Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (40) No. (1) January, 2018

# Ferrocement

**Alaa.A. Elsayed[1], Mahmoud.M. Elsayed[2], Israa.A. Mahrous[3]**
[1] Associate professor, Faculty of Engineering, Fayoum University, Fayoum, Egypt
[2] L Assistant professor, Faculty of Engineering, Fayoum University, Fayoum, Egypt
[3]M.SC Candidates, Faculty of Engineering, Fayoum University, Fayoum, Egypt

**ملخص البحث :**

فى هذا البحث تم دراسه سلوك الأعمده المعرضه للحريق والمدعمه بأستخدام الفيروسمنت وذلك بأستخدام احد برامج تحليل العناصر الانشائيه (ANSYS 13). تم تعريض الاعمده لدرجه تسخين 300°م لمده 3 ساعات وقد تم دراسه عدد من المتغيرات مثل عدد طبقات الشبك (3,2,1),سمك طبقه المونه (30,25,20,15,10) مم, نسبه التسليح الرئيسى للاعمده (4 16 8ø) , (ø 10)/م. وقد أظهرت النتائج ان التدعيم بطبقات الفيروسمنت تزيد من المقاومه للحريق وكلما زاد عدد طبقات شبك الحديد وسمك المونه الاسمنتيه كلما زادت المقاومه .

## Abstract

In this work, numerical study was carried out to investigate the behavior of heated RC short columns confined by ferrocement laminates. Sixty RC columns were analyzed by using finite element software (ANSYS 13).All heated columns were heated at a temperature of 300$^{o}$C for 3 hours. Four parameters were considered; longitudinal reinforcement ratio (4Φ10, 8Φ16), ferrocement thickness (10,15,20,25,30)mm, mortar grade (45,75)MPA, and number of wire mesh (1, 2, and 3).The results proved that the repairing scheme has efficiency in surpassing the failure load of and improving the ultimate strength of heated columns significantly. The ultimate failure load of wrapped columns is increased up to 260.2% compared with heated columns.

**Key Words:** Repair, RC columns, Heat, Ferrocement, ANSYS

## 1. Introduction

A column is a structural element whose main function is to support axial forces. Most of research works in field focus on axially loaded columns. Many old structures became structurally insufficient to carry the new loading conditions requirements their collapse during a fire can be detrimental to the stability of the rest of the structure. The modes of concrete failure under fire exposure vary according to the nature of fire. Concrete structures in general have a reputation of having good behavior in fire conditions as not many fires have led to a collapse of the structure even in severe fires. Consequently, cracking and spalling of concrete columns after fire. Common methods of strengthening columns include fiber reinforced polymer (FRP), concrete jacketing, steel jacketing, or ferrocement jacketing. All these techniques have shown the effective increase in axial load capacity of columns. Reinforcing or confining concrete columns with ferrocement have received significant attention for use in civil infrastructures due to their unique properties. An important application of ferrocement composites is to provide confinement to reinforced concrete (RC) columns to enhance their load-carrying capacity. This research is aimed at investigating numerically the effect of ferrocement on the behavior of axially loaded reinforced concrete columns subjected to heating and to estimate the Increase in the column failure load above heated column. The evaluation of the behavior of building structures in fire is very easy using numerical modeling .Numerical methods are adopted to obtain approximate solutions for differential equations. Nonlinear analyses are done by the use of finite element software, to study the ultimate axial load behavior of the columns. A great number of studies in the field of concrete mechanics has been recently devoted to evaluate the behavior of confined concrete. Structural analysis is probably the most common application of the finite element method.

There are several repair and strengthening techniques are being and used to increase strength and ductility of reinforced concrete structures in an effort to extend their useful service life.

