Journal of Engineering Sciences, Assiut University, Vol. 37, No. 3, pp. 563 -580, May 2009,

RETROFITTING AND STRENGTHENING OF REINFORCED CONCRETE COLUMNS USING STEEL JACKETS; MECHANICAL PERFORMANCE AND APPLICATIONS

Ahmed El-Badawy Sayed,
Assoc. Prof. Civil Eng. Dept., Minia University Minia 6111, Egypt.

(Received April 27, 2009 Accepted May 5, 2009)

Concrete jacketing is a commonly used method to retrofit or strengthen existing columns for axial loads. This can be made by longitudinal steel bars and additional concrete around an existing column or placing a jacket around the column. Each one of these methods has its difficulties regarding the new construction forms needed and the modification in column's dimensions or the difficult welding works and corrosion problems.

Recently, the topic of interest in the infrastructure community is to enhance the confinement of columns by using GFR or FRP composite sheets. Techniques of applying steel jackets around reinforced concrete columns are almost un–covered in the literature.

The main objective of this research is to characterize the mechanical performance of reinforced concrete columns retrofitted or strengthened by using steel jackets made of hot rolled sections. Three types of columns having rectangular, square and circular cross-sections were investigated and tested under static axial compression loading.

Cracking and ultimate loads, deformation properties as well as strains in both the concrete column and steel jacket were recorded and analyzed. Pattern of cracks and mode of failure were identified. The mechanical performance of retrofitted and strengthened columns was significantly improved. The ultimate loads obtained from testing retrofitted columns were found to be higher than the original ones by a value of 15-18%.

The proposed steel jacketing technique, adopted in this research, has been successfully applied to some buildings, in our region, in order to retrofit or strengthen the existing columns. An excellent beneficial serviceability has been achieved. Photographs showing the steps of executing the steel jackets to existed deteriorated columns are attached.

KEYWORDS: *columns, retrofit, strengthen, axial compression, steel jacket.*

INTRODUCTION

Enhancing the confinement of circular columns is relatively easy to be achieved by a concrete jacket, or use of close-spaced hoops or a spiral of a small pitch. However, unless the concrete jacket is made of elliptical or circular shape, it is difficult to achieve proper confinement for rectangular or square concrete columns. Longitudinal bars in the mid region of each face will be susceptible to buckling, and only the corners will be effectively confined [1-3].

Confinement of concrete columns with composite sheets showed many advantages in comparison to other confinement methods. The properties of composite materials, such as high strength, low thickness, and low weight, allow them to be applied on a construction site as confinement without serious difficulties [4]. The confinement effect produced by the wrapping appears in reaction to the deformations caused by lateral expansion of concrete under axial loads [1].

Strength and deformation characteristics of circular and rectangular reinforced concrete columns confined with glass fiber composites has been reported in the literature by the Author [5&6] , an expansive cement mortar was used between wrapping glass fiber sheets and the original column to generate an active confinement around the column.

Using fibers, in general, to retrofit, strengthen or even to enhance the mechanical performance of R.C columns has been widely spread all over the world [7]. Katsuk et al [8] studied the strength and behavior of R.C columns strengthened with Ferro-cement Jackets. H. Seung [4] conducted an experimental research employing the carbon fiber sheets to retrofit reinforced concrete columns damaged by rebar corrosion.

Repair and rehabilitation of damaged reinforced concrete columns using FRP are increasingly becoming a topic of interest in the infrastructure community [9].The effect of thickness, stiffness, and orientation of FRP layers as well as the interfacial bonding between the FRP and the concrete on the strength and stiffness of repaired column was studied and evaluated by Guoqiang, Li, et al [10].

EXPERIMENTAL WORK

- To fulfill the requirements of this research, an experimental program comprises three identical groups of columns was adopted, each of these groups contains eight different columns. Details of the concrete dimensions and reinforcement of these columns are indicated in the following table (1) and illustrated in figure (1).
- The first group of columns was considered as control specimens and used for the purpose of comparison with other columns.
- The second group of columns was loaded up to cracking and then, steel jackets were applied to retrofit these cracked columns. After that, these retrofitted columns were loaded up to failure.
- The third group of columns was strengthened directly, after the standard curing process completed, by applying the same technique of steel jacketing, and then loaded up to failure.

Table (1) Experimental program

Group No.	Column No.	Mix Proportions c: s: g: w/c	Longetudinal Reinforcement	Height cm.	Cross-section cm.		Stirrups	Remarks
(I)	1	1: 2 : 4 : 0,5	$4\Phi8$ mm	75 cm	Rectangular	8 x 12.5	$4\Phi6$ tied	Control Columns
	2							
	3				Square	10 x 10		
	4							
	5				Circular	D= 11.3	$4\Phi6$ loop	
	6							
	7						$4\Phi6$ spiral	
	8							
(II)	9	1: 2 : 4 : 0,5	$4\Phi8$ mm	75 cm	Rectangular	8 x 12.5	$4\Phi6$ tied	Retrofitted Columns
	10							
	11				Square	10 x 10		
	12							
	13				Circular	D= 11.3	$4\Phi6$ loop	
	14							
	15						$4\Phi6$ spiral	
	16							
(III)	17	1: 2 : 4 : 0,5	$4\Phi8$ mm	75 cm	Rectangular	8 x 12.5	$4\Phi6$ tied	Strengthened Columns
	18							
	19				Square	10 x 10		
	20							
	21				Circular	D= 11.3	$4\Phi6$ loop	
	22							
	23						$4\Phi6$ spiral	
	24							

