket whereas the middle layer is the core of the jacketed member. The strain profile used with the three-layer approach is illustrated in Figure (1). The difference in normal strain at the interfaces accounts for the corresponding slip in the longitudinal direction. It is assumed that the three layers deform by the same curvature, (Φ). The difference in the stress resultant between two adjacent cross sections equals the shear flow in the interface. Shear is transferred by means of friction between the contact surfaces and dowel action of the reinforcing bars crossing the interface as shown in Figure (2). Interface friction is calculated as the combined action of the aggregate interlock stresses, (υ_{ci}), and the lateral concrete stresses, (σ_{lat}), multiplied by the frictional coefficient, (μ):

$(\tau) = (\upsilon_{ci}) + (\mu).(\sigma_{lat})$ (1)

The lateral concrete stresses (σ_{lat}) are equal to the clamping forces (provided by adequately anchored stirrups). The friction coefficient (μ)is related to the imposed sliding. Hence, the total shear resistance mobilized is equal to

$V = (\tau)\cdot(A) + (n)\cdot(F_d)$ (2)

where(A) is the contact area and (n) the number of dowels crossing thesliding plane (stirrup legs).

The shear stress versus the slip constitutive relationship used to describe the shear transfer capacity across the overriding faces of a sliding crack was originally developed by Tassios&Vintzileou (1987) and amended recently by Vassilopoulou&Tassios (2003) as,

$\tau_u = 0.44 . (f_c^2 .\sigma_c)1/3$ (3)

Where

τ_u = maximum possible friction resistance

σ_c = total normal stress applied on the shear interface (compression)

f_c = compressive strength of the outside concrete layer

Using equation (1), the shear stress (τ) is given in terms of slip (s) as,

$\tau(s) = 1.14 . (s/s_u)^{1/3} . \tau_u$, when $(s/s_u) \leq 0.5$, and (4)

$\tau(s) = \tau_u . (0.81+0.19 . (s/s_u))$, when $(s/s_u) \geq 0.5$ (5)

Where the limit value for slip, s_u , is taken as 2 mm (for normal aggregate size and small $\sigma_c$values). As shown in Figure (3).

Similarly, the dowel resistance is given by Vintzileou&Tassios, (1987) as,

$F_d(s)= 0.5 . F_{du} . (s/s_{el})$, when $(F_d/ F_{du})\leq 0.5$, and (6)

$s=s_{el} + 1.76 .s_u . [(F_d/ F_{du})^4 - 0.5 . (F_d/ F_{du})^3]$, when $(F_d/ F_{du}) \geq 0.5$ (7)

$F_{du} = 1.3 . d_b^2.(f_{sy} . f_c)^{1/2}$, $s_{el} = 0.006 . d_b$ .and$s_u = 0.05 . d_b$ (8)

Where

d_b = bar diameter

f_{sy} = yield stress of reinforcement

s_{el} = slip mobilized at equilibrium

F_{du} = maximum value for dowel resistance

III. DIFFERENT ANALYSIS TECHNIQUES

Based on the above relationship concerning Shear Stress-Slip used to describe the shear interface behavior ,two method of analysis is introduced depending on the value of compression normal pressure at the interface (σ_c). The first method, based on average σ_c value. as pervious explained that the shear stress depend on the normal stress at the interface, Equation (3) explain the relationship between maximum shear stress and normal compression stress at the interface. Equation (4) and Equation (5) indicate the spring relationship between shear stress and shear slip assuming that maximum shear slip is 2 mm. Figure (3) explain that failure at interface occur if shear slip exceed 2 mm. Special non-linear spring elements are used based on unique shear-slip relationship assuming average (σ_c) to model the contact elements at interface between existing column and concrete jacket. The second method, based on accurate σ_c values, the normal stress at the interface may be different at each node of the interface depending on its nearby to load applied location at the interface, connected to shear links, confined by stirrups....etc. Based on different values of $\sigma_c$levels, variable shear-slip relationship is used with refer to Equations (3), (4) and (5). Special non-linear spring elements are used with multi relationship based on accurate $\sigma_c$level to model the interface area. In order to check the accuracy of the proposed method of analysis , many lab specimens studied by other researchers are modeled and the result outputs is verified with available experimental results as illustrated in the coming topics.

IV. AVAILABLE EXPERIMENTAL WORK

Gamal Esmail, (1988) present an experimental thesis in strengthening exterior and corner columns by concrete jackets. Two variables were studied in the research, jacket height relative to column height and the method of setting jacket stirrups. First parameter, height of the jacket were studied in two cases, case 1 height of jacket is less than height of original column by 5 cm which means that all loads are applied on the existing column only, case 2 height of jacket is equal to height of column so loads are distributed on both columns and jacket. Second parameter, method of fixing jacket stirrups were studied in three cases, case 1 stirrups of jacket are separated and not connected to the core, case 2 stirrups of the jacket is connected to the core by hooking its ends around corner vertical bars of the core, case 3 stirrups of the jacket were welded to the stirrups of the core. The reference original column has a cross section of 20 cm x20 cm, having longitudinal reinforcement of 4 Φ 13, and stirrups 5 Φ 8 \ m as shown in Figure (4-a). The concrete jacket has a thickness of 10 cm around the column side, for edge column the strengthened column cross section is 30 cm x 40 cm with longitudinal reinforcement of 14Φ 13, and stirrups 5 Φ 8 \ m as shown in Figure (4-b) , for corner columnthe strengthened column cross section is 30 cm x 30 cm with longitudinal reinforcement of 11 Φ 13, and stirrups 5 Φ 8 \ m as shown in Figure (4-c).

The crack patterns for most of the specimens starts at the top of the column along the core mainly and then followed by cracks at the top of jacket. Reading measurements are recorded and strains for both existing columns and concrete jackets are measured. The strain distribution was characterized by two zones. First zoneis the upper zone where tensile strains occurred with maximum values at the top neck and decreasing to zero value within a certain heights (twice the core breadth). Second zone is extended below the upper zone till the end of column where all strains are compressive strains with increasing values through a limited transition length at the upper part to nearly constant strain distribution values along the height of column. The formation of tensile strains at the upper part of the column and the formation of the transfer length was due to load eccentricity, as at early load stages all loads are applied at the original column and the participation of concert jacket in raising up loads from the existing core is small, so values of moments were relatively big with respect to the normal force which lead to tensile stresses at the top of column. The crack patterns and modes of failure for both edge and corner columns are illustrated in Figures (5).