Nasser, K.M, andShihada.[1] studied improving fire resistance of reinforced concrete columns. F. Serag.[2] studied effect of fire exposure on residual load capacity of short columns. Bikhiet et al.[3]carried out an experimental and numerical investigation of columns exposed to fire under axial load to evaluate reduction in column compressive capacity after fire. Comparison between experimental results and theoretical analysis indicated that for columns not exposed to fire, the first crack appeared at 80% of column failure load while the first crack occurred at 50% of column failure load for columns exposed to fire, Columns with the same reinforcement percentage but with smaller bar diameters gained less lateral strain and smaller vertical displacement than columns with bigger bar diameters. Mourad and Shannag [4] carried out an experimental investigation to repair and strength of reinforced concrete square columns using ferrocement jackets. The results indicated that ferrocement jackets have been utilized as an alternative repair/strengthening technique for increasing the axial load carrying capacity and ductility of tied R.C. columns. Kaish et. al. [5] studied the effect of ferrocement jacketing with some modifications. Three types of ferrocement jacketing techniques were used to confine the column specimens that are; square jacketing with single layer wire mesh and rounded column corners (RSL); square jacketing using single layer wire mesh with shear keys at the centre of each face of column (SKSL) and square jacketing with single layer wire mesh and two extra layers mesh at each corner (SLTL) are considered for this purpose .Xiong.[6] Studied strengthening the plain concrete columns with ferrocement technique including steel bars. Ahmed M. El-Kholy et al. [7] studied the improving confinement of reinforced concrete columns. The results showed that the columns, confined with proposed lateral reinforcement, revealed significant improvement in the strength and ductility. Lila M. Abdel-Hafiz et al. [8] studied the behavior of RC columns retrofitted with CFRP exposed to fire under axial load. The results showed that CFRP materials were still confined with the column for more than 70min with temperature. Fahmy A. Fathelbab et al. [9] studied strengthening of RC bridge slab using CFRP sheets. The results showed that attaching FRP sheets to the RC slab increased its capacity and enhanced the ductility.

The purpose of this paper is to determine behavior of post-heated RC short columns wrapped by ferrocement overlays.

## 2. Numerical work

Sixty RC columns were analyzed by using finite element software (ANSYS 13) [10].

### Finite Element Model (FEM) 2.1

Three types of elements are employed to model the tested columns. The solid element (SOLID65) was used to model the concrete and mortar. This element includes a smeared analogy for cracking tension zones and a plasticity algorithm to account for the possibility of concrete crushing in compression. SOLID65 element is an eight-node solid element used to model the concrete with or without reinforcing bars, as shown in **Figure (1)**. The internal reinforcement was modeled using the 3-D spar element (LINK8), this element allow the elastic-plastic response of the reinforcing bars. A 3-D link element (ANSYS-Link 8) is used to model the steel reinforcement (tension bars, compression bars, and shear stirrups) of the all tested specimens see **Figure (2)** The link element is a 2-node uni-axial tension-compression element with no bending capability. The solid element (SOLID45) was used to model the wire-mesh laminates. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y and z directions. **Figure (3)** shows the geometry, node locations and the coordinate system of SOLID45. This element is similar to the solid element SOLID65 with the addition of special cracking and crushing capabilities. **Table 1** shows the properties for each element.