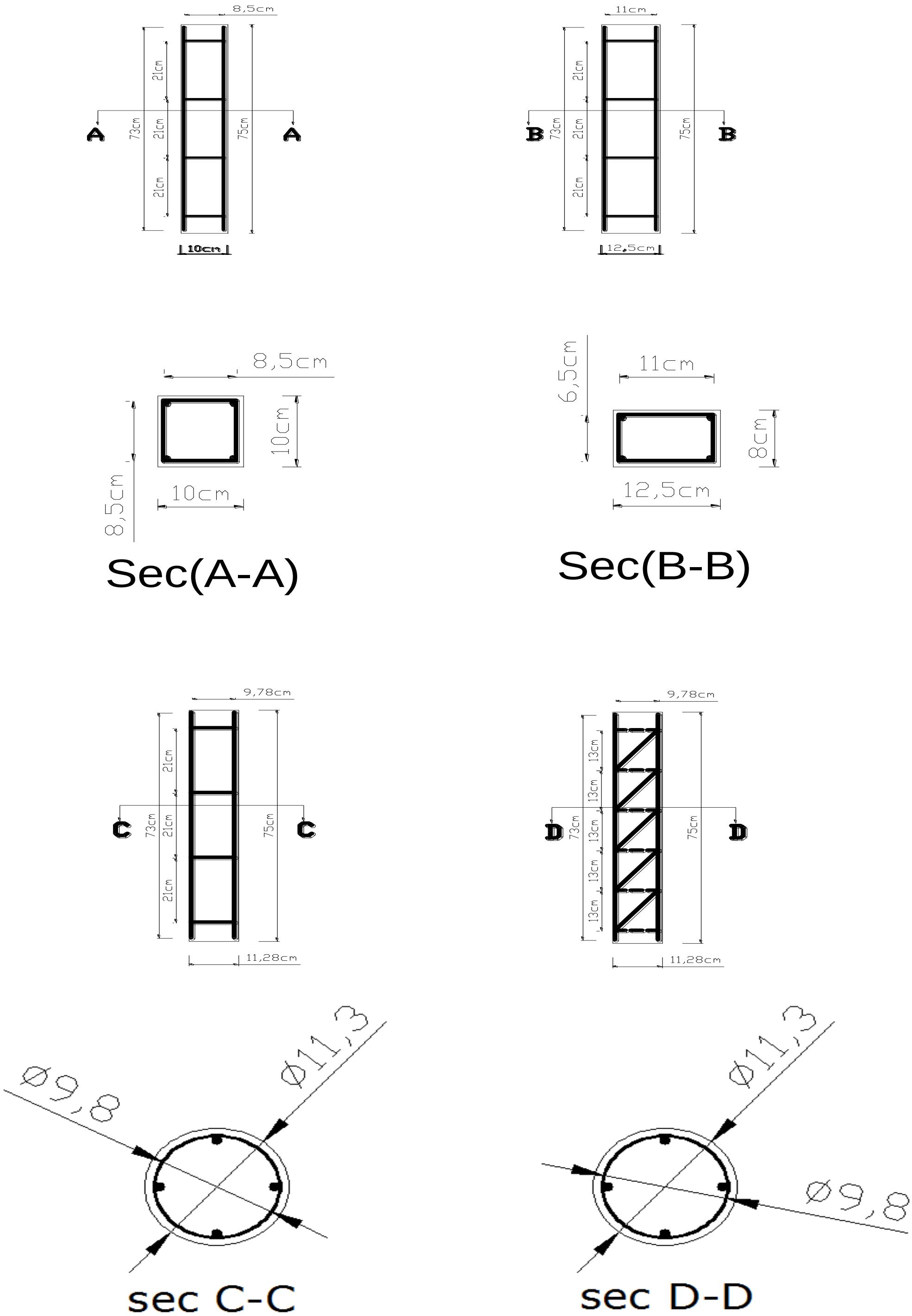

Figure (1) Concrete dimensions and details of reinforcements of tested columns.

- Tied stirrups were chosen to confine the original rectangular and square columns meanwhile, either closed loop or spiral stirrups used with circular columns.
- Steel jackets used for rectangular and square columns were made of hot rolled sections (steel angles and plates) welded together as shown in figure (2). However, steel plates were used as a vertical reinforcement along with the stirrups to fabricate the steel jacket of the circular columns as shown in figure (3). Anti-corrosive epoxy painting was applied to the steel parts of the jacket.

