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Numerical Analysis of Strengthening of Fire Damaged RC columns using GFRP and ppFibre based Cementitious Composites

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Abstract: This paper illustrates the principle aspects connected with numerical analysis of thermal stress induced by high gradient temperature in the reinforced concrete columns. Axial compression test is conducted on two un-strengthened fire affected columns UC (C1, C2) and two strengthened fire affected columns SC (C3, C4) and results are compared. The two phases (up to 500˚Cand900˚C) of standard fire curve ISO834 are simulated for different fire intensities for columns.Numerical analysis is carried out to check the crack patterns, stress and strain distribution in both un-strengthened and strengthened members. The results shows that strengthening is effective for columns affected by fire up to 500˚C, which could effectively restore the strength and stiffness in fire damaged columns.

Keywords:Beams, Corroded rebar, flexure, glass sheets, cement based composites, Epoxy.

1. Introduction

At present concrete structures are vulnerable to fire due to combustible materials and unavoidable accidents. Retrofitting of fire damaged structural components using glass fiber sheet and cement based composite binders is the recent effective technique. This technique does not increase the deadweight of the members (2), (3), (4), (8), (12) and (14).

Concrete which is not densified by micro silica and with moisture content of 3% would not allow for spalling in structural components (6).

The effect of restrained degree, loading level and heating rates on the performance of concrete columns were studied under elevated temperatures and found that use of polypropylene fibers prevent explosive.Studies shows that under restraint condition normal strength concrete showed more spalling compared to high strength concrete. It was decided that explosive spalling occurred after 45min of heating. Minor spallings were followed by severe spallings(5).For flexural components, increasing the cover concrete would not increase the fire resistance (15).

2D transient nonlinear thermal analysis was developed along with smeared rotating crack approach to study the thermal behaviour of concrete structures (16). Design equation with energy based time equivalent approach for evaluating the fire resistance of beams predicted better than the codal provisions (11)Numerical behaviour of reinforced concrete slabs under fire loading was investigated and concluded that the cover of concrete, reinforcement temperature and live load ratio play a major role in fire resistance of slabs(13). Many other researchers carried out the numerical analysis of concrete structures (7), (17)From the above studies it was concluded that strengthening of columns using wrapping technique is very effective. Present study aims in retrofitting fire damaged concrete columns using similar techniques. But the binder used for bonding the glass fiber sheet is polypropylene fiber based cementitious composites.

2. Thermal Analysis

2.1 Principle

The basis of thermal analysis in ANSYS is a heat balance equation obtained from the principle of conservation of energy. The finite element solution uses the nodal temperature to obtain the thermal quantities. It supports two types of thermal analysis they are, Steady state thermal analysis to determine the thermal distribution and other thermal quantities under steady state loading conditions. Transient thermal analysis todetermine the temperature distribution and other thermal quantities under condition that vary over a period of time.

2.2 Modeling

The columns and supports were modeled as volumes whereas the steel rebars were modeled as lines. Knowing the co-ordinates, the key points are joined by the lines. Then area and volume is created.

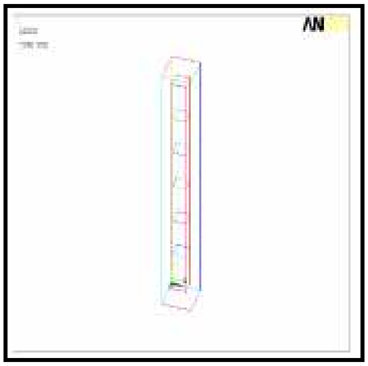
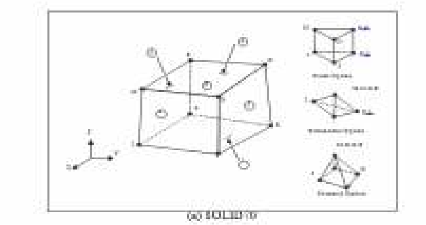