V. CALIBRATION OF THE ANALYTICAL MODELING

5.1Analytical Model

The current study focuses on the finite element modeling of the column, jacket, and the surface of interface between both the original column and jacket, trying to analyze the complicated composite behavior between the column and the jacket, based on the available experimental data accompanied with verification for the analytical model. The original column, edge strengthened column and corner strengthened column tested by Gamal Esmail, (1988) and reviewed in section 4 were modeled using finite element to evaluate the nonlinear response of the strengthened columns.All of the specimens considered were modeled using commercially available finite element program, which offers a series of very robust nonlinear capabilities for analyses. The Solid element was used in modeling the three-dimensional behavior of concrete for both the column and the jacket. Solid element can be used with or without reinforcing bars (rebar). In the current study, the element without rebar was used. 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. Another Solid element was used for the bearing steel plates at the column ends. This element has eight nodes with three degrees of freedom at each node, translations in the nodal x, y, and z directions. A Link element was used to model steel reinforcement and shear connectors. This element is 3D element with uniaxial tension-compression capabilities and it has two nodes with three degrees of freedom, translations in the nodal x, y, and z directions. This element is also capable of plastic deformation. To model the surface of interface between the original column and the concrete jacket,Three Special Spring elements is used, these elements were connected node to node between the old core and the new jacket. This element is a unidirectional element with nonlinear generalized force-deflection capability. The longitudinal option is a uniaxial tension-compression element with up to three degrees of freedom at each node: translations in the nodal x, y, and z directions. No bending or torsion is considered. The element has large displacement capability. The interface elements allow for multi-linear element stiffness. This stiffness can be generated by force-displacement curve which is the input for the nonlinear spring elements. The First Spring is horizontal sliding spring elements represent the translational relationship between the column and the jacket in the horizontal direction. The SecondSpring ishorizontal normal spring elements represent the confinement relationship in horizontal direction as a result of normal pressure (σ_c) applied on the old core . The ThirdSpring is vertical spring element represent the relationship between the slip and shear transfer mechanism at the interface between the old core and the concrete jacket. Shear is transferred by means of friction through the vertical springs.The model mesh of the concrete, steel bars andstirrups areshown in Figures (6).The shear connectors used are same as jacket stirrups properties in which jacket stirrups are hooked by the vertical bar of the original column. The crack patterns at failure loads are shown in Figures (7) and the failure mechanism for the strengthened columns are shown in Figures (8)

5.2 Verification of Analytical Model

The analytical results are verified against the available experimental data to ensure the validity of the mathematical model. Figure (9)toFigure (13) showa comparison between experimental and analytical selected strain results for both the original column and the concrete jacket. The good agreement between the experimental and analytical results validates the used analytical model.

VI. PROPOSED FINITE ELEMENT MODELS

In order to achieve our goals in studying the effect of normal pressure on the behavior of columns strengthened by non-symmetric concrete jackets, eight models are analyzed in addition to the original column, the analytical groups are divided into two main groups. Group(I)is concerning about average σ_c(Normal Pressure) value, this group contains four models, corner column (2-sides jacket) , edge column from longside (3-sides jacket) , edge column from short side (3-sides jacket) and interior column (4-sides jacket). Group(II) is concerning about accurate σ_c(Normal Pressure) value, this group contains four models, corner column (2-sides jacket) , edge column from longside (3-sides jacket) , edge column from short side (3-sides jacket) and interior column (4-sides jacket). The thickness of the jacket, compressive strength, arrangement and number of stirrups are constants over all groups to study the main parameter which is the effect of σ_c(Normal Pressure) values on the structure behavior of the strengthened columns. Reference Original Column has a cross section (25cm x 60cm), having longitudinal reinforcement (8 Φ 16), and stirrups (10 Φ 8 \ m) at the top and bottom ends while stirrups (5 Φ 8 \ m) at middle as shown in Figure (14-a). The compressive strength of original column 150 kg/cm^2 while compressive strength of concrete jacket 350 kg/cm^2. The steel used for longitudinal bars and shear connectors is high tensile strength (36/52) with F_y= 3600 kg/cm^2, while steel used for stirrups is mild steel (24/37) with F_y= 2400 kg/cm^2. The concrete jacket has a thickness 20 cm around the column side. CornerColumn (2-Sided Jacket) the strengthened column cross section is 45 cm x 80 cm with total longitudinal reinforcement of 20 Φ 16, and stirrups spacing same as original column stirrups distribution as shown in Figure (14-b). Edge Column with long side at edge(3-Sided Jacket)the strengthened column cross section is 45 cm x 100 cm with total longitudinal reinforcement of 24 Φ 16, and stirrups spacing same as original column stirrups distribution as shown in Figure (14-c). Edge Column withshort sideat edge (3-Sided Jacket)the strengthened column cross section is 65 cm x 80 cm with total longitudinal reinforcement of 28 Φ 16, and stirrups spacing same as original column stirrups distribution as shown in Figure (14-d). Interior Column (4-Sided Jacket)the strengthened column cross section is 65 cm x 100 cm with total longitudinal reinforcement of 32 Φ 16, and stirrups spacing same as original column stirrups distribution as shown in Figure (14-e). Shear connectors with diameter 12 mm and embedded length 7.5 cm inside original columnare staggered distributed and spaced same as original column and jacket stirrups as of connecting both stirrups.The model mesh of the concrete, steel bars, stirrups and shear connectors areshown in Figures (15).The contact elements were connected node to node between the original column and the jacket at the surface of interface.The crack patterns at failure loads are shown in Figures (16) and the failure mechanism for the strengthened columns are shown in Figures (17).

VII. ANALYTICAL RESULTS AND DISCUSSION

The effect of normal pressure (σ_c) on the structure behavior of jacketed column could be summarized as follows:-

7.1Interior Column (4-sides Jacket)

At failure load, the maximum shear stress extracted from vertical springs for models of (Group I) is 20.1 kg/cm^2, while for (Group II) 56 kg/cm^2 as indicated in Figure (18-a). The maximum normal pressure extracted from horizontal springs of (Group I) is 92 kg/cm^2, while for (Group II) 130.7 kg/cm^2 as indicated in Figure (18-b) The maximum shear slip occur at contact surface of (Group I) is 1.48 mm, while for (Group II) is 1.21 mm indicated in Figure (18-c).

7.2.Long Side Edge Column (3-sides Jacket)

At failure load, the maximum shear stress extracted from vertical springs for models of (Group I) is 12.66 kg/cm2, while for (Group II) 39.85 kg/cm2 as indicated in Figure (19-a). The maximum normal pressure extracted from horizontal springs of (Group I) is 57.84 kg/cm2, while for (Group II) 94kg/cm2 as indicated in Figure (19-b). The maximum shear slip occur at contact surface of (Group I) is 1.17 mm, while for (Group II) is 1.084 mm indicated in Figure (19-c).