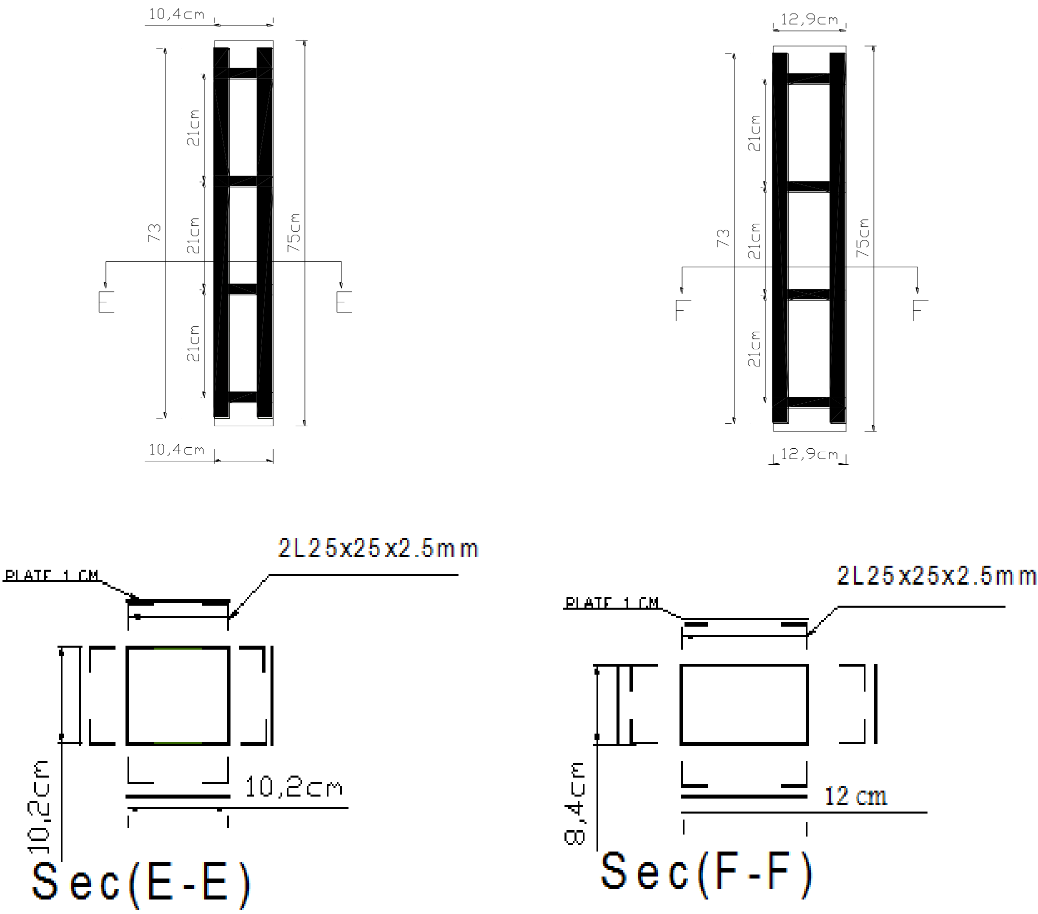

Figure (2) Details of the steel jackets used with rectangular and square columns.

- Polypropylene fiber reinforced mortar was used to cover the steel jacket. The reason of using the polypropylene fiber in the external cover is to control the cracks may occur in the surface of the columns.
- All columns were tested under static axial compression loading.
- Cracking and ultimate loads, deformation properties as well as strains in both concrete and steel jacket were recorded and analyzed for the three groups of tested columns.

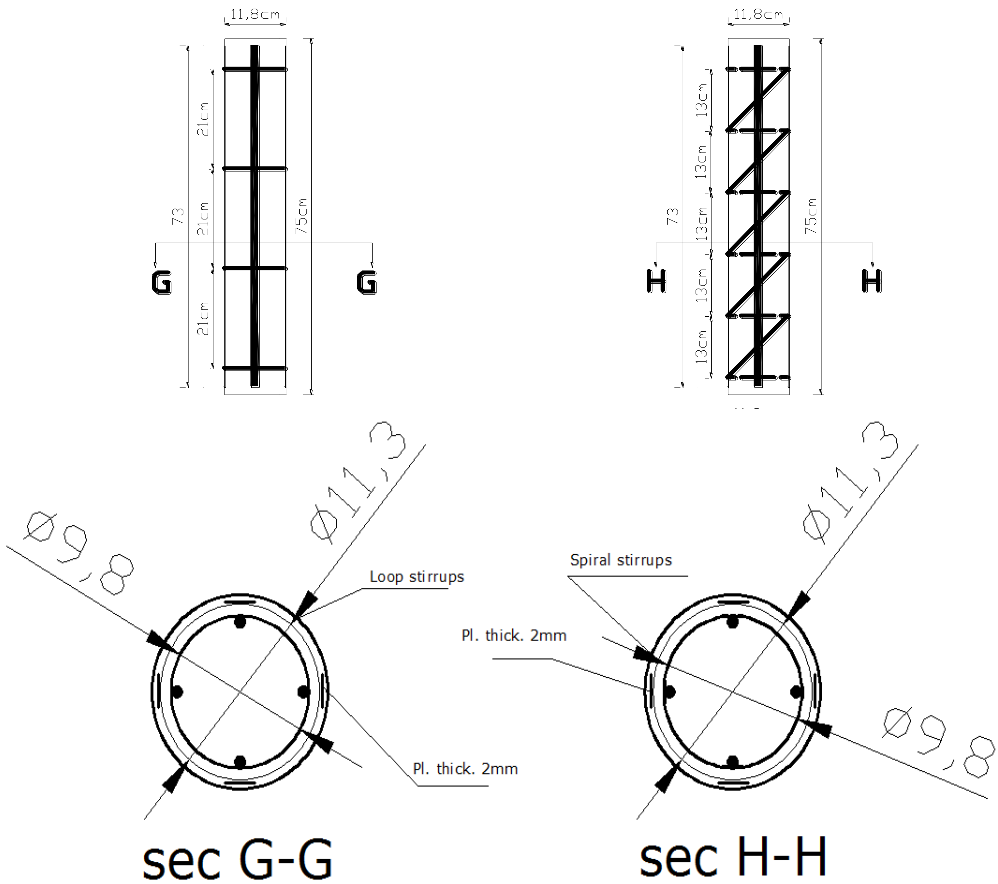

Figure (3) Details of the steel jackets used with circular columns.

The constituent materials used to fabricate the concrete columns were; ordinary portland cement, coarse aggregate (gravel with maximum nominal size = 20 mm.) and fine aggregate (sand). Mixing of concrete components was done by using a horizontal rotating counter flow mixer pan. The mixing operation was carried out in accordance to ASTM (192-81). All columns were cast in standard manner and, then demoulded after 24 hours and cured in laboratory conditions. The three groups of the columns were tested at the age of 28 days.

