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REVIEW ON USING FERROCEMENT AND FRP IN STRENGTHENING RC COLUMNS

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ملخص البحث:

المنشآت الخرسانية المسلحة هى أكثر الأنظمة الإنشائية شيوعاً فى مصر ودول العالم. وتعتبر الأعمدة أهم العناصر الإنشائية نظرا لأن إنهيار العمود قد يؤدى إلى إنهيار المنشأ. أحيانا تتأثر الأعمدة الخرسانية بالتدهور وبالتالى تحتاج الى تقوية وتدعيم. يتم تنفيذ ذلك بطرق شتى مثل إستبدال الخرسانة المتدهورة أو إستخدام الألياف أو إستخدام قمصان خارجية من الخرسانة أو الحديد أو الفيروسيمنت. الكثير من الابحاث قامت بدراسة كيفية تحسين كفاءة الأعمدة الخرسانية. لذلك يهدف هذا البحث إلى تلخيص لمعظم الابحاث التى قامت بدراسة تدعيم الأعمدة الخرسانية باستخدام الفيروسيمنت (Ferrocement) أو ألياف من الفيبر(FRP). وتم تقسيم هذا البحث إلى جزئين: الجزء الأول يشمل أبحاث قامت بدراسة استخدام قمصان من الفيروسيمنت فى عملية تدعيم الأعمدة الخرسانية. بينما الجزء الثانى يستعرض أبحاث قامت بدراسة استخدام ألياف من الفيبر فى تدعيم الأعمدة الخرسانية. وأثبتت هذه الأبحاث مدى كفاءة استخدام كلاً من قمصان الفيروسيمنت وألياف الفيبر فى زيادة حمل الأعمدة وإتزانها عن طريق تقليل التشكل الجانبى لمعظم العينات التى تم صبها فى كل الابحاث.

ABSTRACT

Reinforced concrete (RC) structures are the most common structural systems used in Egypt and all over the world. Columns are very important structural elements. Therefore, failure of column may lead to total collapse of whole building. Sometimes, RC columns be influenced by deterioration and consequently need strengthening. Many studies were carried out to improve the efficiency of RC columns. This research aims at summarizing most of the researches that have studied the strengthening of RC columns by using Ferrocement jacket or Fiber reinforced polymer (FRP) jacket. This research is divided into two parts. The first part includes research that examined the use of ferrocement jacket in the process of strengthening of RC columns. While the second part reviews research that has examined the use of FRP jacket the process of strengthening of RC columns. This research has proved the efficiency of both the ferrocement jacket and FRP jacket to increase column load and balance by minimizing the lateral deformations of most of the samples that have been casted into all research.

Keywords: Ferrocement Jacket, FRP Jacket, Strengthening of Columns.

1. INTRODUCTION

Reinforced concrete (RC) structures are the most common structural systems used in Egypt and all over the world. Columns are considered the backbone of any structure. They are the most important structural elements and the collapse of one column may lead to the total collapse of structure. Many studies were carried out to improve the efficiency of RC columns. Strengthening and restoration of RC columns is necessary for the following reasons:

- Overload column due to increase the number of floors or error in design.
- Poor construction quality and/or design such as reinforcement bars less than provided in engineering drawing or specifications. Also, a tendency column more than allowed in the technical specifications.
- Deterioration of concrete such as aging of old structures.
- Corrosion of reinforcement bars and separation of the concrete cover.
- Honey gaps in the column after casting process.
- Cracks due to any of the previous reasons.
- Accidents as fire, explosions and thus reducing column carrying capacity.
- Improving properties of columns as strength, ductility, durability, fire resistance… else.

