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A NUMERICAL INVESTIGATION FOR ANALYSING REINFORCED CONCRETE COLUMNS STRENGTHENED WITH SHOTCRETE

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It’s clearly obvious that the use of computer programs, especially finite element method in structural analysis, gained a distinguished popularity in the presence of expensive hard experimental works in the field of concrete structures, modeling with a proper finite element program in idealization the considered structure is greatly needed. Today, the use of shotcrete for strengthen of the concrete structures in large scale is increasing due to it's advantage, the properties and the factors effect on it, has been discussed. This work presents an theoretically investigation concerning the efficiency for the reinforced concrete columns Four Columns (20x20x100) were tested under compression loading and had the same cross section of dimensions and main longitudinal reinforcement distribution and cross sections for all columns. (Usama 2002) made four Columns (20x20x100) were tested under compression loading and The deformations were measured by linear variable differential transducers LVDT’s, two transducers in both sides to measure the longitudinal deformations (LO) and three in the lateral direction to measure the lateral deformations: the first (EQ1) was near the end of the column, the second (EQ2) was in the middle and the third (EQ3) was in the middle between the fist and the secondhad the same cross section of dimensions and main longitudinal reinforcement distribution and cross sections for all columns. These Columns had four deformed longitudinal steel bars 10 mm diameter. New formula in the three dimensional for numerical modeling to compare between strengthening columns [5] was produced by the author.

KEYWORDS: *Shotcrete (SpB); strengthen; numerical modeling.*

1. INTRODUCTION

For studying the subject of this paper, the difficulties lie in the selection of the parameters, which are mainly responsible for the overall behavior and failure, respectively. Thus, the aim is to define a model which is developed with respect to a successful reduction of the physical problem. The main characteristics of the composite materials appear at the interactive compound of the individual components. Whereupon, it is impossible to know exactly the inhomogeneity in each constituent. Models for the description of failure can be developed based on micromechanic and macromechanic analysis.

The study of these effects requires highly sophisticated models, developed in the field of material scientists. Here, a great importance is attached to use measurable, mechanical values in the respective material models. The distinction between the properties of these materials is governed by the physical properties of the phases and the phase interface geometry. Considering composites consisting of phases with three-dimensional internal geometries embeded in the second phase, the material is denoted as particulate composite.

2. MODELLING-REBAR ELEMENT

The discrete reinforcrement modeling is used to characterize composites with large, distinct reinforcrements. a homogeneous displacement field. Futhermore. it is assumed that the plane of reinforcement is perpendicular to the element faces. The conceptual illustratration is shown in **Figure 1**.

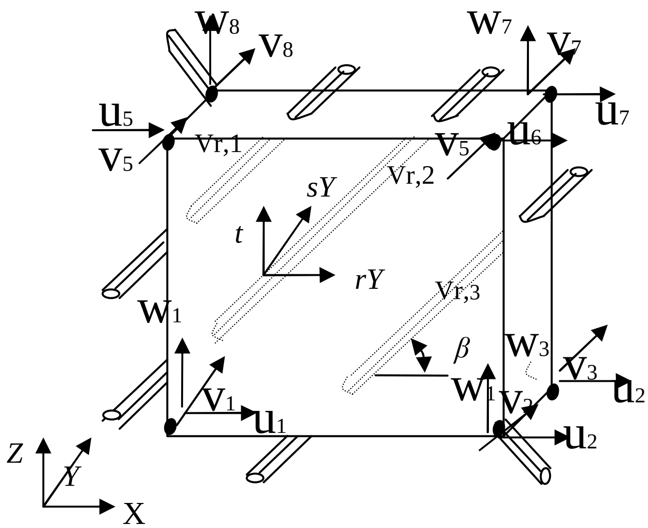


Fig. 1: Three dimensional solid with embedded, skew rebar.

The element stiffness matrix K^e is represented by equation (1)

$$K^e = \int_{Ve} B_m^T D_m B_m \, .dV + \int_{Vr} B_m^T D_r B_m \, .dV \qquad (1)$$

where

B*m* = strain displacement matrix for the (3D) parent element
D*m* = elasticiy matrix of the matrix
Ve = element volume
D*r* = elasticiy matrix of the rebar with respect to local coordinares

In the above equation (1) it can be seen that the strain –displacement matrix B_m of the rebar is expressed by the same Shape Function as for the matrix portion.

By using the eight points Gauss numerical integration (n=8) in the r, s, and z direction, the following matrix [H] contain the interpolation function *hij*=1,…….,8 and is defined as :

$$[H]=\begin{pmatrix} h_1 & 0 & 0 & h_2 & 0 & 0 & h_3 & 0 & 0 & h_4 & 0 & 0 & h_5 & 0 & 0 & h_6 & 0 & 0 & h_7 & 0 & 0 & h_8 & 0 & 0 \\ 0 & h_1 & 0 & 0 & h_2 & 0 & 0 & h_3 & 0 & 0 & h_4 & 0 & 0 & h_5 & 0 & 0 & h_6 & 0 & 0 & h_7 & 0 & 0 & h_8 & 0 \\ 0 & 0 & h_1 & 0 & 0 & h_2 & 0 & 0 & h_3 & 0 & 0 & h_4 & 0 & 0 & h_5 & 0 & 0 & h_6 & 0 & 0 & h_7 & 0 & 0 & h_8 \end{pmatrix}$$

The strains in both domains of the element and rebar, are referenced to the local coordinate (x,y,z), whereas the displacements are axpressed in terms of natural coordinate systems (r,s,t) derivatives and the (x,y,z) derivatives is of the form [4]

$$\partial/\partial r = J\,\partial/\partial x$$

where ***J*** is Jacobian operator.

The elements of strain-displacement transformation matrix Bm are affected by the Jacobian operator as

$$\mathbf{[B_m] = [L_m]\ [H]}$$

where L_m is the differential operator representing small deformation under conditions of stress [3]

$$[\,L_m\,] = \begin{pmatrix} \partial/\partial x & 0 & 0 \\ 0 & \partial/\partial y & 0 \\ 0 & 0 & \partial/\partial z \\ \partial/\partial x & \partial/\partial y & 0 \\ \partial/\partial z & 0 & \partial/\partial x \\ 0 & \partial/\partial z & \partial/\partial y \end{pmatrix}$$

For a smeard modeling of the reinforcement, the numerical integration of the element stiffness matrix equals the terms as shwon in equation (2), [3].

$$K^e = \sum_{i=1}^{GPm} B^T_{m,i} D_{m,i} B_{m,i}\,.det\,J.\alpha_i + \sum_{i=1}^{GPr} B^T_{m,i} T^T_{\beta,i} D_{r,i} T_{\beta,i} B_{m,i} V_r \qquad (2)$$

where

Gpm = number of Gauss points associated to the matrix portion
detJ = Jacobian determinant
α_i = weight of Gauss point
GPr = number of Gauss points associated to the rebar

$T\beta$ = transformation matrix from the local to the natural axis
Vr = rebar volume within an element

The skew reinforcement orientation is merely taken into account by the incorporation of transformation matrix $T\beta$.

