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Analysis of the Composite Columns using Finite Element Modelling in Ansys Environment

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***Abstract*:- In the present study, an attempt has been made on analysis of the composite columns using finite element modelling in ANSYS environment. The static structural module approach has been used to work out specific parameters under a uniformly distributed impact load. A total of twenty-one column cases were analyzed and investigation of the output values has been carried out and compared. The results indicate that the confinement effect of composite columns provide enhancement of strength and ductility up to a certain column height.**

Keywords:-* *Confinement, Retrofitting, Steel columns, Finite element analysis (FEA), Composite columns.

1. INTRODUCTION

Composite materials, plastics and ceramics have been talk of the town for over the last three decades. They have conquered the market covering massively all the domains and sections with its wide range of applications. The most recent engineered material market is ruled by composite materials since most of the day to day life products and alcove applications require them. Composite materials can be varied by making changes in their structural aspects unlike materials like cement, steel etc. Any component made up of composites needs both material and structural design. The designer has the control of varying the properties of composites such as stiffness, thermal expansions etc. A lot of studies and analysis is involved while composing a result with composites such as careful selection of reinforcement types which help in achieving specific engineering requirements. Polymeric composites are the most common matrix materials. There are two major reasons. It is because mechanical properties aren't satisfactory enough for the structural purposes. The stiffness and strength are low as compared to ceramics or even any metal. This can be overcome by reinforcing polymer with other materials.

Fibers are thread like pieces which are in the form of continuous elongated hair like filaments. Composite materials use them as a component. The main advantages of natural fibre composite include having a low specific weight, resulting in a higher specific strength and stiffness than glass fiber. It is a renewable source of energy which gives out oxygen using carbon dioxide and can be generated with low investment at low cost.

Hemp is a bast fibre such as jute, flax and ramie. It possesses excellent qualities of durability, fibre strength, length, absorbency and antimicrobial properties. Cheap and efficient concrete can also be produced using hemp extracts. FRP is a polymer matrix reinforced with fibres. Fibre is the main source of strength while matrix glues all of them together in shape and stress handling positions. The loads are carried along longitudinal directions. Columns are typically wrapped with FRP around their perimeter, as with closed or complete wrapping. This not only results in higher shear resistance, but more crucial for column design, it results in increased compressive strength under axial loading. FRP jackets and reinforcements are cost-effective alternatives to concrete or steel-plate jackets. They can be used to considerably increase ductility and strength without increasing stiffness [1][2]. The two specific design considerations prove to be very beneficial for FRP. First, because of its inert nature, FRP can provide protection against corrosion and stray electrical currents. Secondly, FRP wrapping and jackets can be fabricated to meet specific requirements desirable to a specific structure by adjusting the orientation of the fibres in various directions.

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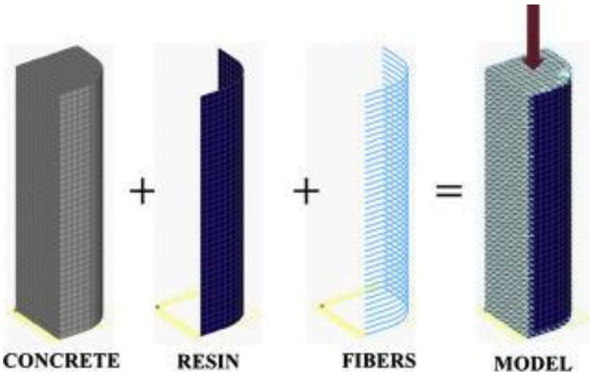

Fig.1. Typical finite element model used in the analysis of concrete column (confined) loaded in compression. [3].

2. LITERATURE REVIEW

Rule of Mixtures

The type, form, quantity and formation of the constituents determine how the mechanical and physical properties of composite materials will be. The rule of mixtures is set of equations which determine these values. It is noted that the unidirectional ply has two different in-plane tensile moduli (E_1 and E_2). [4][5]

Longitudinal modulus, *E_1* denoted by equation 1 as**:**

$$E_1 = E_f V_f + E_m V_m = E_f V_f + E_m (1 - V_f) \quad \text{.........(1)}$$

Poisson's ratio, *v_{12}* is denoted by Equation 2 as**:** ....(2)

Transverse modulus, *E_2* as shown through Equation 3 as:

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \quad \text{.........(3)}$$

and **Shear Modulus, *G_{12}*** represented through Equation 4 as:

$$\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{V_m}{G_m} \quad \text{.........(4)}$$

Where, the terms E_f and E_m are the Elastic modulus of fiber and matrix respectively and G_f and G_m are the Shear modulus of fiber and matrix respectively. The terms V_m and V_f are the Volume fractions of matrix and fiber respectively, and W and ρ represents weights and densities of the respective materials. In the given unidirectional composite, the voluminous capacity of the composite may be represented as Equation 5 and 6:

$$V_m = \frac{\rho_f W_m}{\rho_f W_m + \rho_m W_f} \quad \text{.........(5)}$$

$$V_f = \frac{\rho_m W_f}{\rho_m W_f + \rho_f W_m} \quad \text{.........(6)}$$

Different researchers have studied pertaining to analysis of FRP columns. Stephen Pessiki (2001) has performed experiment on the small circular and square plain concrete and large scale circular and square reinforced concrete confined with fiber reinforced polymer (FRP) composite jackets, subject to monotonic, concentric axial loads and found that axial stress and strain capacity has increased in relative to that of unconfined concrete and increases with the increase in FRP jacket. J.J. Zeng (2018) has experimented on the Behavior of large-scale FRP-confined rectangular RC columns under axial Compression and found that the compressive strength of concrete in a large-scale unconfined concrete column was found to be lower than that of a standard concrete cylinder and was found to be 6% lesser than the conventional concrete the compressive strength and the ultimate axial strain increase with the increase of corner radius ratio or the FRP jacket thickness. Jun-Jie Zeng (2017) tested for axial compression on 33 column specimens and studied the compressive behaviour of circularized square columns (CSCs) and found that significant strength and deformation increases are obtained for the FRP-confined CSCs compared to the fully FRP-confined square columns without circularization and also increase in the net spacing leads to a decrease in the ultimate axial stress and increase in the FRP volumetric ratio leads to an increase in both the ultimate axial stress and the ultimate axial strain.