7.3Short Side Edge Column (3-sides Jacket)

At failure load, the maximum shear stress extracted from vertical springs for models of (Group I) is 12.44 kg/cm2, while for (Group II) 34.22 kg/cm2 as indicated in Figure (20-a). The maximum normal pressure extracted from horizontal springs of (Group I) is 59.4 kg/cm2, while for (Group II) 62.3kg/cm2 as indicated in Figure (20-b). The maximum shear slip occur at contact surface of (Group I) is 1.15 mm, while for (Group II) is 0.94 mm indicated in Figure (20-c).

7.4Corner Column (2-sides Jacket)

At failure load, the maximum shear stress extracted from vertical springs for models of (Group I) is 12.68 kg/cm2, while for (Group II) 37.3kg/cm2 as indicated in Figure (21-a). The maximum normal pressure extracted from horizontal springs of (Group I) is 49 kg/cm2, while for (Group II) 76.4kg/cm2 as indicated in Figure (21-b). The maximum shear slip occur at contact surface of (Group I) is 1.35 mm, while for (Group II) is 1.22 mm indicated in Figure (21-c).

VIII. CONCLUSIONS

A number of main behavior patterns can be deduced from the results of the parametric study described in this chapter. A number of important observations can be deduced from the results pertaining to the different types of models used for simulation of the interactive action of the column-jacket system.

1- Regarding the analysis technique used, it can be seen from the results from Figures (18) to Figures (21) that there is a large difference in results between the models (Group I) utilizing an average value for (σc), and the more sophisticated models (Group II), where the concrete friction relations were varied at different areas of the model to reflect the variation of the normal stress (σc) between the jacket and column surfaces.
2- The above observation indicates that the models (Group I), utilizing average (σc) values are not suitable for accurate determination of jacket-column interactive behavior. Results of the current study indicate that the more sophisticated models (Group II), where variable ranges of (σc) are identified and corresponding shear stress relations were used, can provide more accurate results, and that the difference in results can be highly significant.
3- The advantage of using the models (Group II), is more pronounced in case of 3-sided jackets, where the long side of the column is at the building edge and in case of corner column 2-sided jackets, as shown in Figures (19) and Figures (21) respectively , where for 3-sided jacket the maximum shear stress extracted from vertical springs for models of (Group I) is 12.66 kg/cm^2, while for (Group II) is 39.85 kg/cm^2 (more than 3 times). The maximum normal pressure extracted from horizontal springs of (Group I) is 57.84 kg/cm^2, while for (Group II) is 94 kg/cm^2. The maximum shear slip occur at contact surface of (Group I) is 1.17 mm, while for (Group II) is 1.084 mm. Moreover for 2-sided jacket the maximum shear stress extracted from vertical springs for models of (Group I) is 12.68 kg/cm^2, while for (Group II) is 37.3 kg/cm^2. The maximum normal pressure extracted from horizontal springs of (Group I) is 49 kg/cm^2, while for (Group II) 76.4 kg/cm^2. The maximum shear slip occur at contact surface of (Group I) is 1.35 mm, while for (Group II) is 1.22 mm
4- This phenomenon can be explained by the fact that the variation in normal stress between the column surface and the jacket surface varies greatly in the above cases, resulting in an almost compete loss of

contact at large areas of the interface, thus making it essential to use models of (Group II), in order to predict the actual behavior of the column-jacket system.

5- It is important to point out here, that the above results indicate that models often used by researchers for column jacket interaction, utilizing full bond are clearly very far away from the accurate simulation of the complex behavior. these models do not even reach the accuracy level of model (Group I), let alone the more sophisticated and more accurate (Group II),model results.

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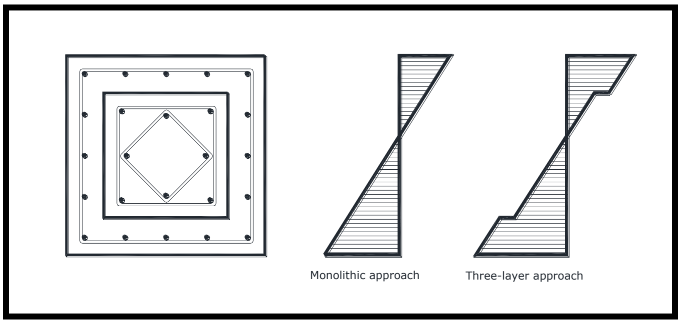


Figure (1) Strain Profile assumed by "Thermou, Pantazopoulou, Elnashai, 2006"

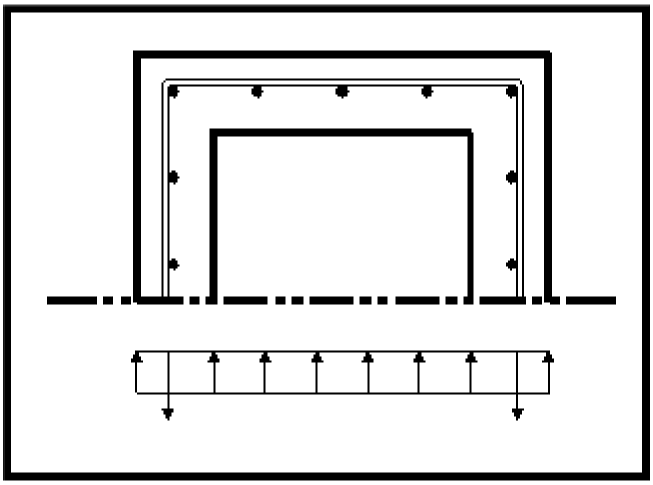


Figure (2) Clamping Stresses assumed by "Thermou, Pantazopoulou, Elnashai, 2006"