Over years, engineers have used different methods and techniques to retrofit existing structures through strengthening and repairing. The famous method of strengthening is applying jackets of reinforced concrete, steel, or fiber reinforced polymer composites. In the last years, fiber reinforced polymer (FRP) materials become more frequently used in civil engineering structures. The principal advantages of this technique are the high strength-to-weight ratio, good fatigue properties, and non-corroding characteristics of FRP. However, the disadvantages of FRP are high cost and need to special skills. In developing countries such as Egypt, they prefer using RC jacketing with ferrocement materials. Ferrocement is generally applied to cement and sand mixture applied over layers of expanded steel mesh and steel rebar that are closely spaced and also have small-diameter. The advantages of ferrocement are low cost, resistance to cracks, and do not require special skill or special fire protection such as FRP. The disadvantages of ferrocement are the need for control to ensure quality products, and a suitable applied curing method. This review will be divided to researches which studied strengthening RC columns by using ferrocement jacket whether short or long columns and some researches which used FRP for strengthening RC columns.

2. Definition of Ferrocement and FRP

The common definition of ferrocement is given by **ACI Committee 549-R97 [1]**. The definition of ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement matrix reinforced with closed spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable material. The fineness of the matrix and its composition should be compatible with the opening and tightness of the reinforcing system it is meant to encapsulate. Fiber reinforced polymer (FRP), also named fiber reinforced plastic is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, or aramid. Other fibers such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use.

3. Using Ferrocement in Strengthening RC Columns

El-kholy et al., [2] discussed effectiveness of combined confinement with metal meshes and ties for preloaded and post-heated RC short columns. This paper studies the effectiveness of practical lateral confinement that utilizes metal meshes combined with typical steel ties for RC columns. Two metal meshes types were used expanded metal mesh (EMM) and welded wire mesh (WWM). Also, thirty square short column specimens were casted and were reinforced laterally with different combinations of ties and metal meshes. The specimens were divided into two groups according to the number of preliminary loads. The first group consisted of sixteen specimens while the second group consisted of fourteen specimens. Each group comprised for axial compression preload 65% of ultimate load. After preload, the second group was exposed to elevated temperature exposure until the core center of reference column reaches 500°C (siliceous concrete loses about 50% of its strength at this temperature). Each group was divided into three phases according to lateral reinforcement (reference, WWM-ties and EMM-ties). Dimensions of column specimens were 150 mm × 150 mm× 1100 mm. All specimens had 4 Ø 10 as vertical bars. Also, phase 1 used 6 Ø 6 as ties with WWM layer, 3 Ø 6 as ties with WWM layer and WWM layer without ties. Phase 2 used 6 Ø 6 as tie with EMM layer, 3 Ø 6 as ties with EMM layer, 3 Ø 6 as ties with 2 EMM layers and EMM layer without ties. The test results showed that using metal mesh with higher strength magnifies the ultimate load. Also, the effectiveness of WWM is higher than EMM because of WWM higher strength.

Shekhar [3] provided experimental study on axial behavior of cylindrical concrete specimens confined ferrocement layers. The study investigated the effect of specimen size on the confinement action of ferrocement jacket. Twenty- seven concrete cylindrical specimens were casted and tested. Specimens were divided to three groups. Each group consisted of nine specimens, three of them were non- jacketed (denoted as NJ), three were jacketed with a single layer wire mesh ferrocement, and three were jacketed with a double layer wire mesh ferrocement. Each group were casted with three different sizes (height and diameter of the cylinders were 300 mm, 200 mm, 150 mm; and 150 mm, 100 mm, 75 mm, respectively). Based on the obtained test results, the load carrying capacity, ductility and energy absorption capacity of concrete specimens were enhanced with the external ferrocement jacket. The improvements were more noticeable in smaller specimens. Also, double layer mesh ferrocement jacket provided sufficient confinement to improve the behavior of confined concrete while single layer mesh ferrocement jacket wasn't provide significant external confinement.

