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Theoretical Analysis of Axial Behavior of Circular Column Confined with Polymer Material

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Abstract

The collapse of the bridge are due to inadequate seismic performance of bridge pier (or pile) and columns, which provided with poor ductility and energy dissipation. Deep study of strengthening structural element concern elasto – plastic behavior of concrete would be important to increase the capacity of structures elements. Considering the rapid development of economic construction and the Traffic volume through different regions has been escalating, there is a substantial contribution has been developed in traffic construction and structures. This research focus on new strengthening method to provide effective confinement to the concrete core and obtain elastic deformation of the circular columns. The finite element software ABAQUS used for the nonlinear numerical analysis of the concrete column strengthening with polyurethane cement composite mix. Results shows that the use of new technique for strengthening has greatly improved the ultimate capacity of column. The thickness of strengthening material is the main parameters in this study and govern by the behavior of polyurethane-cement material. The improvement ratio in loading capacity with confinement thickness 40 mm and density of confinement material 1600 Kg/m^3 is 277% compared with non-strengthening model.

Keywords: Column strengthening, nonlinear finite element, polyurethane-cement composite.

1. Introduction

Different studies have been investigated the external confinement for reinforced concrete column and the flexural behavior, flexural strength and ductility, and these researches has showed the importance of the resistance of sever seismic attacks [1, 2]. The commonly composite material used for retrofitting column or other structural element are Fiber Reinforced Polymer (FRP) , these types include carbon FRP (CFRP), aramid FRP (AFRP), steel FRP (SFRP), glass FRP (GFRP) and Basalt Fiber Reinforced Polymer (BFRP) composites are less frequently used. Different method of jacketing were applied to improve the column capacity and ductility behavior [3,4]. Due to the development of construction of a large number of highway and railway bridges, and because of lack of maintenance and standards, many old bridges has become unsatisfied the current traffic volume and load age of vehicles and most of the bridges come within highly risk. So its need to develop a new application would lead to improve the effective strengthening technique of bridge.

Some of standard and guidelines report has been published recently for the design purpose and strengthening structural element such as confined reinforced columns using FRP [5, 6]. The wrapping with FRPs has become widely used and known well with special technique for column strengthening. Most researches used FRP-confined concrete column have been applied on reinforced or unreinforced, small scale, circular concrete cylinders or short column loaded under concentric.

In last decades, SFRP sheets have given a wide attention by the researchers, interest for confinement applications due to the significant improvement to the RC columns compared to the conventional FRP sheets [7–10].

FRP composites possess several advantages over steel, which are excellent in strength comparing with weight and have significant corrosion resistance. The major structural use of FRP in infrastructure projects almost based on the using of these advantages. FRP have been approved as a material with high tensile strength, can generally be used because of its greatest advantages, when compared with concrete which is strong in compression but poor in tension. Therefore, the use of FRP in concrete structures has been a major target of existing research [11-13].

The disadvantage of FRP confinement or jacketing columns should be addressed carefully. The special technique to perform the FRP need skill labour especially the prestressed laminate of FRP. The adhesive material using in attached the layer still have some defect when expose to sever environmental parameters , while the bonding need to be fully under control with accurate procedures [14]. Haleem.K et al [15, 16] have been using the polyurethane-cement composite (PUC) to strengthen RC beams and the result indicates that the PUC material enhanced the flexural strength of beams.

In this paper using polyurethane cement mix as a new material to strengthening the column aimed to enhance the strength capacity and ductility of column. This new method are simple and easy to perform without special technique and the improvement rate will be depend on the density value of this material (PUC).

2. Methodology

This work studied the flexural behavior of reinforced concrete column and the deformation in confinement material, moreover axial displacements of column were predicted versus the axial load. Theoretical calculation of the axial compression applied as axial displacement and use ABAQUS FEM model, then plotting the variation of displacement versus the applied load. The results obtained from the control column compare with that from confined columns with polyurethane cement material (PUC).

3. Finite Element Analysis

3.1 Specimens Geometry

The ABAQUS finite element analysis program used to analyze the model. Geometry and material properties furnish as input data for this purpose. The column model geometry shown in Fig. (1).

