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Laboratory Study of the Effect of Reinforcement Strips (Cfrp) on the Ductility and Confinement of Reinforced Concrete Columns

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Abstract

The issue of repairand reinforcement of structures is one of the major branches of civil engineering. In this direction, the reinforcement of the pressure members, especially the reinforced concrete columns by reinforced polymer sheetsis considered as one of the conventional methods in reinforcing these members. By confining the pressure member and preventing lateral expansion resulting from the Poisson's effect,the FRP sheetbrings about an increase in compression strength and ductility. In this laboratory research, the effects of different methods of reinforcing concrete columns by CFRP sheets including the effect of the width of reinforcing sheets on ductility and stress-strain behavior of the concrete columns in the presence of internal reinforcement of the column were studied. The steel reinforcement of column includes evaluation of the effect of longitudinal and transverse steel bars, number of transverse bar, and also development bar of longitudinal reinforcement on the rate of confinement.

The results of this research show that by suitable arrangement of CFRP reinforcing sheets, the confinement in the reinforced concrete columns can be created appropriately.

Keywords: CFRP, Confinement, Reinforced concrete columns, Ductility, Internal reinforcement

Introduction

Nowadays, due to the high cost of construction,the maintenance of reinforced concrete structures is very important. The study of bearing capacity of the existing structures shows that many of these structures in the current situation are weak considering their bearing capacity and require reinforcement and improvement of the reasons effective in the need for reinforcement one can refer to mistakes in calculations, design and supervision;structural change of use; demand for more capacity due to an increase in the number of stories; or an increase in the traffic volume; location of the structures in damaging environment; and finally, damages resulting from accidental loads on the other hand, changes in the building codes also redoubles the need for evaluation and review of the design of structures.

Reinforcement of reinforced concrete columns as the major members of the structural bearing transferring the axial load with or without bending moment to foundation is very important in the improvement of the performance and safety of the structure. The use of concrete and metal wraps over the last decades for the reinforcement of reinforced concrete columns was very common and today, it is also one of the common methods. But, these reinforcement methods require great equipment and workforce. Additionally, concrete wraps greatly increases the weight of the structure and steel wraps also bear the great share of the weight in addition to their weakness against fire while they suffer buckling due to their small thickness. On the other hand, due to the lack of full connection between the metallic wraps and the surface of the column in steel wraps in the initial stages of loading, the empty space between the two materials results in delay in the confinement of the column.

The continuous advancement ofscience in the field of structure and earthquake engineering has architecture to the use of modern methods and new constructional materials by researchers in recent years. Among these innovations, the use of CFRP (carbonfiber reinforced polymer) has enjoyed such a special position in reinforcing buildings that some specialists believe that CFRP should be called the third millennium constructional material. Since the CFRP composite enjoys exceptional features such as [1]:

1- very high tensile strength
2- high strength against environmental damaging agents
3- high strength proportional to weight
4- speed and ease of transportation and installation

5- unlimited access to the size, shape, and dimensions
6- low thickness leading to no change in appearance of the reinforced member and
7- closeCFRP Poisson's coefficient to concrete have opened a new door to civil engineersso that numerous structures are reinforced with these materials around the world these days.

The first research in this area was conducted in the beginning of the 1980's in Swiss and its results in reinforcing the reinforced concrete bridges were employed in 1991. The 1990 earthquake in California and the 1995 earthquake in Kobe, Japan led to more studies on the application of CFRP composites to reinforce concrete structures and buildings in earthquake-prone areas [2].

Studies show that most of the damages inflicted on reinforced columns in the past earthquakes, have been due to the insufficiency ofbending ductility and also weakness in shear capacity of the column. The occurrence of damage due to these factors in structures designed according to old earthquake codes is not surprising. Insufficient transverse steel leads to weakness in the confinement of the column core and can lead to the buckling of the longitudinal steel bars, crushing of the concrete pressure region and ultimately resulting in ductility weakness [3].

Polymeric composite materials are abundantly used for the confinement of concrete to reinforce the reinforced concrete columns today and due to this appreciation and acceptance over the last two decades, many researches have been conducted both in laboratory and in numerical modeling to study the behavior of the confined concrete columns.Most of these researches are devoted to the study of the confinement behavior of the columns in small dimensions and without internal reinforcement [4]. It is evident that the presence of internal reinforcement (longitudinal and transverse reinforcements) can be effective in the confinement of the member depending on the rate of reinforcement and can also overshadow the effects of the external reinforcement.Little attention has been paid to the issue of the confinement of the columns with low specified strength in the presence of internal confinement in these researches.