Tarkhan [4] focused on Strengthening of Loaded Reinforced Concrete Columns Using Ferrocement Jackets. This study aims to investigate the possibility of strengthening partially loaded RC columns using ferrocement jacket as a new method. The variables in that research were the slenderness ratio of column (λ= 10.00 and 15.83), the pre-loading level of the original column (50% and 70% from ultimate load), and the orientation of ferrocement mesh (170and 730). The experimental program included fourteen specimens. The specimens were divided to twelve strengthened RC columns in addition to two RC columns without strengthening as controls. RC column specimens were casted, strengthened and tested under concentric load. The cross section of original column was 60 mm × 130 mm in additional to 50mm as jacket from all directions. Also, 60mm thickness of RC slab was casted in the ends of columns to overcome the excessive tensile stresses in the lateral direction. Seven columns have 600 mm clear height between the RC slabs to represent the short columns, while the others have 950 mm to represent long columns. The results show that RC columns can be strengthened significantly with enhanced strength and performance using ferrocement jacket. All results show higher improvement at ultimate load, increase in ductility ratio, and considerable increase in energy absorption as well. Specimens with pre-loaded to 50% of the ultimate load of control column showed higher gain in the ultimate load and energy absorption than those pre-loaded to 75% however the increase in the ductility ratio was the least. The orientation of expanded steel mesh has a little effect on ductility ratio. According to the previous results, it is clear that ferrocement jackets provided the strengthened columns with strong confinement effect.

El-kholy and Dahish [5] studied improved confinement of reinforced concrete columns. This study displays a practical confinement configuration consisting of single Expanded Metal Mesh (EMM) layer in additional to regular tie reinforcement. This EMM layer was warped above ties directly. The variables considered in this study are the slenderness ratio of column and the volumetric ratios of ties. Sixteen short squares RC column specimens were casted. These specimens divided to two groups with various slenderness ratios (λ= 7.33 and 14). Each group consisted of 8 specimens with dimensions 150 mm × 150 mm× 1100 mm and 150 mm ×150 mm ×2100 mm respectively. Also, the specimens were reinforced laterally with various volumetric ratios of ties. The volumetric ratios were 0.2714, 0.2714, 0.1629 and 0.0543 for first group while it was 0.2714, 0.2714, 0.1629 and 0.0814 for second group. All specimens were tested under axial compression load by hydraulic jack till failure. The results indicate to significant improvement in the strength and ductility for confined columns with lateral reinforcement. For example, the ultimate load increased 11.02% for first group and 18.55% for second group with reference to volumetric ratio of ties 0.2714. The increment in the ultimate load carrying capacity is more significant for second group whose slenderness ratios almost double the ratio of group1. The other specimens with less volumetric ratio of ties, the results show a minor decreasing in ultimate load for first group specimens, while it revealed a minor increasing in ultimate load for second group specimens. Also for axial deformation, the results present that the use of lateral reinforcement of EMM layer is not useful and prefer to reject it. Because of all specimens with lateral reinforcement of EMM layer were exhibited higher axial deflection than reference. Unlike, the results illustrate that the lateral displacement for all specimens was enhanced. This achievement is a suitable for columns especially long column.

Shinde and Bhusari [6] examined Response of Ferrocement Confinement on Behavior of Concrete Short Column. In this study, it was used ferrocement as an external confinement to concrete specimen is investigated with reference to layers of confinement and orientation of meshes. Experimental investigation has to investigate the influence of no .of layers and orientation of meshes on compressive strength of ferrocement confined column. Thirty of cylindrical specimens were casted and three unconfined specimens also casted. Cylindrical specimens were used with 120 mm diameter and 600 mm height. Welded wire mesh (WWM) of a single layer mesh or double layer mesh as per the requirement was wrapped around the specimen. Ferrocement confinement thickness was equal to 20 mm around the specimen. It is observed that load carrying capacity of confined specimen was increased in a range of 17, 25, 36, 40, 47 percentage as compared to controlled specimens in single layer and in double layer this increase is found to be 50, 52, 54, 54, 56 percentage research for orientation 90°,80°,70°,60°,45°. This increase in load carrying capacity is due to the improvement of dimensional stability as well as integrity of this composite material was caused by the presence of a large volume fraction of mesh which was provided as confinement to the core concrete, also due to the change in orientation from 90° to 45°. Double layer WWM gives nearly double strength than the single layer of WWM.