TEST RESULTS AND DISSCUSSION

The experimental values of cracking and ultimate loads obtained from testing the twenty four specimens of the three groups of columns are recorded in table (1) and illustrated in figures (4&5). Table (1) also contains the ratios between the cracking and ultimate loads (Pcr / Pult) for each column individually. It can be resulted that, the lowest ratios of (Pcr / Pult) were recorded with rectangular columns regardless of being them retrofitted or strengthened. The average value of these ratios was found to be 0.35 compared with 0.47 and 0.53 for square and circular columns respectively.

Generally, the highest values of ultimate loads were resulted from testing the rectangular columns. These values were found to be as twice as those obtained from the two types of circular ones. This result is true for the three groups of the tested columns – see table (1) and figure (5).

The theoretical values of the ultimate loads calculated from the well-known equations of the working design theory of reinforced concrete short columns are also included in table (1). A comparison between these calculated values and the experimental ones have been made in form of ratios between them (Pult exp / Pult theo). The highest ratios of (Pult exp / Pult theo) were recorded with the rectangular and square columns.

It is of interest to declare that, the ratio of (Pult exp / Pult theo) of the control columns is found to be ranging between 1.0 to 2.7 depending on the cross-section of the columns and their condition (control, retrofitted or strengthened). The experimental values of the ultimate loads recorded with rectangular and square columns were found to be 2.5 times higher than the theoretical ones meanwhile, 1.3 times higher was recorded with circular ones.

The ultimate loads resulted from testing either the retrofitted or strengthened rectangular and square columns were compared with the theoretical ones and found to be about 1.5 times higher than them meanwhile, circular columns showed a slight increase in the load bearing capacity (about 10 %).

Figures (6&7) illustrate the beneficial effect of steel jacketing technique, adopted in this research, in form of % increase in the cracking and ultimate loads for the different cross-sections used with retrofitted and strengthened columns.

Table (1) Cracking and ultimate loads of the tested columns.

Group No.	Column No.	P_{cr} Exp.	P_{ult} Exp.	P_{cr} / P_{ult} Exp.	P_{ult} Theoretical	P_{ult} exp / P_{ult} theo
I	1&2	8	22	0.36	8.112	2.71
	3&4	9	19	0.47	8.112	2.34
	5&6	6	10.5	0.57	8.112	1.30
	7&8	6.5	12	0.54	9.29	1.30
II	9&10	9	26	0.35	17.43	1.49
	11&12	10.5	22	0.48	17.43	1.26
	13&14	6	14	0.43	13.15	1.06
	15&16	7	15	0.47	15.06	1.00
III	17&18	10.5	28	0.37	17.43	1.61
	19&20	11.5	24	0.48	17.43	1.34
	21&22	9	16	0.56	13.15	1.22
	23&24	9.5	16.5	0.57	15.06	1.10

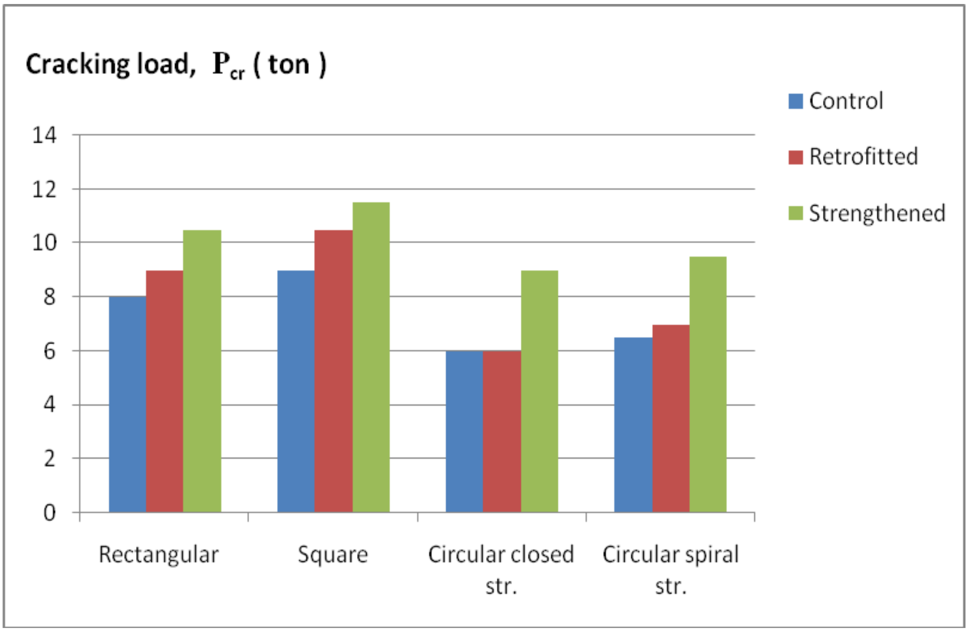

Figure (4) Comparison between cracking loads of the tested columns.