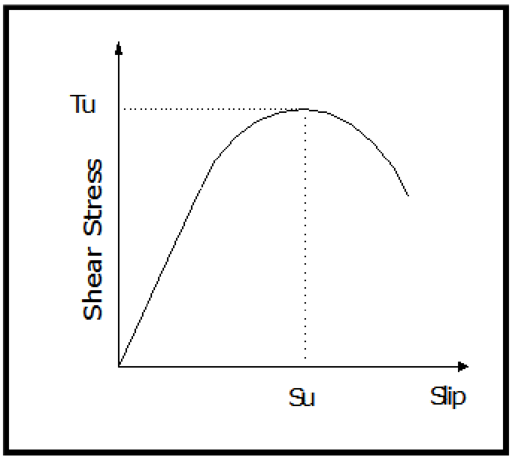
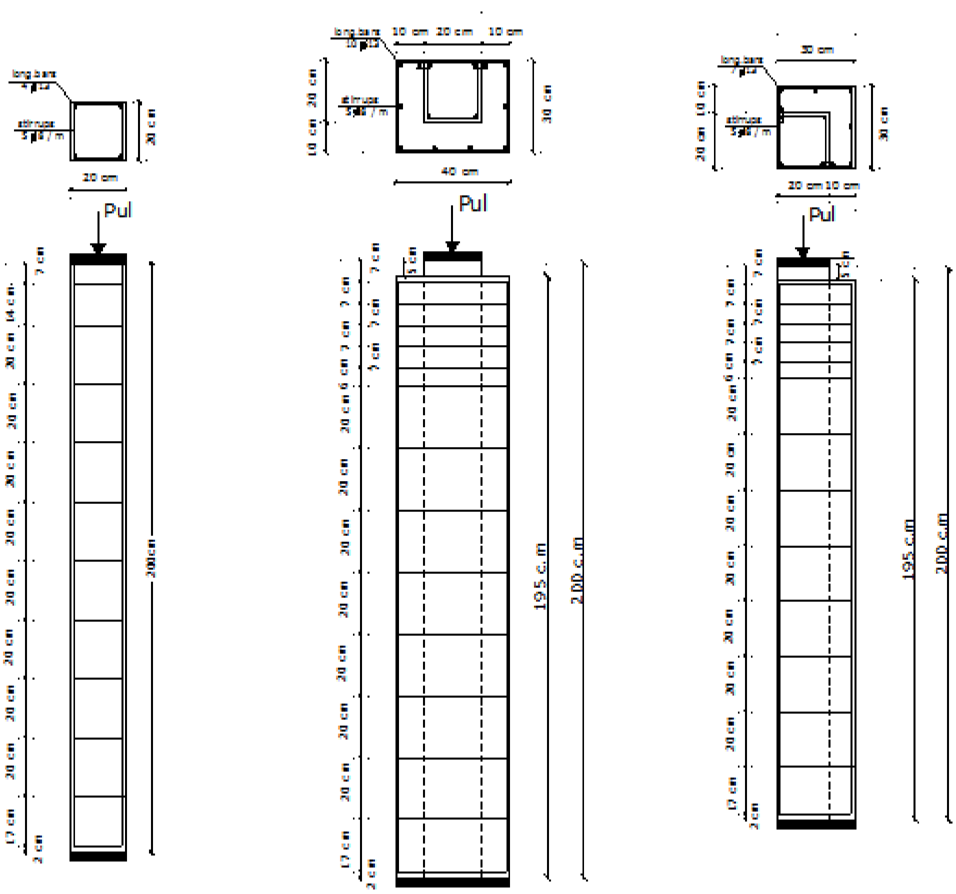
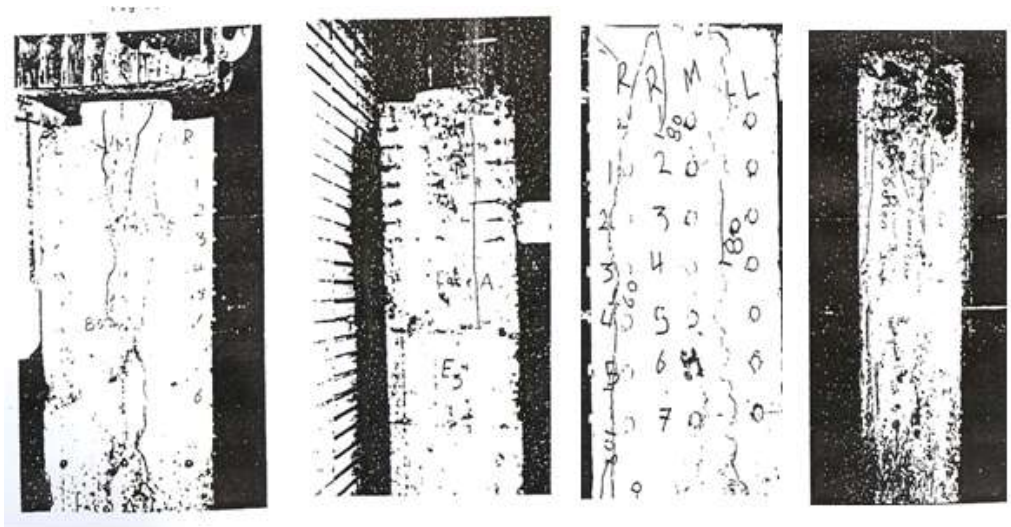


Figure (2) Shear Stress-Slip Relationship assumed by "Thermou, Pantazopoulou, Elnashai, 2006"



(a) (b) (c)

Figure (3) Dimension Details for Strengthened Columns Done by " Gamal Esmail, (1988)", where (a) Original Column, (b) Edge Strengthened Column and (c) Corner Strengthened Column



(a) (b) (c) (d)

Figures (4), Crack Patterns and Tensile Failure for Columns Done by " Gamal Esmail, (1988)", where (a , b) for Edge Column and (c , d) for Corner Column.

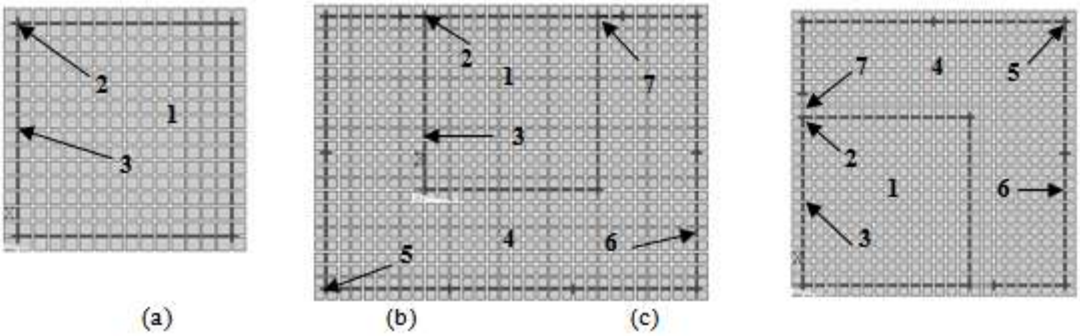


Figure (5) Plan Shows Different Elements of Strengthened Column where (a) Original Column, (b) Edge Strengthened Column and (c) Corner Strengthened Column

Where : 1- Concrete Original Column, 2- Vertical Reinforcement for OriginalColumn, 3-Stirrups for Original Column, 4-Concrete Jacket, 5-Vertical Reinforcement for Concrete Jacket, 6-Stirrups for Concrete Jacket, and 7- Shear Connectors.