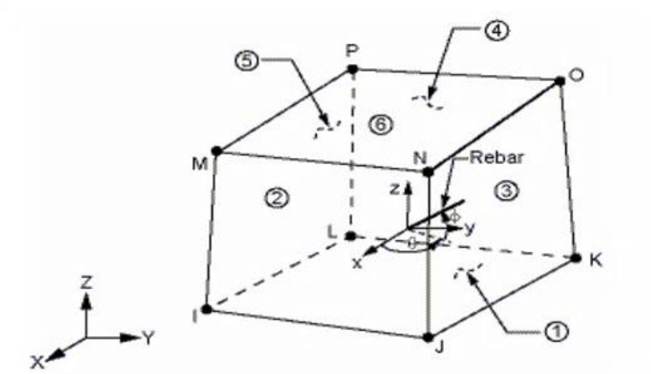



**Figure (1):** Node Locations and the Coordinate System of SOLID65

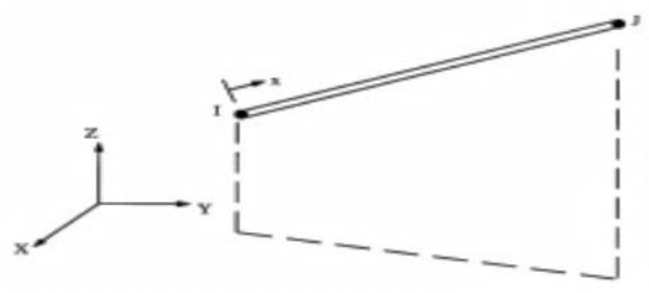



**Figure (2):** Node Locations and the Coordinate System LINK8.

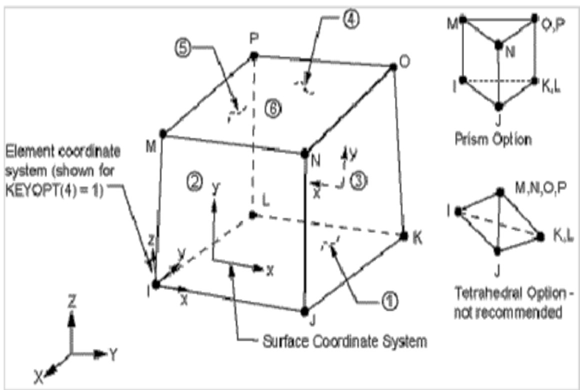



**Figure (3):** Node Locations and the Coordinate System of SOLID45.

**Table (1):** Material properties for each element.

| Material | Element type | Material properties | |
|---|---|---|---|
| **Concrete** | Solid 65 | Elastic modulus (Ex) | $4400\sqrt{fcu}$ Mpa |
| | | Uniaxial crushing stress (fc`) | fcu Mpa |
| | | Uniaxial tensile stress (ft) | $0.6\sqrt{fcu}$ Mpa |
| | | Poisson's ratio (υ) | 0.20 |
| | | Shear coefficient for open shear (ßt) | 0.20 |
| | | Shear coefficient for closed shear (ßc) | 0.85 |
| **Longitudinal reinforcement** | Link 8 | Elastic modulus (Ex) | 195000 Mpa |
| | | Yield stress (fy) | 412 Mpa |
| | | Tensile Strength | 628 Mpa |
| | | Poisson's ratio (υ) | 0.30 |
| **Stirrups** | Link 8 | Elastic modulus (Ex) | 200000 Mpa |
| | | Yield stress (fy) | 282 Mpa |
| | | Tensile Strength | 459 Mpa |
| | | Poisson's ratio (υ) | 0.30 |
| **Mortar** | Solid 65 | Elastic modulus (Ex) | 24100 Mpa |
| | | Uniaxial crushing stress (fcu) | 35 Mpa |
| | | Uniaxial tensile stress (ft) | 3.60 Mpa |
| | | Poisson's ratio (υ) | 0.20 |
| | | Shear coefficient for open shear (ßt) | 0.02 |
| | | Shear coefficient for closed shear (ßc) | 0.4 |
| **Wire Mesh** | Solid 45 | longitudinal Elastic modulus | 175000 Mpa |
| | | Yield stress (fy) | 370 Mpa |
| | | Poisson's ratio (υ) | 0.30 |
| | | Thickness | 1.35 mm |

## 2.2 Geometry and Modeling

**Figure (4)** shown ansys numerical model . a model with volumes, areas, lines and key points, a finite element analysis requires meshing of the model. The model is divided into a number of small elements, In order to gain accurate results, the full height of the columns is considered for the creation of the models with a mesh size equivalent to 50 mm. And after loading, stress and strain are calculated at integration points of these small elements.

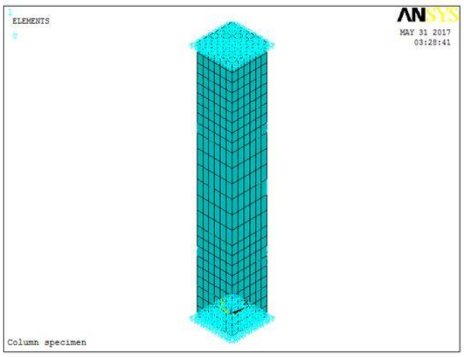



**Figure (4):** ANSYS numerical model for Specimens

## 3.3 Results and Discussion

**Table 2** shows the failure loads of the finite element models. On the basis of the numerical results, ferrocement jackets can be used to improve the load carrying capacity of the heated RC columns. The results clearly showed that ferrocement confinement leads to significant enhancements in the failure loads of the confined columns.

