CFRP external reinforcement effect on the behavior of high slender reinforced concrete columns subjected to compression monotonic cyclic loading

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Abstract

In this experimental research work, we explored the efficiency of external reinforcements, made of carbon fiber composite materials CFRP on high slender reinforced concrete columns. A particular attention has been paid to the reduction of the instability risk of the existing slender columns, using various arrangements of CFRP strengthening. The behavior under monotonic cyclic compression loads, has been explored on 7 reinforced concrete columns, having a very high geometric slenderness equivalent to l/a=29. Experimental responses allowed us, the idealization of the global behavior by elastic perfectly-plastic simplified models, the highlighting and evaluation of the stiffness variation according to the load, to note the changes on the columns deformability, to measure energy characteristics induced by the different provisions of reinforcements. As interesting observation, we cite the positive effect in terms of bearing capacity and deformability on all of the reinforced columns.

Keywords: *Reinforced-concrete, column, slender, composite material, instability.*

1. Introduction (12 gras)

More the column is slender more it is sensitive to the phenomenon of buckling instability. One of the principal design actions to limit this phenomenon consists of using composite materials based on carbon fiber fabric. In this paper, we propose to investigate the contribution of external CFRP reinforcement with varying the orientation of fibers on enhancing strength, deformability, ductility and stiffness.

2. Experimental program

2.1. Design of the columns

The dimensions of the tested columns and their steel reinforcement are shown on the Fig. 1, the length-to-section depth ratio l/a= 29 corresponding to slenderness λ = 100. Seven columns were tested, one control column, and six columns, differently strengthened with a composite of CFRP, appointed as follows: PC0 : Control column without strengthening, PC1, PC2, PC3 : 3 confined columns respectively with 1, 2 and 3 CFRP layers disposed transversally, PC45L45 : The strengthening is composed of 2 CFRP layers, for the first layer the fibers are disposed in winding inclined by +45° with respect to the column axis, the second layer by -45°, PL0 : The strengthening consists of a layer of CFRP which the fibers are disposed longitudinally to the column axis, PL0C0 : The strengthening consists in two layers, one the same as that of PL0, on this is added another CFRP layer, such as the fibers are arranged perpendicularly to the column axis.

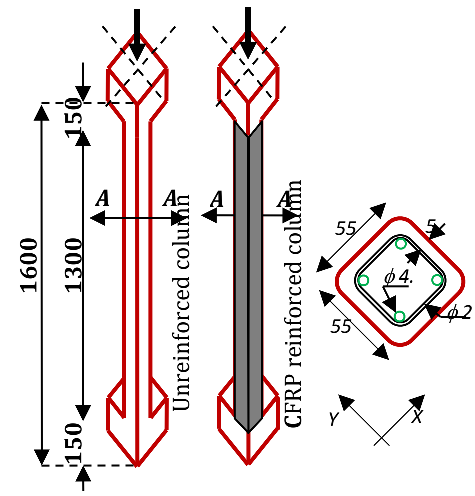

Fig. 1. Geometrical characteristics of the columns

1.1. MATERIALS

Table 1 : SikaFrance fabric and adhesive characteristics.

1.	SikaWrap 230C	Sikadur 330	Composite
Tensile strength	4300 MPa	30 MPa	----
Elongation at rupture	1.8%	0.9%	----
Tensile modulus	234 GPa	4.5 GPa	25 GPa
Thickness	0.13 mm	----	1 mm
Ultimate load	----	----	350 kN/m of width
Mass per unit of area	230 g /m² ± 10 g/m²	----	----
Density of fibers	1,76 g/cm3	----	----

We used a micro-concrete, the average resistance was $f_{c28} = 29.2\ MPa$ (measured on 11x22 control cylindrical concrete specimens). The longitudinal reinforcement steels used were of the high-adherence type, of average measured resistance 630 MPa.

2.2. Buckling tests, results and discussion

The compression tests control is made in displacement at a loading rate of 0.05mm/s. LVDT posed in the direction of the inflexion were used to measure the transverse displacement of the columns. The experimental responses of the seven column tested are represented on Fig. 2 to Fig. 6.

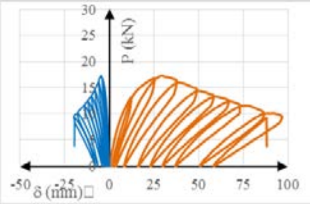

Fig. 2. Load–displacement response of PC2.

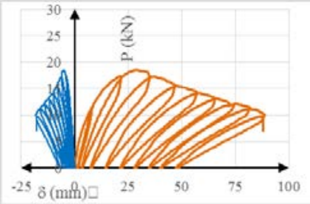

Fig. 3. Load–displacement response of PC3.