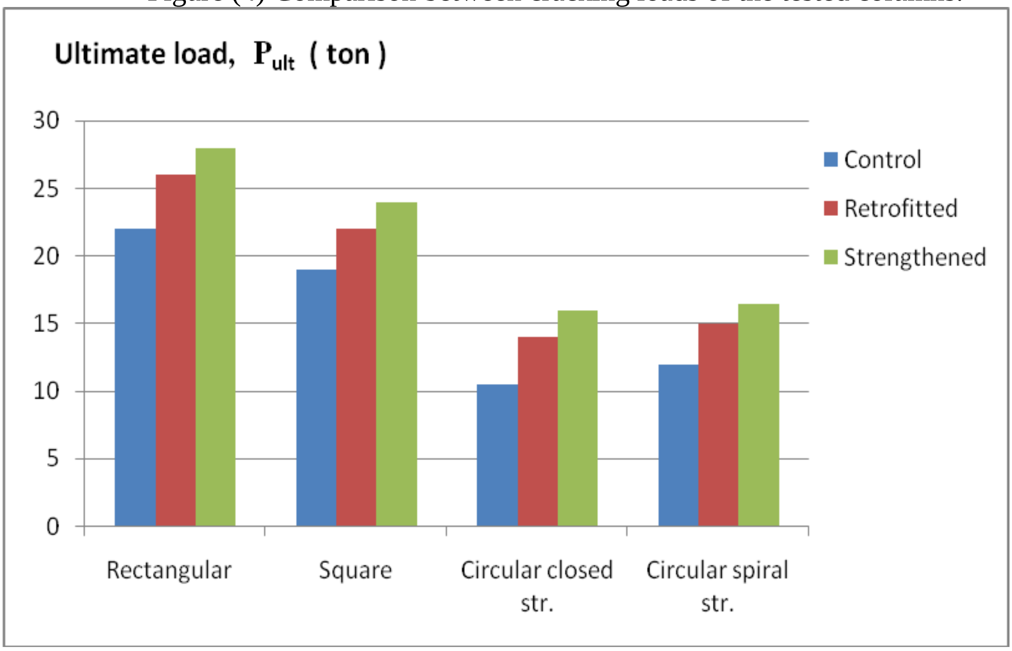

Figure (5) Comparison between ultimate loads of all tested columns.

Figure (6) explains how the cracking loads of retrofitted and strengthened columns have been improved when compared with the control ones. About 10 % increase in the cracking loads have been achived as a result of retrofitting cracked columns by applying steel jackets around them. However, strengthening original columns produced about 30 % increase in cracking loads of rectangular and square columns whereas, circular colums produced about 50 % improvement.

The significant increase in the load bearing capacity of the retrofitted and strengthened columns when compared with the values of ultimate loads obtained from the control ones is represented in figure (7). An improvement of about 20 and 30 % has been recorded with retrofitted and strengthened respectively. This tremendous achievement could be attributed to the effect of increasing the percentage of reinforcements (µ %) resulted from applying the additional reinforcement of the steel jacket, (µ % increased from 2% to 4% in rectangular and square columns meanwhile, increased to 2.3% in circular columns) as well as to the effect of the extra confinement produced from the welded tied plates used with the steel jacket which works as stiffeners.

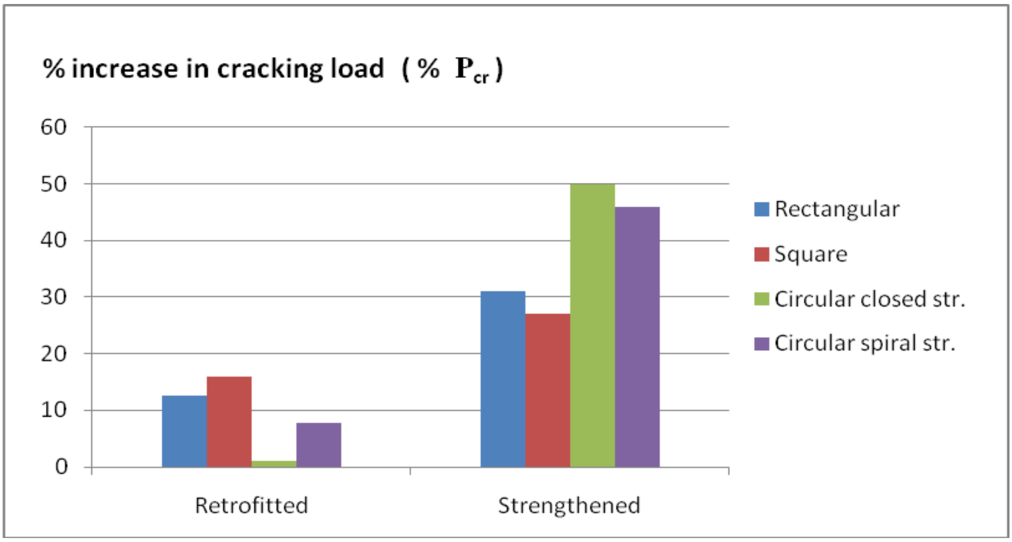

Figure (6) % Increase in the cracking loads of retrofitted and strengthened columns as a result of applying the steel jackets.

