Effectiveness of Composite CFRP Confinement on Very Slender Reinforced Concrete Columns

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Abstract

This research work is based on an experimental study resulting from tests carried out on six square-section slender reinforced concrete columns. The columns were confined by single-layer wraps of carbon fiber composites. They were tested under eccentric compression loading, to study the effects of confinement by the carbon fiber composite on resistance loading, rigidity, ductility and slender column behavior in general.

1. Introduction

More the column is slender more it is sensitive to the phenomenon of buckling instability (1). One of the principal design actions to limit this phenomenon consists of using composite materials based on carbon fiber fabric (2). In this paper, we propose to investigate the contribution of confinement to solving the problem of instability in high slender columns subjected to a loading which generates buckling.

2. Experimental program

2.1. Design of the columns

The geometrical dimensions of the tested columns were chosen to be similar to existing columns. There exist constructions with ground floors of around 4.00m in height, and column sections of about 200x200mm. In this case, the geometrical slenderness approaches $\lambda \approx 70$. These constructions are in a state of permanent risk of stability loss through buckling, particularly in zones experiencing seismic activity. The height of the tested columns was fixed at 1600mm, due to the height limitation of our testing machine; the scale of work is thus reduced to 1/2.5. The cross sections of the columns had sides of 55, 85 and 100mm, ratios (l/a) of 29.09, 18.82 and 16.00, corresponding to slendernessλ (calculated with respect to the main axes X and Y of the cross section) respectively of 100, 65 et 55 mm (see Figure 1). Six columns were used to study the effect of confinement, 3 unconfined control columns and 3 similar to the controls, confined using one layer of CFRP composite. The steel reinforcement of the columns was composed of 4 longitudinal bars, transversally tied by stirrups, of 100 mm equal spacing, distributed over the entire length (Figure 1)**Error! Reference source not found.**, and the coating was of 5mm. The ratio of longitudinal steel reinforcements on the columns was selected in the interval $[\rho \cong 1\% - 2\%]$. The ends of the columns consisted of bumps of dimension 200x200x150mm. These bumps were used to apply the load (Figure 1), to avoid the localized ruptures by punching at the ends and to ensure a good distribution of this load in the interior of the column. They were over-reinforced with $\emptyset 6$ diameter stirrups.

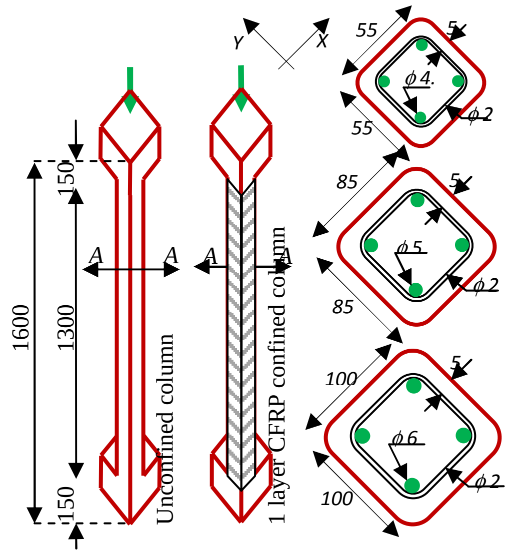

Figure 1 Geometrical characteristics of the columns

2.2. Materials

To respect the reduction of the scale to1/2.5, we manufactured the columns with a micro-concrete, composed for 1m^3 of concrete of: 342 kg cement of type CEMI /52.5 N CE CP2 NF, 1086 kg (0/4) sea-sand, 743 kg quarry crushed gravel with a maximum diameter < 4mm and 206 l water, thus giving a ratio E/C = 0.60. 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. The transverse stirrups were 1.2 mm diameter made from ordinary wire. The confinement was made of CFRP. SIKA France provided the one-way carbon fiber fabric "SikaWrap 230C", and the epoxy adhesive "SIKADUR 330". The compression tests were carried out on a traction-compression hydraulic machine of a maximum capacity of 250kN controlled in force and displacement. Control was 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.

Figure 2 Load reception plate & application of the load to the top of the column

Figure 3 : Column during test.