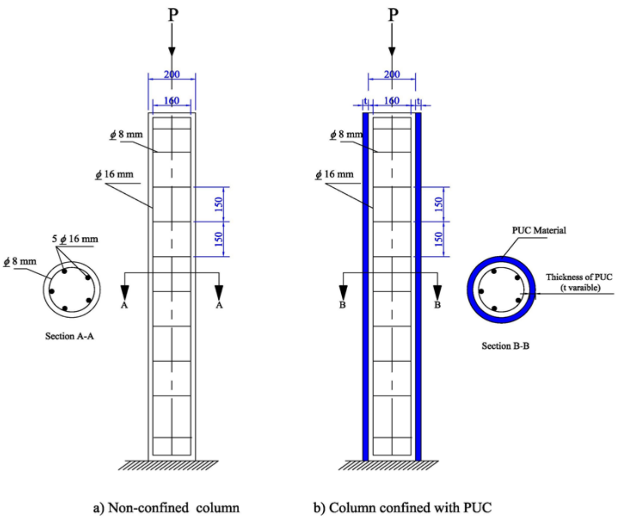


Fig. (1) Column model geometry (a- Non-confined column, b- Column confined with PUC)

The longitudinal reinforcement of the columns were considered as five bars of 16 mm diameter, the steel yield strength (f_y)=400 MPa and 265 MPa of 8 mm diameter of stirrup , modulus of elasticity (E_s) 210 GPa and the poisons ratio (ν) = 0.3. The control column was 100 mm diameter, height 1500 mm, concrete cover 20 mm. Concrete properties with modulus elasticity of concrete was calculated according to ACI, $E_c = 4700\sqrt{f'_c}$ (MPa) and poisons ratio (ν) around 0.2 [17].

3.2 Polyurethane-Cement (PUC)

Polyurethane is a polymeric material selected have highly adhesive properties, the components of polyurethane is a foam materials used in this research, where these raw materials can product different series of Polyurethane-Cement, mainly based on the isocyanate and strong chain of oligomeric polyols as the chemical compounds according to the mixing ratio components (polyether: polyisocyanate: cement). The main component of polyurethane-cement component is polyol (20%) Polyisocyanate (20 %) and ordinary Portland cement (60 %) [15,16]. Table (1) present the adopted series of polyurethane-cement (varying densities) in jacketing of circular column.

Table (1). Densities of Polyurethane –Cement (PUC) and normal concrete [15].

Model No.	Density (kg/m^3)	Compressive Strength (Mpa)	Tensile strength (MPa)
RC-Pure	2350	30.0	2.48
D1	790.7	20.6	12.3
D2	1198.5	42.1	27.6
D3	1648	60.6	44.3

The FEM analysis of each model was considered by varying the parameter thickness of polyurethane –cement and the density of polyurethane-cement. Table (2) presents the geometry column and dimension details.

Table (2) the column model strengthen with polyurethane-cement.

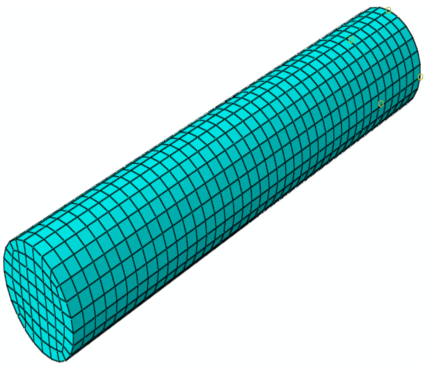
Model No.	Jacketing thickness (t)	Column Dimension
RC-Pure	Control Column	200 mm diameter and 1.5 m Height
M1	10 mm thick of PUC	220 mm diameter and 1.5 m Height
M2	15 mm thick of PUC	230 mm diameter and 1.5 m Height
M3	20 mm thick of PUC	240 mm diameter and 1.5 m Height
M4	30 mm thick of PUC	260 mm diameter and 1.5 m Height

M5	35 mm thick of PUC	270 mm diameter and 1.5 m Height
M6	40 mm thick of PUC	280 mm diameter and 1.5 m Height

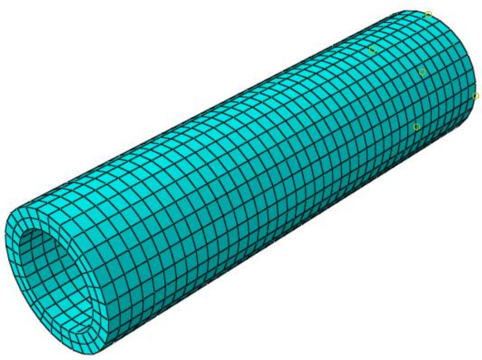
4.3 Modeling Assumptions

The ABAQUS finite element software was used to create models of the tested columns. The model's details were given in Fig. (2) and (3). The appropriate boundary conditions chosen and the displacement controlled mode will be considered. The columns are modeled as one end free and other end fixed.