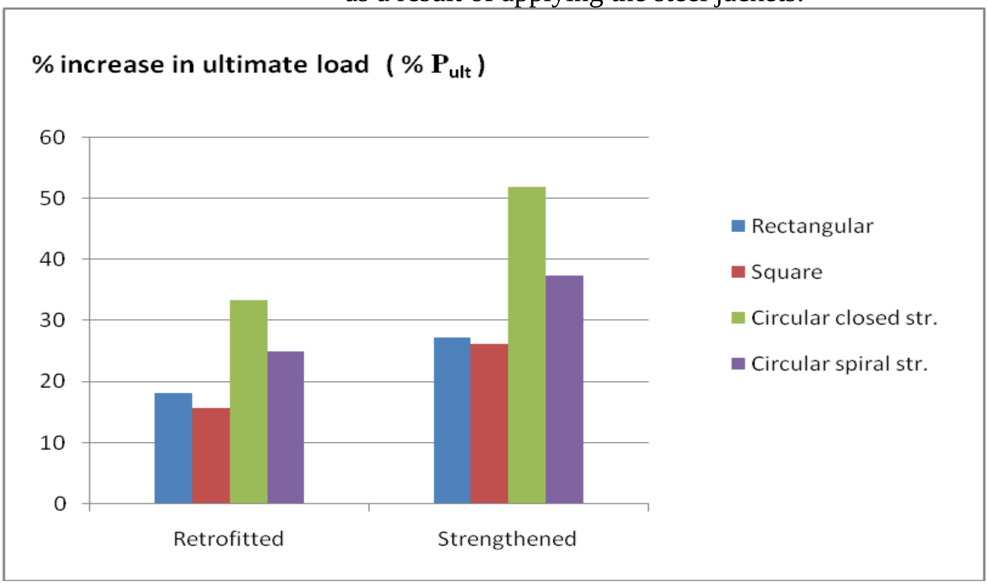

Figure (7) % Increase in the ultimate loads of retrofitted and strengthened columns as a result of applying the steel jackets.

Figures (8, 9, 10 and 11) plot the load – concrete strain relationships for the three different groups of columns. Figures (8) and (9) consider the rectangular and square columns meanwhile; figures (10) and (11) illustrate the circular columns with loop and spiral stirrups respectively. The concrete strain was measured using extensometer through the demic points (studs) stuck on two opposite sides of the columns at the middle third. It can be observed that, same trends were obtained from testing the three categories of columns except for slight differences in the strain values were noticed.

From these figures it can be observed that, at a constant load, strengthened columns showed lower strain values than the retrofitted ones meanwhile, the values of strains accompanied with the original control columns were less than both. Therefore it can be concluded that, steel jacketing technique increases the stiffness of the reinforced concrete columns.

Electrical strain gauges were also stuck on the outer surface of the angles around the columns to detect the strain readings in the reinforcement of the steel jackets. Actually, there was no general trend or certain relationships can be identified between the strain readings and the applied loads. The discrepancy in the plotted values of strains against load may be attributed to the buckling of steel angles occurred during carrying out tests. The only result can be drawn is; the values of strains resulted from the strengthened columns were found to be about 25% lower than the retrofitted ones. In general, the ductility of either retrofitted or strengthened columns is also enhanced

Figures (12 - 17) show the damaged reinforced concrete retrofitted and strengthened columns at the end of the tests. The Steel jacketed rectangular and square columns first experienced vertical cracks in the concrete cover followed by cover spalling and eventually a buckling in the longitudinal bars occurred. However, the steel jacketed circular columns exhibited also vertical cracks and spalling of the new concrete cover followed by a local buckling around the mid-height of the columns, which eventually led to buckling at very large axial displacements followed by a fracture in the vertical reinforcement of the jacket around the column. In general, it could be strongly conclude that, the strength and stiffness of columns are greatly improved as a result of applying the steel jackets.

This proposed retrofitting technique has been successfully applied in several construction projects since 1999 particularly; to retrofit the deteriorated reinforced concrete columns damaged by the occurrence of rebar corrosion. The cases studied in this part of the research are, the following projects;

- The Intensive Care Unit at El-Minia University Educational Hospital, (1999).
- Student residential buildings at El-Minia University, (2006-2008).
- A number of schools at Beni-Suef Governorate, (2002-2008).
- 104 columns in the basement of Salah El-din Mosque, El-Minia (2007- 2008).
- A large number of residential buildings and towers in the private sector.

These projects are being inspected regularly. They exhibited a marvelous serviceability results. Plates (1-6) show the steps of executing the steel jackets in the above mentioned projects.

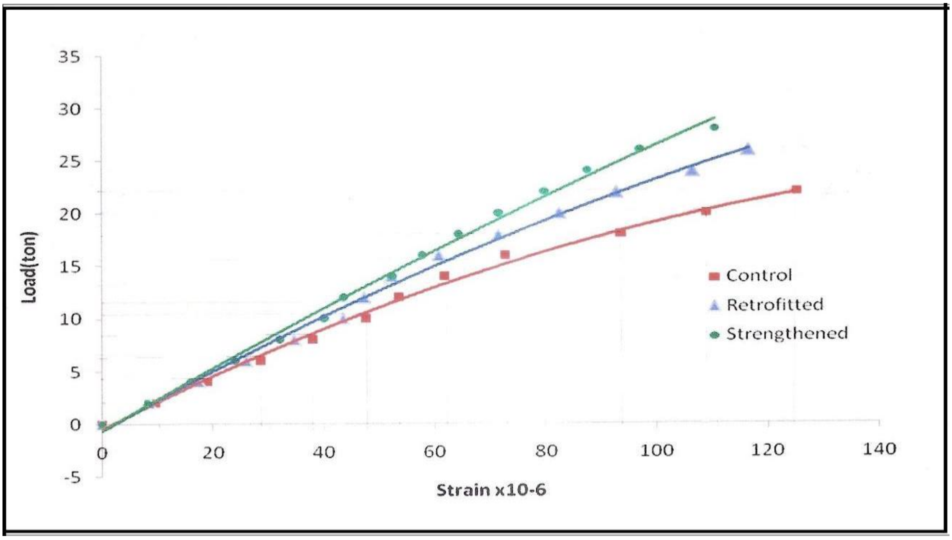

Figure (8) Load – strain relationship for rectangular columns.