Rami Eid (2017) has experimented in six FRP/TRP confined reinforced concrete columns under compressive axial loading and analyzed the behaviour of circular, square and rectangular columns. the higher the number of FRP layers, the higher the axial concrete compressive strength and its corresponding strain and this is well documented in the literature of Marijn R. et al., (1999), Laura De Lorenzis et al., (2003), Silvia Rocca et al., (2008). Nadeem A. Siddiqui (2014) has experimented on the effectiveness of hoop and longitudinal Carbon FRP (CFRP) wraps in reducing the lateral deflections and improving the strength of slender circular RC columns and was experimented on a total of 12 small-scale circular RC columns of 150 mm diameter. The results showed that CFRP hoop wraps provide confinement to concrete and lateral support to the longitudinal fibers and thus increase the strength of both short and slender RC columns. However, the effect of hoop wraps on the strength of columns is more significant for short columns than slender columns. Marinella Fossetti (2018) In this paper a generalized criterion for the determination of the increase in strength, in ductility, and in dissipated energy for varying corner radius ratios of the cross section and fiber volumetric ratios is shown. Numerical results using a finite element analysis, calibrated on the basis of experimental data available in the literature, are carried out to calibrate the new analytical models and results shows that the strength increase does not require definition of the lateral confinement pressure.

Thomas Vincent (2015) experimented on the influence of shrinkage on compressive behaviour of concrete filled FRP of FRP-confined normal- and high-strength concrete (NSC and HSC). A total of 30 aramid FRP (AFRP) confined concrete specimens with circular cross-sections were manufactured. Six of the specimens were instrumented to monitor long term shrinkage strain development of the FRP-confined NSC and HSC, with three specimens allocated to each mix. The remaining 24 specimens were tested under axial compression, where nine of these specimens were manufactured with NSC and the remaining 15 with HSC and results shows that there is a decrease in strength enhancement ratio whereas it leads to a significant increase in strain enhancement ratio and also decrease in the ratio of the ultimate axial strains obtained from mid-section and full-height LVDTs (MLVDT/ FLVDT) due to a partial or complete loss of bond at the interface between the concrete core and FRP shell.

Manal K. Zaki (2011) experimented on cylindrical reinforced concrete (RC) columns confined with fiber reinforced polymer (FRP) composites. The columns studied are under combined axial loads and biaxial bending moments. The fiber method modeling (FMM) together with finite element analysis (FEA) are adopted to investigate the behavior of such columns and results shows that a remarkable increase in the tension zone can be achieved due to the contribution of the longitudinal direction of the FRP in flexural capacity. For columns under uniaxial bending, a remarkable increase in M_u and F_{xu} are recorded by FRP confining. The increase in column capacity of the FRP confined columns compared to the reference columns increases as the balance point is approached and similar results were from J.L. Pan (2007). Haider Al Abadi (2016) investigated for the individual effect of the confinement parameters including unconfined concrete strength and confining pressure on the strength of FRP-confined concrete cylinders and results show that utilizing a FRP jacketing material which contains a higher tensile strength will not be effective when used to confine high strength concrete samples.

3. MATERIALS AND METHODS

Certain materials were used to perform the modelling according to their respective codes and specifications. The materials used are Concrete and Structural steel for the composite columns, and Epoxy Resin matrix and a 100% Hemp composite is used to form a fresh composite. (CTPT-12) [3]. The fresh composite so formed includes 30% of Hemp fibres and remaining 70% is the epoxy resin which binds the fibres together to provide exceptional tensile strength to the composite. New Composite formed is denoted as "FRP". Thus, FRP ingredients can be written as:

"FRP" ingredients = 70% Epoxy resin + 30% Hemp fibers

The reinforcements as well as the H-Section bar is made up of structural steel conforming to Grade A of IS 2062. The dimensions of H-Section column are defined as per GB standard Beams (300x300x10x15) mm.

FRP Casing Properties

The FRP jacket provided in the problem is derived from combining two different materials viz. Hemp Fibers (30%) and an Epoxy resin matrix (70%). The composite so formed is employed in designing the FRP jacket and comprises of 10 layers of the new formed composite, 0.8 mm thick each. Further a 0.8 mm layer of Epoxy is provided in between these layers and the column to make the adhesive bond firm and a 0.2 mm spray of Epoxy resin is also taken in consideration at the outer face of the FRP after the layers are applied. The orientations of the composite laminas are unidirectional (0°) and are parallel to the axial load direction. The properties of different materials used in the analysis are provided in table 1. [3]

Table 1: Mechanical properties of materials used in the FEM analysis

MATERIAL / PARAMETER	Concrete	Structural Steel	Hemp fiber	Epoxy resin	FRP
Density (g cm^{-3})	2.3	7.85	1.249	1.16	1.1042
Young's Modulus (MPa)	30000	2.e+005	6460.849	3780	4490.4
Poisson's Ratio	0.18	0.3	0.06	0.35	0.27315
Bulk Modulus (MPa)	15625	1.6667e+005	2447.3	4200	3299.1
Shear Modulus (MPa)	12712	76923	3047.6	1400	1763.5

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Table 2: Lay-up of the layered section of composite

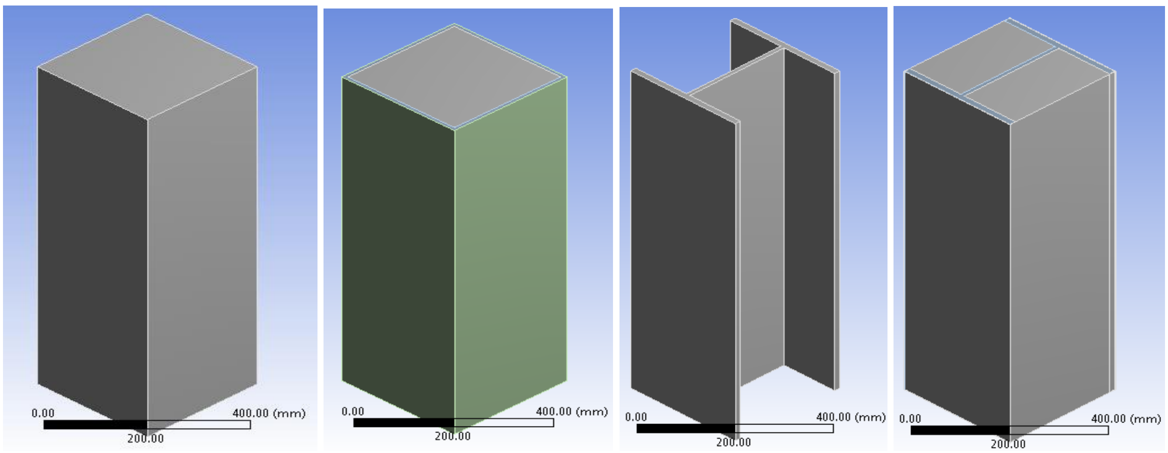
Layer	Material	Thickness (mm)	Angle (°)
12	Resin Epoxy	0.2	0
11	HEMP-EPOXY COMPOSITE	0.8	0
10	HEMP-EPOXY COMPOSITE	0.8	0
9	HEMP-EPOXY COMPOSITE	0.8	0
8	HEMP-EPOXY COMPOSITE	0.8	0
7	HEMP-EPOXY COMPOSITE	0.8	0
6	HEMP-EPOXY COMPOSITE	0.8	0
5	HEMP-EPOXY COMPOSITE	0.8	0
4	HEMP-EPOXY COMPOSITE	0.8	0
3	HEMP-EPOXY COMPOSITE	0.8	0
2	HEMP-EPOXY COMPOSITE	0.8	0
1	Resin Epoxy	0.8	0

