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ASSESSMENT OF STRUCTURAL BEHAVIOR OF LONG RC COLUMNS LATERALLY REINFORCED WITH EMM METAL MESH AS UNTRADITIONAL REINFORCEMENT

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ملخص البحث باللغة العربية:

تُعد المنشآت الخرسانية من أكثر المنشآت استخداماً على نطاق واسع في جميع أنحاء العالم. وبذلك فان دراسة سلوك هذه المنشآت من أهم ما يُدرس بمجال الهندسة الإنشائية. وتُعتبر الأعمدة الخرسانية أهم العناصر داخل المنشآت الخرسانية فالأعمدة هى ركائز الكمرات والبلاطات ومن خلالها تنتقل الأحمال الرأسية للأساسات. إن انهيار بعض الأعمدة في المبانى قد يؤدي إلى الانهيار الكامل للمنشأ الخرسانى. وكثيراً ما تعاني الأعمدة الخرسانة المُسلحة من أضرار بسبب الأحمال الزائدة والكوارث الطبيعية كالحرائق. يتناول ذلك البحث تقديم تقنية حديثة للتسليح العرضى فى الأعمدة الخرسانية الطويلة والتى تهدف الى التغلب على عيوب الكانات وتحسين السلوك الأنشائى للأعمدة الخرسانية من حيث رفع المقاومة القصوى و تحسين الممطولية. وقد تم تنفيذ دراسة معملية يمكن من خلالها دراسة سلوك الأعمدة الخرسانية الطويلة المُسلحة افقياً بواسطة الشبك المعدنى الممدد كتسليح بديل مبتكر تحت تأثيرالأحمال الاستاتيكية. تم الاخذ فى الاعتبار دراسة عدة متغيرات مؤثرة على سلوك الأعمدة الخرسانية لأكتشاف مدى فعالية هذه التقنية باستخدام الشبك مع او بدلًا من الكانات كإحدى وسائل التسليح الأفقى فى الأعمدة الخرسانية الطويلة. وقد أثبتت نتائج الدراسة التى تم اجراؤها كفاءة التسليح العرضى المقترح من حيث زيادة قيمة الحمل الأقصى للعمود وتحسين الممطولية.

ABSTRACT

Using traditional confinement in reinforced concrete columns with small spacing between ties may be lead to reinforcement congestion of concrete core and limitations in confining the concrete core. Moreover, ties interrupt the continuity and creates plane of weakness between core and concrete cover. Therefore, ties may not provide enough confinement for RC columns. This paper presents a new technique of confinement using metal meshes with high mechanical properties with or instead of ties as lateral reinforcement for long RC columns studying the pre-load effect. Eight square RC column specimens with ƛ= 16.296 were reinforced laterally by ties with volumetric ratios (ρ=0.413%, 0.206%, and 0%) and expanded metal mesh. The experimental results indicated that the columns (confined with that new technique of lateral reinforcement)exhibited significant improvement in the column capacity, energy absorption and ductility. Ties may be completely replaced with double layer of metal mesh with high mechanical properties without reduction in ultimate load capacity.

Keywords: Reinforced Concrete Column; Long Column; Confinement; Lateral Reinforcement; Expanded Metal Mesh.