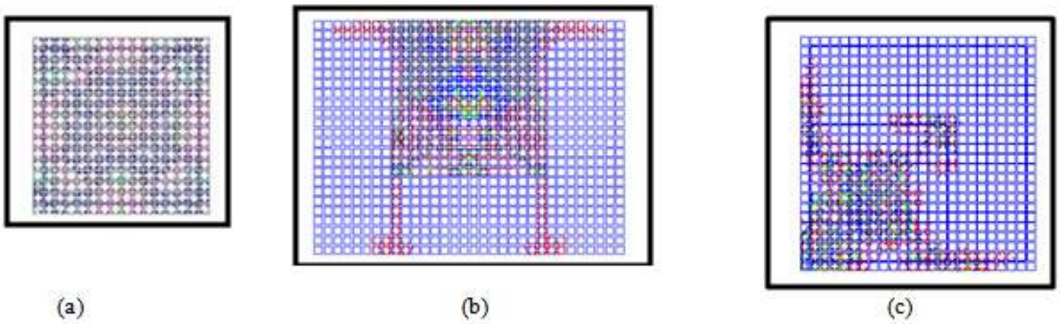


Figure (6) Crack Patterns ofStrengthened Column at Failure Load where (a) Original Column, (b) Edge Strengthened Column and (c) Corner Strengthened Column

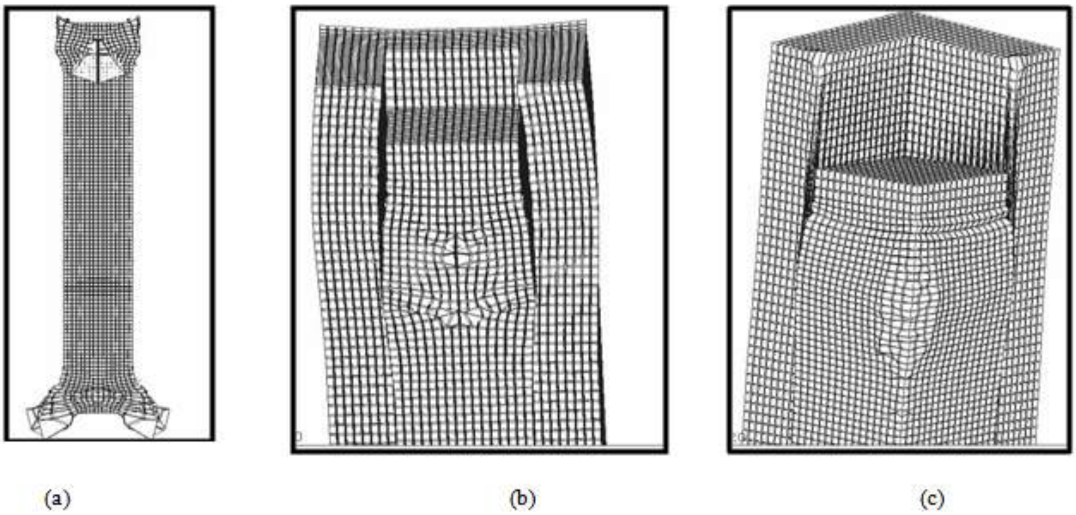


Figure (7) Failure Mechanism of Strengthened Column at Failure Load where (a) Original Column, (b) Edge Strengthened Column and (c) Corner Strengthened Column

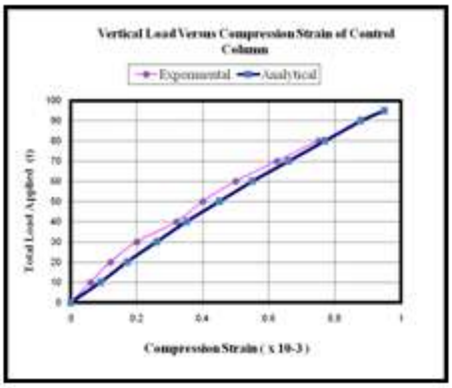


Figure (9) Compression Strain of Old ControlColumn

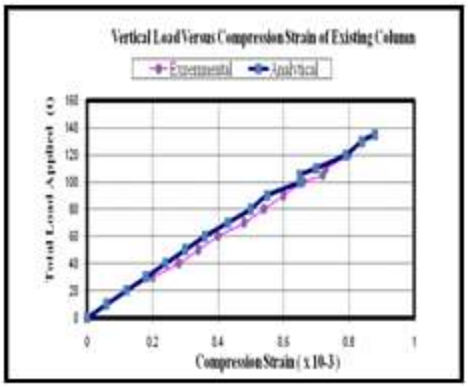


Figure (10) Compression Strain of Core for EdgeStrengthened Column

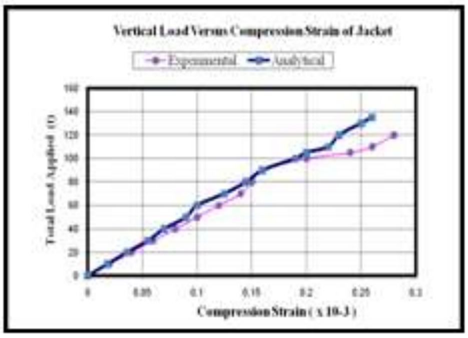


Figure (11) Compression Strain ofJacket for EdgeStrengthened Column.