Quantitative Analysis

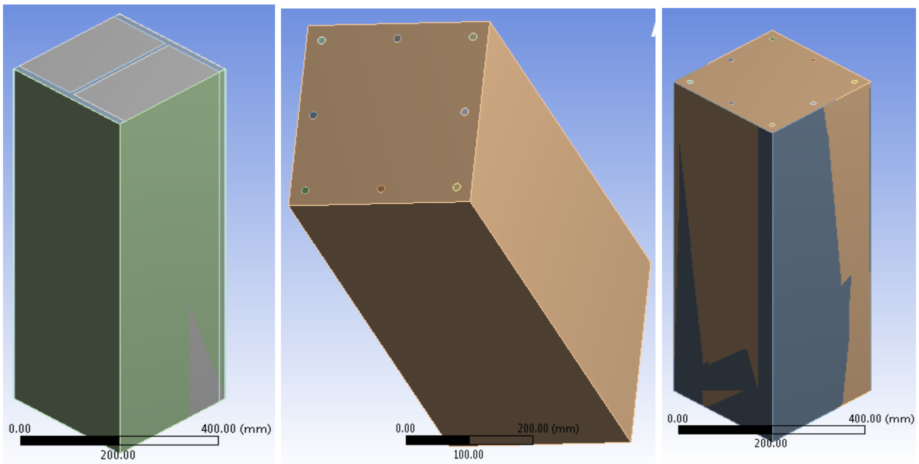
The behaviour of FRP-encased composite columns under UDL – uniformly distributed axial load is determined when it is impacted at an instance. It is carried out by performing a preliminary design of seven different types of column structures and the investigation includes the given columns in three different specified storey heights viz. 900mm, 1500mm and 2100mm. An efficient 3-D finite element model for each column's prototype is modelled, and then comparison is done accordingly with different parameters such as total and directional deformation, equivalent von-mises stress criteria, equivalent elastic strain, normal and shear stresses as well as the strains developed due to them. The 7 types of column structures employed in the present investigation as shown through figure 2 (a-g) are as:

(a) Concrete column of dimensions = (300x300) mm. – (C)
(b) Concrete column of dimensions = (300x300) mm with a FRP casing of 9mm thick layers. – (CF)
(c) H- Section Steel column = flange (300x15)mm and web (270x10)mm. – (S)
(d) Composite steel-concrete column. (S) embedded in (C). – (SC)
(e) Composite steel-concrete column with FRP casing. 9mm layer over (SC)
(f) Concrete column (C) with 8 nos. 12mm dia steel reinforcements. – (SRC)
(g) Reinforced concrete column with FRP casing of 9mm layup. – (SRCF)

Therefore, a total of 21 cases are investigated to justify the use of Hemp Fibre reinforced polymer jackets. The Impact Force as applied in all the cases is 5×10^6 N.



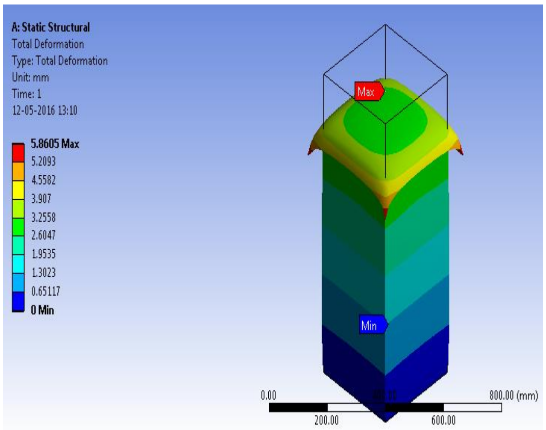
(a) (b) (c) (d)



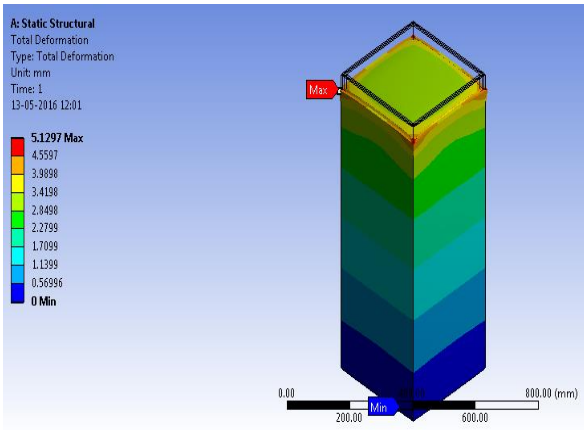
(e) **(f)** **(g)**

Fig.2 (a-g): Different types of column models in the problem

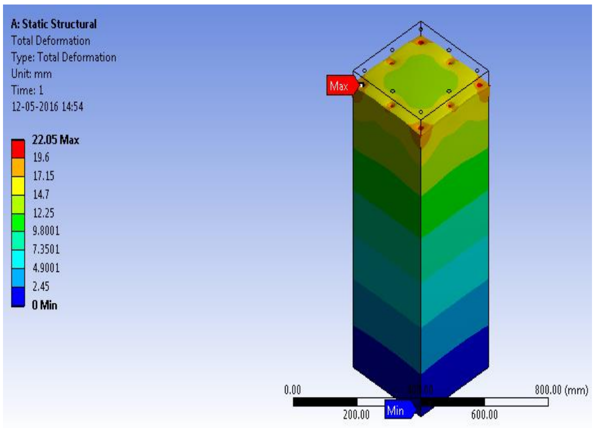
A uni-axial compressive force is applied on the column from the top at an instance providing an impact to the structure. This uniformly distributed load provides a direct compressive stress to the structure and thus, deformation and strains are produced in the element. These parameters are thoroughly defined and plotted to compare the efficiency and strength of these different types of columns. The deformed structural models with their respective maximum and minimum values are shown in Fig.3 (a-g).