1. Introduction

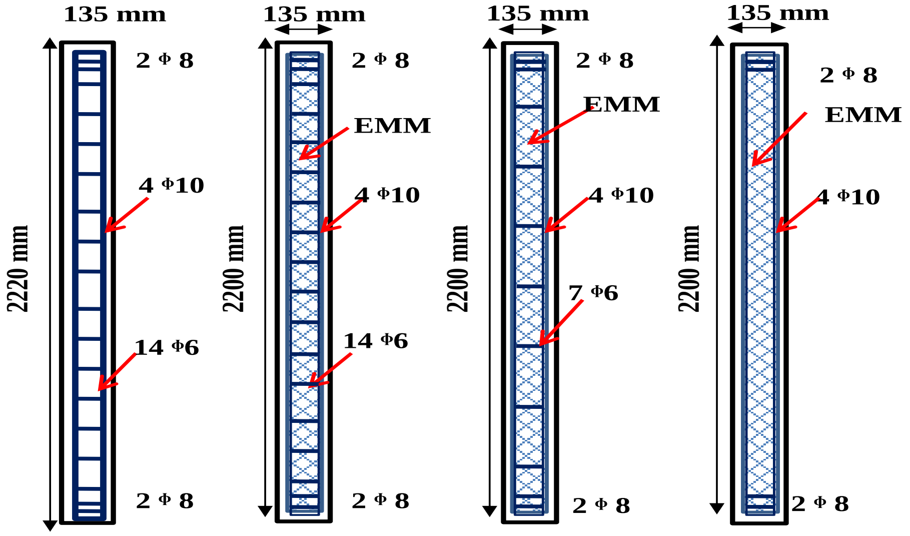
Reinforced Concrete (RC) structures are the most widely structural system used all over the world. Reinforced concrete is a composite material in which relatively low tensile strength and ductility, of concrete, are counteracted by high tensile strength and ductility of reinforcement. The behavior of reinforced concrete structures and their failure modes were extensively studied by numerous researchers. RC columns are the main structural elements which transmit the total vertical loads of the building to foundation. RC columns may be classified to short and long columns according to their slenderness ratio [1]. The reinforcement of concrete columns consists of vertical reinforcement and lateral reinforcement. In 1989, Salim and Murat [2] indicated that confining RC columns by reinforcement provided significant improvement in their strength and ductility. Ties are used as traditional lateral reinforcement in columns. The ties provide the confinement for concrete core to save the column from crushing. Moreover, ties have great benefits such as eliminating longitudinal reinforcement buckling, resisting lateral loads, reducing concrete shrinkage and increasing column load capacity. On the other hand, ties have some limitations in confining the concrete core. Kumar et al. [3] indicated that ties interrupt the continuity and creates plane of weakness between core and concrete cover. In addition, the small spacing between ties may be lead to reinforcement congestion of concrete core. Therefore, ties may not provide enough confinement for RC columns [3 and 4]. Fiber Reinforcing Polymer (FRP) [5] and metal meshes [6] are the common materials that used for internal or external confinement in concrete columns. Metal meshes (expanded metal mesh EMM & welded wire mesh WWM) were used for repairing and strengthening RC columns and may be used instead of ties in confining RC columns. Shekhar et al., 2016 [7] studied the axial behavior of cylindrical concrete specimens confined ferrocement layers. Kaish et al., 2016 [8] provided experimental study for different approaches to improve conventional square ferrocement strengthening jacket. Mourad and Shannag, 2012 [4] strengthened square RC columns using ferrocement jackets. Xiong et al., 2011 [9] studied the load carrying capacity and ductility of circular plain concrete columns confined by FRP and ferrocement including steel bars. Moghaddam et al., 2010 [10] provided experimental study on axial compressive behavior of concrete actively confined by metal strips. Takeuti et al., 2008 [11] strengthened the preloaded RC columns with high-strength concrete jackets that tested under uniaxial compression. El-sayad and Shaheen, 2005 [12] investigated experimental study on externally confined (ferrocement and glass fiber sheets) RC columns. Katsuki and Abdullah, 2000 [13] provided experimental study on RC columns strengthened by circular Ferrocement jacket, steel plate, and carbon fiber. Until now, few researches [2, 14 and 15] are available for using metal meshes as confining reinforcement instead of ties. El-Kholy and Dahish, 2016 [14] confined short RC column specimens laterally by both ties and EMM with various slenderness ratios and ties volumetric ratio. Shaheen and Hassanen, 2011 [15] confined short RC columns with various materials (welded wire meshes, fiber glass meshes, polypropylene meshes). Satjapan and Trakool, 2008 [16] investigated experimental study on confinement of RC behavior of short columns reinforced with WWM as transverse reinforcement under concentric loading. El-sayad and Shaheen, 2005 [12] investigated experimental study on internal confinement using cage of EMM on RC columns. Murat and Mongi, 1999 [17] provided experimental study on confinement of RC columns with welded reinforcement bars and ties. All these researches were forwarded to short columns. Unfortunately, this technique has not been investigated for long columns. The motivations, for this study, were overcoming the defects of using ties as lateral reinforcement in RC columns and obtaining higher capacity for RC columns.