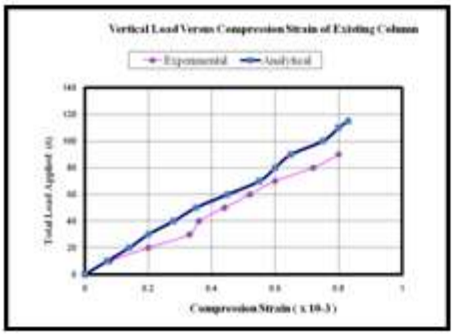


Figure (13) Compression Strain ofCore forCornerStrengthened Column

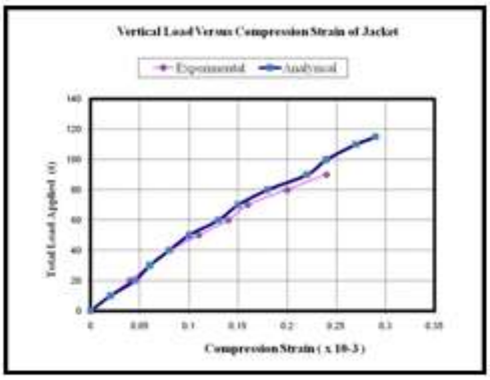
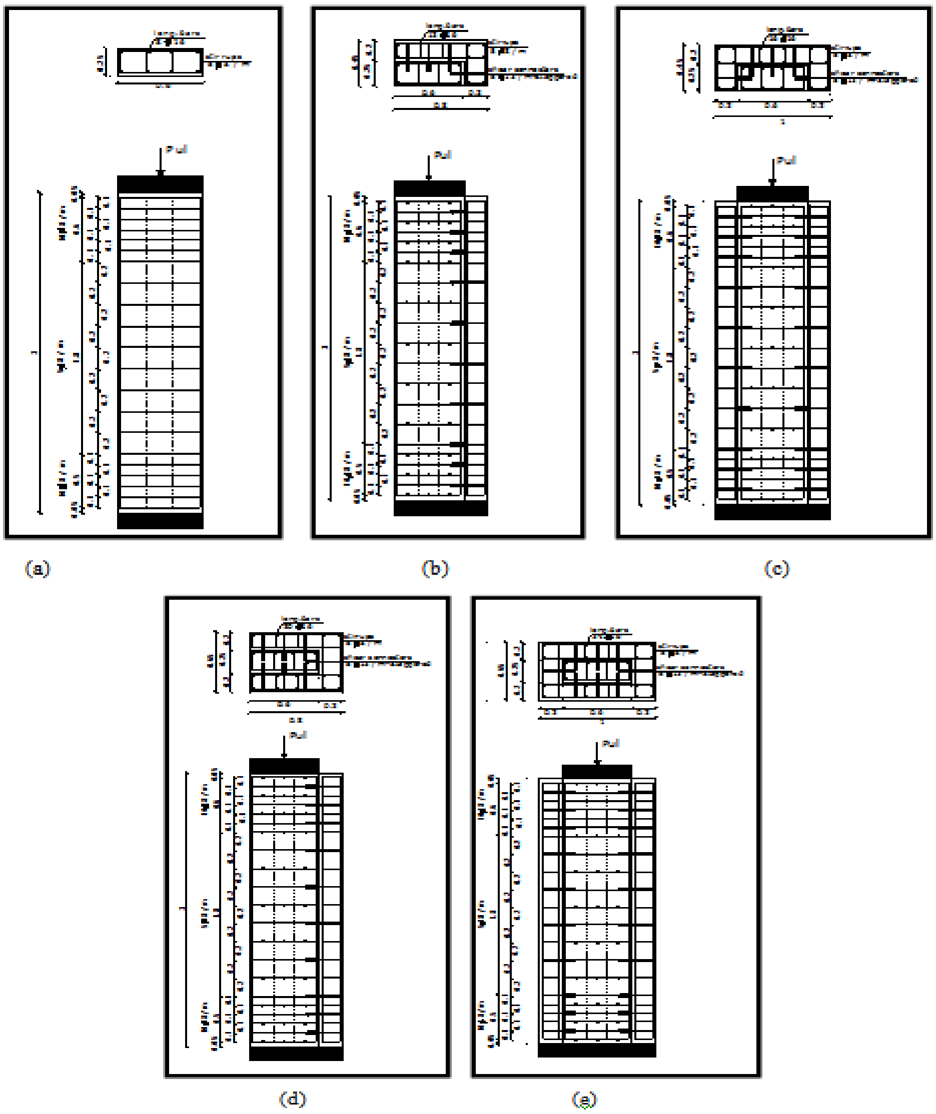
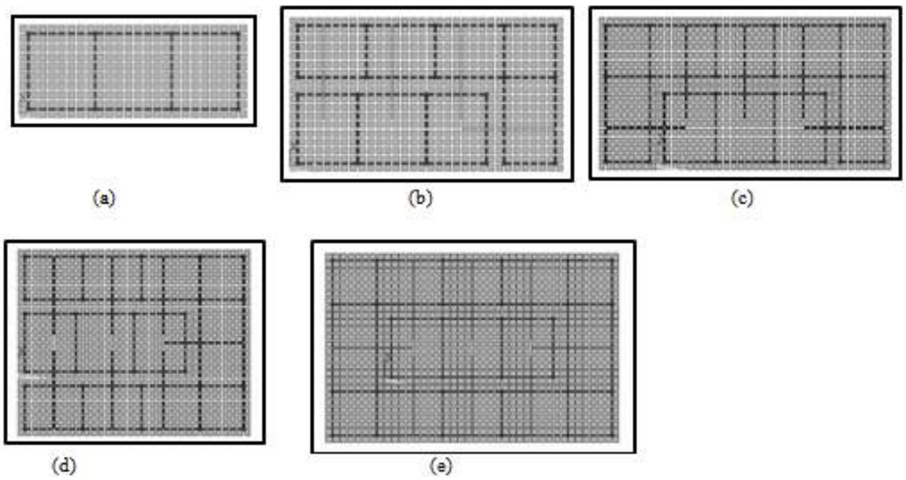


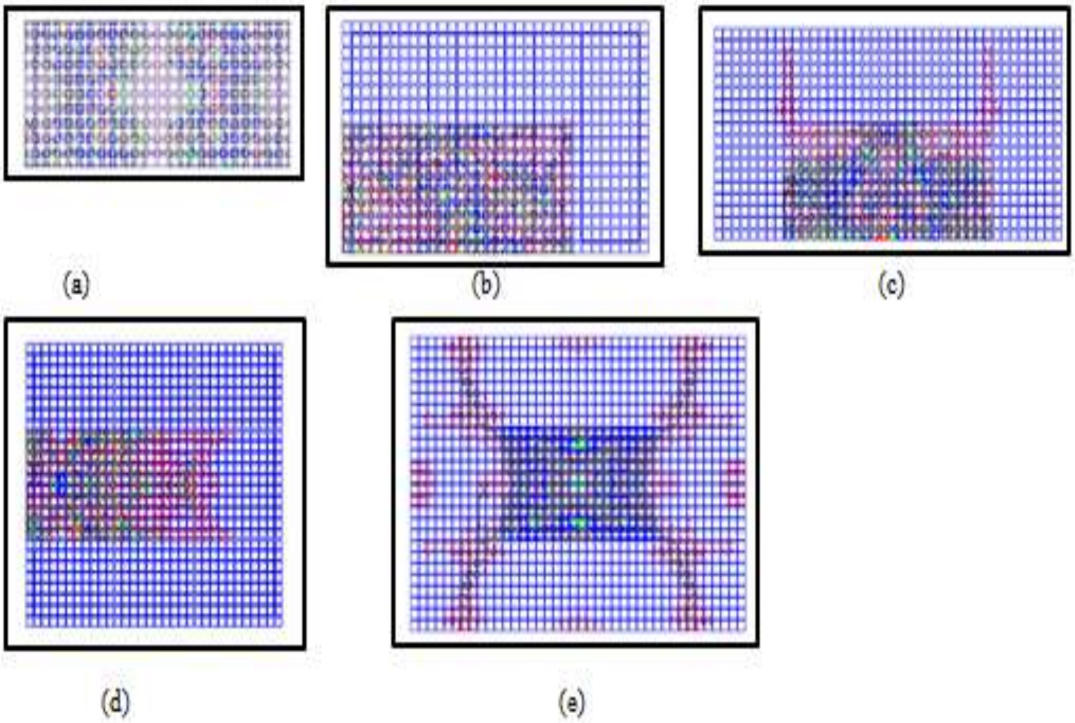
Figure (12) Compression Strain ofJacket forCornerStrengthened Column