In the present research, the effects of internal reinforcement comprising the effect of the longitudinal round bars and pitches of transverse binding round bar, as well as the manner of longitudinal round bar bracing on the increase of the external confinement and ductility in circular columns in which the specified strength of concrete is lower than the expected limit of the design due to the execution are studied.

Materials and Samples Details

In the present research, 20 cylindrical samples with a diameter of 120 mm and a height of 300 mm including a sample with no reinforcement (the control sample), 4 samples with internal reinforcement, 3 samples with external reinforcement only, and 12 samples including internal reinforcement and reinforced with CFRP sheets to study the effects of internal and external reinforcement on the confinement of reinforced concrete columns, were tested. Since one of the goals of this research work is to reinforce and strengthen reinforced concrete columns, the concrete specified strength (f_c') was considered to be 16.9 MPa for the test samples to experimentally study. the effects of confinement in reinforcement of real columns that do not enjoy the design requirements of the existing structures due to executive problems and weak in-situ concreting.

In order to perform the internal reinforcement of the samples similar to real columns, the longitudinal and transverse reinforcements were employed in a binding manner. The longitudinal reinforcements of the samples included 6 steel bars of $\phi 8$(ρ= 2.7 %) type. The steel bars were used for the binding reinforcement. The steel wire was with diameter of 3 mm according to the codes of standards. The distance of the spiral pitches in some samples was 20 mm and in some it was considered to be 50mm (Fig. 1).

Figure 1: The internal reinforcement in samples without end bracing

Figure 2: The internal reinforcement is samples with end bracing

Figure 3: The external reinforcement in the experimental samples

With regard to the diversity of the experimental samples and for better comparison, the experimental samples were categorized into 5 groups according to tables 1 to 5.In these tables, the samples with no the internal reinforcement are abbreviated to N and samples with longitudinal steel bars and transverse binding reinforcement are abbreviated to R…S. Also, in order to study the effects of the rigidity of the support in a number of the samples with internal reinforcement, the presence of bracing for the longitudinal reinforcements and also for more uniform load distribution, two circular steel sheets with a thickness of 6 mm and a diameter equal to the diameter of the cylindrical sample welded to the end of the longitudinal steel bars, were used. These samples are specified with LR…S abbreviations (Fig. 2).

The specifications of group 1 samples comprising of cylindrical samples without internal reinforcement are shown in table 1.In this table, the N 12 sample; the control sample; and N 12-2, N 12-5, and N 12-C samples are sequentially the samples without internal reinforcement and reinforced with FRP sheets. The reinforcement of N 12-2 sample is done in the form of external reinforcement with strips of FRP sheet with a width of 20 mm and a clear distance of 22 mm in a circular manner.Also, the FRP sheet strips with a width of 50 mm and a clear distance of 65 mm are used in sample N 12-5. In the reinforcement sheet in sample N 12-C is in the form of full binding. Fig. 3 shows the condition of the external reinforcement in the samples.

Tables 2 to 5 also show the specifications of cylindrical samples with internal and external reinforcement. Tables 2 and 3 shows the specifications of the samples withspiral reinforcement with a pitch of 20 and 50 mm and without the end binding sheet, while tables 4 and 5 show the specifications of the samples with spiral reinforcement with a pitch of 20 and 50 mm with the end binding sheet. The reinforced samples in tables 2 to 5 are strengthened by the use of a CFRP sheet layer with a width of 20 or 50 mm and a clear distance of 22 and 65 mm or by the use of full binding of the reinforcing sheet.

It is required to explain that the area of the reinforcing sheet in the samples with full binding is twice as much that of the reinforcing sheets in the samples with broken binding and with a width of 20 or 50 mm; in other words, the cross section of the reinforcing sheet in the samples with a width of 20 and 50 mm is equal and only the clear distances between the bindings are different.