2. Experimental Program

Eight RC column specimens were confined by metal meshes. One-third scale was used in the experimental program. The dimension are (135x135x2200) mm with slender ratio ƛ=16.296. The specimens were initially loaded before testing to study the pre-load effect. The specimens were tested in laboratory of concrete research & material properties in the faculty of engineering at Fayoum University. All columns specimens have the same concrete strength and concrete cover. The vertical reinforcement was typical for all specimens. However, the horizontal reinforcement was variables as studied in parameters. Expanded metal mesh was used in confining the specimens as lateral reinforcement in combination with ties. The specimens were divided into two phases according to the lateral reinforcement as follows; Phase1 (Control): two control specimen column (one pair) with ties only of volumetric ratio ρ=0.413% as confining reinforcement, Phase2 (EMM & Ties): six column specimens (three pairs) were confined by combined confining reinforcement consisting of single or double layer of expanded metal mesh and ties with variable volumetric ratio ρ=0.413%, 0.206% and 0%. The dimensions, reinforcement details and classification of the tested column specimens are given in Table 1 and shown in Fig. 1.

Table 1: Details of Tested Column Specimens

Specimen name	**Phase**	**Dimensions**			**Reinforcement**				
		Length	width	Height	Longitudinal	ties		Metal Mesh	
		mm	mm	mm		No	ρ%	Type	N layer
LS14-P-C	1	135	135	2200	4Φ10	14Φ6	0.413	---	
LS14-P-E1	2	135	135	2200	4Φ10	14Φ6	0.413	EMM	1
LS7-P-E1		135	135	2200	4Φ10	7Φ6	0.206		1
L-P-E2		135	135	2200	4Φ10	---	---		2



Phase1
LS14-P-C
Ties 14ϕ6

Phase2
LS14-P-E1
Ties 14ϕ6
One layer EMM

Phase2
LS7-P-E1
Ties 7ϕ6
One layer EMM

Phase2
L-P-E2
Two layers EMM

Fig. 1: Dimensions and Reinforcement Details of Tested Column Specimens

2.1 Material Properties

The utilized concrete constituent conformed to Egyptian Standard Specifications (ESS). Portland Cement type I (CEMI) of grade 52.5N ES 4756-1/2006 conforming (ES 4756-1, 2009) [18] was used. Two different sizes of coarse aggregate basalt1 and basalt2 were mixed together to obtain uniform distribution. Sieve analysis for the coarse and fine aggregate were performed to obtain the grading of aggregates. The used basalt is well graded with maximum size 19 mm, specific gravity of 2.7, bulk density of 1.75, crushing strength of 23% and percentage of absorption 2%. The used fine aggregate is natural sand with fineness modulus 2.36, specific gravity of 2.63, bulk density of 1.65, and percentage of clay and other fine material of 1.65%. All physical and chemical results conformed the (ESS 1109, 2008) [19]. High grade tensile steel with grade 360/520 MPa and plan mild steel with grade 280/450 MPa were used as longitudinal and transversal reinforcements respectively. Tests were achieved to obtain the mechanical properties of used steel according to Egyptian standard specifications (ES 262-1, 2009) [20] and (ES 262-2, 2009) [21] for horizontal and vertical, respectively. All test results for steel conform the ESS. Expanded metal mesh 1.2 x 2.3 mm thickness with hexagonal opening of 50 x 25 mm. The weight per unite area and the weight per untie volume for expanded mesh was 1.628 Kg/m2 and 6 t/m3 respectively. Different mixes were designed and prepared in order to obtain a target cubic compressive strength of 36 MPa after 28 day. The rations taken for the mix were cement 420 kg/m3, crushed basalt 1139 kg/m3, sand 644 kg/m3 and fresh water 200 kg/m.

2.2 Preparation of the Specimen

The column specimens were prepared according the following procedure.