**Table 2:** Description of strengthened models and result

| **Group** | **Model** | **Main RFT.** | **Ferrocement thickness (mm)** | **No of wire mesh** | **Vf %** | **Compressive strength of mortar (MPA)** | **Failure Load (kN)** | **% Increase in the column failure load above heated column** |
|---|---|---|---|---|---|---|---|---|
| ------ | **C0** | 4Φ10 | Post-heated/non-jacketed ($C_0$) | | | | 283 | 0.0 |
| **1** | **C1** | 4Φ10 | 10 | 1 | 1.86 | 45 | 304.2 | 7.5 |
| | **C2** | 4Φ10 | 15 | 1 | 1.24 | 45 | 339 | 19.8 |
| | **C3** | 4Φ10 | 20 | 1 | 0.93 | 45 | 426.2 | 50.6 |
| | **C4** | 4Φ10 | 25 | 1 | 0.74 | 45 | 501.2 | 77.1 |
| | **C5** | 4Φ10 | 30 | 1 | 0.62 | 45 | 596.4 | 110.7 |
| **2** | **C6** | 4Φ10 | 10 | 2 | 3.72 | 45 | 334.4 | 18.2 |
| | **C7** | 4Φ10 | 15 | 2 | 2.48 | 45 | 362.5 | 28.1 |
| | **C8** | 4Φ10 | 20 | 2 | 1.86 | 45 | 462.6 | 63.5 |
| | **C9** | 4Φ10 | 25 | 2 | 1.48 | 45 | 544.1 | 92.3 |
| | **C10** | 4Φ10 | 30 | 2 | 1.24 | 45 | 635 | 124.4 |
| **3** | **C11** | 4Φ10 | 10 | 3 | 5.58 | 45 | 340.9 | 20.5 |
| | **C12** | 4Φ10 | 15 | 3 | 3.72 | 45 | 366.8 | 29.6 |
| | **C13** | 4Φ10 | 20 | 3 | 2.79 | 45 | 491.4 | 73.6 |
| | **C14** | 4Φ10 | 25 | 3 | 2.23 | 45 | 551.9 | 95.0 |
| | **C15** | 4Φ10 | 30 | 3 | 1.86 | 45 | 644.1 | 127.6 |
| **4** | **C16** | 4Φ10 | 10 | 1 | 1.86 | 75 | 374 | 32.2 |
| | **C17** | 4Φ10 | 15 | 1 | 1.24 | 75 | 511.2 | 80.6 |
| | **C18** | 4Φ10 | 20 | 1 | 0.93 | 75 | 643.5 | 127.4 |
| | **C19** | 4Φ10 | 25 | 1 | 0.74 | 75 | 795.7 | 181.2 |
| | **C20** | 4Φ10 | 30 | 1 | 0.62 | 75 | 935.3 | 230.5 |
| **5** | **C21** | 4Φ10 | 10 | 2 | 3.72 | 75 | 406.6 | 43.7 |
| | **C22** | 4Φ10 | 15 | 2 | 2.48 | 75 | 533 | 88.3 |
| | **C23** | 4Φ10 | 20 | 2 | 1.86 | 75 | 688 | 143.1 |
| | **C24** | 4Φ10 | 25 | 2 | 1.48 | 75 | 828.4 | 192.7 |
| | **C25** | 4Φ10 | 30 | 2 | 1.24 | 75 | 985.9 | 248.4 |
| | **C26** | 4Φ10 | 10 | 3 | 5.58 | 75 | 439.5 | 55.3 |
| | **C27** | 4Φ10 | 15 | 3 | 3.72 | 75 | 568.7 | 101.0 |
| | **C28** | 4Φ10 | 20 | 3 | 2.79 | 75 | 697.2 | 146.4 |
| | **C29** | 4Φ10 | 25 | 3 | 2.23 | 75 | 849.7 | 200.2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **6** | **C30** | 4Φ10 | 30 | 3 | 1.86 | 75 | 1019.5 | 260.2 |
| **----** | **C00** | 8Φ16 | Post-heated/non-jacketed ($C_{00}$) | | | | 598 | 0.0 |
| **7** | **C31** | 8Φ16 | 10 | 1 | 1.86 | 45 | 651.7 | 9.0 |
| | **C32** | 8Φ16 | 15 | 1 | 1.24 | 45 | 656.7 | 9.8 |
| | **C33** | 8Φ16 | 20 | 1 | 0.93 | 45 | 665.1 | 11.2 |
| | **C34** | 8Φ16 | 25 | 1 | 0.74 | 45 | 746.9 | 24.9 |
| | **C35** | 8Φ16 | 30 | 1 | 0.62 | 45 | 840.7 | 40.6 |
| **8** | **C36** | 8Φ16 | 10 | 2 | 3.72 | 45 | 721.8 | 20.7 |
| | **C37** | 8Φ16 | 15 | 2 | 2.48 | 45 | 723 | 20.9 |
| | **C38** | 8Φ16 | 20 | 2 | 1.86 | 45 | 730.7 | 22.2 |
| | **C39** | 8Φ16 | 25 | 2 | 1.48 | 45 | 764.6 | 27.9 |
| | **C40** | 8Φ16 | 30 | 2 | 1.24 | 45 | 846.2 | 41.5 |
| **9** | **C41** | 8Φ16 | 10 | 3 | 5.58 | 45 | 788.8 | 31.9 |
| | **C43** | 8Φ16 | 15 | 3 | 3.72 | 45 | 796.3 | 33.2 |
| | **C43** | 8Φ16 | 20 | 3 | 2.79 | 45 | 820.4 | 37.2 |
| | **C44** | 8Φ16 | 25 | 3 | 2.23 | 45 | 888.7 | 48.6 |
| | **C45** | 8Φ16 | 30 | 3 | 1.86 | 45 | 982.4 | 64.3 |
| **10** | **C46** | 8Φ16 | 10 | 1 | 1.86 | 75 | 808.8 | 35.3 |
| | **C47** | 8Φ16 | 15 | 1 | 1.24 | 75 | 913.8 | 52.8 |
| | **C48** | 8Φ16 | 20 | 1 | 0.93 | 75 | 1052.8 | 76.1 |
| | **C49** | 8Φ16 | 25 | 1 | 0.74 | 75 | 1192.7 | 99.4 |
| | **C50** | 8Φ16 | 30 | 1 | 0.62 | 75 | 1336.3 | 123.5 |
| **11** | **C51** | 8Φ16 | 10 | 2 | 3.72 | 75 | 835.8 | 39.8 |
| | **C52** | 8Φ16 | 15 | 2 | 2.48 | 75 | 949.6 | 58.8 |
| | **C53** | 8Φ16 | 20 | 2 | 1.86 | 75 | 1067.7 | 78.5 |
| | **C54** | 8Φ16 | 25 | 2 | 1.48 | 75 | 1215.4 | 103.2 |
| | **C55** | 8Φ16 | 30 | 2 | 1.24 | 75 | 1361.4 | 127.7 |
| **12** | **C56** | 8Φ16 | 10 | 3 | 5.58 | 75 | 881.7 | 47.4 |
| | **C57** | 8Φ16 | 15 | 3 | 3.72 | 75 | 992.3 | 65.9 |
| | **C58** | 8Φ16 | 20 | 3 | 2.79 | 75 | 1110.6 | 85.7 |
| | **C59** | 8Φ16 | 25 | 3 | 2.23 | 75 | 1243.2 | 107.9 |
| | **C60** | 8Φ16 | 30 | 3 | 1.86 | 75 | 1377.7 | 130.4 |