Solid element type C3DR8 was adopted to represent the concrete material and Polyurethane-Cement (PUC) material, while steel bar was represented by using truss three dimensional element (T3D2). Fig. (2) and Fig (3) show the modeled control and Polyurethane-Cement beams in ABAQUS software. The load applied automatically with small time increment to achieve accurate and convergence solution. The bonding between Polyurethane-Cement material and concrete was assuming good bonding and represent in ABAQUS by standard contact interaction element [18].



(a) Concrete mesh



(b) PUC material Mesh

Fig. (2) Mesh generation of concrete column (a- unconfined column, b- PUC material).

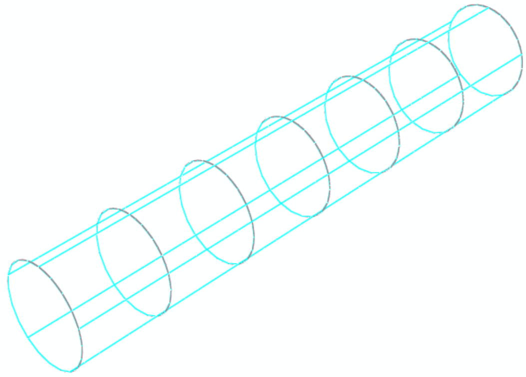


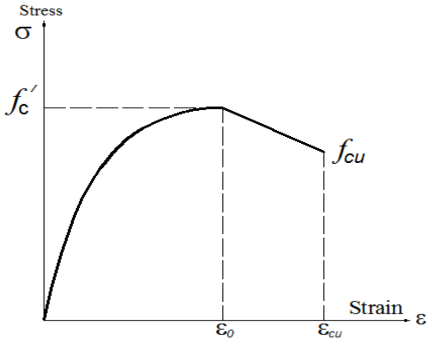
Fig. (3) Steel rebar model in ABAQUS

3.4 Constitutive curve of materials.

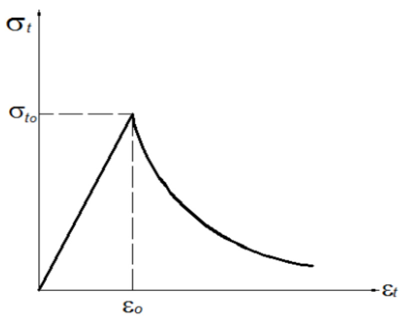
The constitutive curve of concrete was used in this research represent the linear and (elastic) and nonlinear (plastic range) showing the behavior of concrete. The mechanism of concrete failure has two main cases, tensile cracking and compressive crushing of concrete material.

Fig. (4). describe the plasticity based concrete constitutive model is used in this analysis. In compression, multi-linear stress strain relationship for concrete used, the stress increases gradually up to the maximum compressive strength (σ_u) and eventually crushing failure occurs at an ultimate strain (ε_{cu}= 0.0033) [19].

In tension, the stress strain curve for concrete is linear elastic up to the maximum tensile strength. After this point, the concrete cracks and the strength decreases gradually.



(a) Compression



(b) Tension

Fig. (4). Stress-strain relation for concrete (a-compressive

For: $\varepsilon_c \leq \varepsilon_0$

$$\sigma_c = f'_c\left[1-\left(1-\frac{\varepsilon_c}{\varepsilon_o}\right)^2\right] \qquad \text{.......(1)}$$

For: $\varepsilon_o \le \varepsilon_c \le \varepsilon_{cu}$

$$\sigma_c = f'_c\left[1-0.15\left(1-\frac{\varepsilon_c-\varepsilon_o}{\varepsilon_{cu}-\varepsilon_o}\right)\right] \qquad \text{.......(2)}$$

Where: ε_o: maximum compressive strain.

ε_{cu} : Ultimate compressive strain =0.0033.