2.2.1 Reinforcement

Eight long RC column specimens were prepared. Four vertical bars of 10 mm diameter were used for vertical reinforcement. The vertical bars height was 216 cm. The ends of vertical bars were flexed horizontally to make both concrete and longitudinal bars work together to resist compression load. The lateral reinforcement was distinct for every pair of column specimens as shown in Table 1. All the ties were box ties 6 mm with dimensions 95 x 95 mm. For phase2 column specimens, the metal meshes were shaped with the same parameter dimension of ties with 210 cm height where there are splices in the third ends of column specimen. The length of splice was 30 cm. Then the expanded metal meshes were warped around the ties with and connected to ties and longitudinal reinforcement by using tying steel wire. All column specimens were confined at both column ends by two ties of 8 mm to provide more confinement at column ends against failure during testing on hydraulic jack. Figure 2-a shows the reinforcement of phase1 and phase2 column specimens.

2.2.2 Special Timber Formwork

Timber formworks with sizes of 13.5 x 13.5 x 225 cm were designed and manufactured to cast the concrete in vertical position, similar to construction in field. The formwork were designed and manufactured to cast the concrete in vertical position where the concrete must pass from the core of column specimen through the opening of metal meshes to the cover without making voids in the concrete. The inner face of formwork was overlaid by Zetolan SH2, which is a special formulated agent with chemical release properties, enabling easy stripping from concrete. The prepared reinforcement cage was placed in the formwork. The formworks were closed tightly by stiffeners to be intended for casting the concrete Fig. 2-b.

2.2.3 Mixing and casting concrete of RC column specimens

The used basalt was washed by water before mixing. The concrete materials were mixed using electric concrete mixer according to the specific ratios given in section 2.1. The fresh concrete was conveyed to formwork and poured vertically. Each specimen was compacted by mechanical vibrating for 1 minute to satisfy good concrete without voids. The top surface of concrete was finished smooth using a trowel. A smooth wooden was put in the top surface of the specimen to provide completely smooth surface for effecting on it by load. In the second day, after casting the columns specimens, the columns were cured for 28 day by water. Figure 3 shows the column specimens after curing. Six cubes 150x150x150 mm from each mix were cast in steel molds and cured under the same conditions of columns specimens. The average compressive strength was 27.6 and 36 MPa after 7 and 28 days, respectively.

(a) Reinforcement of column specimens (b) Formworks for column specimens

Fig. 2: Preparation of Column Specimens.

2.3 Instrumentation and Test Setup

All the specimens were tested under axial compression loading up to failure using hydraulic loading machine of 1000 KN capacity. The machine was calibrated before testing to ensure the accuracy of results. The specimens were applied to primary loads (50% of ultimate capacity of control column specimen of this group). Two rigid steel plates were placed at the top and end of specimens to distribute uniformly load on the area of column specimen. Two steel caps were prepared for testing columns specimens. They were formed from two steel angles connected together with steel bolts. The caps placed in the top and bottom end of column specimens to provide enough confinement at loading and avoid the end effect reaction while loading. All column specimens were placed in vertical alignment so the verticality of the column specimen was examined carefully to avoid any eccentricity in loading. Electrical strain gage for concrete was used for measuring the axial and lateral strain in specimens. Two strain gages were put in vertical directions at top and bottom third height of column for measuring axial strain and one strain was put in horizontal direction at the mid height for measuring lateral strain. Three Linear Variable Differential Transformer (LVDT) were used in testing to measure axial and lateral displacement for each specimen. For measuring the axial displacement, one LVDT fixed in vertical direction and other two LVDT's were mounted on a rigid wooden-stand which was manufactured and fixed into a RC base to be stable enough to monitor the deformation. They were at mid-height of specimen in horizontal directions on two perpendicular faces of tested specimen to measure lateral deflections. Figure 4 shows instrumentation and test setup of column specimens.

Fig. 3: Column specimens after curing.