Considering a discrete modeling of reinforcement, the numerical integration of element stiffness matrix reads

$$K^e = \sum_{i=1}^{GPm} B_{m,i}^T D_{m,i} B_{m,i} . det J . \alpha_i + \sum_{j=1}^{nr} \sum_{i=1}^{GPr} B_{m,i}^T T_{\beta,i}^T D_{r,i} T_{\beta,i} B_{m,i} . l_{r,i} . A_{r,i} \quad (3)$$

where
nr = number of rebars
lr,i = length of the i-th rebar
Ar,i = cross-sectional area of the i-th rebar

From equation (3) it is obvious, that the length lr,i of each rebar has to be estimated. Thereby, the intersection points of rebars with the element faces are detected. Accordingly, the user has to map these points back to global coordinates, or to give the isoparametric coordinates back as input to the FE-computation [1], [2].

With the knowledge of the intersection points, the location of the integration points associated to the rebars can be detemined. Consequently, the element stiffness matrix in equation (3) can be evaluated.

3. MODELING OF CONCRETE

Advanced methods for the design of concrete structures have placed increasing emphasis on the stress-strain behavior of concrete subjected to bi-axial stresses. Under such state of stress concrete exhibits not only a different stress-strain behavior but also varying strength characteristics. The considered material constitutive relations are those for orthotropic one. These relations are modified when failure is detected to represent the gradual decay of strength due to the onset of failure. The failure includes either crushing and for cracking reduced the elascticity modules of concrete by half precentage of elastic modules.

4. EXPERIMENTAL PROGRAM

In order to verify the analytical results obtained by the finite element analysis , a group of seven Columns (20x20x100) were tested under compression vertically loading and had the same cross section of dimensions and main longitudinal plain and fibrous concrete walls are adopted. This experimental work tested by the auther [5] aimed to compare between the different strengthening systems.

5. COMPARISON BETWEEN THERETICAL AND EXPERIMENTAL PROGRAM

Axial stress-axial strain and axial stress-lateral strain curves for columns are shown in **Figs. 2** to **9**.

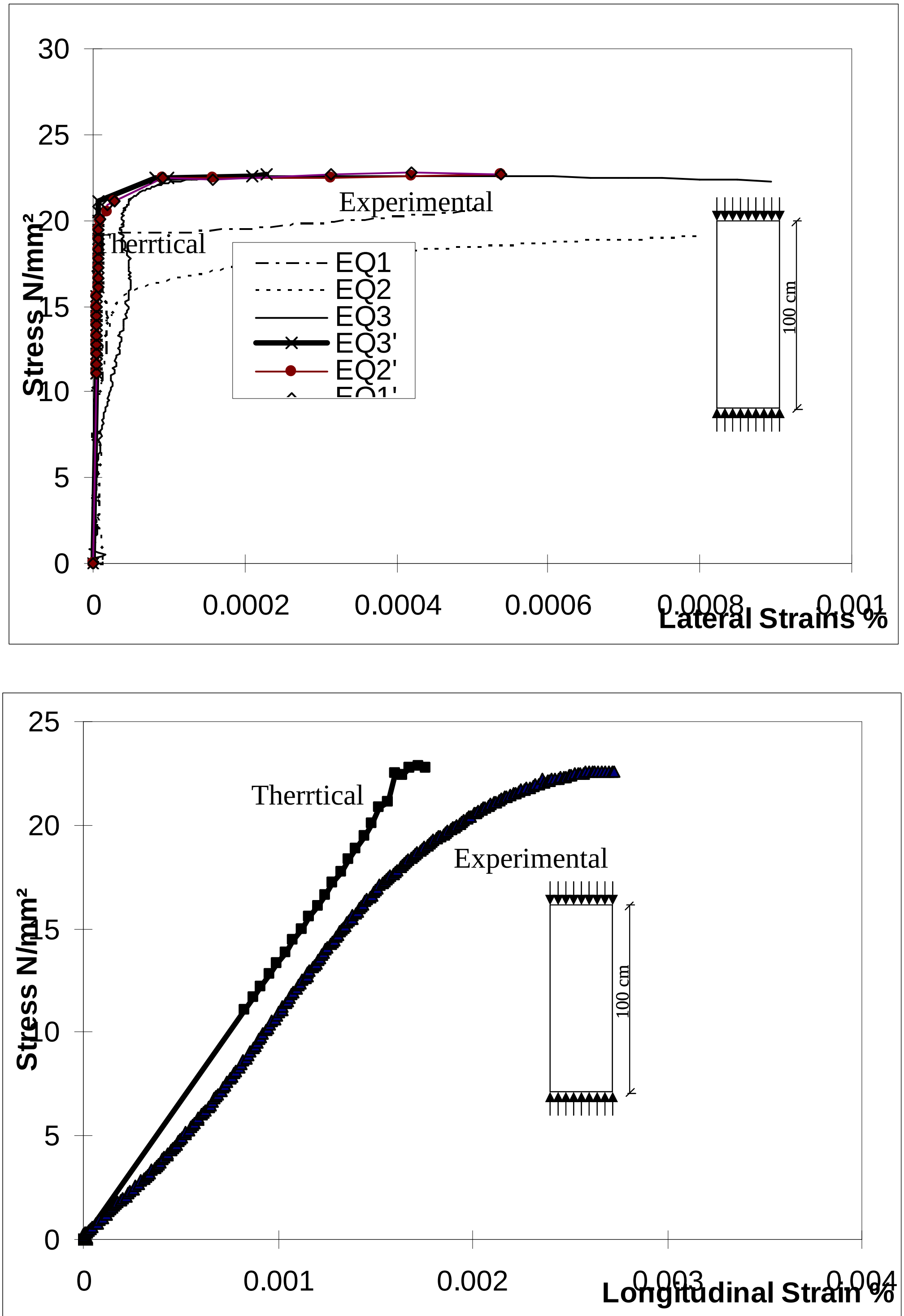
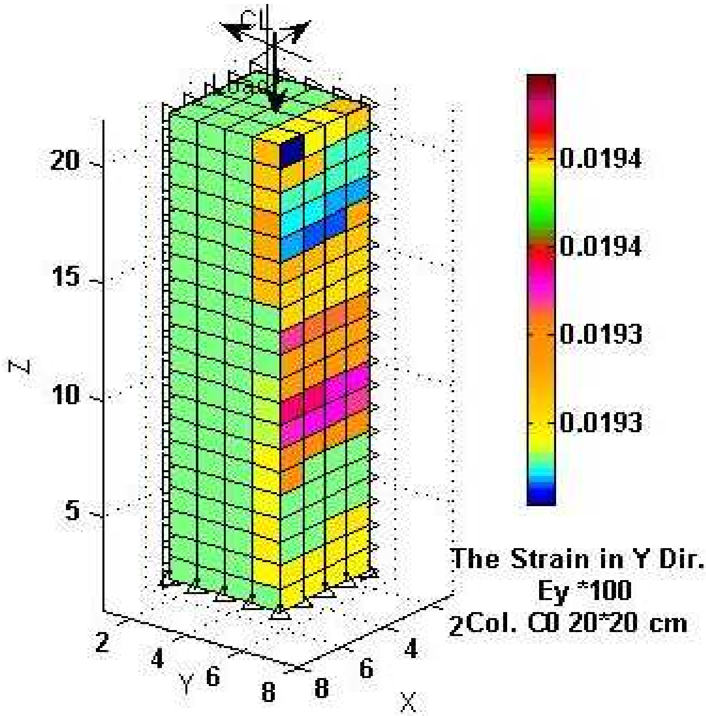
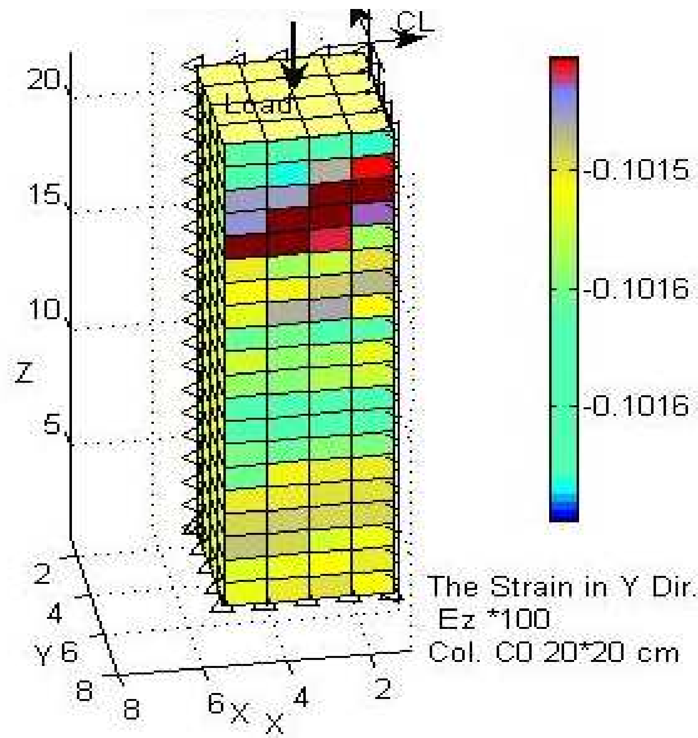