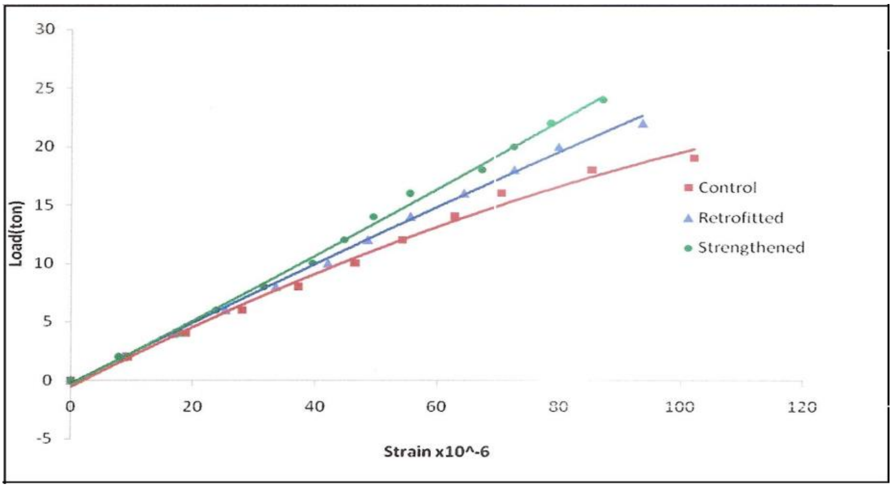

Figure (9) Load – strain relationship for square columns.

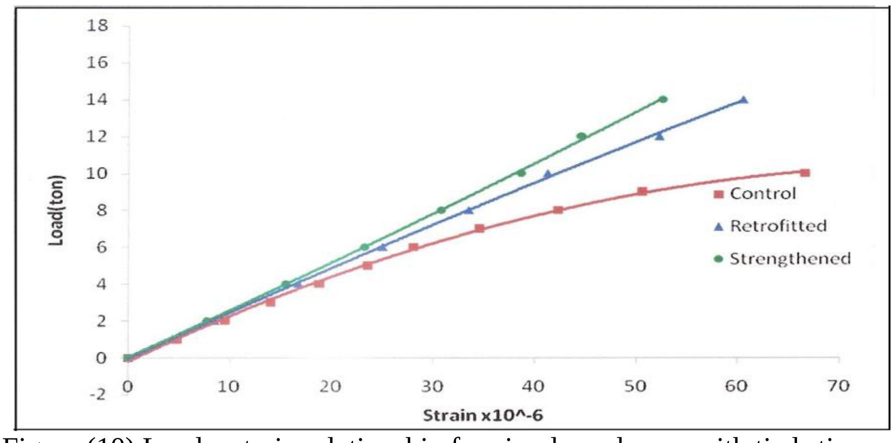

Figure (10) Load – strain relationship for circular columns with tied stirrups.

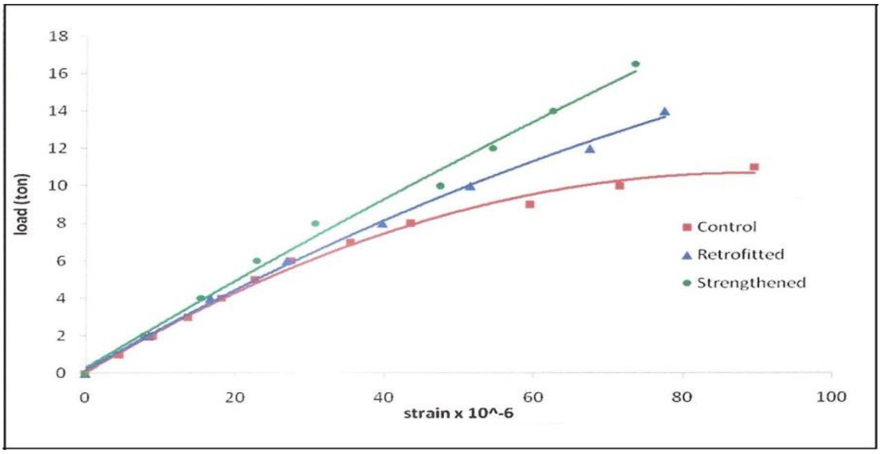

Figure (11) Load – strain relationship for circular columns with spiral stirrups.

Figure (12) Testing one of the strengthened column.

Figure (13) Cracking of circular column and the .The cover stated to spall out.

Figure (14) Spalling of the concrete cover of rectangular column.

Figure (15) Spalling of the concrete cover of circular column.

Figure (16) Buckling of the vertical steel plates of the circular column.

Figure (17) total fracture of the column and the steel jacket of the circular column.

Plate (1) Deteriorated column before applying the steel jack.

Plate (2) The steel angles and both the transverse and diagonal plates of the jacket.

Plate (3) Casting of the new concrete cover starting from above the footing.

Plate (4) Focused view for the components of the used steel jacket.

Plate (5) The concrete cover of the connection between the column and the beam.

Plate (6) The concrete cover has been finished after the execution of steel jacket.

CONCLUSIONS

Based on the present investigation, the following conclusions can be drawn:

1. The mechanical performance and properties of retrofitted and strengthened columns were significantly improved. The rectangular and square columns exhibited a tremendous improvement in strength of 20 and 30 % with retrofitted and strengthened columns respectively, when compared with the original control columns.
2. The most beneficial achievement of applying steel jacketing technique is to be used in retrofitting of the damaged or deteriorated columns. The strength produced from testing the pre-cracked retrofitted columns were found to be higher than the strength of the original ones by an average value of 15-18%.
3. The application of the proposed steel jacketing technique in different projects, either in retrofitting or strengthening, provides a marvelous improvement in stiffness and strength of the existing reinforced concrete columns as well as it

enhances the ductile behavior of columns and prevents their brittle crushing mode of failure.