### 3.3.1. ULTIMATE failure load of strengthening columns.

The failure loads for groups are plotted in **Figure (5:10)** and compare with the failure loads for heated columns of under and over RFT columns ($C_0$, $C_{00}$).

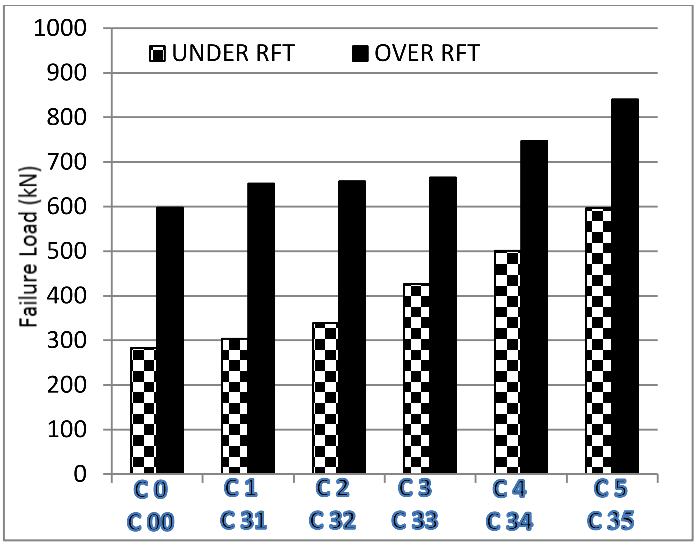