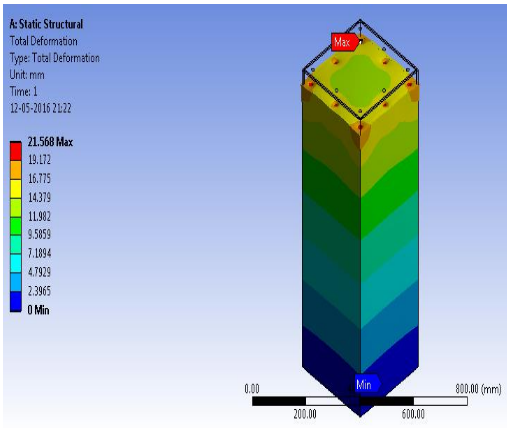
(a) Concrete Column "C"



(b) Concrete + FRP Column "CF"



(c)Steel-Reinforced Concrete Column "SRC"



(d) Steel-Reinforced Concrete Column + FRP "SRCF"

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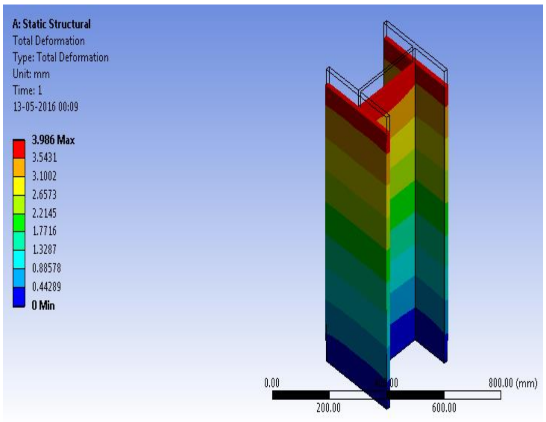
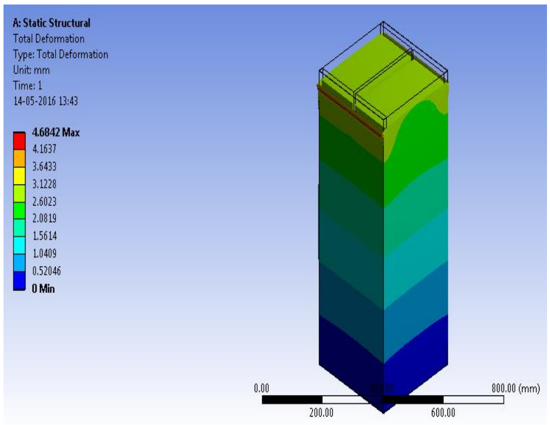
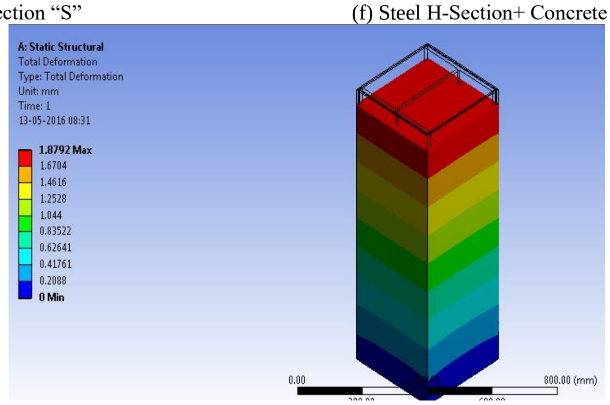


(e) Steel H-Section “S”



(f) Steel H-Section+ Concrete Column “SC”



(g) Steel H-Section+ Concrete + FRP Column “SCF”

Fig.3 (a-g): Deformed Structural models of the seven column cases.

4. RESULTS AND DISCUSSION

The main purpose of the study was to determine the effects of axial compressive load on the structural steel-reinforced concrete and composite columns. To achieve this, an analysis on the concept of finite element method was conducted with all appropriate parameters and data was acquired. This data was then analyzed to provide insights into encased composite column behaviour under uniformly distributed impact loading. Factors explored include von-mises stress calculation, various forms of stresses and strains (shear and normal) and deformations. Observations are made with the help of plots of reduced data and graphics of the column behaviour.

Further, graphs are plotted against their comparable column cases, and their significance is presented.

The total deformation & directional deformation are general terms in finite element methods. Directional deformation can be put as the displacement of the system in a particular axis or a defined direction whereas, Total deformation is the vector sum all directional displacements ofthesystems.

Von-Mises stress criterion is considered the best way for design engineers to predict the strength of a specific material. Using this information, a structural engineer can say if his designs will fail. It definitely will, if the maximum Von-Mises stress value formed in the material is greater than strength of material. It works on the basis of Distortion energy theory.

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Table 3: Obtained parametric values under different conditions.

PARAMETERS	Concrete Column (C)			Concrete + FRP (CF)			Steel Reinforced Concrete (SRC)			Steel Reinforced Concrete + FRP (SRCF)		
Column Height (mm)	900	1500	2100	900	1500	2100	900	1500	2100	900	1500	2100
Total Deformation (mm)	5.8605	7.7729	9.7857	5.1297	7.1464	9.2922	22.05	32.662	43.245	21.568	31.84	42.089
Directional Deformation (mm)	0.9324	0.84866	0.78576	0.6343	0.5818	0.5335	2.3103	2.2423	2.1334	2.1356	2.0659	1.8518
Equivalent (Von-Mises) Stress (MPa)	2948	1956.7	1425.6	419.37	365.5	330.21	50742	71203	79758	47724	49968	38026
Equivalent Elastic Strain (mm/mm)	9.8266 e-002	6.5224 e-002	4.752 e-002	6.38 e-002	5.6353 e-002	5.1272 e-002	0.4954	0.4116	0.44524	0.4853	0.5127	0.48605
Normal Stress (MPa)	576.98	376.59	273.2	114.49	94.66	80.904	5614	3263	5884.4	5073	5343.1	6578.1
Normal Elastic Strain (mm/mm)	2.2382 e-002	1.4718 e-002	1.0763 e-002	1.5511 e-002	1.2012 e-002	7.5673 e-003	9.2766 e-002	0.1257	0.13428	6.6436e-002	8.8977 e-002	6.9844 e-002
Shear Stress (MPa)	422.72	278.18	200.48	156.8	138.52	125.82	13450	15264	16980	11734	13412	14378
Shear Elastic Strain (mm/mm)	3.3254 e-002	2.1883 e-002	1.5771 e-002	8.8912 e-002	7.8551 e-002	7.1349 e-002	0.5087	0.4858	0.49246	0.4665	0.59059	0.5711

PARAMETERS	H-Section Steel (S)			H-Section Steel+ Concrete (SC)			H-Section Steel + Concrete + FRP (SCF)		
Column Height (mm)	900	1500	2100	900	1500	2100	900	1500	2100
Total Deformation (mm)	3.986	6.5383	9.1255	4.6842	6.5059	8.4544	1.8792	3.1334	4.3886
Directional Deformation(mm)	0.2588	0.2473	0.2456	0.28375	0.30167	0.25877	9.2457	9.2402e-002	9.1592e-002
Equivalent (Von-Mises) Stress (MPa)	2940.6	1675.3	2234.5	12271	8460	6868.3	815.6	714.01	719.29
Equivalent Elastic Strain (mm/mm)	1.4703 e-002	8.3767 e-003	1.118 e-002	0.40903	0.28202	0.22896	5.1779e-003	4.3319e-003	3.9492e-003
Normal Stress (MPa)	794.43	242.22	258.13	662.84	563.86	596.32	72.056	63.251	51.543
Normal Elastic Strain (mm/mm)	4.4314 e-003	2.4919 e-003	4.0764 e-003	1.7192e-002	1.302e-002	6.608e-003	1.2037e-003	1.1588e-003	1.11e-003
Shear Stress (MPa)	594.38	459.31	353.43	931.88	549.82	661.16	221.48	198.56	182.43
Shear Elastic Strain (mm/mm)	7.7269 e-003	5.971 e-003	4.5947 e-003	7.3308e-002	4.3253e-002	5.2011e-002	2.8793e-003	2.5812e-003	2.3716e-003

Comparison between Concrete (C) and Concrete +FRP (CF) Columns

Total and directional deformation

The plots in fig.4 (a) and (b) clearly depicts how even after increasing the surface area of impact with marginal 9mm of FRP casing, the total deformation and the directional deformation along the planar axis is less than the original concrete column. This shows how the casing increases the compressive strength of the structure.