Malhotra and Bansal [7] studied behavior of RC columns Confined with Ferrocement. This thesis focused on analysis the behavior of RC columns confined with different values of slenderness ratio and ferrocement. Twenty-seven specimens were casted and it classified to three groups according to slenderness ratio (λ= 3.00, 7.00 and 15.00). Each group consisted of nine specimens. These specimens in each group divided to three specimens as control (unconfined), three specimens confined with one layer of wire mesh and three specimens confined with two layers of wire mesh. The cross section of specimens was 100 mm ×100 mm and different height 300,700 and 1500 mm. After strengthened process, the cross section increased by 25mm from all directions, so the cross section began 150 mm ×150 mm. The results illustrate ultimate load increased for confined columns for all groups. Also, the results refer to increase the slenderness ratio decrease the strength provided. For columns with slenderness ratio (λ= 3.00), the strength provided achieved 92% while columns with slenderness ratio (λ= 15.00) the strength provided increased 36% only. Columns with one layer of wire mesh, the lateral deflection were a significantly minimized unlike columns with two layers of wire mesh were marginal decrease.

Mourad and Shannag [8] examined repair and strengthening of reinforced concrete square columns using ferrocement jackets. Ten specimens were casted and tested till failure. All specimens was with dimensions 150 mm × 150 mm × 1000 mm with slenderness ratio (λ= 6.67). Two specimens was a control without ferrocement jacket and two specimens for each pre load .The used technique was a various pre-load (0%, 60%, 80%, and 100%) from ultimate load in addition strengthening by one layer or two layers from EMM ferrocement for pre-load (60%, 80%, and 100%). the specimens were investigated in terms of load carrying capacity, axial displacement, axial stress and strain, lateral displacement, and ductility. The results illustrate increasing ultimate load by 33% for confining specimens with two layers in addition to increase 26% in axial stiffness compared to control specimens. Also, the results show increasing of ultimate load up 28% for pre-load 60% and increasing of ultimate load up 15% for pre-load 80%. The confining columns failed in a ductile manner compared to a brittle failure in control specimens.

Kaish et al., [9] investigated improved ferrocement jacketing for restrengthening of square RC short column. Three new techniques were used in strengthening of columns. These techniques were square jacketing with single layer wire mesh and rounded column corners (RSL), square jacketing using single layer wire mesh with shear keys at the center of each face of column (SKSL) and square jacketing with single layer wire mesh and two extra layers mesh at each corner (SLTL). Fourty-one specimens were casted and tested under both concentric and eccentric modes of loading. The cross section of specimens was 100 mm ×100 mm and height equal 600mm. these specimens divided to two phases under monotonically increasing load. In the first phase, seventeen column specimens with normal tie were tested under concentric mode of loading. In the second phase, twenty-four column specimens with seismic tie were tested under concentric mode of loading as well as eccentric mode of loading. Among twenty-four specimens of second phase, twelve specimens were tested under concentric mode of loading and the rest of twelve specimens were tested under eccentric mode of loading. All specimens were tested under hydraulic compression machine with capacity 2000kN. The results show that all three improved square ferrocement jacketing techniques are effective to overcome the stress concentration problem of conventional square ferrocement jacketing. SLTL type jacketing displays the best performance in carrying concentric loading, however, in case of eccentric loading, the best performance is found in RSL type ferrocement jacketing.

Xiong et al., [10] studied load carrying capacity and ductility of circular concrete columns confined by ferrocement including steel bars. The aim of this study was a comparatively experimental study on uniaxial compression behaviors of concrete columns wrapped with three different confining systems, namely bar mat-mortar (BM), steel bars (FS), and fiber reinforced polymer (FRP). Fifty –one concrete cylindrical specimens were casted (thirty-three specimens with a diameter of 105 mm and the other eighteen specimens with 150 mm) with a height of 450 mm. Specimens with diameter 105 mm were strengthened with BM or FS, while specimens with diameter 150 mm were strengthened with different FRP laminates. Analysis of results show that the strength, ductility and energy absorption capacity of existing concrete columns can be simultaneously enhanced significantly by constructing additional ferrocement cage including steel bars. For example, compressive strength of the FS columns increased 30% compared with that of the BM columns, the ductility of the former reached about twice as that of the latter. Due to using ferrocement caging along with steel bars, specimens illustrated higher ductility, compression strength and energy absorbing capacity than BS or FRP strengthen circular columns.