**Figure (5):** Ultimate failure loads supported by specimens of group 1 and 7

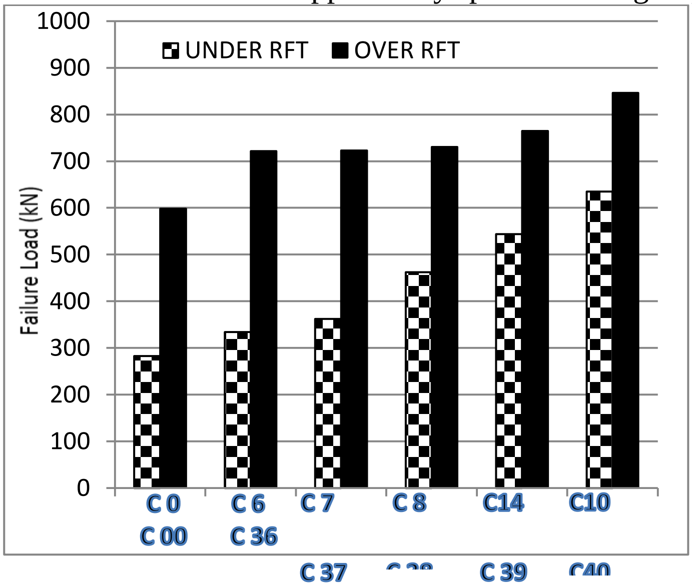



**Figure (6):** Ultimate failure loads supported by specimens of group 2 and 8

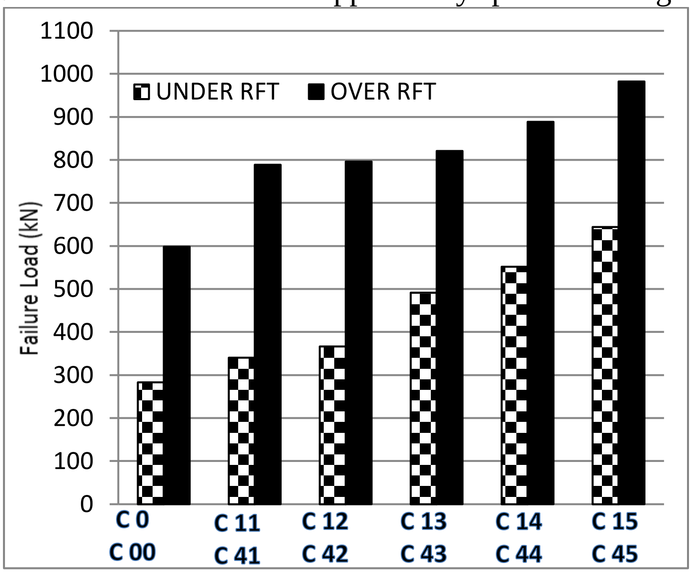



**Figure (7):** Ultimate failure loads supported by specimens of group 3 and 9

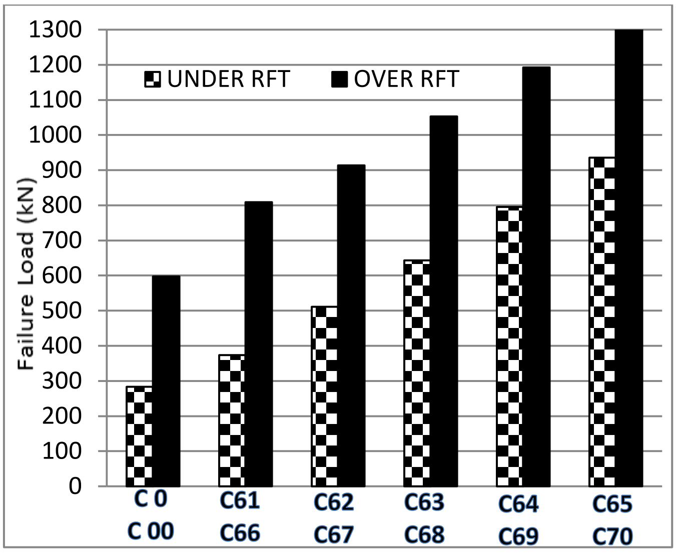