σ_c: Compressive stress (MPa).

f'_c : Concrete compressive strength (MPa)

Typical tensile stress-strain curve for concrete represented according to the formula [17]:-

$$\sigma_t = E_c\varepsilon_t \qquad 0 < \varepsilon_t \le \varepsilon_o \quad \text{....Eq.(3)}$$

$$\sigma_t = \sigma_{to}\, e^{-\beta(\varepsilon_t-\varepsilon_0)} \qquad \varepsilon_t > \varepsilon_o \quad \text{...........Eq.(4)}$$

$$\varepsilon_0 = \frac{\sigma_{t0}}{E_c} \qquad \text{................Eq.(5)}$$

Where:-

β: The control of descending softening coefficient of concrete fracture is related to the general range of 1 - 2 × 10^4.

E_c: The tangent modulus of concrete compressive stress-strain relationship (MPa).

σ_{to} : Tensile strength of concrete (MPa).

ε_0: Concrete cracking strain at maximum tensile stress.

The constitutive behavior of steel was using as elastic perfectly plastic model. Properties which used to define this model are elastic modulus E_s, yield stress, f_y and Poisson's ratio (ν). The Perfect bond was assumed between the steel and the concrete. Fig. (5). show the stress–strain curve relationship of steel [20].

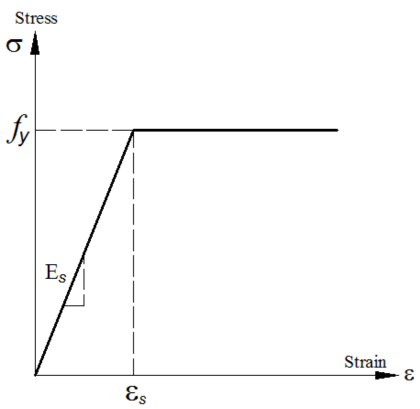


Fig. (5). Stress-Strain relation

The new material (Polyurethane-Cement) constitutive curve in tension zone was adopted according to the experimental study which carried out in study performed by Haleem K. et al (2014) [16].

Fig. (6) explains the relation between the confinement of core concrete with Polyurethane-Cement material. The Polyurethane-Cement material will confine the lateral deformation of core concrete when the column subjected to axial compressive stress.

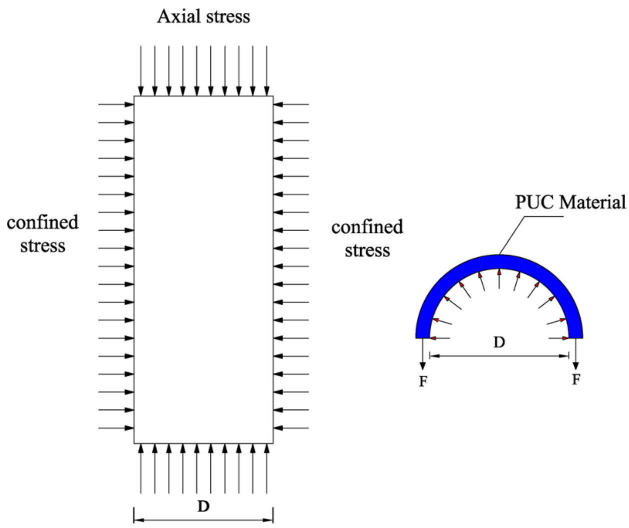


Fig. (6) Stress in concrete core confinement with PUC material

Analysis simulation procedures is applied on models with the axial compression load using finite element analysis (ABAQUS). First, accordance to the requirements build the model with suitable meshing work, then using load displacement with an axial displacement applied on free end of column (concentric load). Non-linear finite element simulations was adopted due to the high computational requirements.

3.5. Finite Element Analysis Results

The analysis results of strengthening column are represented in Fig (7), Fig (8) and Fig (9) showing the axial load versus the axial displacement compared with reference column (RC).it obviously that the Polyurethane-Cement material has slightly increase the load capacity of the concrete columns. Model with constant small thickness of Polyurethane-Cement and increasing the density of Polyurethane-Cement material shows similar behavior and no much devolved column load capacity. Initially all model have similar the load-displacement curves before concrete core cracked. When the concrete yield, the Polyurethane-Cement material provides effective lateral restriction to the concrete core and with large deformation higher than the reference concrete columns with increasing the density of Polyurethane-Cement.