Figure 1. Modelling of columns

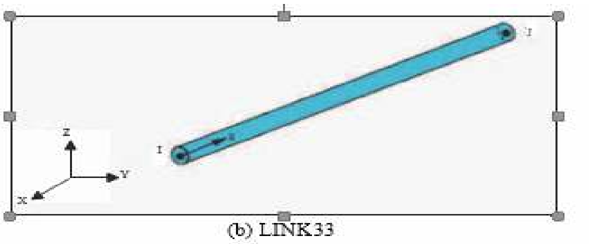
2.3Elements for meshing

Solid 70 shown in Fig 1 is used to model the concrete. It has eight nodes with a single degree of free dom at each node, defined as temperature as well as3-Dthermal conduction capability. It also has 2×2×2 integration scheme for both conductivity and specific heat matrices crushing.



(a) SOLID 70

Figure 2. Element Solid 70

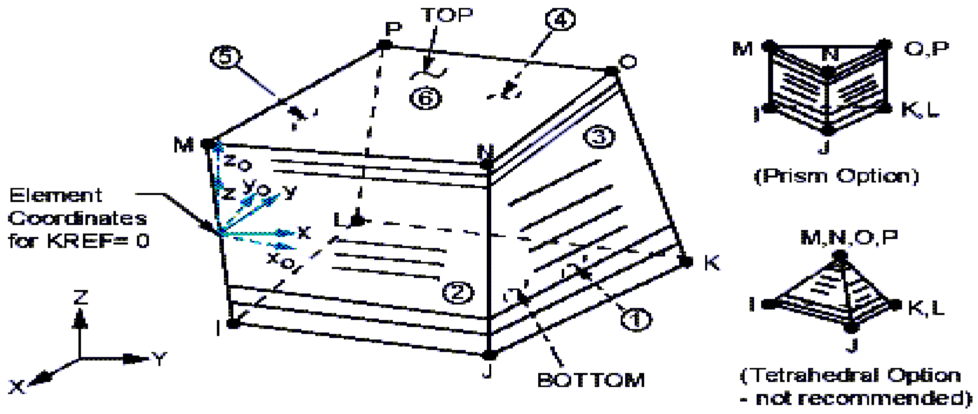


(b) LINK33

Figure 3Element Link33

Link33 is a thermal uni axial element with the ability to conduct heat between its two nodes shown in Fig.2. The element has a single degree of freedom, temperature, at each node. In addition, both elements are applicable to conduct3-D, steady-state and/or transient thermal analysis. Steel reinforcement is modeled using Link 8 element shown in Fig. 3. It is a 3D spar element having two nodes with three degrees of freedom – translations in the x, y and z directions. This element is also capable of plastic deformation.

A 3-D layered structural element Solid 46 was used to model FRP composites shown in Fig.4. This element allows up to 250 layers. The element has three degrees of freedom at each node- translation in x, y and z directions. The element is defined by eight nodes, layer thickness, layer material direction angles and orthotropic material properties.



x_o = Element x-axis if ESYS is not supplied.

x = Element x-axis if ESYS is supplied.

Figure 4. Element Solid 46

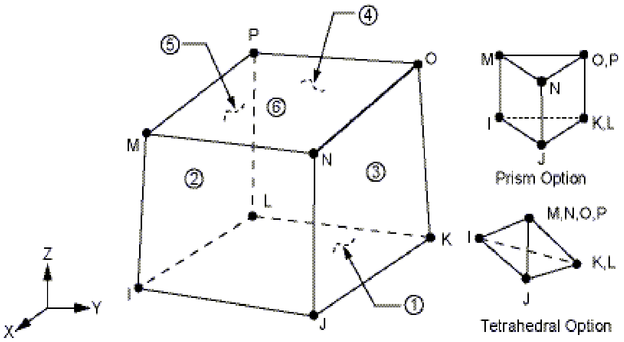


Figure 5.Element Solid 65

The Solid 65 element was used to model the concrete shown in Fig.5. 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.