Equivalent von-mises stress and elastic strain

The graph fig.4 (c) shows that the encased column induces less magnitude of stress for the same compressive force applied. This in turn shows how FRP confinement will lead to less strain formation, thus deformation will be minimized. Here, plot in fig.4 (d) shows that the strain produced will be marginally less in short columns than their Non-encased counterpart while the same concept will fail in longer and much slender columns for the same load, with a unidirectional FRP casing.

Normal stress and normal elastic strain

The plots (e) and (f) in fig.4 depicts the advantageous behaviour of FRP casing, as the magnitude of normal stress and strain, thus produced is less than that in original column without confinement.

Shear stress and shear elastic strain

The plots in fig.4 (g) and (h) depict the stress and strain produced in the structure. While it manages to induce less amount of stress in the structure, the strain so formed surpasses the barrier and leads to shear failure. This shear failure is observed due to the orientation of the FRP casing. Had it been orthogonally or multi-directionally oriented, the casing would have been able to withstand this stress.

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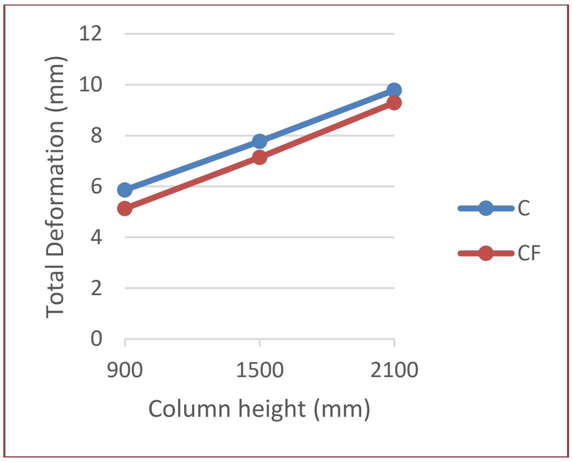

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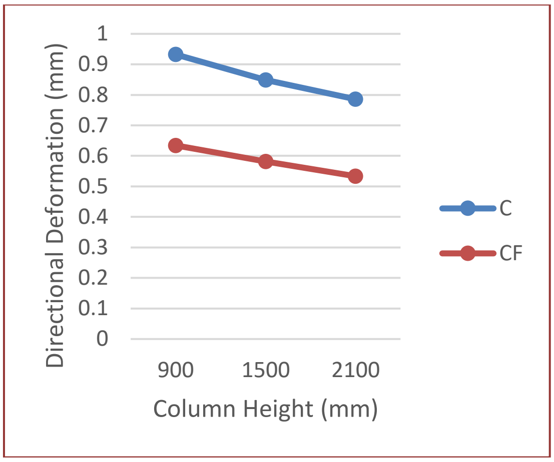

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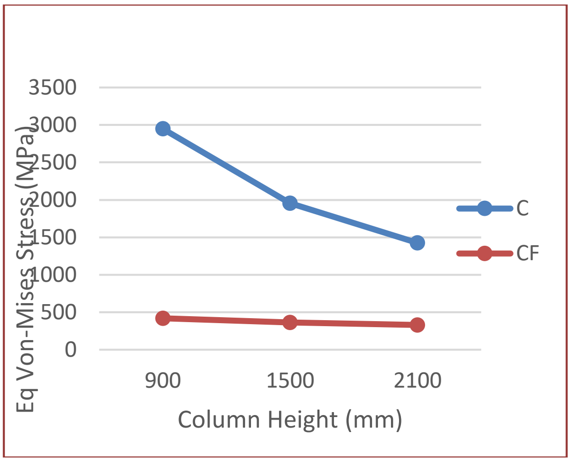
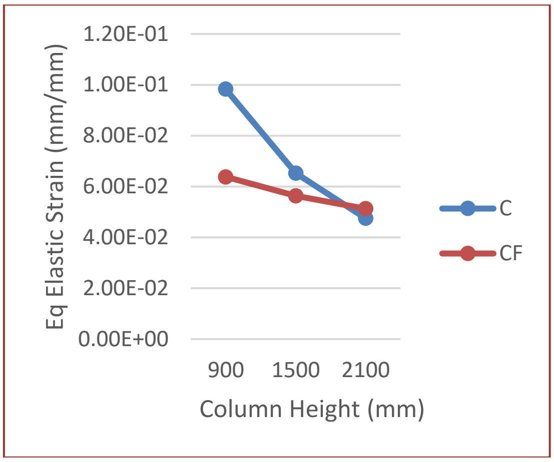
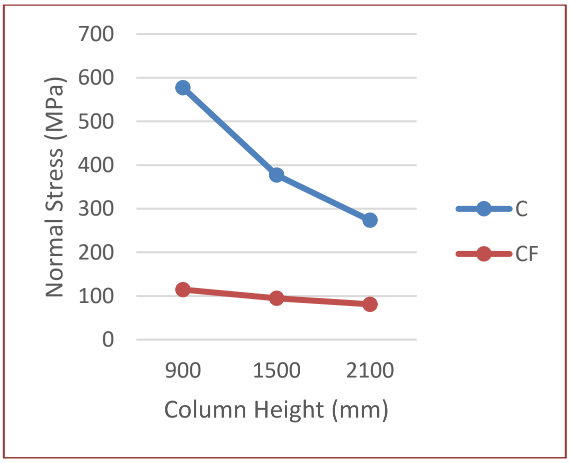


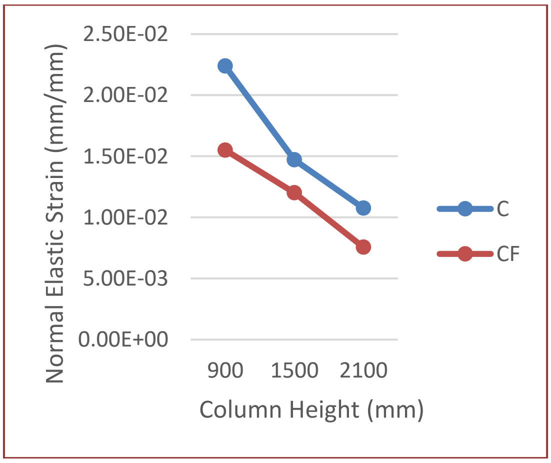
(c)