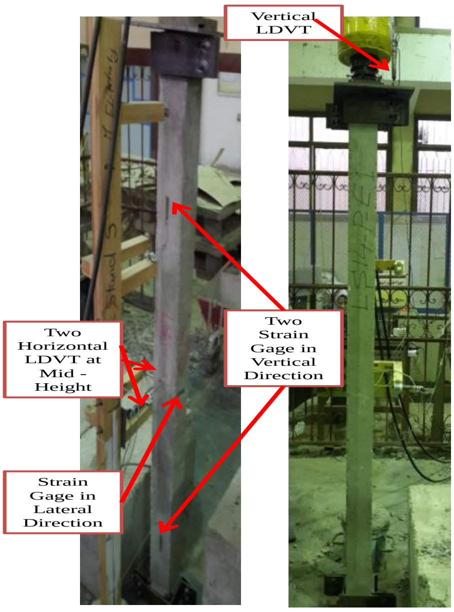


Fig. 4: Instrumentation and test setup.

3. Experimental Results and Discussion

The results of every pair of column specimens (two identical column specimens) varied within 10%. Table 2 Summarizes the maximum ultimate load, vertical displacement, lateral displacement, % vertical strain, % lateral strain and energy absorption at maximum ultimate load for long column specimens. Figure 5 shows the load-vertical displacement curve for phase2 with respect to phase1. Figure 6 shows the load-%vertical strain curves for phase2 with respect to phas1. Figures 5-10 visualize the increments in ultimate load, vertical displacement, vertical strain and energy absorption, respectively, for phase2 with respect to the reference. Figure 11 illustrates the failure modes and crack patterns of tested specimens. The tabulated and illustrated results (Figs.5–11 and Tables 2) are analyzed and discussed in Sections 3.1–3.8.

3.1 Ultimate Load

Results indicated that one EMM layer (LS14PE1, phase2) as an additional lateral reinforcement for long column specimens with volumetric ties ratio ρ= 0.413%, increased the ultimate load with 30.32% over (LS14PC, phase1) for pre-loaded long column specimens. One EMM layer with reduction 50% of ties (LS7PE1, phase2) increased the ultimate load with 18.97%. Two EMM layers (LPE2, phase2) increased the ultimate load with 10.64%. This value indicated that the ties may be completely replaced by double layers of expanded mesh for long column specimens.

3.2 Axial Deflection

At failure, all phase2 column specimens exhibited higher vertical displacement than reference phase1 specimens (Fig.8). Therefore, the additional lateral reinforcement of EMM layer resulted in higher vertical displacement of long column. The increments were 84.85%, 71.65% and 13.59% for LS14PE1, LS7PE1 and LPE2, respectively. It can be observed that there is less increment in vertical displacement when the ties are totally replaced by EMM.

3.3 Lateral deflection

Lateral deflection is an important issue for long columns. Table 2 shows that in phase2, the increments were 48.13%, 32.81% and 7.19% for LS14PE1, LS7PE1 and LPE2, respectively. The increment values indicate that phase2 column specimens experience lateral displacement more than the traditional phase1 considering pre-load effect. The source of huge increments ratios in lateral displacement is the additional confinement by EMM. With no ties, the metal meshes achieve the same or smaller increment in lateral displacement than control specimens.

3.4 Vertical Strain

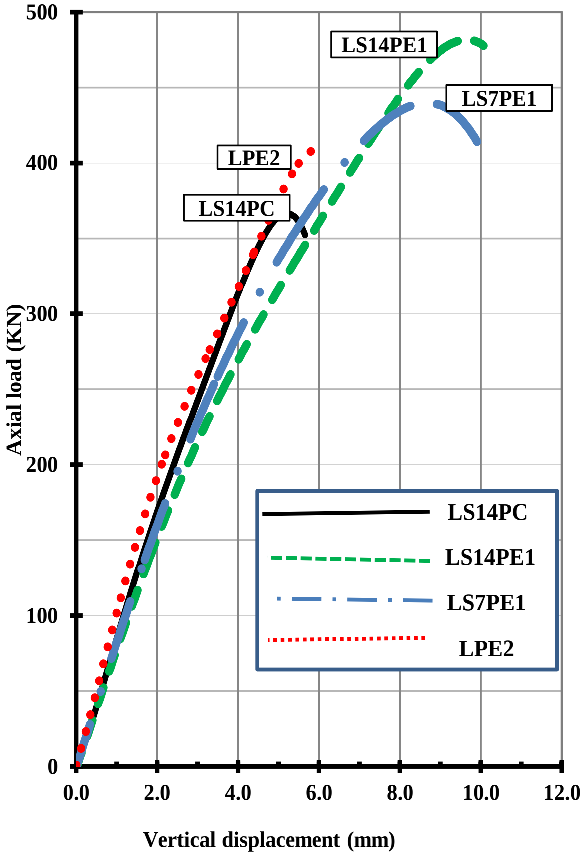
Table 2 shows that the increments in vertical strain in phase2 were 31.77%, 15.13% and 8.72% for LS14PE1, LS7PE1 and LPE2, respectively. Figure 9 showed that all specimens that reinforced laterally by EMM experience vertical strain more than the traditional specimen phase1 for long column specimens.