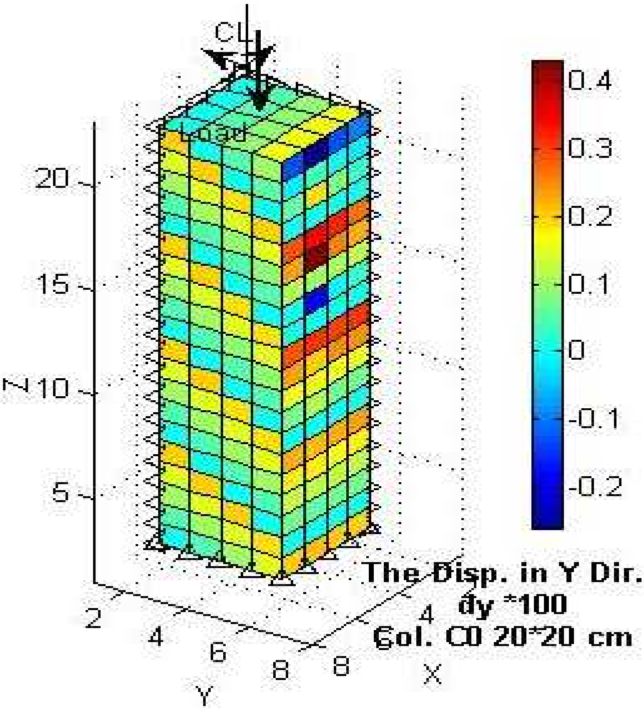
Fig. 2: Behaviour of column specimen **C**o without strengthening under axial load [5].



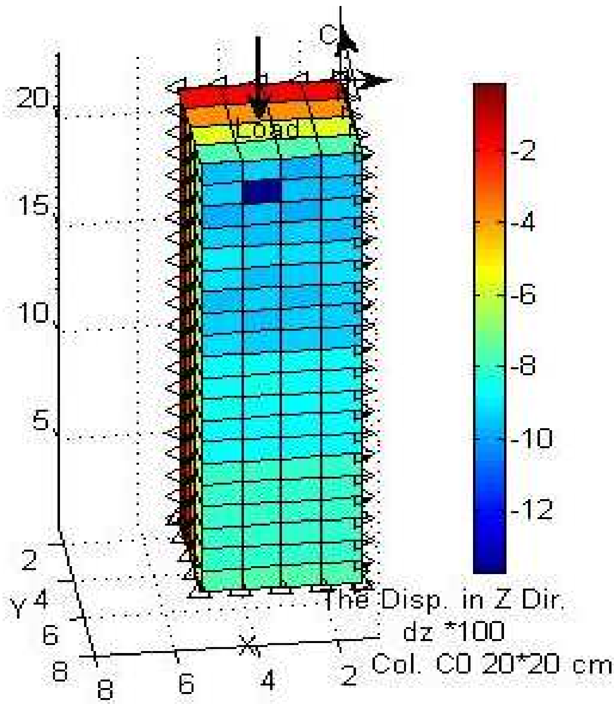
Strain in Y Direction for C0



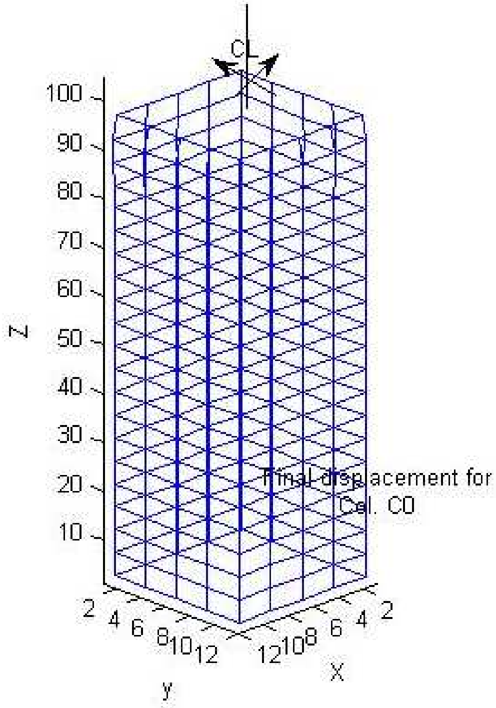
Strain in Z Direction for C0



Displacement in Y Direction for C0

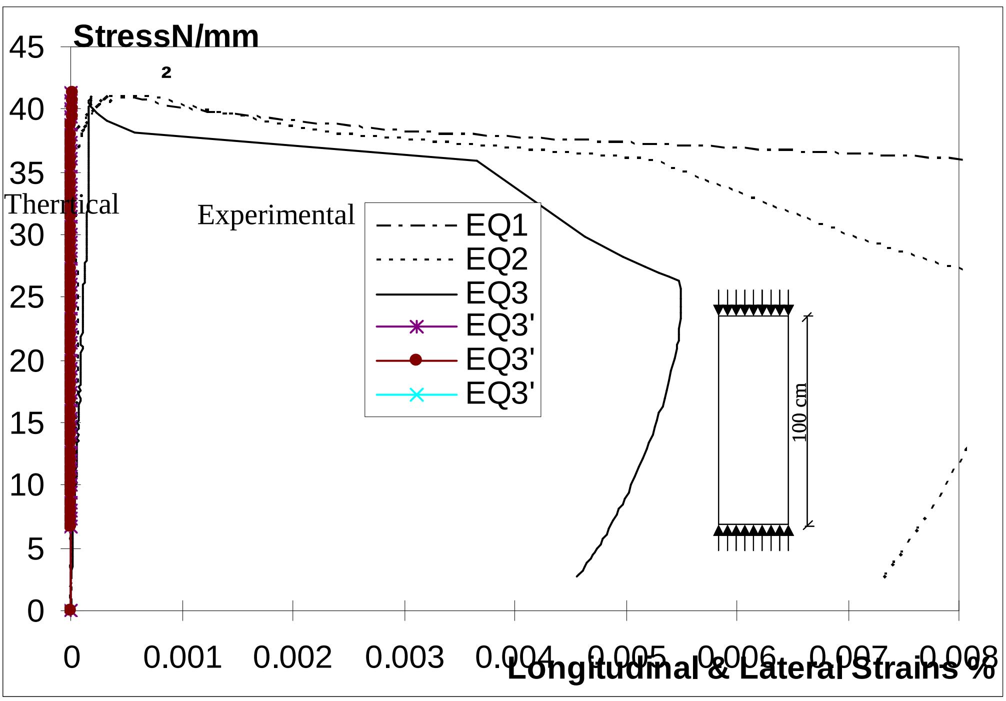


Displacement in Z Direction for C0



Final Deformations for C0

Fig. 3: Behaviour of column specimen C0 with [USA] program.