2.4 Material properties

The material model for each element has multiple inputs. Linear material property for concrete includes Young’s modulus and poisson’s ratio. The stress- strain values from compression test was given us input for nonlinear material property as multilinear isotropic. Similarly both linear and nonlinear properties were given as input for steel. Nonlinear property was given as bilinear isotopic. GFRP along with pp fiber based cementitious composites was orthotropic and the material property given was as shown in Table 1.Thermal properties were given as input for both steel and concrete in thermal analysis. To get the crack pattern.

Table 1. Orthotropic material properties for Solid 46

Properties	Values	Properties	Values	Properties	Values
EX N/mm^2)	21000	PRXY	0.26	GXY(N/mm^2)	1520
EY(N/mm^2)	7000	PRYZ	0.26	GYZ(N/mm^2)	1820
EZ(N/mm^2)	7000	PRXZ	0.3	GXZ(N/mm^2)	2650

2.5 Meshing

The generated model was meshed using mapped mesh which helps in controlling the number of elements. The fewer the number of elements, the mesh is coarse. Refinement of the mesh increases the accuracy of the simulation. Element attributes were assigned to the respective elements. The reinforcement model was meshed using line elements so that the nodes of the line elements come exactly over the node of the solid elements which were later merged to act as a single node.

2.6 Numbering Controls

Merging process must be carried out after meshing the model. If key points are merged in advance to the nodes some of the nodes may be left out. These nodes may result in boundary condition transfers, surface load transfers and so on. Therefore merging is carried out for the nodes.

2.7 Load and Boundary Conditions

Displacement Boundary conditions are necessary to constraint the model and get a unique solution. Boundary conditions were bottom end is fixed and loading end is released in Y direction to allow for axial movement.Load was applied uniformly on the upper end as nodal loads.Reaction from bottom plate would apply equal compressive force on the column.

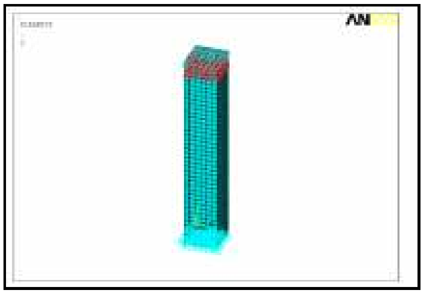


Figure 6.Loading and boundary conditions

2.8 Nonlinear Solution

A nonlinear structural analysis was performed using Newton-Raphson approach. The load is subdivided into a series of load increments. The iterative procedure is continued until the problem converges. A number of convergence enhancement features like automatic load stepping, bisection help the problem to converge. The concrete crushes when its ultimate compressive strength is reached.

3. Results And Discussion

The columns are loaded on three faces treating them as exterior columns. The temperature load was used to calculate thermal stress. Load was applied on fire damaged columns without and with wrapping. The results are compared.

3.1 Thermal load of 500°C

The temperature distribution in column are as shown in Figure 7.Crack pattern in C3 shows that strengthening have controlled the cracking in C1 as shown in Figure 8 (a) and Figure 8 (b).

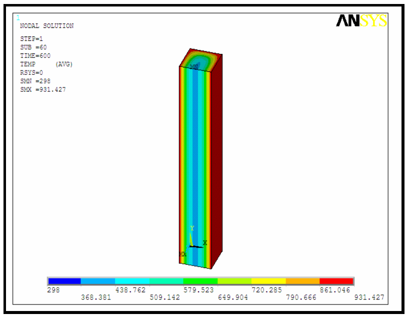
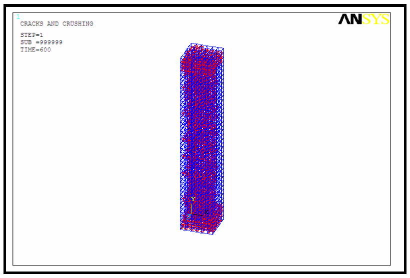
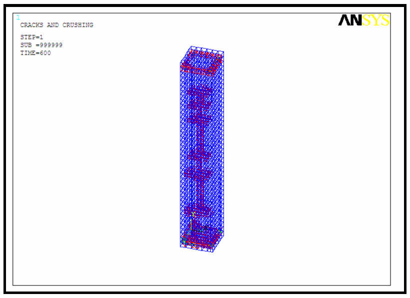