Table 2: Test Results for Tested Column Specimens.

Specimens					**Ultimate load**		**Vertical displacement**		**lateral displacement**		**% vertical strain**		**% Lateral strain**		**Energy absorption**	
Specimen name	**Phase**	**ρ%**	**Metal mesh**		**KN**	**%Higher ultimate load**	**mm**	**%Higher vertical displacement**	**mm**	**%Higher lateral displacement**	**%**	**%Higher vertical strain**	**%**	**%Higher later strain**	**KN.mm**	**%Higher energy absorption**
			Type	**N layer**												
LS14-P-C	1	0.413	----		623.60	-----	3.75	-----	0.60	-----	0.186	-----	0.031	-----	1310.97	-----
LS14-P-E1	2	0.413	EMM	1	844.53	35.43	5.45	45.33	1.85	208.33	0.284	52.20	0.073	136.27	2683.65	104.71
LS7-P-E1		0.206		1	805.80	29.22	5.25	40.00	1.10	83.33	0.278	49.20	0.066	114.10	2658.21	102.77
L-P-E2		---		2	741.60	18.92	4.51	20.27	0.75	25.00	0.234	25.70	0.035	13.11	2141.87	63.38

3.5 Lateral Strain

Table 2 lists that phase2 increments were 136.27%, 114.10% and 13.11% for LS14PE1, LS7PE1 and LPE2, respectively. The increment values indicate that phase2 column specimens experience lateral strain more than the traditional phase1. The source of huge increments ratios in lateral strain is the additional confinement by EMM. With no ties, the metal meshes achieve smaller lateral strain than control specimens.



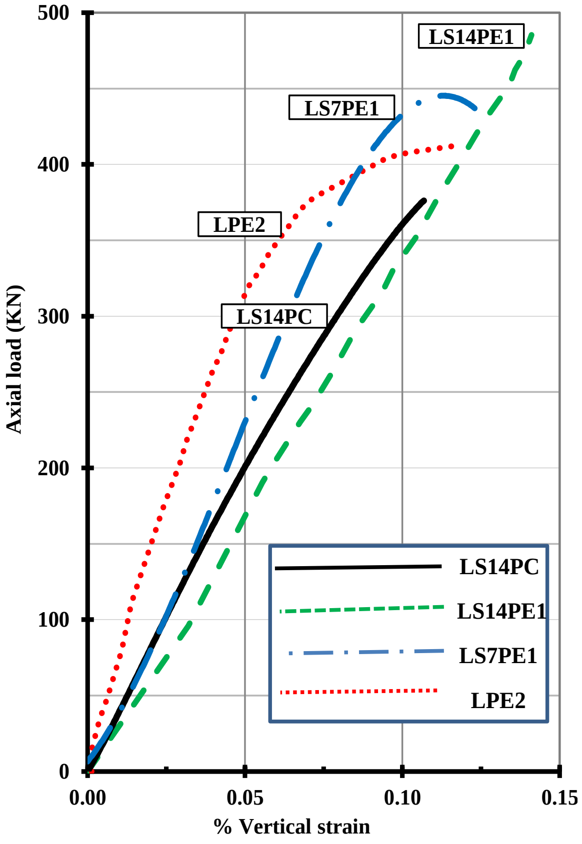
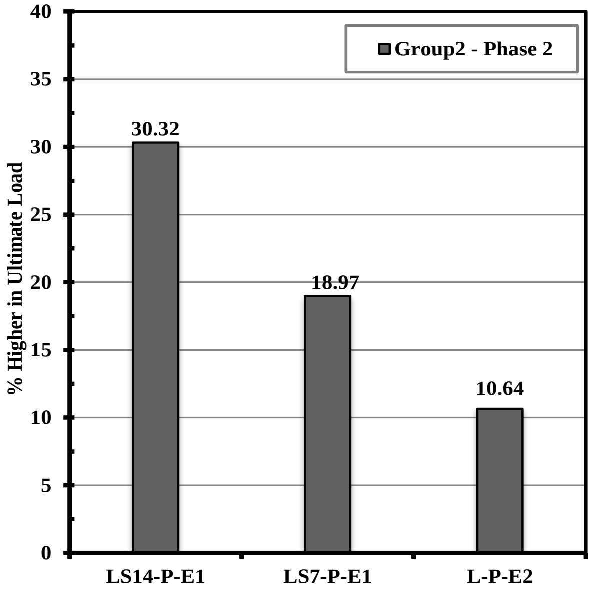