(d)



(e)



(f)

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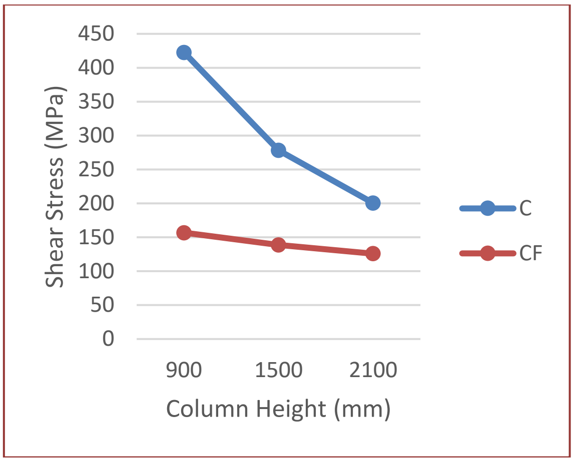
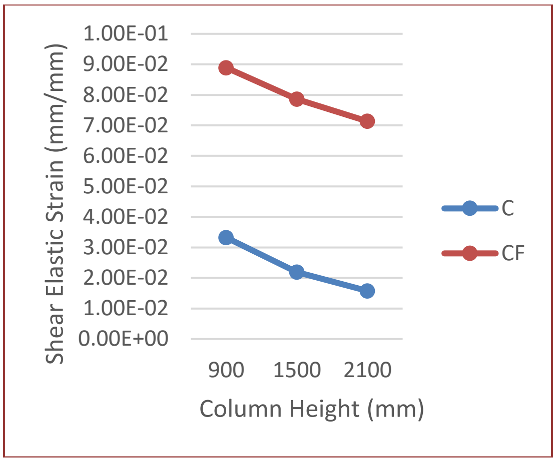


(g)



(h)

Fig.4. Graphical plots of parameters between Concrete (C) and Concrete +FRP (CF) Columns

Comparison between Steel-Reinforced Concrete (SRC) and Steel-Reinforced Concrete + FRP (SRCF) Columns

Total and directional deformation

The plots in fig.5 (a) and (b) depicts how after increasing the surface area of impact with 9mm of FRP jacket, the total deformation and the directional deformation along the planar axis is less in SRCF than the SRC column. This shows how the casing increases the compressive strength of the structure.

Equivalent von-mises stress and elastic strain

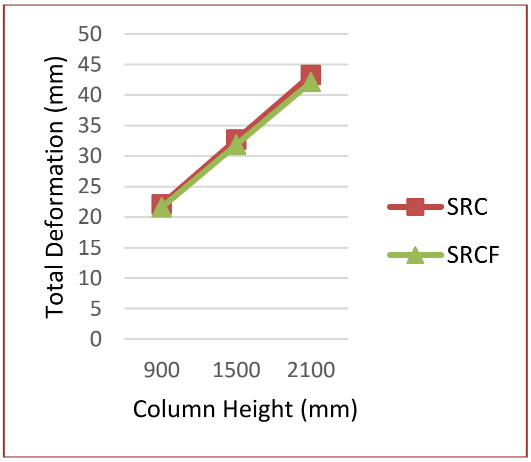
The graph (c) in fig.5 shows that the encased column SRCF induces less magnitude of stress for the same compressive force applied, as the height of column is increased. This in turn shows how FRP confinement will lead to less strain formation, thus deformation will be minimized. The second plot (d) in fig.5 shows that the strain produced will be marginally less in short columns than their Non-encased counterpart while the same concept will fail in longer and much slender columns for the same load, with a unidirectional FRP casing.

Normal stress and normal elastic strain

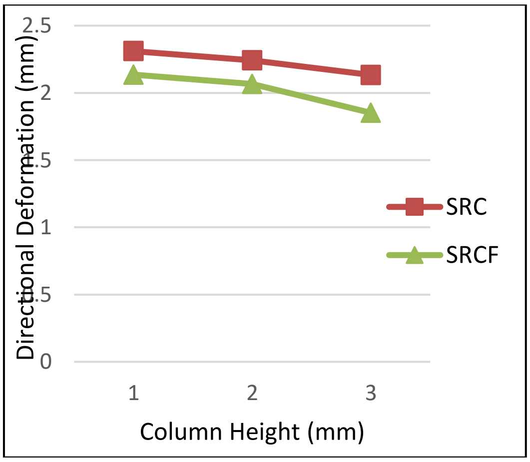
The graph (e) in fig.5 shows how normal stress acts with a steel-reinforced concrete column structure. In a short column, the presence of the confining retrofit proves to be beneficial whereas when the column height is increased, the stress values soars above their counterparts due to the brittle nature of the composite. The Resin matrix in any composite is responsible for this brittle nature and is a topic of further research. The plot in fig.5 (f) depicts the advantageous behaviour of FRP casing when it boils down to calculating strain and deformation in the structure, as the magnitude of normal strain produced in SRCF is less than that in original column SRC.

Shear stress and shear elastic strain

The plots (g) and (h) in fig.5 depict the stress and strain produced in the structure. While it manages to induce less amount of stress in the structure, the strain so formed surpasses the barrier and leads to shear failure. Still, the casing is able to resist shear failure in short columns, but fails when slenderness or height is increased. This shear failure is observed due to the orientation of the FRP casing. Had it been orthogonally or multi-directionally oriented, the casing would have been able to withstand this stress.



(a)



(b)