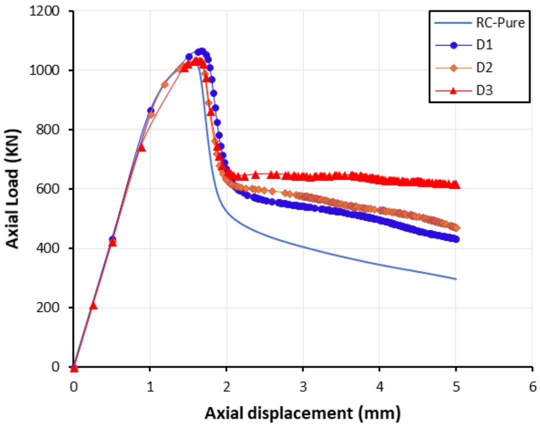


Fig. (7) Load - axial displacement relation (PUC thick=10 mm)

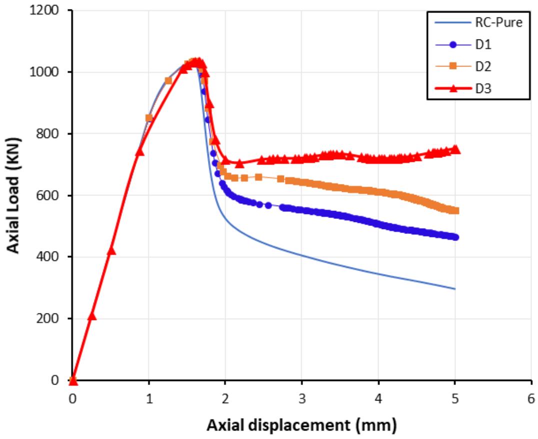


Fig. (8) Load - axial displacement relation (PUC thick=15 mm)

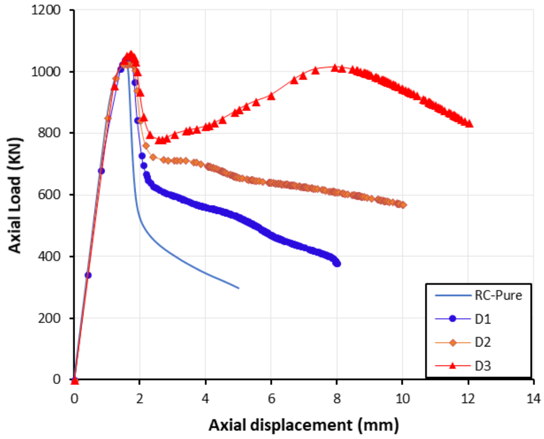


Fig. (9) Load - axial displacement relation (PUC thick=20 mm)

A significant increase in column loading capacity clearly getting when thickness of PUC equal to 25 mm and over, especially for model D3 (Density of PUC 1600 Kg/m^3) shows excellent improvement of column capacity with large deformation. The maximum load was 1394.89 KN and axial displacement 9.1 mm while for reference column (RC-Pure) the ultimate load was 1026.6 KN and very limited deformation 1.6 mm as shown in Fig. (10).

With increasing the PUC thickness to 40 mm the behavior of models D1 and D2 modified clearly showing increase load capacity of confinement column compare with RC-Pure (reference column) while the a significant improvement were getting from model D3 (higher density of PUC 1600 Kg/m^3) and the increment ratio of loading capacity was around 277%, 245%, 172% and 135% for thickness of PUC 40 mm, 35 mm, 30mm and 25 mm respectively comparing with reference column. The axial deformation was increase up to 27mm at the maximum value of applied load compare with 1.6 mm for RC column.

The Other model (D1 and D2) with different thickness of PUC the improvement in loading capacity relatively low, while the deformation has improved well. Fig. (10), Fig (11) , Fig. (12) and fig. (13) shows these relation of axial load and axial displacement for different density of PUC with varying of thickness.

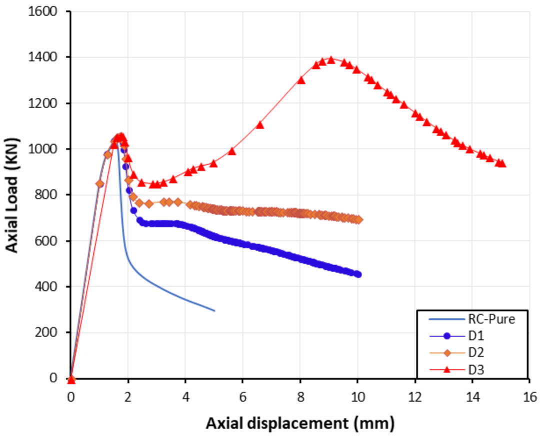


Fig. (10) Load - axial displacement relation (PUC thick=25 mm)