Figure 7. Temperature distribution in column C1



(a)Crack pattern in C1



(b) Crack pattern in C3

Figure 8.Control of cracking in C1 due to wrapping

Percentage reduction in stress and strain due to wrapping are 50.3% and 77.02% respectively. Similarly the load deflection behavior shows an increase in stiffness and energy absorption as 38.88% and 20.32% respectively compared to C1.

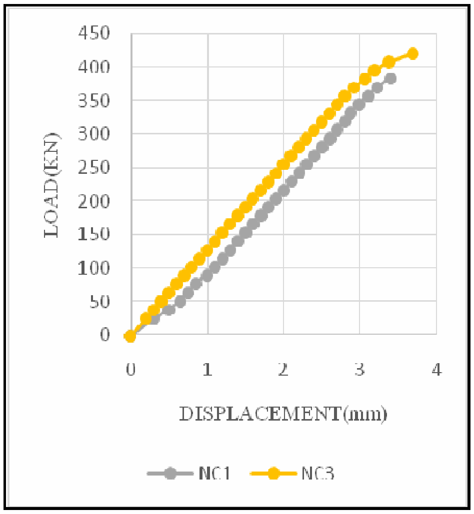


Figure 9. Load-Deflection behavior for thermal load of 500°C

3.2 Thermal load of 900°C

The temperature distribution in column are as shown in Figure 10. Crack pattern in C4shows that strengthening have controlled the cracking in C2 as shown in Figure 11 (a) and Figure 11 (b).

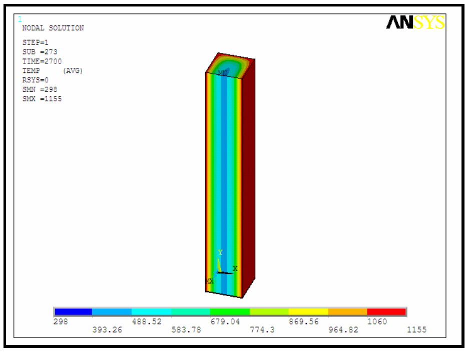
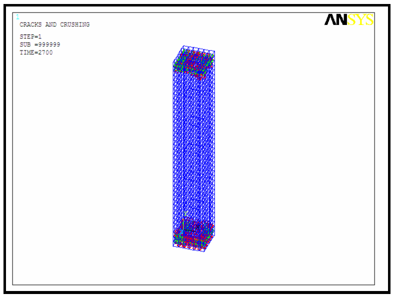
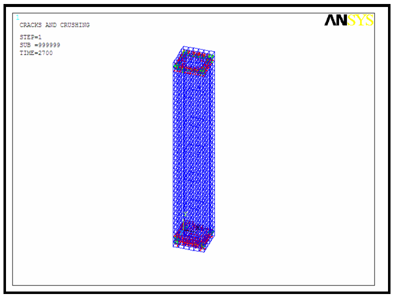


Figure 10. Temperature distribution in column C2



(a) Crack pattern in C2



(b) Crack pattern in C4
Figure 11.Control of cracking in C2 due to wrapping

Percentage reduction in stress and strain due to wrapping are 19.65% and 62.66% respectively. Similarly the load deflection behavior shows an increase in stiffness and energy absorption as 8.86% and 20.54% respectively compared to C2.