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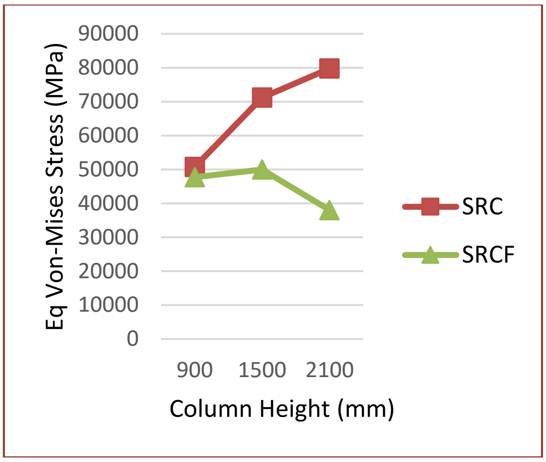
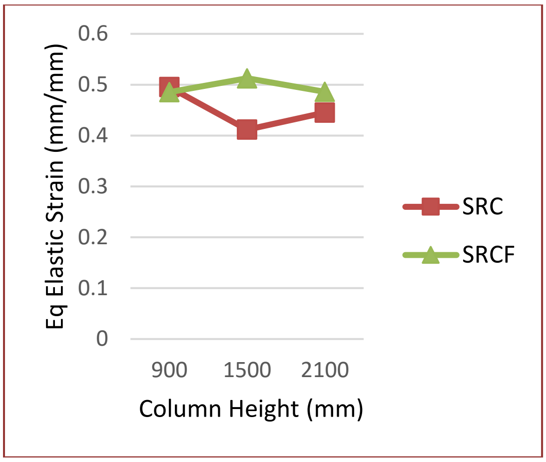
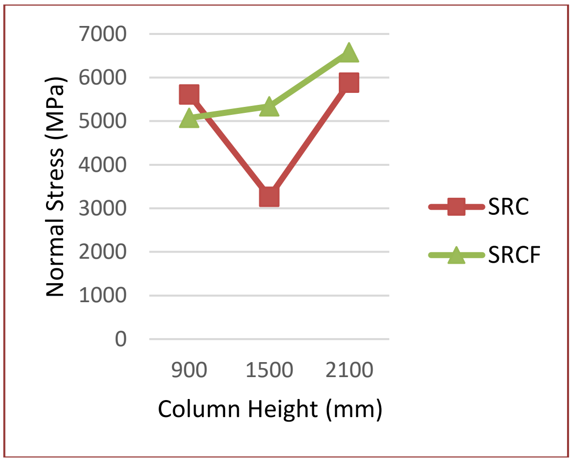


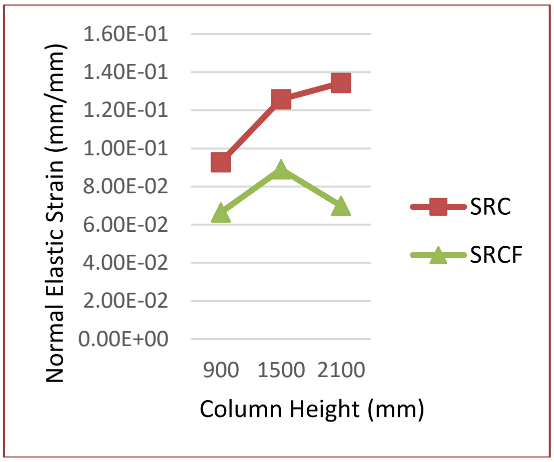
(c)



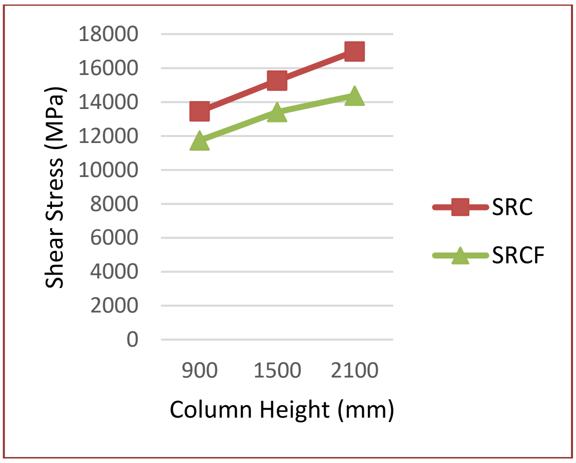
(d)



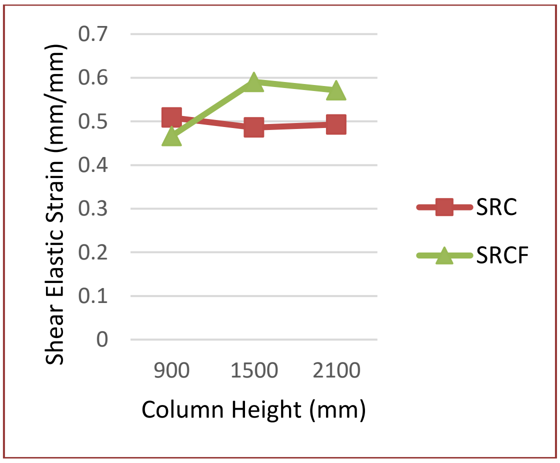
(e)



(f)



(g)



(h)

Fig.5 (a-h): Graphical plots of parameters between Steel-Reinforced Concrete (SRC) and Steel-Reinforced Concrete + FRP (SRCF) Columns.

Comparison between Concrete (C), Steel (S), Steel +Concrete (SC) and Steel +Concrete +FRP (SCF) Columns

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Total and directional deformation

The plots in fig.6 (a) and (b) proves how even after increasing the surface area of impact with marginal 9mm of FRP casing, the total deformation and the directional deformation along the planar axis is the least in SCF than their basic counterparts C, S or SC. This shows how the casing increases the compressive strength of the structure.

Equivalent von-mises stress and elastic strain

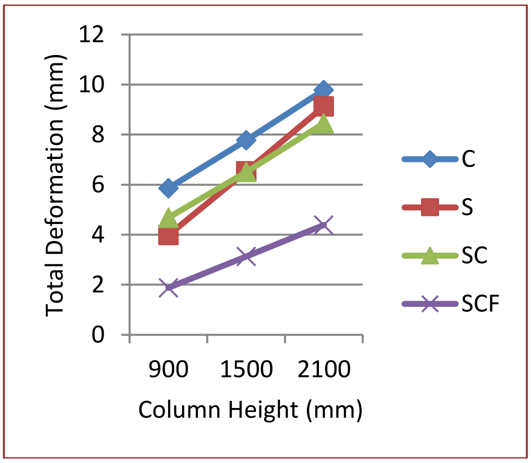
The graphs (c) and (d) in fig.6 shows that the encased column induces less magnitude of stress for the same compressive force applied. This in turn shows how FRP confinement will lead to less strain formation, thus deformation will be minimized. The same concept is applied on strain produced in the column. The amount of strain produced is marginally less in the FRP-encased column, than its counterparts. Thus, deformation will be slightly less.

Normal stress and normal elastic strain

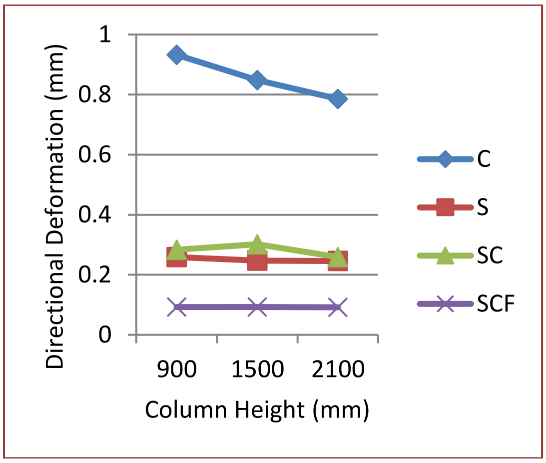
The plots (e) and (f) in fig.6 proves that the FRP casing provides a positive impact on the stress and strain produced due to a normal force. Both of these parameters are less in SCF column when compared to its counterparts, C, S and SC.