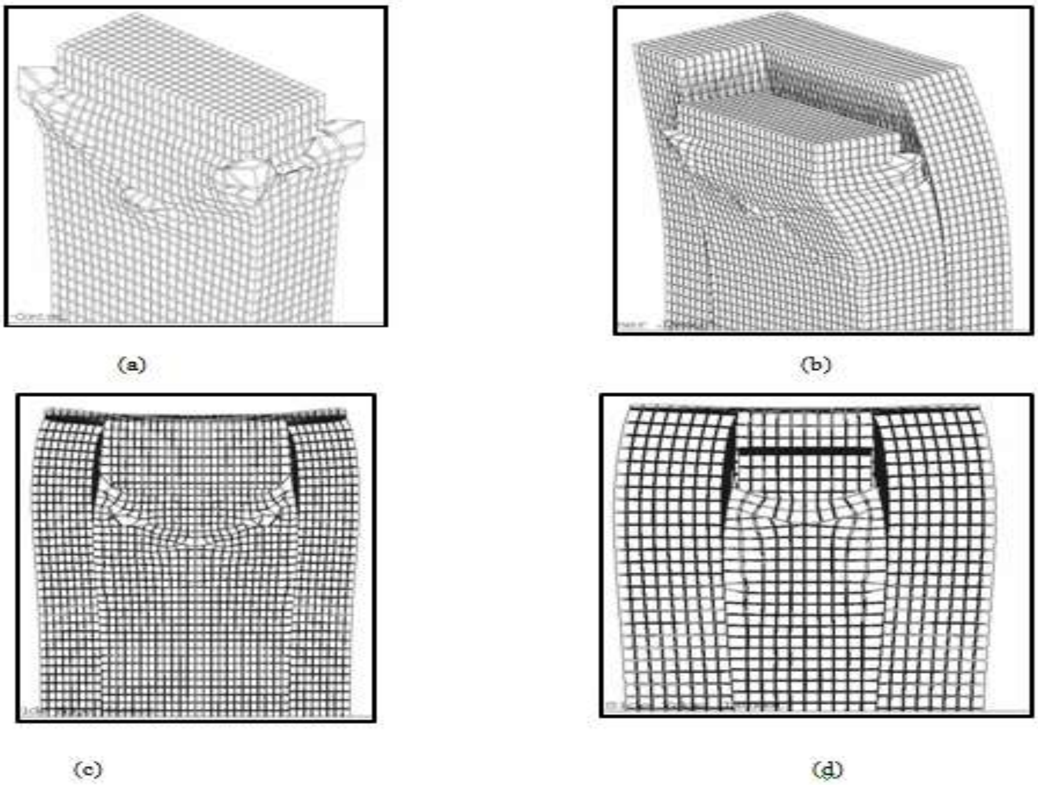
Figures (8) Dimension Details for Strengthened Column where (a) Original Column, (b) Corner Column, (c) Edge Column (Long Side at Edge), (d) Edge Column (Short Side at Edge) and (e) Interior Column

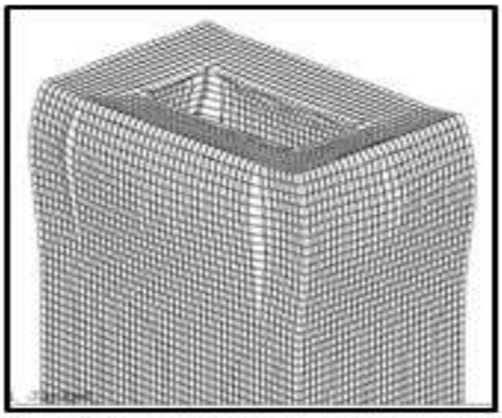


Figures (9) Plan Shows Different Elements of Strengthened Column where (a) Original Column, (b) Corner Column , (c) Edge Column Long Side at Edge, (d) Edge Column Short Side at Edge and (e) Interior Column



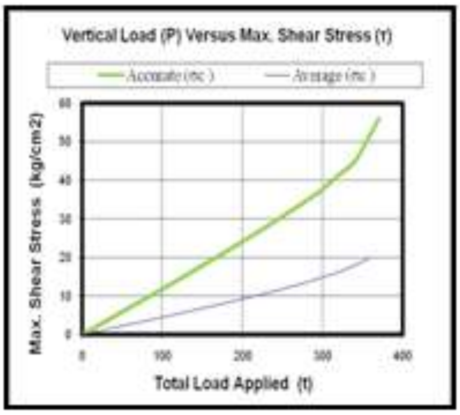
Figures (10) Crack Patterns ofStrengthened Column at Failure Load where (a) Original Column, (b) Corner Column , (c) Edge Column Long Side at Edge, (d) Edge Column Short Side at Edge and (e) Interior Column



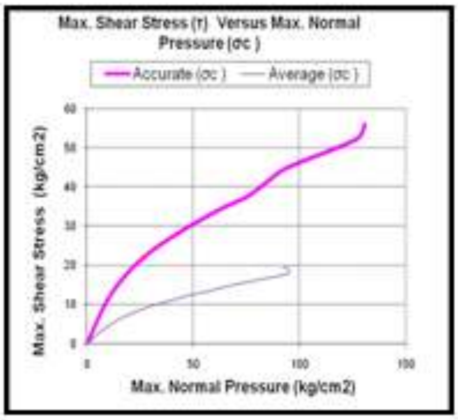


(e)