Table 1: Group 1 (samples without internal reinforcement)

Sample abbreviation	Bracing thickness (mm)	Specifications of the transverse binding steel bar	Longitudinal steel bar	CFRP sheet width (mm)	CFRP clear distance (mm)
N12	-	-	-	0	0
N12-2	-	-	-	20	22
N12-5	-	-	-	50	65
N12-C	-	-	-	Full wrap	-

Table 2- Group 2 :(samples with internal reinforcement and 20-mm spiral pitch distancewithout end sheet)

Sample abbreviation	**Bracing thickness (mm)**	**Specifications of the transverse binding steel bar**	**Longitudinal steel bar**	**CFRP sheet width (mm)**	**CFRP clear distance (mm)**
R12-S2	-	ϕ 3 @ 20	6 ϕ 8	0	0
R12- S2-2	-	ϕ 3 @ 20	6 ϕ 8	20	22
R12- S2-5	-	ϕ 3 @ 20	6 ϕ 8	50	65
R12- S2-C	-	ϕ 3 @ 20	6 ϕ 8	Full wrap	-

Table 3- Group 3: (samples with internal reinforcement and 50-mm spiral pitch distance without end sheet)

Sample abbreviation	**Bracing thickness (mm)**	**Specifications of the transverse binding steel bar**	**Longitudinal steel bar**	**CFRP sheet width (mm)**	**CFRP clear distance (mm)**
R12-S5	-	ϕ 3 @ 50	6 ϕ 8	0	0
R12- S5-2	-	ϕ 3 @ 50	6 ϕ 8	20	22
R12- S5-5	-	ϕ 3 @ 50	6 ϕ 8	50	65
R12- S5-C	-	ϕ 3 @ 50	6 ϕ 8	Full wrap	-

Table 4- Group 4: (samples with internal reinforcement and 20-mm spiral pitch distance with end sheet)

Sample abbreviation	**Bracing thickness (mm)**	**Specifications of the transverse binding steel bar**	**Longitudinal steel bar**	**CFRP sheet width (mm)**	**CFRP clear distance (mm)**
LR12-S2	6	ϕ 3 @ 20	6 ϕ 8	0	0
LR12- S2-2	6	ϕ 3 @ 20	6 ϕ 8	20	22
LR12- S2-5	6	ϕ 3 @ 20	6 ϕ 8	50	65
LR12- S2-C	6	ϕ 3 @ 20	6 ϕ 8	Full wrap	-

Table 5- Group 5: (sample with internal reinforcement and 50-mm spiral pitch distance with end sheet)

Sample abbreviation	**Bracing thickness (mm)**	**Specifications of the transverse binding steel bar**	**Longitudinal steel bar**	**CFRP sheet width (mm)**	**CFRP clear distance (mm)**
LR12-S5	6	ϕ 3 @ 50	6 ϕ 8	0	0
LR12- S5-2	6	ϕ 3 @ 50	6 ϕ 8	20	22
LR12- S5-5	6	ϕ 3 @ 50	6 ϕ 8	50	65
LR12- S5-C	6	ϕ 3 @ 50	6 ϕ 8	Full wrap	-

Preparation of the Samples

To reinforce and perform external confinement of the columns, the CFRP sheets with a thickness of 1 mm are used through the wet lay-up method. Since the connection of the sheets in the form of wet lay-up requires the saturation of fibers with epoxy resins, so the SikaDur 300 was used for soaking the fibers and their sticking on the concrete bed; SikaDur 31N which has more density relative to the first adhesive is used for the repair and filling the likely voids on the surface of the samples (before the connection of the sheets). The thickness of each layer of the adhesive under and on the surface of CFRP is 0.4 mm and with the thickness of a reinforcing sheet layer, the finished thickness of the reinforcing layer will be about 0.9 mm. The length of the patches of the reinforcing sheets was considered to be about 100 mm and with regard to the double-layered CFRP on the location of the patches, the thickness of the composite material in this area is over 1.3 mm. The mechanical specifications of the fibers and the adhesive used are shown in tables 6 and 7, respectively. Figs. 4 and 5 show the CFRP sheets and the adhesives used in this research work.