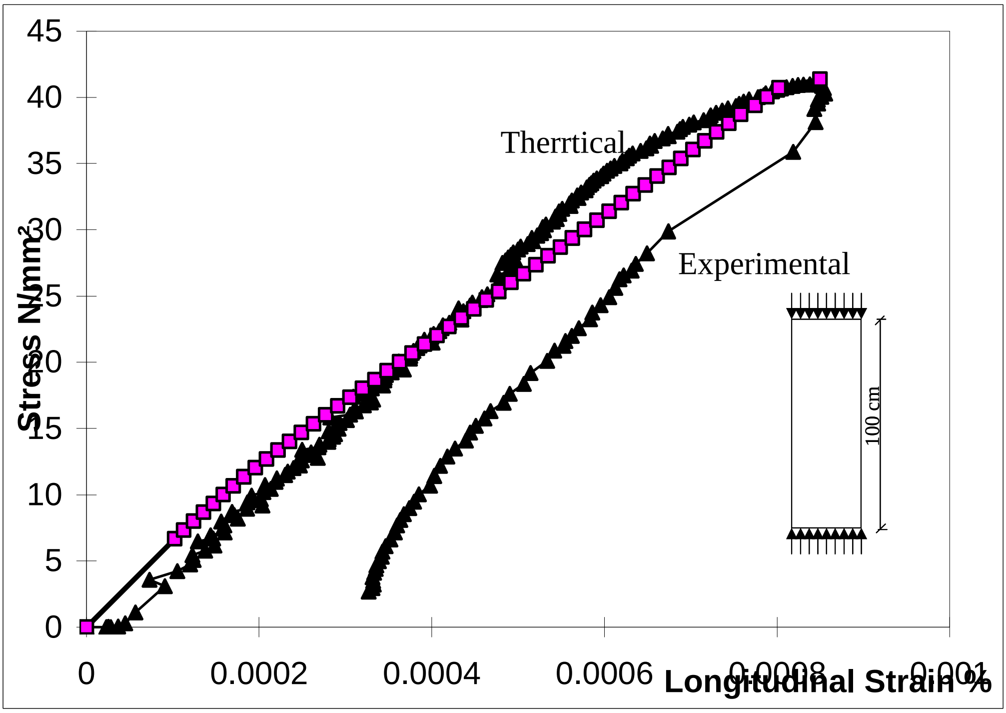
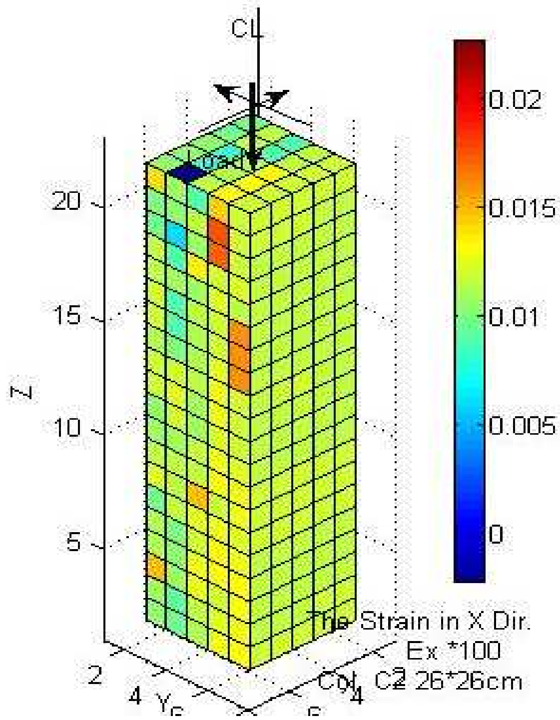
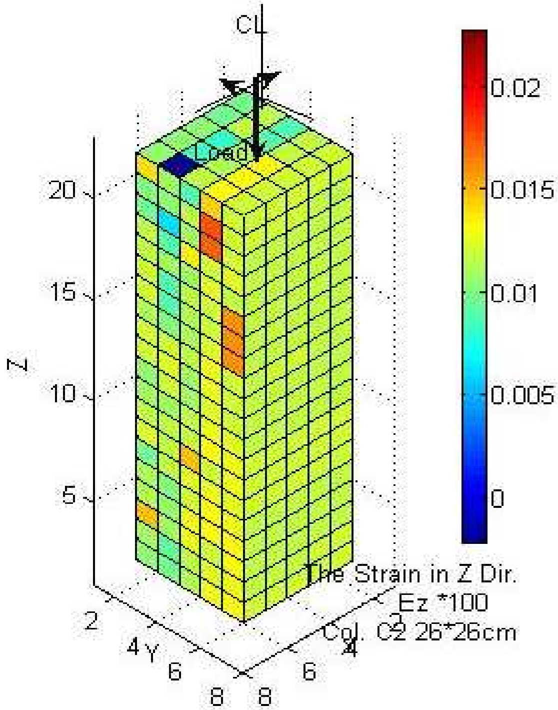


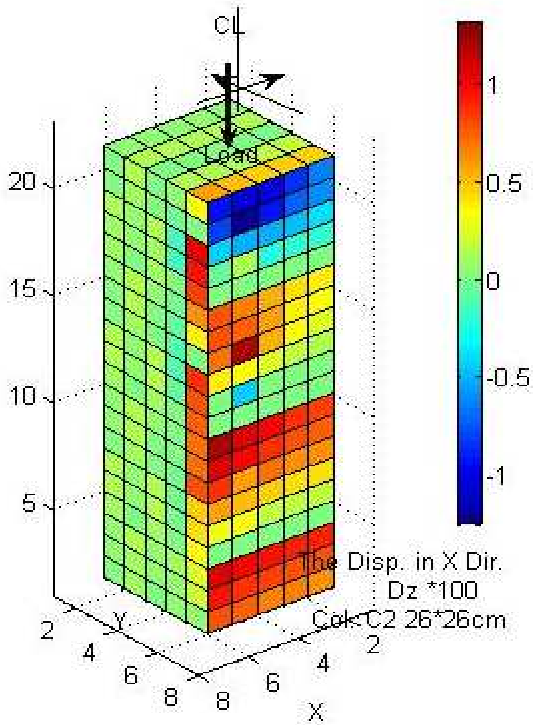
Fig. 4: Behaviour of column specimen **C**2 strengthened with SpB under axial load [5].