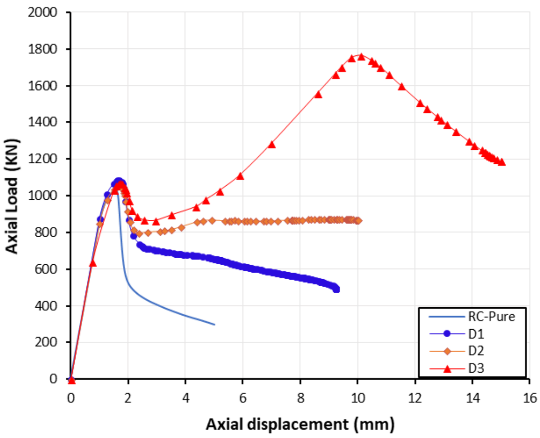


Fig. (11) Load - axial displacement relation (PUC thick=30 mm)

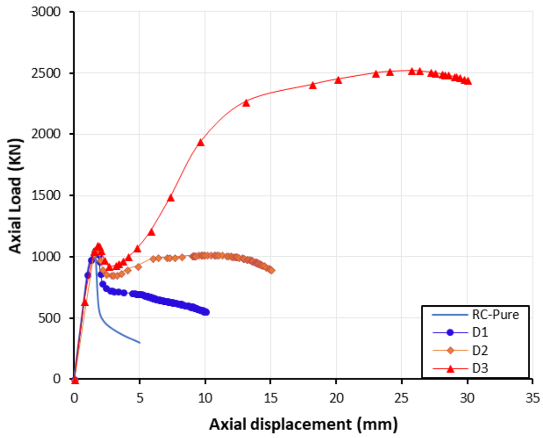


Fig. (12) Load - axial displacement relation (PUC thick=35 mm)

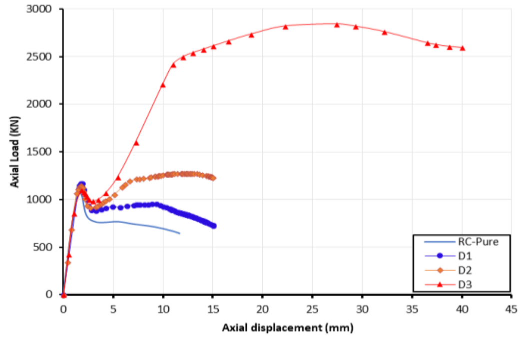


Fig. (13) Load - axial displacement relation (PUC thick=40 mm)

Fig (14) summarize the best case of strengthening of model properties D3 (1600 Kg/m^3) and shows highly improvement loading capacity with large displacement of loaded column compare with RC column (un-strengthen column). The other model (D1 and D2) have no any a specific improvement of ultimate loading capacity but a large deformation were conducted of these models which improve the elastic column behavior as shown in Fig. (15) and Fig. (16).

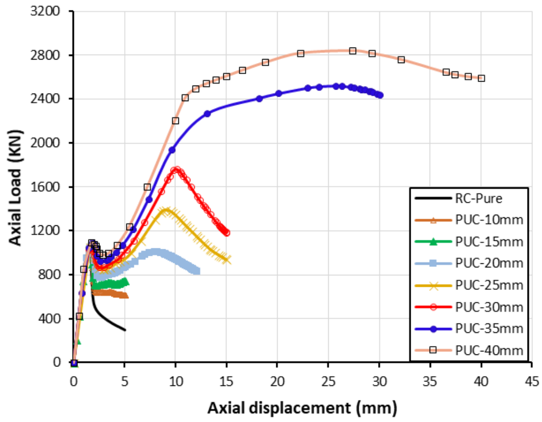


Fig. (14) Axial Load - axial displacement relation with varying PUC thickness (model D3)

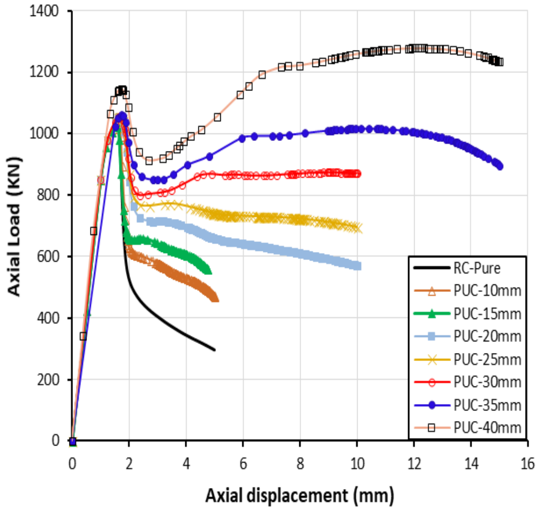


Fig. (15) Axial Load - axial displacement relation with varying PUC thickness (model D2)