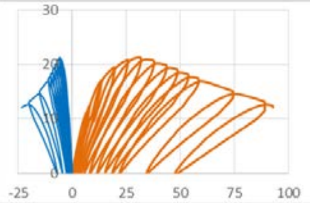

Fig. 4 . Load–displacement response of PC45L45.

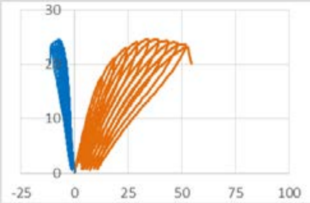

Fig. 5 . Load–displacement response of PL1.

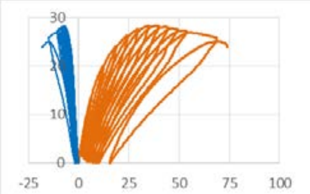

Fig. 6. Load–displacement response of PL1C1.

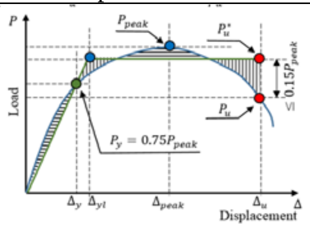

Fig. 7. Envelope curve simplified model.

To analyse the envelope curves, it is necessary to pass through a simplified models (Fig. 7) with common assumptions. Given the behavior laws of concrete materials, steel and CFRP previously exposed, and the conclusions on similar work [1] [2] [3], it is sensible to assume that simplified representation of the overall behavior is represented by an ideal behavior of elastic plastic type, whether for (P-δ), (P-Δ) or (M-φ) responses.

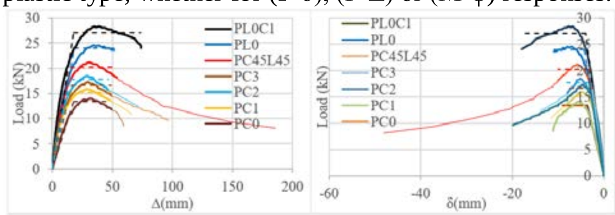

Fig. 8. (P-δ) and (P-Δ) envelopes curves

We note immediately the increase in peak load P_{peak} for all cases of adopted CFRP reinforcements. The peak load corresponds practically to the same value of imposed displacement δ for all columns. Indeed, the post peak branch originates when stretched steel are plastified. Given that the geometry of the columns, and the nature of the steel reinforcement and concrete resistance of the seven columns are identical, therefore the imposed displacement δ that will cause plastic deformation of tension steel is necessarily the same [4]. While the displacement at failure increased or decreased as the case as shown in Fig. 8. The confinement on PC1 with one CFRP layer increased P_{peak} by 14% with two layers on PC2, it was found, an increase of 33%, adding a third layer on PC3 seems to be with no contribution. The one CFRP layer posed on PL0 which the fibers are arranged longitudinally has resulted in a contribution of 76%, on the column, PL0C1, two CFRP layers were glued, the first with the fibers arranged longitudinally the fibers of the second are arranged transversely, it was noted an increase of 100% in peak load. For the particular case of the column PC45L45 with 2 layers of CFRP crossed at ±45°, there was a significant increase in a value of 52% which is nevertheless below the 2 previous cases. By focusing to the ultimate displacement, compared to the control column, it is observed, a decrease in average of 2.5% for the 3 confined columns PC1, PC2 and PC3, and a relatively small increase in the rest of columns, in the particular case of column L0C1 the increase is around 17%. However, the respect of the restrictive condition which limits the load loss in post peak at 15% P_{peak} , it is observed on experimental responses (represented by thin line) that it penalizes the intensity of failure displacement, especially for confined columns PC1, PC2 and PC3 and more particularly the column PC45L45, Indeed the latter shows exceptional deformability in its post-peak branch.

On the Fig. 9, one distinguishes a first curve in bold, which represents the experimental response that respects the loss limit of 15% P_{peak} .