Table 6: Mechanical specifications of CFRP sheet

Material properties	weight of surface unit gr /m^2	tensile strength MPa	Tensile elasticity module MPa	Bending elasticity module MPa	Failure strain %	Thickness mm
CFRP	200	3900	230000	-	1.69	0.13

Table 7: Mechanical properties of the consumed resin (adhesive)

Type of adhesive	tensile strength (MPa)	tensile module (MPa)	Bending module (MPa)
SikaDur 300	45	3500	2800
SikaDur 31	24.8	5200	6900

Table 8: Specifications of the steel reinforcement

Type of steel reinforcement	Diameter (mm)	Weight (kg/m)	tensile strength (MPa)	yield strain	elastic module (MPa)
Longitudinal bar	8	0.635	520	0.0025	208000
Spiral bar	3	0.238	495	0.0024	206250

Figure 4: Carbon fibers used in this research

Figure 5: The epoxy adhesive employed

Strengthening Trend

According to ACI440-02 code, it is required to perform surface clearance before the installation of the CFRP. Surface clearance is performed to prepare a suitable bed for the connection of CFRP on the concrete surface to increase the efficiency of the reinforced member. The stages of surface clearance are as follows:

1. A thin surface layer of the concrete is accurately removed by special grindstone from where the CFRP sheet is to be installed so that the surfaces of the sand and gravel are exposed.
2. By the use of air pressure, the remaining dust on the surface of concrete is removed and the surface is fully clean.
3. By the use of special epoxy adhesive (Sika Dur-31) as the primer coating, the concrete surface is repaired and the existing corrosions are filled to prevent stress concentration so that the whole surface of the sample is smooth.

After surface preparation, the intended surface is coated with a layer of Sika Dur-300 adhesive to retrofit it and then carbon fibers are placed on it so that no trapped air and warping is seen in the fibers stuck on the concrete. At the end, another layer of the same adhesive is applied on the fibers.

After reinforcing the samples and passage of the curing time, the pressure testing of the samples are done according to Fig. 6. In this research, a hydrolytic jack with a capacity of 100 tons is used. The intended testing device can function in a controlled manner by displacement control or controlled by load control force. In order to plot the stress-strain curveof the samples and the data related to the downward slope of the stress-strain curve in this study, the displacement control system was necessarily used. The rate of the application of displacement in the samples was considered 0.05 mm/sec. Also, in order to determine the rate of longitudinal and transverse strain under different levels of load, the values of displacement were collected and saved by two LVDT in the middle region of the column and a load cell by a data logger during the experiment

Figure 6: Loading and recording the longitudinal and transverse strains in the samples

Compressive Strength of the Samples

The results related to the maximum load and the axial strain corresponding to this load for different tested samples is shown in table 8. According to the results, an increase in the value of the loading capacity of the samples with full CFRP binding in the presence of internal reinforcement and the end sheets of the sample, is more than other samples.

Table 9: Results of load and stain corresponding to the maximum load in the experimental samples

Group	Sample name	P_{max} (KN)	ε_{Max}(strain corresponding to maximum load)	Ratio of maximum load to control sample load	Concrete confinement stress MPa
1	N12	206.5	0.00336	1	18.6
	N12-2	394.9	0.0182	2	40
	N12-5	410.1	0.0187	1.99	37
	N12-C	426.7	0.0186	2.26	42
2	R12-S2	350.4	0.003516	1.69	21
	R12-S2-2	472.4	0.0204	2.67	39
	R12-S2-5	512.3	0.02011	2.48	35.6
	R12-S2-C	575.4	0.02045	2.79	41.3
3	R12-S5	324	0.003447	1.57	18.6
	R12-S5-2	502.9	0.02017	2.62	38.3
	R12-S5-5	545.9	0.019998	2.45	35.1
	R12-S5-C	568.8	0.019828	2.75	40.7
4	LR12-S2	586.6	0.00383	2.84	42.3
	LR12-S2-2	696.5	0.02176	3.37	52.3
	LR12-S2-5	713.2	0.02109	3.07	46.6
	LR12-S2-C	734.8	0.0235	3.56	55.6
5	LR12-S5	479.8	0.0036	2.32	33.6
	LR12-S5-2	689.1	0.0215	3.34	51.5
	LR12-S5-5	715.2	0.02096	2.99	45
	LR12-S5-C	728.8	0.0233	3.53	55.1

As it is observed, in general state an increase in the rate of internal and external confinement in the reinforced concrete columns results in the bearing capacity of the column. More rate of confinement can be attained by lessening the distance of the binding stirrups or reducing the clear distance of CFRP strips.