**Figure (8):** Ultimate failure loads supported by specimens of group 4 and 10

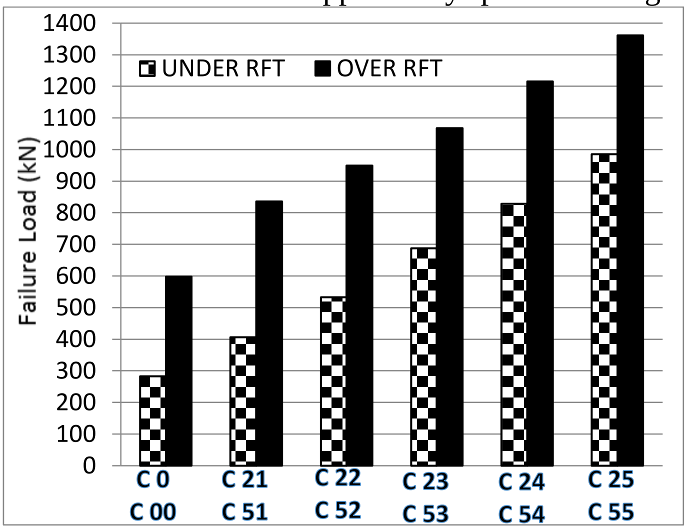



**Figure (9):** Ultimate failure loads supported by specimens of group 5 and 11

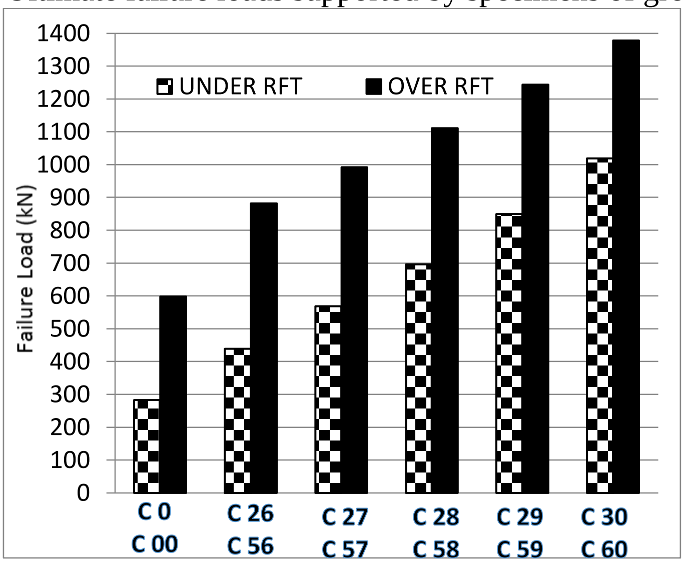
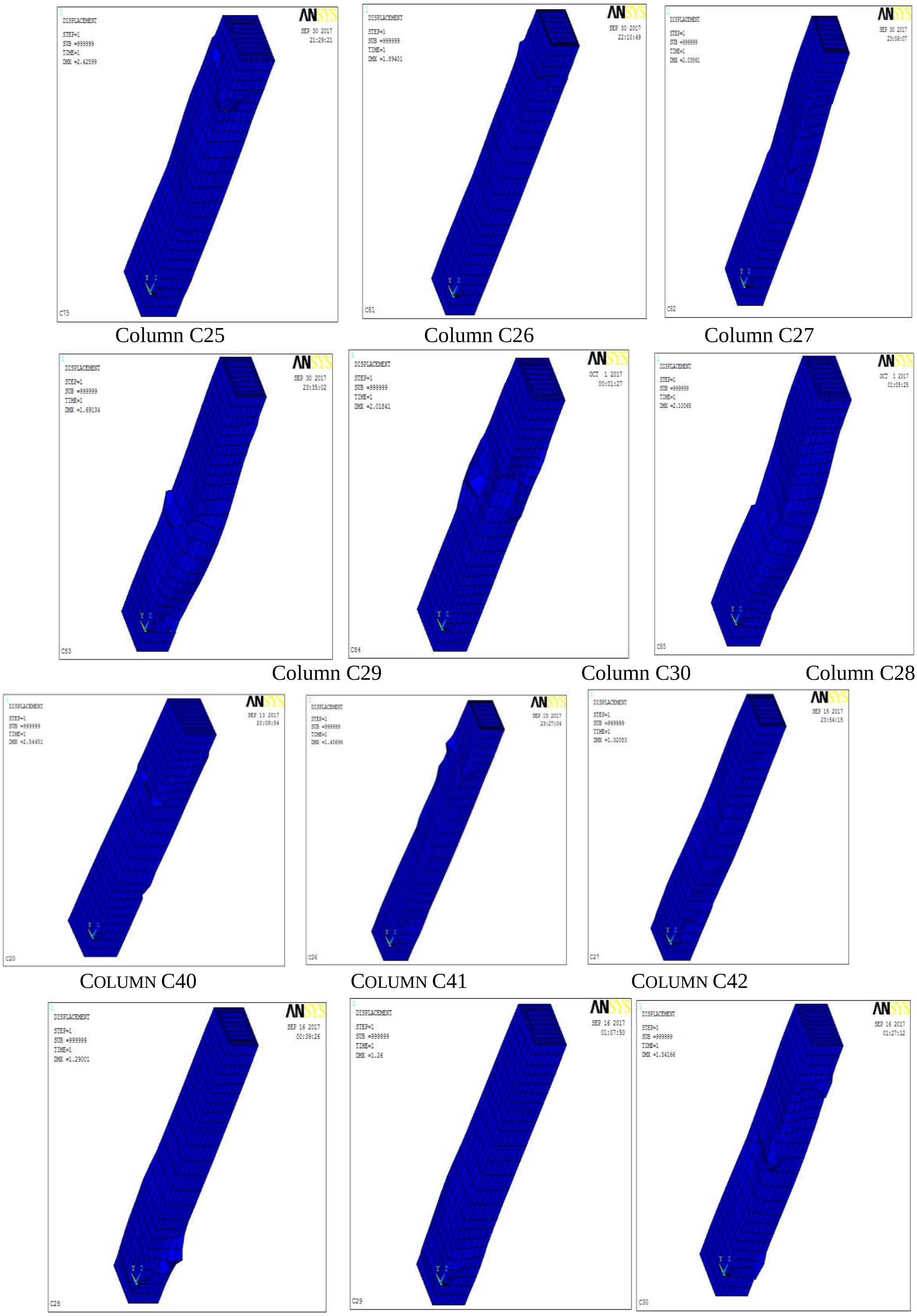