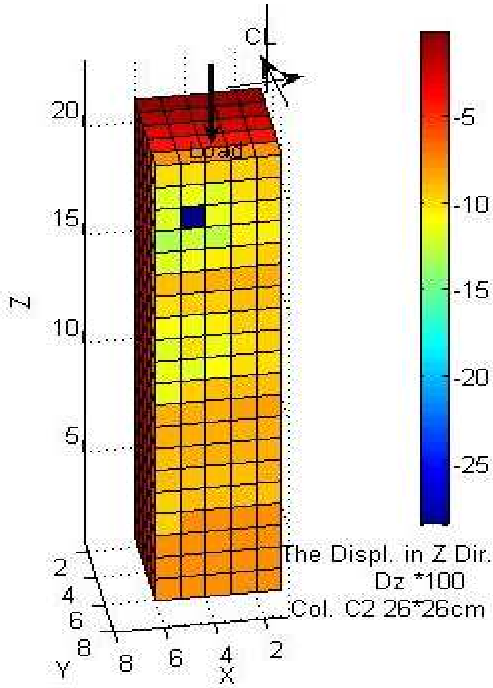
Strain in X Direction for C2



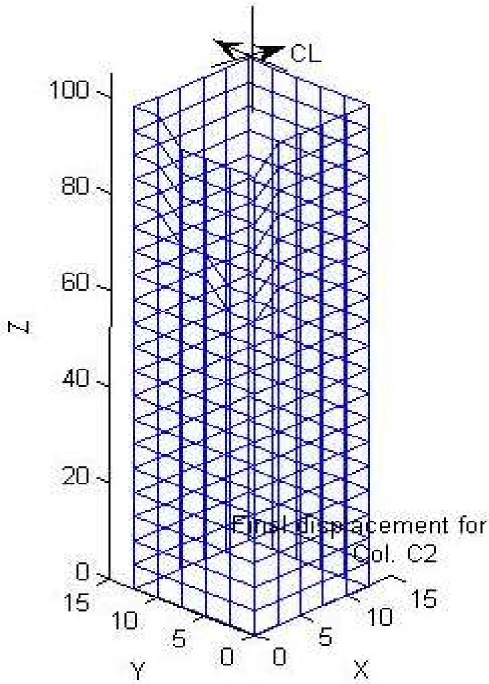
Strain in Z Direction for C2



Displacement in X Direction for C2

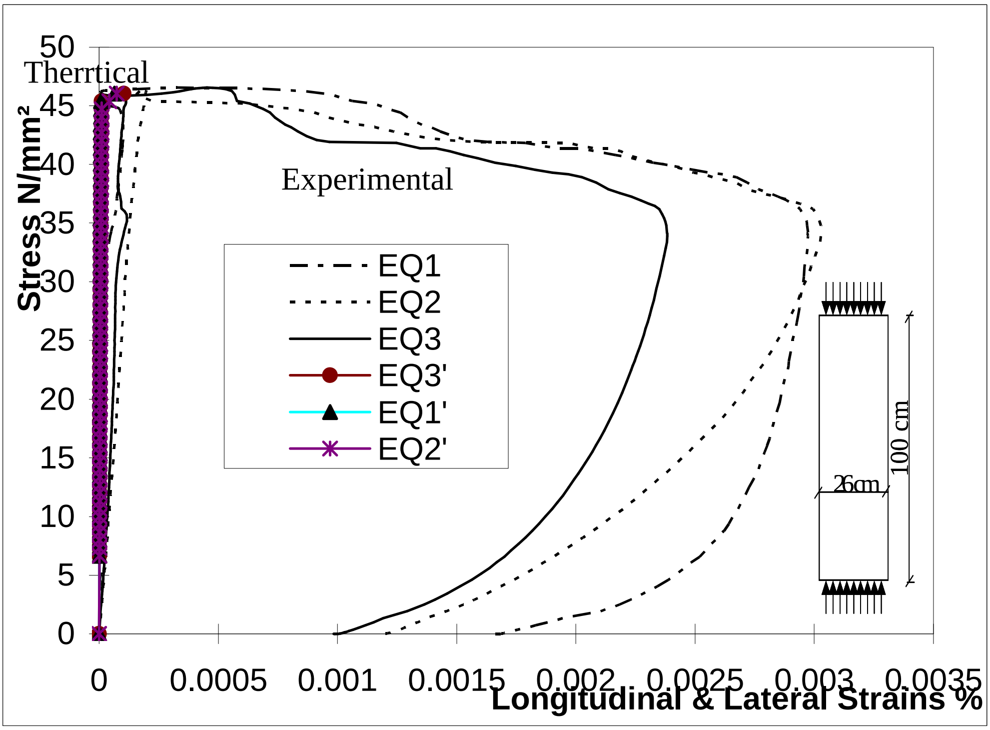


Displacement in Z Direction for C2



Final Deformations for C2

Fig. 5: Behaviour of column specimen C2 with [USA] Program.



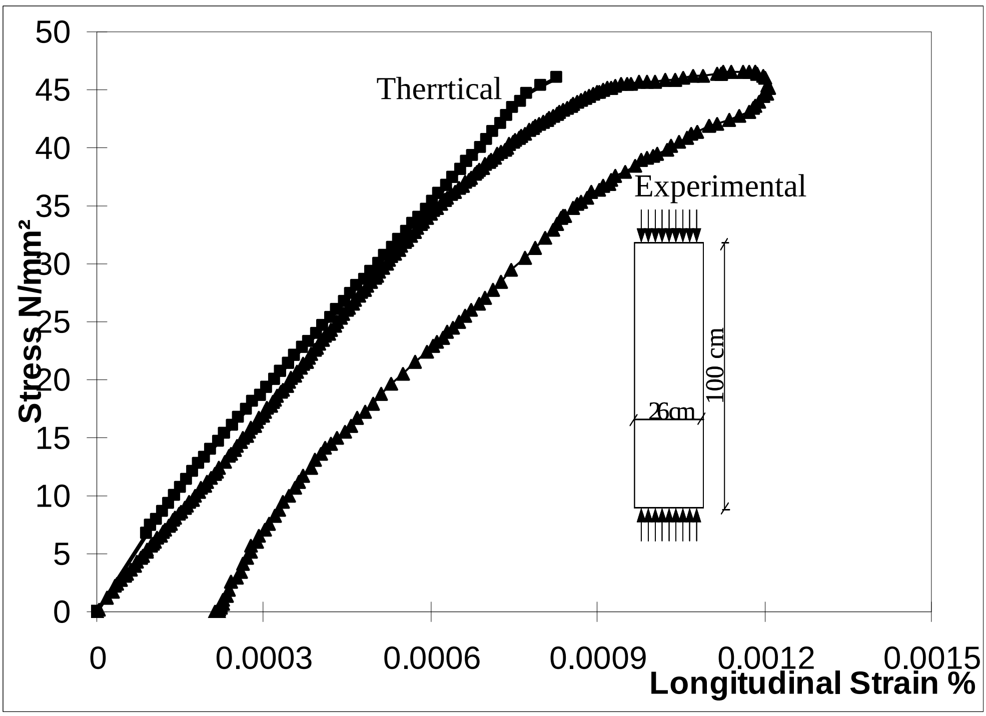
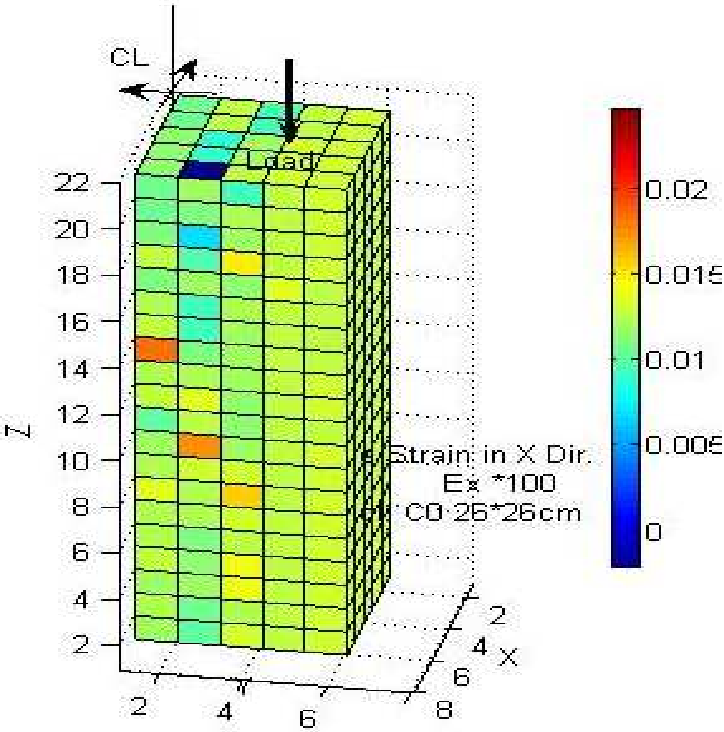
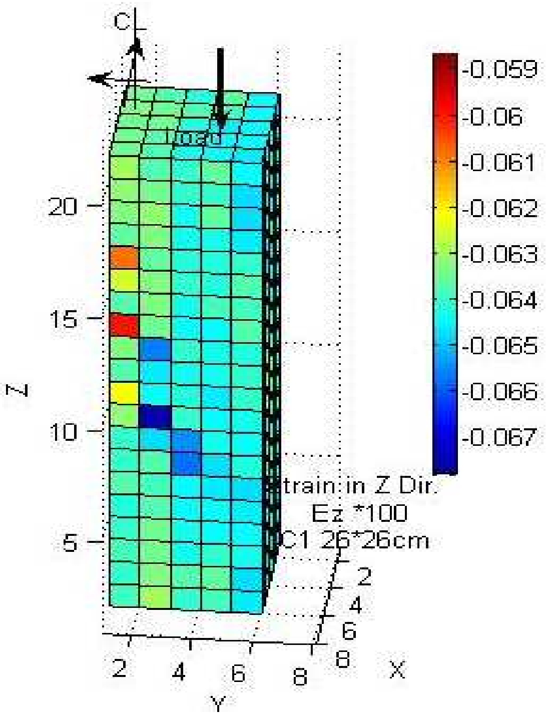