Fig. 5: Average variation of load – vertical displacement.

Fig. 6: Average variation of load – vertical strain

3.6 Ductility

The concept of structural ductility is the ability of structural members to suffer internal forces through large deformations without damage or collapse. The load displacement curve, given in Fig.5, shows that phase2 column specimens have improved ductility over those of phase1. It can be seen that LS14PE1, (no reduction in ties + one layer of EEM), exhibited highest ductility then LS7PE1 (50% reduction in ties + one layer of EEM). This improvement in ductile is a result of the confining provided by single EMM layer with high mechanical properties combined with ties. When the ties are totally replaced by two layers of expanded metal mesh (LPE2), the specimen exhibited approximately the same ductility of control specimens.



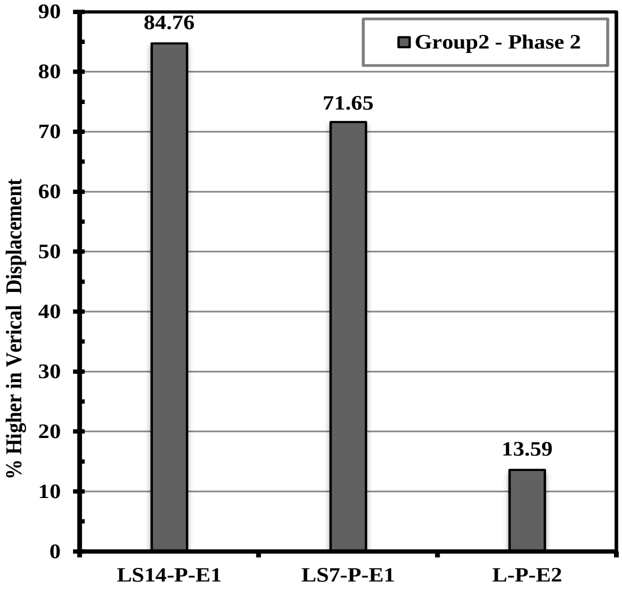
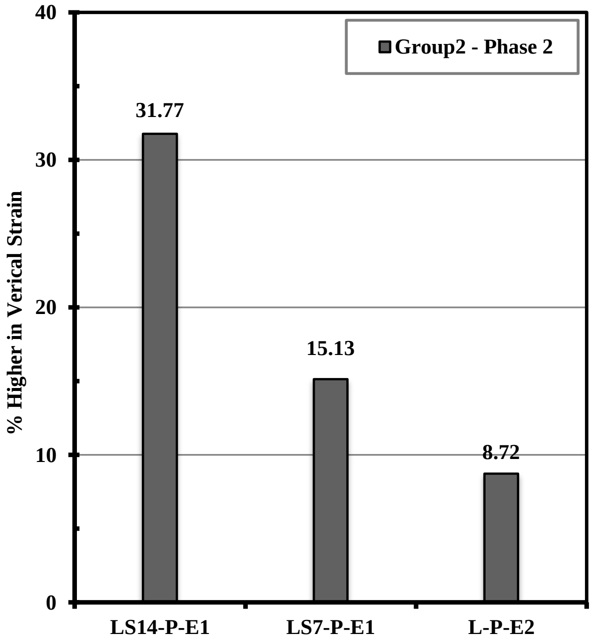


Fig. 7: Percent increment in ultimate load.