**Figure (10):** Ultimate failure loads supported by specimens of group 6 and 12

### 3.3.2 FAILURE MODES

**Figure (11)** shows deformed shapes and the concrete cracks for sample of numerical models at failure load.



Column C25 Column C26 Column C27

Column C29 Column C30 Column C28

COLUMN C40 COLUMN C41 COLUMN C42

COLUMN C43 Column C44 Column C45

**Figure (11):** Deformation of part of models at failure load.

## 4. Conclusion

1. The strength of heated wrapped columns is significantly affected by both the ferrocement thickness and mortar strength.

2. Increasing the percentage volume of the wire mesh layer subsequently increasing the ultimate load of the columns.

3. Increasing the ferrocement thickness leads to ultimate load enhancement of repaired columns.

4. It can be noticed that the strength of the heated column with three weld mesh layers greater compared to with that of two layers for the same thickness of slab.

5. Increasing the mortar strength leads to ultimate load enhancement of repaired columns

## 5. References


1. Nassar,K.M,andShihada, S, "Improving Fire Resistance of Reinforced Concrete Columns" ,(2011), Civil Engineering Department,Higher Education Deanship,Islamic University of Gaza.

2. F. Serag, "Effect of Fire Exposure on Residual Load Capacity of Short Columns", M.Sc. Faculty of Engineering, Thesis Fayoum University, 2007.

3. Bikhiet M. M., "Behavior of Reinforced Concrete Columns Exposed to Fire", M.Sc. Faculty of Engineering, Thesis Cairo University, 2004.

4.Mourad, S.M. and Shanng, M.J. (2012).Repair and Strengthenin of ReinforcedConcrete Square Columns Using Ferrocement Jackets. Journal of Cement & ConcreteComposites, Vol. 34, No. 2, pp. 288-294.

5. Kaish, A. B. M. , Alam, M.R., Jamil, M. and Wahed,M.A. "Improved ferrocement jacketing for restrengthening of square RC short column ", Construction and Building Materials, 2012; (36), pp228–237.

6. Xiong, G. J., et al. "Load Carrying Capacity And Ductility Of Circular Concrete Columns Confined By Ferrocement Including Steel Bars." Construction and Building Materials 25.5 (2011): 2263-2268.

7. El-Kholy, et al. "Improved Confinement Of Reinforced Concrete Columns", Ain Shams Engineering Journal 7.2 (2016): 717-728.

8. Lila,M. A., Abouelezz,A.E.Y., Hassan AM, "Behavior of RC columns retrofitted with CFRP exposed to fire under axial load" HBRC Journal ,(2015) ;(11),PP 68–81.

9. Fahmy E. H., Y. B. Shaheen, and Y. S. Korany, "Repairing Reinforced Concrete Columns Using Ferrocement Laminates"," Journal of Ferrocement, vol. 29, pp. 115-124, 1999.

10. ANSYS, "ANSYS User's Manual and Help Revision 13," ANSYS Inc., PA, USA, 2010.

11. ACI Committee 216 (ACI 216R-89), ``Guide for Determining the Fire Endurance of Concrete Elements``, American Concrete Institute, Detroit, 1989