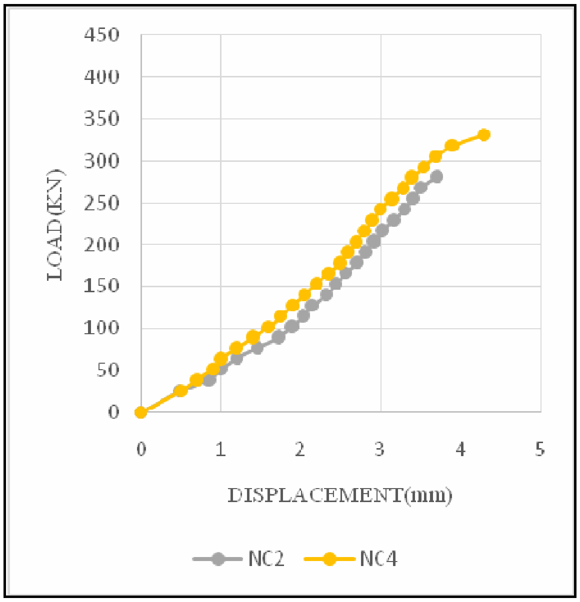


Figure 12. Load-Deflection behavior for thermal load of 900˚C

Failure in columns subjected to thermal load of 900˚C was by local material crushing. While the load deflection behavior of strengthened columns were compared for both fire intensities, strengthening was found to be effective for fire load of 500˚C. The percentage increase in energy absorption for column C3 was 211.44% compared to column C4. Similarly percentage increase in stiffness for column C3 was 45.34% compared to column C4.

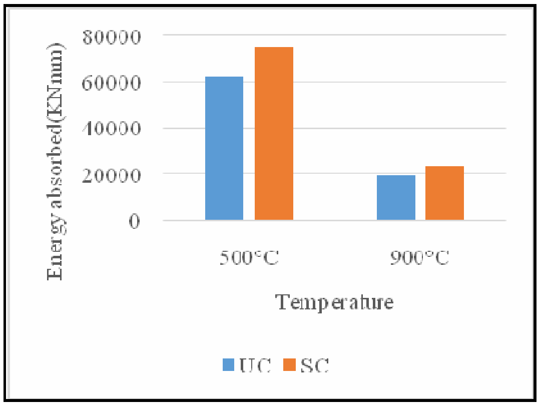


Figure 13. Comparison of energy absorption in columns

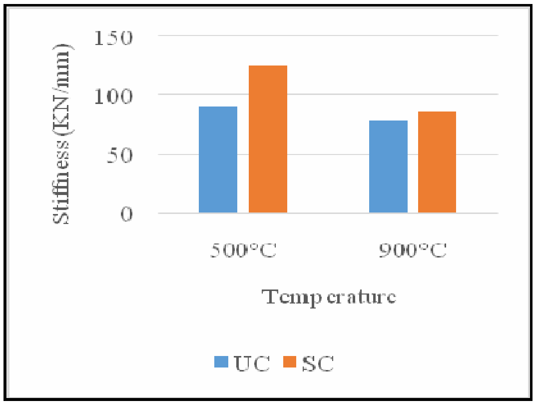


Figure 14. Comparison of stiffness in columns

Conclusion

Numerical thermal stress analysis were carried out on four columns. Two phases of ISO834 fire curve was followed. Column C1 and C3 are subjected to 500˚C. Column C2 and C4 are subjected to 900˚C. Nonlinear stress analysis were carried out on fire damaged columns without (C1 and C2) and with wrapping(C3 and C4).Following conclusions were arrived.

- Due to wrapping cracking is controlled for both fire intensities.
- Percentage reduction in stress and strain in C3 due to wrapping are 50.3% and 77.02% respectively compared to C1. Percentage reduction in stress and strain in C4 due to wrapping are 19.65% and 62.66% respectively compared to C2.
- Percentage increase in stiffness and energy absorption in C3 are 38.88% and 20.32% respectively compared to C1.Percentage increase in stiffness and energy absorption in C4 are 8.86% and 20.54% respectively compared to C2.

- Percentage increase in energy absorption for column C3 was 211.44% compared to column C4. Similarly percentage increase in stiffness for column C3 was 45.34% compared to column C4.
- Ultimate load carrying capacity was decreased by 27% in column C4 compared to column C2.
- Restoration of the strength and stiffness of the fire damaged columns depends on the intensity of applied heat. Though wrapping was effective for thermal load up to 500°C, it was not successful for members under fire intensity of 900°C
- Present strengthening technique is very effective for rehabilitating fire damaged RC members fired upto 500°C.Comparison of results shows that present strengthening technique is effective for fire damaged reinforced concrete columns for fire intensity up to 500°C.