Fig. 8: Percent increment in vertical displacement



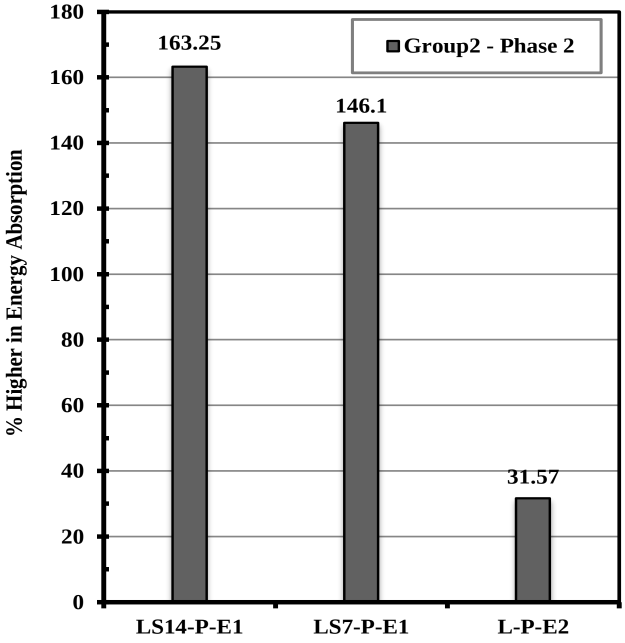


Fig. 9: Percent increment in vertical strain.

Fig. 10: Percent increment in energy absorption.

3.7 Energy absorption

The energy could be defined as the work done in straining or deforming the columns up to the limit of functional deformation. The area under the load–displacement curve of column specimen represents the energy absorbed by column. Figure10 shows the energy absorption in phase2 that higher than control specimen. For phase2 column specimens the increments were 163.25%, 146.1% and 31.57% for LS14PE1, LS7PE1 and LPE2, respectively. The source of increments in absorbed energy for phase2 column specimens is their flexible behavior generated by high increment values in the vertical displacement.

3.8 Cracks

Longitudinal cracks occrued at approximately 70% of ultimate load of tested column specimens. The lengths and widths of cracks became hard at approximately 90–95% of ultimate load. The longitudinal cracks eventually led to the spalling of concrete cover and the stiffness decreased gradually. It can be seen that the failure of control column specimen (phase1) was sudden and brittle. It was failed in compression by crushing of concrete core with buckling of longitudinal reinforcement as shown in Fig.11-a unlike the failure of column specimens that confinement with metal meshes (phase2). It is expected that increasing the number of layers of EMM or using better mechanical properties of metal meshes will reduce the buckling of both longitudinal bars and EMM layer, and minimize the crushed volume of concrete core.


LS14PC LS14PE1 LS7PE1 LPE2

(a) Phase 1 (b) Phase 2

Fig. 11: Crack pattern of column specimens

4. Conclusions

This paper presents investigation for using single or double EMM layers combined with ties of various volumetric ratios as lateral reinforcement for square long RC columns. Based on results of tested column specimens, the following conclusions can be drawn:

1. The columns, confined with the considered technique of lateral reinforcement, exhibited significant improvement in the column capacity, energy absorption and ductility.
2. Confining long column specimens with single layer of EMM combined with ties (ρ=0.413%), increases the ultimate load with 30.32%.

3. With 50% reduction in ties (ρ=0.206%), single layer of EMM increased the ultimate load with 18.97%.
4. Two EMM layers, as only the lateral reinforcement increased the ultimate load with 10.64%.
5. Column specimens confined with metal mesh layer combined with ties exhibits more plastic deformation and more ductile behavior, compared to specimens confined with only ties or metal mesh.

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