Moghaddam et al., [11] developed experimental study on axial compressive behavior of concrete actively confined by metal strips. Thirty five cylindrical specimens were confined by pre-stressed metal strips. The effects of various parameters were studied including compressive strength of concrete, mechanical volumetric ratio of confining strips, post-tensioning force in the strip, number of strip layers wrapped around the specimens and details of strip joint. Test results presented significant increment in the strength and ductility of specimens due to active confinement by metal strips. It was observed that ductility of confining material plays the most important role in enhancement of concrete ductility.

Takeuti et al., [12] provided experimental study on preloaded RC columns strengthened with high-strength concrete jackets under uniaxial compression. Twelve RC-jacketed columns circular and square sections were tested with and without preloading under uniaxial compression. The preload was 44~87% of the predicted capacity of the primary columns. The jacket consists of longitudinal reinforcement (6 Ø 8 for circular specimens and 4 Ø 8 for square specimens) and Three different types of transverse reinforcement in the jacket were used (welded wire mesh 2.5 mm diameter 50 mm spacing, 5 mm diameter steel ties and hoops at 70 and 50 mm spacing). The results indicated that preloading does not adversely affect the capacity of the jacketed column, while it may reduce its deformability especially in square sections. Circular columns have a better ductility than square columns, due to a uniform confinement around the section. Also, Transverse reinforcement in the jacket directly improves ductility of the strengthened column, especially in circular sections where confinement is uniform around the section.

Abdullah and Takiguchi [13] illustrated experimental study on reinforced concrete column strengthened with ferrocement jacket. In this study, a strengthening method using circular ferrocement jacket to improve the confinement of a substandard column was investigated and compared with control specimens and different strengthening methods. Five 1:6 scale model square columns were constructed. Specimens CS-1 and CS-2 were tested as control specimens and three specimens were named as SCCF, and SCFC, were strengthened by steel jacket, carbon fiber sheet, and ferrocement jacket, respectively. The cross sections area was 120 mm x 120 mm and height 600 mm. Round R-2 (diameter = 2 mm) hoops spaced at 35 mm intervals were used as transverse reinforcement. The results of this investigation indicated that strengthening of a square reinforced concrete column with circular ferrocement jacket was considered to successful. Also, using carbon fiber sheet and ferrocement jacket to the origin columns, the stiffness, strength, energy dissipation, and ductility were improved significantly.

4. Using FRP in Strengthening RC Columns

Wang et al., [14] studied axial compressive behavior of concrete confined with polymer grid. Fourteen cylindrical concrete specimens were prepared and tested under axial compression. Specimens had diameter 150 mm and height 300 mm. it was selected two types from polymer grid with different mechanical properties. The first type polymer grid (36 mm × 36 mm) was manufactured from polypropylene fibers, while the second type polymer grid (36 mm × 24 mm) was manufactured from high modulus polyester fibers. One layer, two layers, and three layers were used to investigate the influence of the amount of polymer grid confinement on the axial compressive behavior of concrete specimens for each type. The results present concrete specimens confined with polymer grid obtained much higher deformation capacity than unconfined concrete specimens. Also, the first type polymer grid performed better in improving the strength and deformation capacity of concrete specimens than the second type polymer grid.

Hadi et al., [15] discussed the behavior of GFRP tube reinforced concrete columns under axial compression. Eight columns with 150 mm diameter and 300 mm height were casted and tested under axial compression. Specimens were divided to four groups. The first group had two columns of plain concrete, and the remaining three groups were reinforced with solid, axially perforated and diagonally perforated GFRP tubes, respectively. The test results showed that using GFRP tubes can be a viable option for reinforcement of columns. Also, the load-carrying capacity and the ductility capacity improved significantly for solid GFRP tubes. Perforated GFRP tubes have been found effective in integrating concrete core with concrete cover.