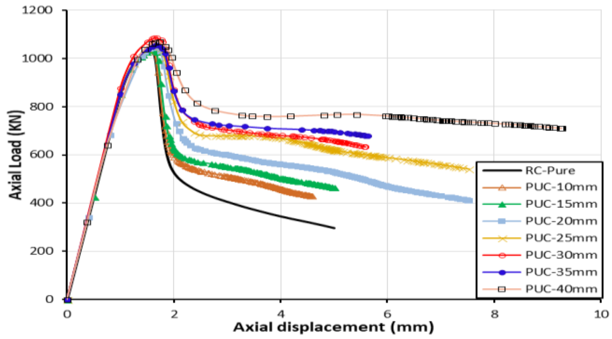
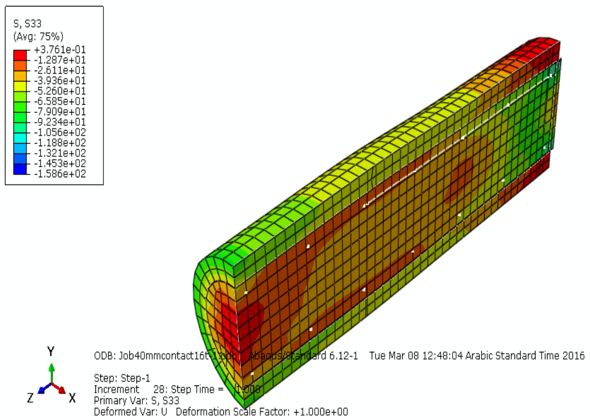
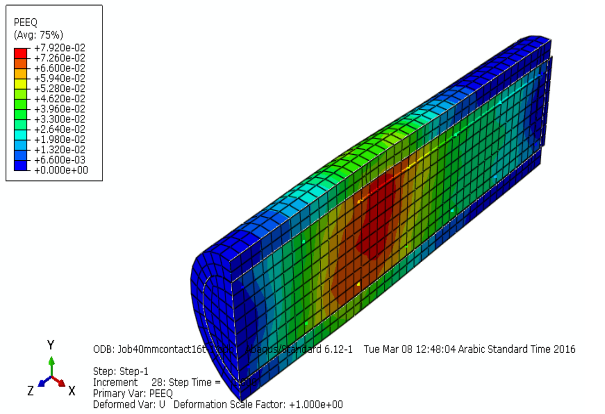


Fig. (16) Axial Load - axial displacement relation with varying PUC thickness (model D1)

Fig. (17) showing the stress and plastic strain contours of core concrete for strengthen column and Fig (18) and (19) showing the plastic strain, axial stress and axial displacement for model with PUC material indicate the concentration of stresses in core concrete and PUC material.

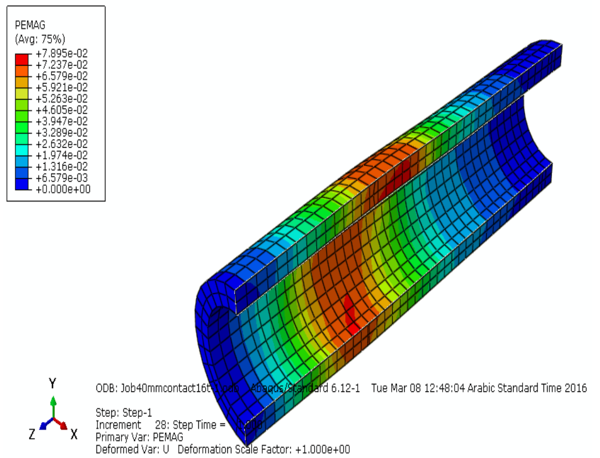


(a)