Comparison of the results of rows 5 and 9 of the table 9 with row 1 shows the effect of internal confinement on the bearing capacity of the column. As it is observed,exertion of concrete core confinement by circular shear reinforcements with 20 mm and 50 mm pitches increases the bearing capacity of the column relative to the samples without spirals up to 69% and 57%, respectively. Figure (7)shows the effect of external confinement on the bearing capacity of the samples withoutreinforcementwith 20 mm and 50 mm pitches with samples withoutspiral at different levels of loading

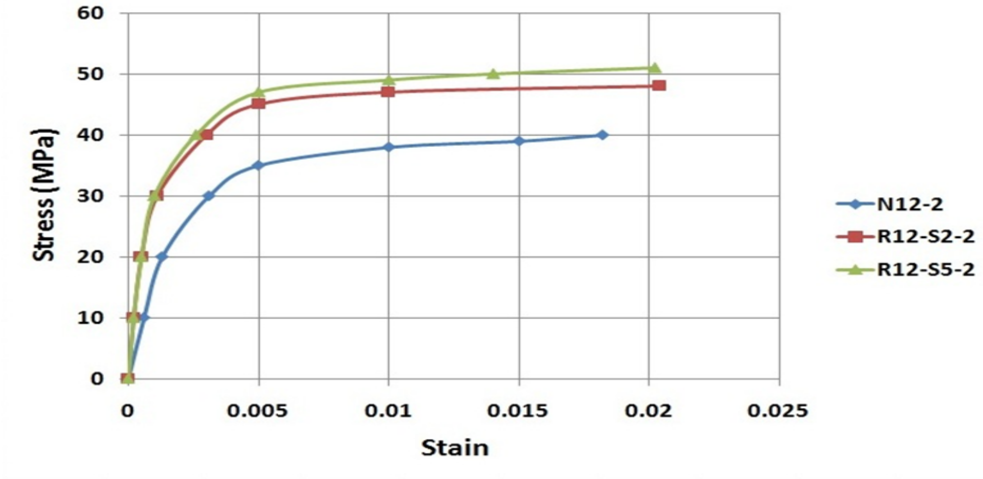

Figure 7: Effect of internal confinement on the bearing capacity of the column

- As it is shown in the figure 7, the stress-train curve of the samples with a less binding space is placed over the other curves due to its better confinement of the concrete core.
- Application of concrete core confinement by internal reinforcement can also create significant effects on the increase of bearing capacity and the concrete confinement stress. Comparison of the second, third, and the fourth rows of table 8 with row 1 shows that the column bearing capacity in the state of using CFRP sheets with a width of 20 mm and 50 mm and also use of CFRP full binding in one layer, increases the bearing capacity of the column by 1.99, 2.15, and 2.26 times relative to the control sample, sequentially.

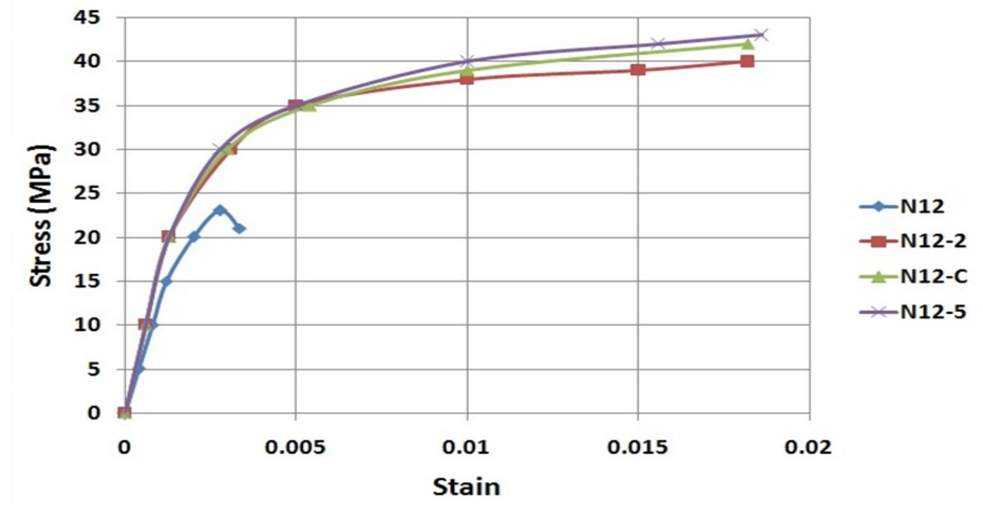

Figure 8: Effect of external confinement on the bearing capacity of the columns without reinforcement