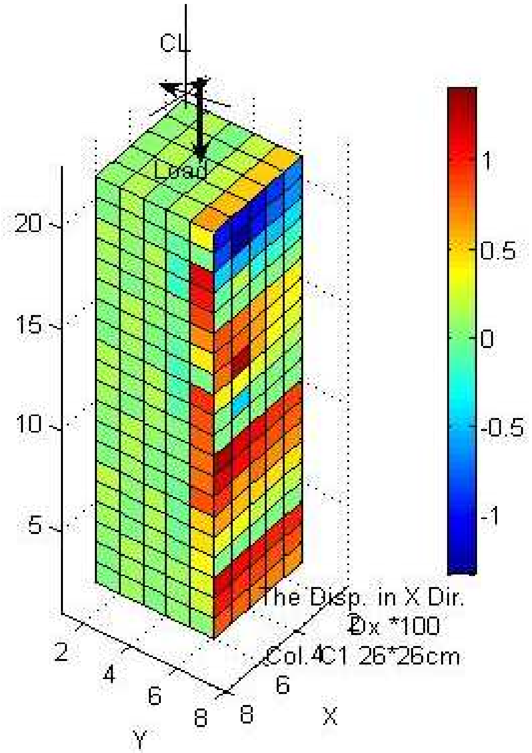
Fig. 6: Behaviour of column specimen **C**1 SpB+ stirrups under axial load [5].