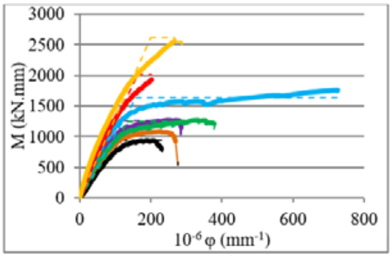

Fig. 9. (M-φ) envelopes curves

The second curve that appears on its prolongation, with thin continuous line, is the experimental response in its totality. The third curve shown in dotted lines is the simplified model with elastic perfectly plastic behavior of the latter. One distinguish easily for all columns a global two-phase behavior [1] [3]. Knowing that ($\varphi = M/EI$), then, the slope at each point of the curve represents the flexural stiffness (*EI*) for a value of the load *P*. The transition from the first phase to the second is characterized by a sudden change in the flexural stiffness (*EI*). Phase 1 is actually composed of two parts, the first, under the effect of the low intensity of the load at the beginning of the test is characterized by the elastic behavior of the materials that compose the column, namely concrete, steels and strengthening CFRP, its stiffness (EI_1) is high, also note that this branch is short, identified with difficulty, particularly for PL0 and PL0C1. Also, the second branch is quasi linear, except that its rigidity (EI_2) is less intense, because at this time the column has suffered a loss of stiffness, which is the direct result of cracking of concrete in tension. The first branch is short because the strength of concrete in tension is low. The limit of this second branch occurs with the plastification of tension steels. At this time, begins the second phase, which lasts until the rupture of the column. This is a quasi linear branch with a flexural stiffness (EI_3) smaller than(EI_2). According to the form of the (M-φ) responses, two distinct groups of columns are highlighted. The first is composed of the columns PC0, PC1, PC2, PC3 and PC45L45, the second contains the PL0 columns and PL0C1.

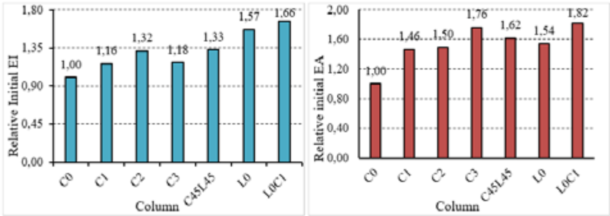

Fig. 10. Initial stiffness bending *EI* and compression *EA*

Fig. 10, is an overview of the contribution in initial stiffness of each type of CFRP reinforcement. One CFRP layer glued transversely on column C1 provides an increase of 16% compared to the stiffness of the control column, adding a second CFRP layer on column C2 that contribution is doubled it passes to 32%, curiously adding a third layer on column C3, the contribution is not significant, this leads us to conclude that the confinement has a limited effectiveness, in our case it is two layers. One notes for the column C45L45 a contribution equivalent to that of the column C2 with two CFRP layers. For the column L0, the contribution in stiffness is more significant, it generates an increase of 57%. If one CFRP confinement layer is added like on the L0C1 column, the stiffness is increased by 9%, the overall contribution of this type of the two layers glued on this column is of 66%. It is observed that the stiffness intake, of the CFRP reinforcement by confinement is relatively limited, indeed, the latter opposes the swelling of concrete in compression [1] but has no effect on limiting the opening of cracks in tension zone. The effectiveness of the column L0 is much better, this is explained by the fact that the fibers arranged longitudinally opposed directly to the crack opening in the tension zone, while in the compressed area the effectiveness is limited, given that the thickness of the CFRP composite is small. The added confinement layer on L0C1 column, slightly corrects this defect by resisting the expansion of compressed concrete. The bending in the columns during test is caused by the eccentricity of the compression load P, therefore the columns undergo a shortening δ, and the compression behavior is described by the classical relation $EA/l = P/\Delta l$. EA/l represents the linear stiffness in compression. On the Fig. 10 is observed, the contribution in stiffness EA of each type of reinforcement relatively to that of the control column EA_{C0}. The confinement of columns C1, C2 and C3 increases the compression stiffness respectively of 46%, 50% and 76% which is equivalent to a contribution of 46% of the first CFRP layer, a contribution of 4% of the second layer and a contribution 26% of the third. It is observed the non-regularity of this compressive stiffness, depending on the number of CFRP layers applied on the columns. In the case of the column C45L45 the increase is equal to 62%. For the columns L0 and L0C1 the increased is respectively of 54% and 82%. The highest contribution is achieved by the column L0C1, and in all CFRP reinforcement cases the increase is effective with a mean of 61.6% ± 0.15%.

3. Conclusion

It was noted what follows:

- All responses $(P-\Delta)$, $(P-\delta)$ and $(M-\varphi)$ are composed of two main parts, the first has an elastic behavior the second with a plastic behavior in the case of C0 to C3 and C45L45 columns For L0 and L0C1 columns, the behavior is elastic rigid up to failure.
- The six types of reinforcement adopted allowed a relative increase of the bearing capacity. It is maximum when the fibers are longitudinally arranged, column L0C1 with a rate of 100%. They also relatively increase the initial compressive and bending stiffness, it is maximum for the case of L0C1 column respectively with 66% and 82% compared to that of the column C0.
- From Fig. 13, is measured, the curvature ductility factor defined by $\mu = \varphi_u/\varphi_{yl}$. In the case of C0 to C3 columns, there is an increase respectively of 19%, 22% and 46%, for the column C45L45 this increase is of 139%. The reinforcements adopted on L0 and L0C1 columns have a negligible contribution.
- From then, if the aim is a rigidity, we will use reinforcements whose fibers are disposed longitudinally, if one is interested in increasing the ductility we will use as the case, may be a reinforcement by confinement, or a reinforcement whose fibers are arranged at ± 45°. The combination reinforcement at ± 45 °, with a reinforcement which fibers are arranged longitudinally will give an intermediate increasing value between the L0 and C45L45 columns.

Références

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