With regard to the superposition of two curves of N 12-C and N 12-2, it seems that the external reinforcement of the columns with the FRP broken strips can bring about relatively equal confinement effects with full binding state of reinforcement sheet in the column. The nearness of the rate of the load increase for the binding samples with the pitch of 20 mm relative to the rate of load increase for the samples with full binding in the table confirms the fact. Since the rate of the reinforcing sheet used in the broken binding samples with a 20-mm pitch is about half the amount of the sheet used in the samples with full binding, regardless of being more economical, it seems that the ease of the execution of the binding strips can be a reason for the preference of the CFRP strip reinforcing method. Also, comparison of the bearing capacity of the samples with broken bindings of different width of reinforcing sheets (samples N 12-2 and N 12-5) show that confinement in the samples with more broken sheets (and less width of the sheet) is done better. It is worth mentioning that the amount of the CFRP consumed in these samples is completely equal and only the width and the clear distance between the FRP sheets are different. With regard to the above issue, it can be concluded that with an equal number of reinforcing sheets, the more the number of the CFRP sheets (with less width) is the more the bearing capacity of the sample increases. It seems that the major reason for an increase in the bearing capacity of the samples with more reinforcing sheets might have been due to more homogeneity of the samples and confinement of smaller ranges of the experimental samples.

Figure 9 also shows the effects of the presence of the end sheet that can be considered as the development of longitudinal reinforcements or as more appropriate distribution of the axial load on the axial load capacity of the samples. With regard to the results in table 8, the effect of the end sheet alone on an increase in bearing relative to the presence of annular spiral stirrup with 20 mm and 50 mm is about 0.4818 and 0.395, respectively. This increase in bearing needs some deliberation and can show the importance of even distribution of the load and also the development of longitudinal reinforcements for the bearing capacity.

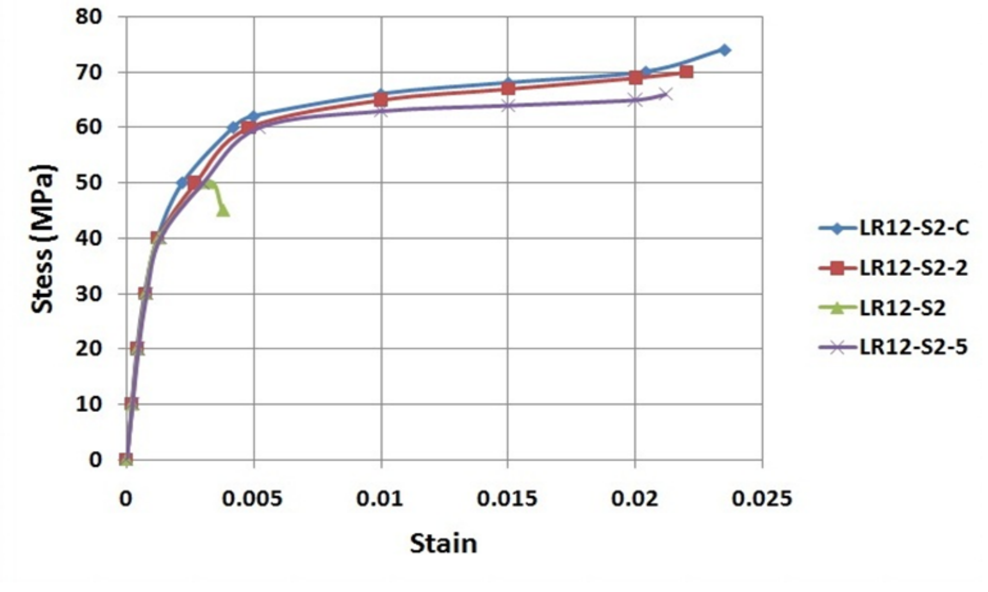

Figure 9: Effect of the end development sheet on the bearing capacity of the reinforced columns

The concrete confinement stress values under the influence of internal and external reinforcement at the moment of maximum bearing is calculated in the last column of table 8.To calculate this stress, it is assumed that during the time of final strength of the column, the longitudinal steel bars have reached the yield load. Hence, the value of the product of the yield stress of the longitudinal steel bars and the cross-section is deducted from the maximum bearing capacity.The remaining of the column load is divided by the cross-section of the samples.The confinement is so much that it increases the characteristic strength of the concrete in the unconfined state to several times as much as in the confined state.