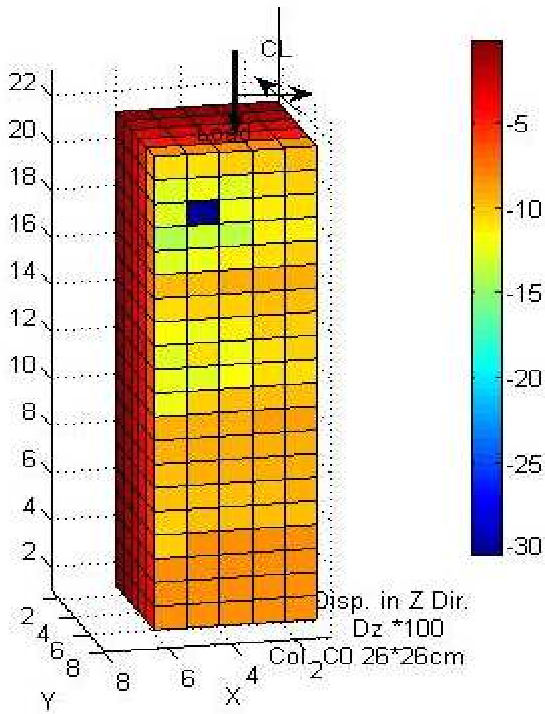
Strain in X Direction for C1



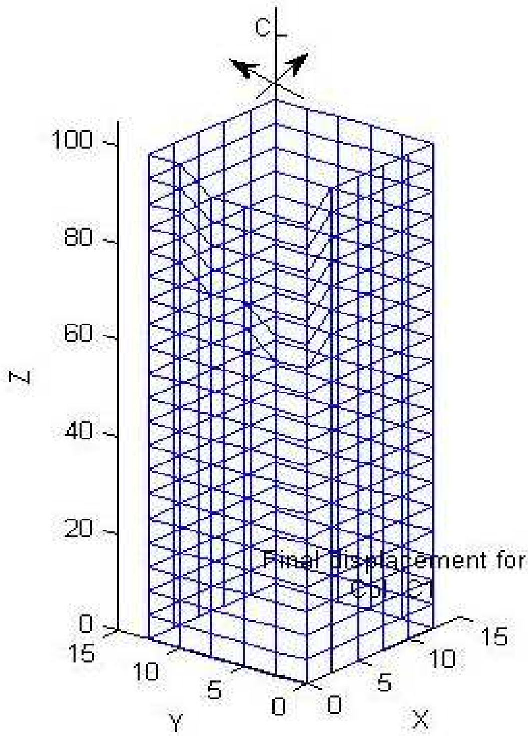
Strain in Z Direction for C1



Displacement in X Direction for C1

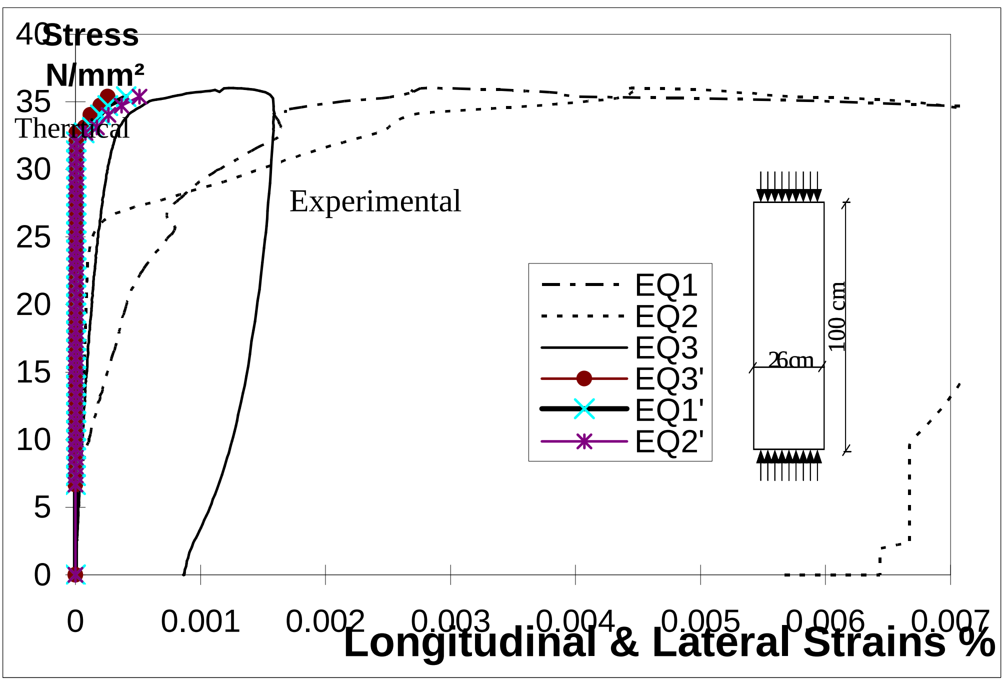


Displacement in Z Direction for C1



Final Deformations for C1

Fig. 7: Behaviour of column specimen C1 with [USA] Program.



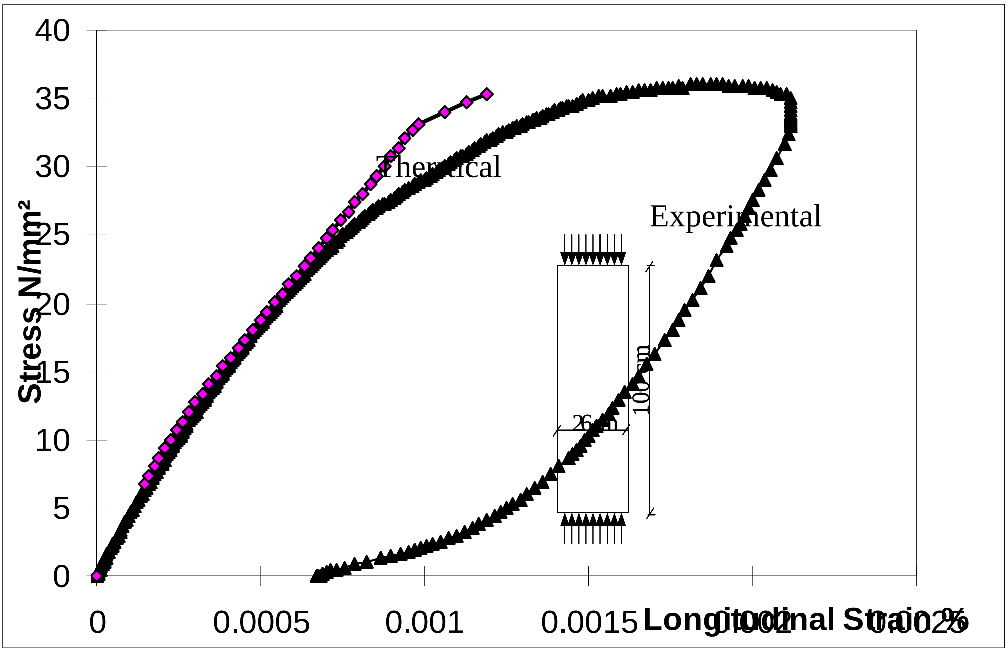
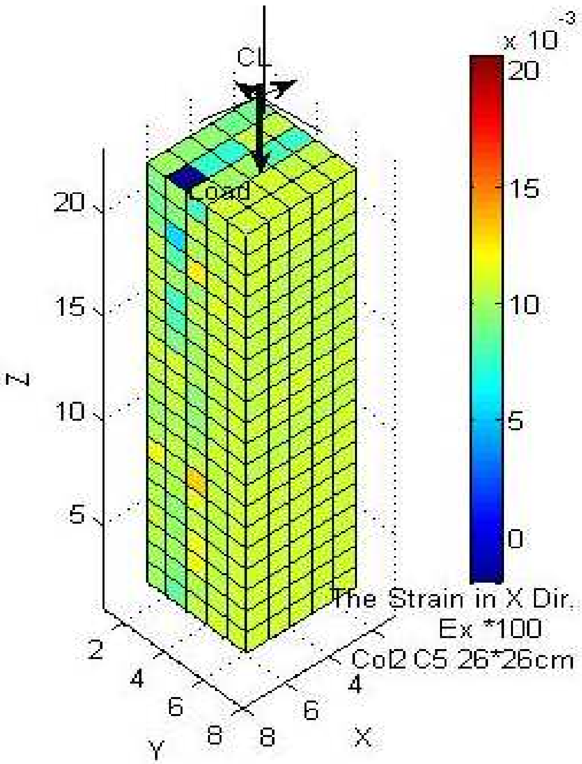
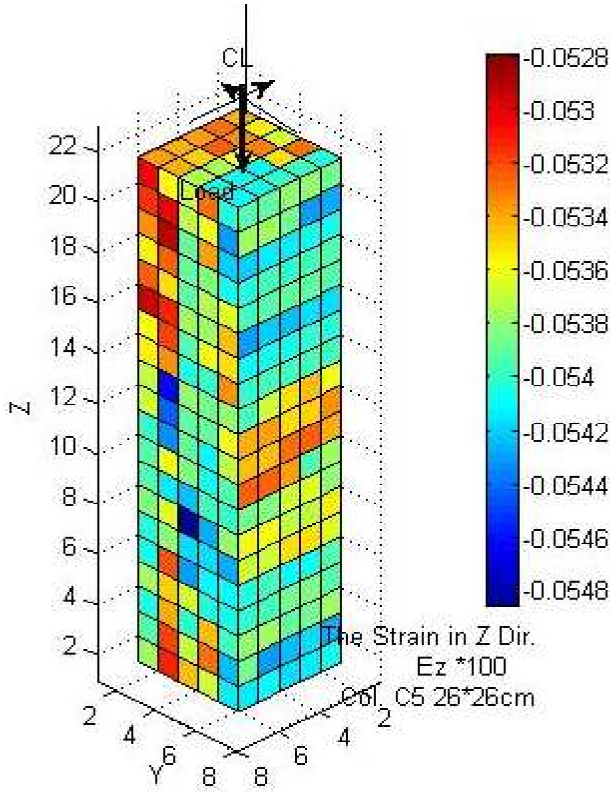


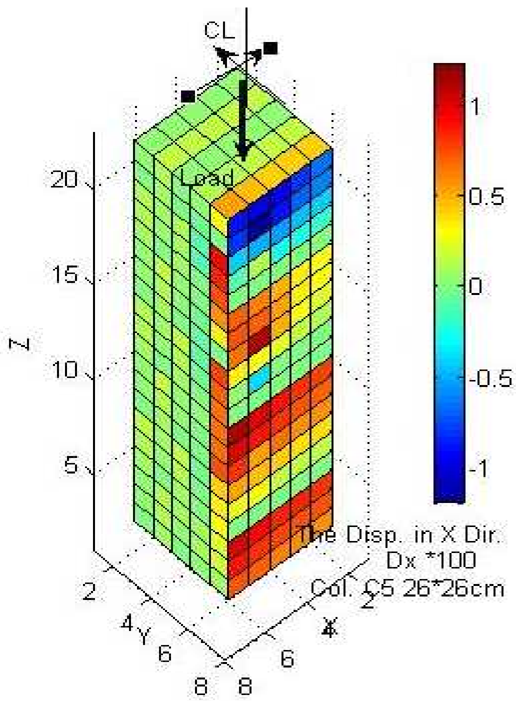
Fig. 8: Behaviour of column specimen **C**5 without strengthening under axial load [5].