4. The existing transverse and diagonal plates welded in the steel angles of the jacket cause an active confinement and further enhancement in the load bearing capacity of the columns.

REFERENCES

1. A. E. Khodary, " Behaviour of Reinforced Concrete Columns Confined with Advanced Composite Materials ", PhD Thesis, Minia University, Egypt, 1997.
2. K. Galal, A. Arafa and Ghobara, " Retrofit of R.C Square Short Columns ", Engineering Structures, Volume 27, Issue 5, April 2005, http://www.science direct.com.
3. H. Seung Lee, T. Kage, T. Nougchi and F. Tomosawa, " An Experimental Study on the Retrofitting Effects of Reinforced Concrete Columns Damaged by Rebar Corrosion strengthened with Carbon Fibre Sheets ", Cement and Concrete Research, 33(2003), Pp 563-570.
4. A. Abou-elezz, A. E. Sayed, T. H. Abdellatif and G. Abdel-sayed," Retrofitting of Square Columns Using Advanced Composite Materials", First International Civil Engineering, "Egypt-China-Canada", Symposium 1997, AEIC"97, Egypt. 18-20 December. 1997.
5. A. Abou-elezz, A. E. Sayed, O. T. Ibrahim, and G. Abdel-sayed, " Strength and deformation Characteristics of Short RC Circular Columns confined with Glass-Fibre Composites", Journal of Engineering Science, El-Minia University, part 20(1), July 2001.
6. M.N. Hadi, " Using Fibre to Enhance the Properties of Concrete Columns ", Construction and Building Materials, 21(2007), Pp 118-125.
7. Abdallah and Kaatsuki Takiguchi, " Behaviour and Strength of reinforced concrete Columns strengthened with Ferro Cement Jackets ", Cement and Concrete Composites, 25 (2003), Pp 233-242.
8. A. Mortazavi, K. Pilakoutas and K. Sangson, " R.C Column Strengthening by Lateral Pre-Tensioning of FRP ", Construction and Building Materials, 17(2003), Pp 491-497.
9. G. Li, S. Hedlund, S. Kidane, S. Pang, J. e. Helms and MA. Stubblefield, " Investigation into FRP Repaired RC Columns ", Composite Structures 62 (2003),Pp 83-89. http://www.science direct.com.
10. H. Seung Lee, T. Kage, T. Nougchi and F. Tomosawa, " An Experimental Study on the Retrofitting Effects of Reinforced Concrete Columns Damaged by Rebar Corrosion strengthened with Carbon Fibre Sheets ", Cement and Concrete Research, 33(2003), Pp 563-570.

علاج وتقوية الأعمدة الخرسانية المسلحة بإستخدام القمصان المعدنية
الخواص الميكانيكية والتطبيقات

إن تنفيذ قمصان للأعمدة الخرسانية المسلحة يعتبر من الطرق المتداولة والشهيرة سواء لعلاج أو تقوية للأعمدة. هذه القمصان تتم عن طريق إستخدام حديد إضافى رأسى وكانات حول العمود وتغطيته بقميص خرسانى جديد حول هذا العمود هو القميص الخرسانى وهذا النوع من العلاج أو التقوية له مشاكله عن طريق إستخدام شدات جديدة وزيادة قطاع العمود الخرسانى وأيضا مشاكل الصدأ التى يمكن ان يتعرض لها الحديد.

حديثا أهتم العلماء باستخدام أنظمة ومواد جديدة لعمل قمصان الأعمدة منها أستخدام GFR ، FRP شرائح الألياف الزجاجية أو ألياف بوليميرية – مع العلم بان استخدام القمصان المعدينة لم يتم تغطيته بالكامل فى الأبحاث السابقة.

لذلك كان الغرض الرئيسى من هذا البحث هو دراسة معملية لبيان امكانية استخدام القمصان المعدنية سواء فى علاج الأعمدة المشرخة أو تقويتها.

لذلك تم صب ثلاثة محموعات متشابهة من الأعمدة حيث ان كل مجموعة تتكون من ثمانية اعمدة (2 عمود مستطيل + 2 عمود مربع + 2 عمود دائرى بكانات مقفولة + 2 عمود دائرى بكانات حلزونية) والغرض من الثلاث مجموعات كالآتى:

1- المجموعة الأولى تم أختبارها كما هى بغرض المقارنة
2- المجموعة الثانية تم تحميلها حتى حدوث الشروخ بها ثم تم علاجها بالقمصان المعدنية المتقدمة تم إعادة اختبارها لبيان مدى الأستفادة من العلاج
3- المجموعة الثالثة تم تقويتها بنفس القمصان المعدنية المستخدمة فى المجموعة الثانية لبيان مدى الأستفادة من التقوية

القمصان المعدنية المستخدمة عبارة عن زوايا حديد وشرائح معدنية ثم لحامها حول العمود بعد دهانها بمادة ايبوكسية مانعة للصدأ ثم استخدام غطاء خرسانى حولها به الياف من البولبيروبلين.

وكانت النتائج ممتازة الى حد كبير حيث ان مقاومة الأعمدة سواء المقواه او المعالجة زادت بنسبة كبيرة تفوق الأصل.

تم تنفيذ القمصان المعدنية على اعمدة حقيقية لبعض المشاريع القائمة بالفعل والتى بها مشاكل وذلك منذ حوالى 10 سنوات وهى مازالت بحالة ممتازة.