Soliman [16] studied Behavior of long confined concrete column. This study was investigated including failure mechanisms and subsequently their failure mode with theoretical model for calculation of the column capacity. In addition to the influence of column slenderness ratio on their axial load capacity, axial strains, and radial strains were also investigated. The tested specimens were divided into three groups G1, G2 and G3. Six filled plastic tube concrete column specimens without steel reinforcement and one unconfined concrete specimen were fabricated. Groups G1 and G2 included three specimens of heights 1500, 1800 and 2100 mm with diameter 150 mm and 120 mm respectively, While group G3 was of one column specimen of height 1500 mm with diameter 150mm. The results showed that utilizing plastic tube for confinement significantly influences the failure mechanisms of concrete columns. Also, it showed that the stiffness of the tested long confined concrete columns specimens increases as slenderness ratio decreases. The column slenderness ratio has a significant effect on the confinement behavior of long concrete column, and this effect must be taken into consideration in design.

Turgay et al., [17] investigated the effect and failure mechanism of large-scale square columns warped with FRP. The aim of this research was studying the effect longitudinal and transverse reinforcement and FRP jacket on behavior of concentrically loaded columns. Twenty specimens were casted and tested till failure. These specimens were with dimensions 200 mm ×200 mm ×1000 mm. Also, it was divided to five series as follows: unwrapped (C1), partially wrapped (C2), fully wrapped (C3), partially wrapped with two layers (C4) and fully wrapped with two layers (C5). Each specimen was tested under a hydraulic machine with capacity 2000 kN. The results indicate increasing of ultimate load. For fully wrapped columns, the failure was at top or bottom quarters but the failure was at ends of confined regions for partially regions. The stress–strain curves of the columns are successfully predicted by the analytical approach previously proposed for FRP-confined concrete. Also, increasing the diameter of transverse reinforcement generally leads to a higher ductility while the ultimate strength of columns is almost identical; there is no evident effect of the longitudinal bars on the ductility. For all RC columns fully wrapped with layer of CFRP, transverse reinforcement with a diameter of 12 mm clearly enhances the beneficial effect of CFRP on ductility.

Bae and Belarbi [18] studied the effectiveness of CFRP sheet in protecting the RC columns from corrosion of the steel reinforcement. The research has shown that FRP retrofit was a practical alternative to conventional methods due to its superior performance in enhancing the strength and ductility of RC columns. Performance was markedly improved by increasing the number of FRP layers and by providing sufficient anchorage for each layer. FRP composites are very efficient as repair materials which can also decrease the rate of corrosion.

Uddin et al., [19] tested the effects of low velocity impact loading on high-strength concrete confined by a prefabricated polypropylene (PP) jacket and compared the results with conterparts CFRP-confined concrete columns. PP-confined specimens were not able to achieve similar compressive strength as CFRP-confined columns. However, PP-confined columns exhibited higher energy absorption capacity and deflection as compared to CFRP-wrapped columns. Therefore, polypropylene jacket might be more suitable for columns subjected to impact load.

Lacobucci et al., [20] examined the effectiveness of FRP jacketing to retrofit RC columns designed with non-seismic transverse detailing. Substantial increase in the ductility and energy dissipation capacities was observed due to FRP wrapping of deficient RC columns. Similar seismic behavior was noticed for hollow rectangular bridge columns retrofitted with FRP sheets under axial and cyclic lateral loads. FRP sheets effectively improved the ductility factor and shear capacity of hollow rectangular bridge columns.

5. Conclusions

This paper presents a summary of the effect of using ferrocement and FRP materials in strengthening and repairing of RC columns. From the investigation of ferrocement jacketed and FRP jacket under concentric loading, confinement improves the ultimate load carrying capacity, axial deflection, lateral deformations, energy absorption capacity and ductility of RC column. These properties improve with number of layers increase.

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