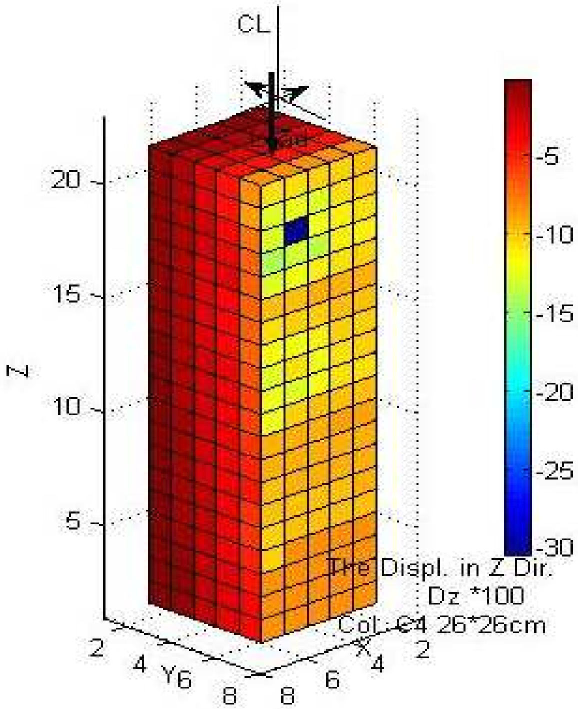
Strain in Z Direction for C5



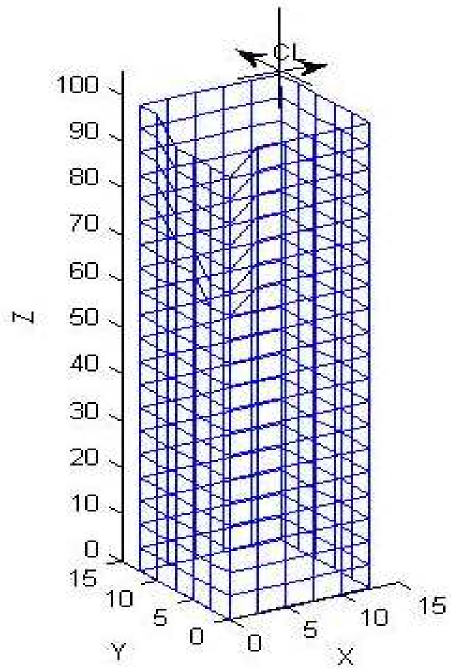
Strain in Z Direction for C5



Displacement in X Direction for C5



Displacement in Z Direction for C5



Final Deformations for C5

Fig. 9: Behaviour of column specimen C5 with [USA] Program.

6. CONCLUSIONS

The new formula in the three dimensional for numerical modeling gives results closer to with the experimental work in cracking loads, ultimate loads, displacements, deflections and the longitudinal and lateral strains are smaller.

The influence of shotcrete on the structural performance of reinforced concrete columns retrofitted with fibers was investigated [5].

1- For RC columns strengthened with SpB and having jackets with longitudinal steel reinforcement and stirrups have high loading capacity than these strengthened without reinforced jackets.
2- Using the shotcrete strengthening layer gives some improvement for the jacket than the concerte jacket and subsequently in the load capacity.

7. REFERENCES

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دراسة نظرية لبعض الأعمدة الخرسانية المسلحة المقواه بخرسانات مقذوفة (shotcrete)

إن استخدام طرق التقوية للأعمدة الخرسانية من الدراسات ذات الأهمية والتى تجد اهتماماً بالغاً من الدارسين حيث يمكن من خلال تلك الدراسات معرفة سلوك الأعمدة الخرسانية المسلحة من حيث بدء ظهور الشروخ أقصى وإمتداداتها وحمل التشريخ وأقصى حمل بعد عملية التقوية بالمقارنه بالعمود الأصلي وتأثير وجود قميص من حديد فى طبقة العلاج من عدمه والعوامل التي تؤثر عليها. والتحليل النظري للكمرات من الموضوعات ذات الصعوبه البالغة حيث عدم تجانس الخرسانة واختلاف سلوكها تحت تأثير الأحمال المختلفه وبصفة خاصة بعد تكون الشروخ بها والذي يعطى سلوكاً لاخطياً. ومعرفة السلوك اللاخطي للخرسانة المسلحة أهميه كبيرة لمعرفة السلوك اللدن للخرسانة. ويحاول كثير من الباحثين إدخال هذا السلوك اللدن فى صور مختلفة وهو فى المواد

المتجانسة القاصفة يختلف فى طبيعته كثيراً عن السلوك اللاخطي للمواد الغير متجانسه، ولذلك فانه عند الدراسة النظرية لسلوك الخرسانة المسلحه يجب الأخذ فى الاعتبار السلوك الخطى للخرسانة مع الأخذ فى الاعتبار تكون الشروخ. وفى هذا البحث تم اعتبار ذلك فى الدراسة لتحليل الأعمدة الخرسانية المسلحه. حيث استخدمت طريقة العناصر المحددة وذلك بتمثيل الخرسانه بالعنصر الثماني لجاوس واعتبار سلوك الخرسانه خطى إلى حدوث الشروخ وبعدها يحدث نقص خمسين بالمائه حيث فى هذا النموذج يتم اعتبار أن الاجهادات الواقعة على العنصر.

ويعتبر هذا الفرض لنموذج الشروخ من افضل النماذج لدراسة سلوك العناصر الخرسانية غى الثلاث أبعاد من حيث سهولة استخدامه فى التحليل النظري واعداده فى داخل برنامج الحاسب الآلي. وقد تم فى هذه الدراسة إيجاد مصفوفات المتانه باستخدام عامل الشكل (**Shape Function**) الكلية للعنصر الثماني الخرساني بعد حدوث الشروخ ووضعها فى صيغه رياضيه لاستخدامها فى الحل على أساس تمثيل الحديد فى مرحلة المرونة وما بعدها فى مرحلة التصلد الانفعالي. وفى هذه الدراسه تم تطوير برنامج حاسب آلي باستخدام طريقة العناصر المحدده لتحليل الكمرات الخرسانيه المسلحه يأخذ فى الاعتبار سلوك كلاً من الخرسانه وحديد التسليح من صفر التحميل حتى الكسر.

ويلخص البحث إلى :

1- سلوك الخرسانه خطى مع تغير اتجاهات الشروخ وان تظل العلاقة توصف بمعامل المرونة الخطى للخرسانة.

2- تعطى مصفوفات المتانة المماسية والكلية للعنصر الرباعي الخرساني بعد حدوث الشروخ والمثبته فى هذا البحث حلاً نظرياً لسلوك الأعمدة الخرسانية المسلحة بنسبة عليه يتطابق مع السلوك الفعلي المعملي خلال مراحل التحليل المختلفه من حيث تكون الشروخ واتجاهاتها وحمل التشريخ والكسر ونوعية الانهيار.