References

1. ACI 440R, State-of-the-art report on fiber reinforced plastic reinforcement for concrete structures, *American Concrete Institute Committee 440, 1996.*
2. Bruce Ellingwood and Lin,T.D.(1991). "Flexure and Shear behaviour of concrete beams during fires", *J.ofStruct. Engrg,* Vol.117 (2): 440-458.
3. Francisco, J., De Caso y Basalo, Fabio Matta, and Antonio Nanni. (2012). "Fiber reinforced Cement based composite system for concrete confinement". *Construction and Build. Mater.,*Vol.32: 55- 59.
4. Farhat. A.Farhat, DemetrisNicolades, AntoniousKanellopoulos and Bhushan. L.Karihaloo(2010). "Behaviour of RC beams retrofitted with CARDIFRC after thermal cycling", *J.ofStruct. Engrg,* Vol. 22 (1): 21-28.
5. Fasis Ali, Ali Nadjai, Gordon silcock and Abid Abu Tair(2004). "Outcomes of a major research on fire resistance of concrete columns", *Fire saf. J.,* Vol.39: 433-445.
6. Hertz, K.D.(2003). "Limits of spalling of fire exposed concrete", *Fire saf. J.,* Vol.38:103-116.
7. HayderQaisMajeed. (2012), "Nonlinear finite element analysis of steel fiber reinforced concrete deep beams with and without openings"*.J.of.Engrg,* Vol.18 (12), 1421 – 1438.
8. Haddad R.H, Al-Rousan R.Z, Al-Sedyiri. (2013)."Repair of shear deficient and sulphate damaged concrete beams using FRP composites"*.EngrgStruct,* Vol.56:228-238.
9. IS456-2000. Indian standard code of practice for plain and reinforced Concrete. Fourth revision Bureau of Indian Standards (BIS): New Delhi.
10. IS: 10262-1982. Indian standard code of practice for recommended guidelines for concrete mix design-Bureau of Indian Standards (BIS): New Delhi.
11. Kodur, V.K.R, and Dwaikat.M (2011). "Design equation for predicting the fire resistance of reinforced concrete beams", *Engrgstruct,* Vol. 33: 602-614.
12. Rui Zhang, Koji Matsumoto, Takayoshi Hirata, Yoshikazu Ishizeki and Junichiro Niwa. (2014). "Shear behaviour of polypropylene fiber reinforced RCC beams with varying shear reinforcement ratio". *J. of Japan Society of Civil Engineers, Vol.2: 39-53.*
13. Said. M.Allam, Hazem M.F. Elbakry and Alaa. G. Rabeai. (2013). "Behaviour of one-way reinforced concrete slab s subjected to fire". Alex Engrg J, Vol.52: 749-761.
14. Thomas Blansksvärd, Bjorn Täljsten, and Anders Carolin. (2009), "Shear strengthening of concrete structures with the use of Mineral based composites", *J.CompoConstr,* Vol.13 :(1): 25-34.
15. Xudong Shi, Teng- Hooi Tan, Kang-Hai Tan and ZhenhaiGuo (2004). "Influence of concrete cover on fire resistance of reinforced concrete flexural members". *Alex Engrg J,* Vol.130:(8): 1225-1232.
16. YasmeenTalebObaidat, Susanne Heyden, Ola Dahlblom, Ghazi Abu-Farsakh, and YahiaAbdel-Jawad.(2011). "Retrofitting of reinforced concrete beams using composites laminates", *Constr Build Mater,* Vol.25: 591-597.
17. Zhou.C.E. and Vecchio.F.J(2005). "Nonlinear finite element analysis of reinforced concrete structures subjected to transient thermal loads", Comp concr, Vol.2: (6), 455-479.

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