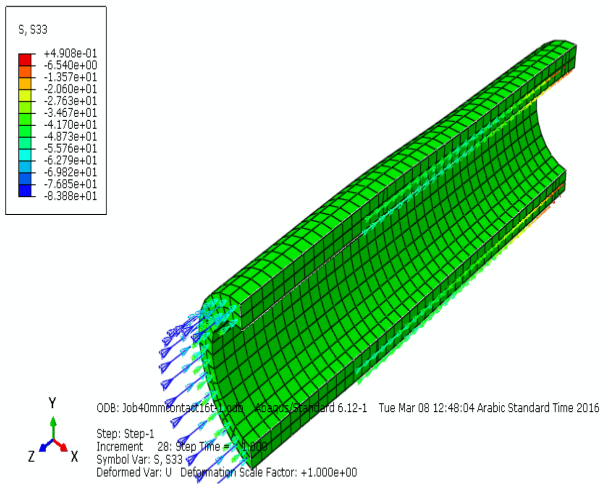


(b)

Fig. (17) Stress and plastic strain of half model (a- axial stress and b- axial plastic strain)

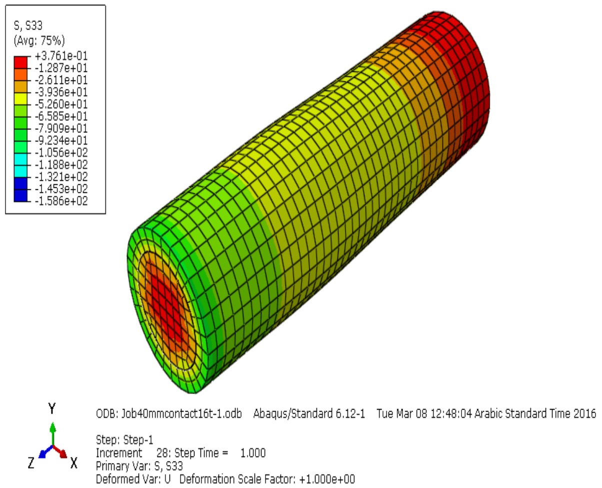


(a)

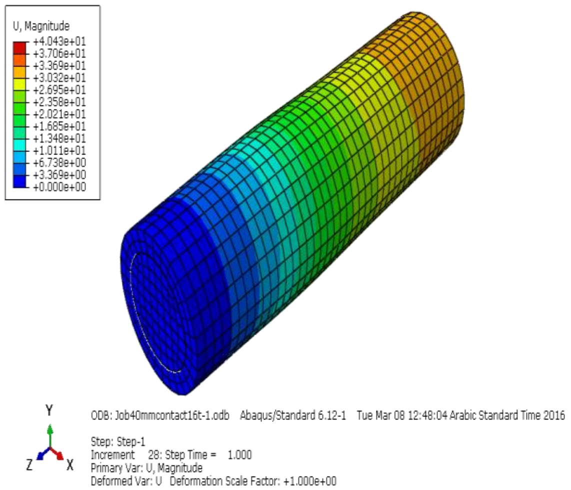


(b)

Fig. (18) Strain and stress contour of PUC material (a- plastic strain of PUC and b- axial stress of PUC)



(a)



(b)

Fig. (19) Axial stress and Axial displacement for whole model (a- stress and b- displacement)

Table (3) present a comparing the strengthening column with normal RC column and showing the ratio of modification in ultimate capacity of column with different jacketing of PUC material varying from 10 to 40 mm with increment 5 mm

Table (3) Ultimate load capacity with different thickness of confinement of model D3

Model No.	**Max. Load (KN)**	**Displacement (mm)**	**Ratio**
Control column	1026.6	1.6	1
10 PUC mm	1035.6	1.5	1.01
15 mm PUC	1036.04	1.6	1.01
20 mm PUC	1059.67	1.7	1.03
25 mm PUC	1394.89	9.1	1.36
30 mm PUC	1765.12	10.1	1.72
35 mm PUC	2522.2	25.7	2.46
40 mm PUC	2843.51	27.4	2.77

4. Conclusion

The PUC material in this study can be used in the strengthening the concrete columns and the theoretical analysis of different densities of PUC material used to strengthen the circular column. The composite material of PUC could be considered a very effective material and can be used in the rehabilitation or strengthening concrete structures element such as column, pier, beam,….. etc , due to the high strength in compressive and tensile strength in addition to the large deformation especially the PUC with density 1600 Kg/m^3

The ultimate load capacity (axial strength) improved significantly by 227% with PUC thickness 40 mm compared with unstrengthening model and this material provide effective confinement to the concrete core. Excellent mechanical and adhesive properties provide good bonding between concrete and PUC surfaces which lead to enhance the confinement of concrete. The analyzed model with low density of PUC shown a slightly improvement in carrying capacity with large deformation compared with un-strengthening column.

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