Deterioration of the Samples

Figures 10 to 12 show the manner of the deterioration of the experimental cylindrical samples. As it is observed, the major deterioration of the compression samples starts from the middle zone of the height as in the figures. In the samples without reinforcement, pure axial stresses are governing and there are no effects of the stress confinement resulting from the presence of support on the top and bottom of the samples.

After the crushing of the concrete at the middle zone of the height, the bearing capacity of the sample is suddenly reduced in the non-reinforced samples. Since there is no reinforcement in the samples, reduction in bearing capacity, deterioration and failure of the sample takes place immediately. It was found there is no significant different result the axial strain between the samples by with CFRP and without CFRP, after attaining the maximum load in the sample, due to slow-curing of the CFRP sheets, disintegration of the sample takes place at strains which are more than the previous state. But, at the final moment, the CFRP sheets are broken and collapse of the sample takes place simultaneously (Fig. 10).

For the samples with internal reinforcement, the disintegration of the sample is accompanied with more ductility, so that the final failure takes place due to the yield of the longitudinal steel bars, buckling, and bending of the reinforcements and then breakage of the reinforcing sheets (Figs. 11 and 12).

It seems that the breakage potential and failure of the sample is more in the columns with internal and external reinforcements at the zones near the support. It might be due to more bending of the sample near the support, but anyhow, future complementary experiments performed on samples with more height can add to the accuracy of this issue.

Figure 10: CFRP sheet failure and sample collapse

Figure 11: Final failure due to the yield effect and buckling of longitudinal steel bars and sheet failure

Figure 12: Final failure due to the yield effect and buckling of longitudinal steel bars and sheet failure

Conclusion

The effects of internal reinforcement including the presence of binding longitudinal and transverse reinforcements and the sheets at the end of longitudinal reinforcements as well as the effects of external reinforcement including the broken CFRP strips and full binding of reinforcing sheets on the confinement capacity of the reinforced concrete columns were studied in this research work. The results obtained are briefly inferable as follows:

1. The reinforcing broken sheets especially with small distances have a performance similar to the full binding of the column with CFPR sheets.
2. Use of the end sheets for bracing longitudinal reinforcement and even

distribution of load have significant effect on the bearing capacity of the samples made.

3. Due to the confinement effects, the internal and external reinforcement of the column greatly increases the axial strain of reinforced concrete column disintegration.
4. The failure of the samples without reinforcement in the columns usually occurs at the middle of the height. In the reinforced samples, the issue of failure mostly takes place in the zones near the support.

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دراسة مختبريه لتأثيرصفائح الكربون البوليمر المسلحة على ليونة والحجز الأعمدة الخرسانية المسلحة

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الخلاصة:

موضوع إصلاح وتقوية الهياكل هي واحدة من الفروع الرئيسية للهندسة المدنية.في هذا الصدد، تعتبر تقوية أعضاء الضغط، وخاصة الأعمدة الخرسانة المسلحة بواسطة صفائح البوليمرات المقوى واحدة من الطرق التقليدية في تقوية هؤلاء الأعضاء. بواسطة حصر أعضاء الضغط ومنع التوسع الجانبي الناتجة عن تأثير بواسون، صفائح الكربون البوليمر المسلحة تحقق زيادة في مقاومة الانضغاط و ليونة. في هذا البحث المختبري، تمت دراسة تأثيرات الأساليب المختلفة لتقوية الأعمدة الخرسانية بواسطة صفائح الكربون البوليمر المسلحة بما في ذلك تأثيرعرض صفائح الكربون البوليمر المسلحة الليونة والسلوك الإجهاد- الانفعال في الأعمدة الخرسانية في ظل وجود التقوية الداخلي للعمود. يتضمن البحث تقييم تأثير قضبان الحديد الطولي والعرضي مستديرة، تظهر نتائج هذا البحث أنه من خلال صفائح الكربون البوليمر المسلحة التقوية و الحجز في أعمدة الخرسانة المسلحة تحسين قابلية التحمل لمقاومة الانضغاط وليونة بشكل ملحوظ.

الكلمات الرئيسية:CFRP، الحجز، أعمدة من الخرسانة المسلحة، ليونة، وتقوية الداخلية