Shear stress and shear elastic strain

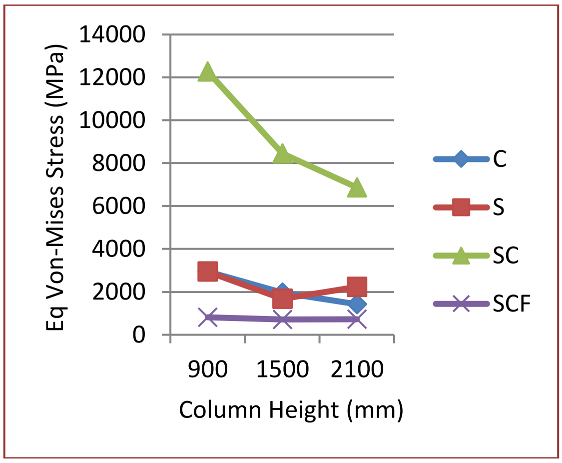
The plots fig.6 (g) and (h) depicts the stress and strain produced in the structure. The FRP casing in the SCF column is able to cut down the Shear stress and strain with a marginal difference, thus leading to less probability of deformation and shear failure.



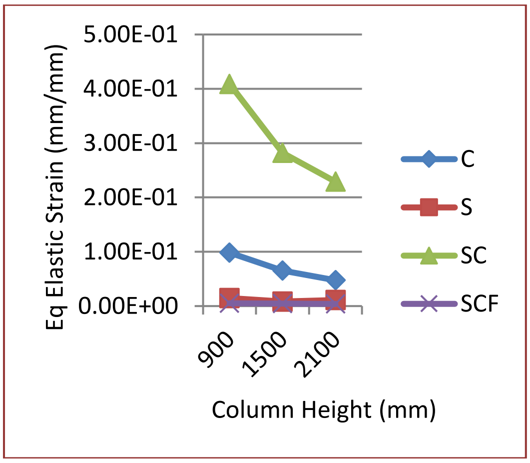
(a)



(b)



(c)



(d)

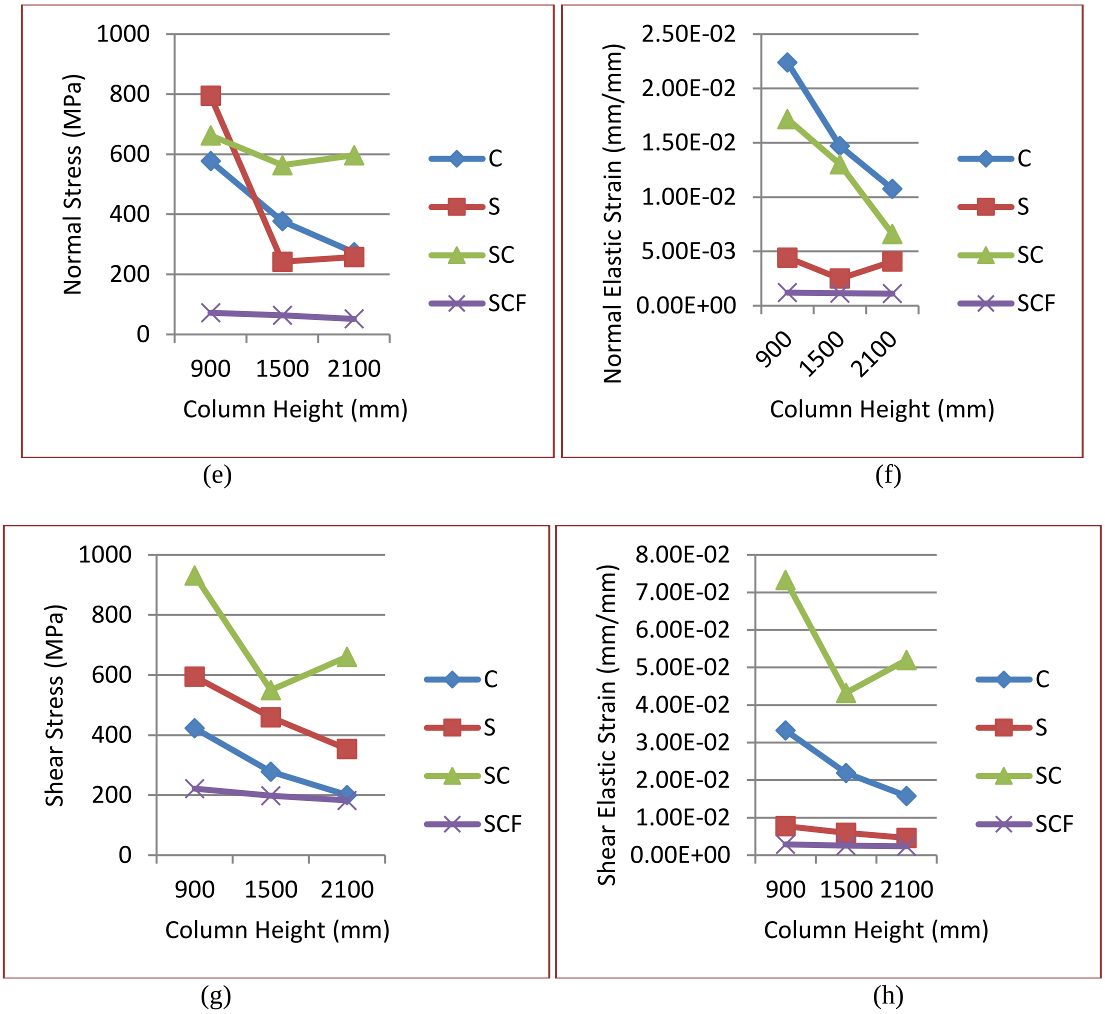


Fig.6 (a-h): Graphical plots of parameters between Concrete (C), Steel (S), Steel + Concrete (SC) and Steel + Concrete + FRP (SCF) Columns

5 CONCLUSIONS

It is apparent from results and comparisons that confinement effect of composite columns provides enhancement of strength and ductility up to a certain column height. The strain produced in the structure increases with respect to the increase in slenderness ratio. Different forms of composite columns indicate different behavior when it comes to shear or normal strains. Column with embedded steel H-section shows better performance with FRP casing while a steel-reinforced concrete column fails to do so. In present study numerical model is proved to be very successful as with respect to the results obtained under different conditions. Therefore, the same can be used in under different conditions such as loading type, size of columns, non-elasticity of concrete or the resistance or ductility of columns. The present numerical model is proved to be successful for the safe design and economical strengthening of concrete columns using natural FRP.

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