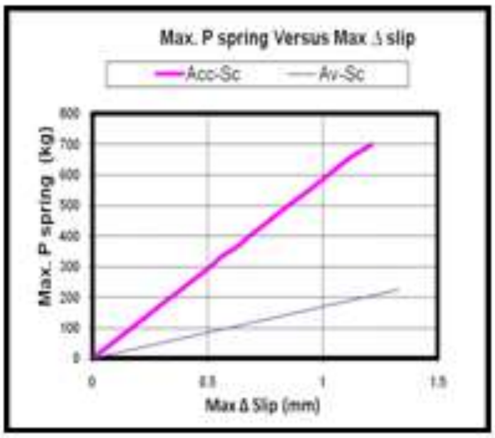
Figures (17) Failure Mechanism of Strengthened Column at Failure Load where (a) Original Column, (b) Corner Column , (c) Edge Column Long Side at Edge, (d) Edge Column Short Side at Edge and (e) Interior Column



(a)

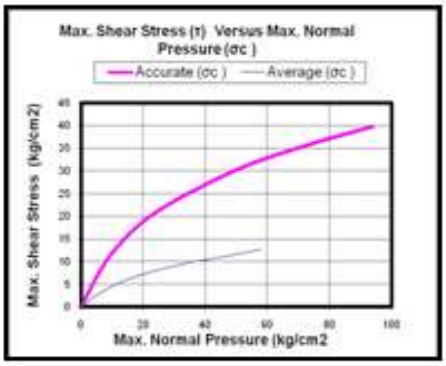


(b)

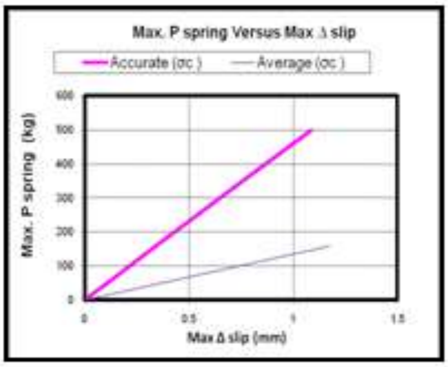


(c)

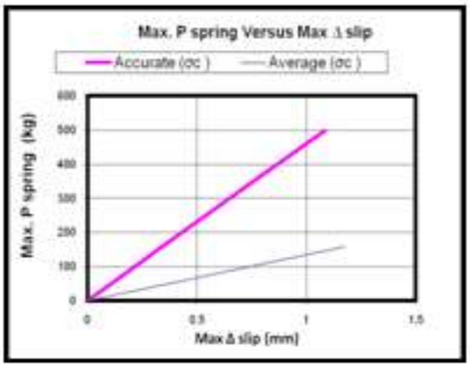
Figures (18) Effect of Normal Pressure on Interior Columns where (a) Maximum Shear Stress at the Interface, (b) Maximum Shear Stress Versus Maximum Normal Pressure at the Interface and (c)Maximum Force in Vertical Springs Versus Maximum Slip (Δ) at the Interface.



(a)

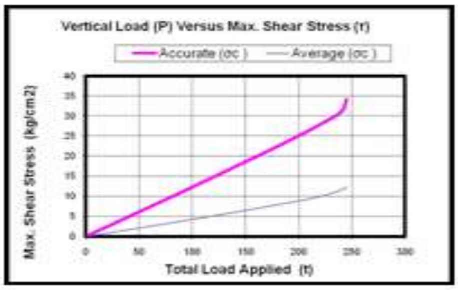


(b)



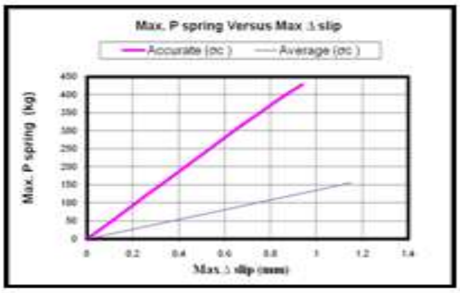
(c)

Fig**ures (19**) Effect of Normal Pressure on Long Side Edge Columns where (a) Maximum Shear Stress at the Interface, (b) Maximum Shear Stress Versus Maximum Normal Pressure at the Interface and (c) Maximum Force in Vertical Springs Versus Maximum Slip (Δ) at the Interface.



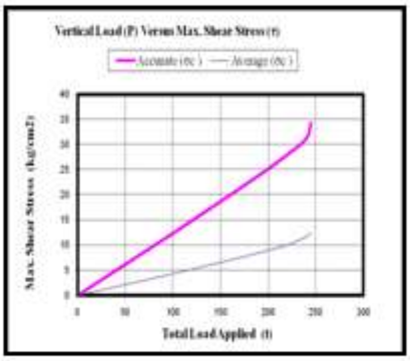
(a)

(b)

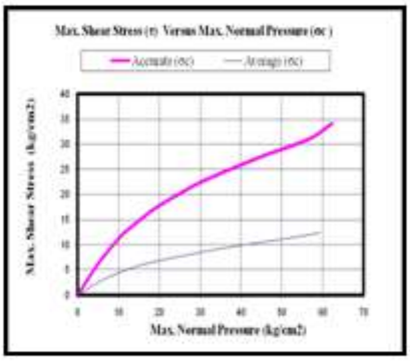


(c)

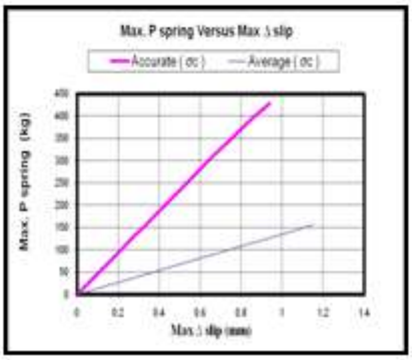
Fig**ures (20)** Effect of Normal Pressure on Short Side Edge Columns where (a) Maximum Shear Stress at the Interface, (b) Maximum Shear Stress Versus Maximum Normal Pressure at the Interface and (c) Maximum Force in Vertical Springs Versus Maximum Slip (Δ) at the Interface



(a)



(b)



Figures (21) Effect of Normal Pressure on CornerColumns where (a) Maximum Shear Stress at the Interface, (c (b) Maximum Shear Stress Versus Maximum Normal Pressure at the Interface and (c) Maximum Force in Vertical Springs Versus Maximum Slip (Δ) at the Interface

Mohamed A.Al-Azzouny" Effect of Contact Surface Normal Pressure on the Structural Behavior of Non-Symmetric Concrete Column Jackets" The International Journal of Engineering and Science (IJES), 8.2 (2019): 56-70