3. Buckling Tests, results and discussion

3.1. Bearing capacity under load

The experimental load-displacement responses of the columns tested are shown in Figures 4, 5 and 6. These responses are composed with curves of two principal separate branches and whose frontier is the peak load point. This point corresponds to the load which causes plastification in tensile steels. Indeed, we observed that the inflection points of the curves almost correspond to the same deformation of longitudinal steels, which is on average 2.6 ‰. This value almost coincides with the yield stress of the steels used. The pre-peak branch is composed of two sub-branches. The first represents perfectly elastic behavior; steels and the concrete become deformed in the elastic range. The second is characterized by the initiation and increase of the crack depth and its propagation along the column with the increase in the load. Continuous cracking of concrete under tension causes a relative loss of rigidity that makes the response of the column become nonlinear. The point corresponding to the plastification of steel under tension marks the end of this branch. It should be noted that the pre-peak response has the same shape as the column, whether confined or not. The post-peak branch of the unconfined column is characterized with respect to the pre-peak branch by a rapid load drop. The load decreases with increasing displacement (longitudinal and transverse). The deformation of the concrete under compression consequently increase until it reaches its ultimate limit. The concrete undergoes rupture, leading at the beginning to a local buckling of the compressed steel bar, followed by a tensile failure of steel bar tension. Without confinement, breaking the concrete under compression is the cause of a local buckling of the compressed steel bar. In the presence of confinement, the carbon envelope is subjected to a local puncture, which induces its rupture and consequently the buckling of the compressed bar. The role of CFRP reinforcement was to contain the compressed concrete which is already largely destroyed. The rupture of the envelope causes the expulsion of the concrete, which leads to an instability of the compressed steel bar. The post-peak branch of the confined columns differs from that of unconfined columns. It is characterized by a slower load loss, especially when the slenderness $\lambda = 100$. From its anti-swelling function, provided by its rigidity, the effect of confinement created by the CFRP envelope prevents the expansion of the concrete. This situation results in increased strength and an ultimate strain extended beyond the limits observed for the case of the unconfined column shown in Table 1. The load value, the longitudinal and transversal displacement are measured experimentally. The ultimate moment is calculated by $M_u = N_u(e_0 + \Delta)$.

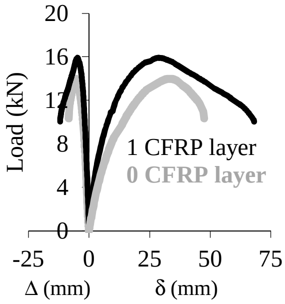

Figure 4 *N-Δ* responses of columns 55x55 ($\lambda = 100$)

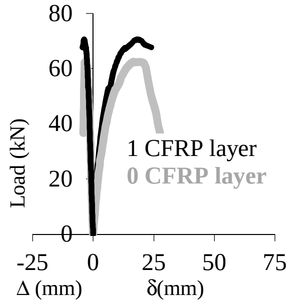

Figure 5 *N-Δ* responses of columns 85x85 ($\lambda = 65$)

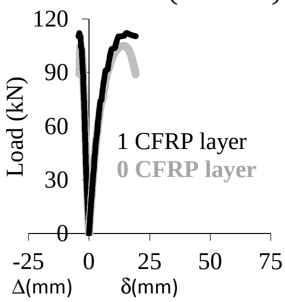

Figure 6 *N-Δ* responses of columns 100x100 ($\lambda = 55$)

Table 1: Experimental results (3)

λ	n	N_{pic} (kN)	Δ_{pic} (mm)	δ_{pic} (mm)	N_u (kN)	Δ_u (mm)	δ_u (mm)	M_{pic} (kN.mm)	M_u (kN.mm)
1	0	13.9	33.2	5,6	13,2	39,6	8,5	882	919
	1	15,9	29,5	5,2	10,0	68,1	11,2	946	985
65	0	62,4	16,6	3,2	36,6	27,6	4,0	2914	2108
	1	70,5	18,3	3,8	67,7	23,9	4,3	3406	3652
55	0	104,8	14,2	3,3	88,9	19,2	3,8	4643	4380
	1	111,8	11,9	4,0	110,3	19,3	4,4	4687	5438

3.2. Moment-curvature and rigidity relations

The direct evaluation of rigidity EI is difficult, considering the nonlinear behavior of the reinforced concrete columns; EI varies according to the load. In the present work, this rigidity was experimentally deduced. It is represented by the slope of the moment-curvature response $(\mathrm{M}\text{-}1/\mathrm{r})$ obtained experimentally using the GomAramis camera. The moment-curvature responses $\left(\mathrm{M}\text{-}\frac{1}{\mathrm{r}}\right)$ obtained are presented in Figure 7, Figure 8 and Figure 9. The typical shape of responses $(\mathrm{M}\text{-}1/\mathrm{r})$ shows a behavior with three branches. The first, linear and very short, corresponds to the elastic behavior of materials, with a high slope of rigidity EI_1, but remains not easily identifiable, particularly for the unconfined column. The second branch is quasi linear, of slope EI_2 and of less intensity that the previous one; the column has suffered a loss of rigidity, a direct consequence of the concrete cracking in the tension zone. The unconfined columns possess a relatively short third part, of negative slope EI_3 caused by constant cracking, and increasing for the concrete under tension after yielding of the steel tension. Results are similar for the confined columns, whose responses $(\mathrm{M}\text{-}1/\mathrm{r})$ showed a behavior with three branches; nevertheless, the presence of confinement, by its anti-swelling role on the compressed concrete, has on the contrary resistance to column damage. The slope EI_3 remains positive, creating pseudo-ductility behavior. The behavior of the unconfined column can be approximated by a Bi-linear law with a short ductile behavior; that of the confined columns can also be approximated by a Bi linear law.

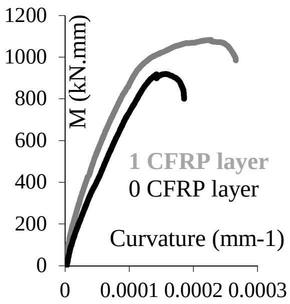

Figure 7 *M-1/r* responses for $\lambda = 100$

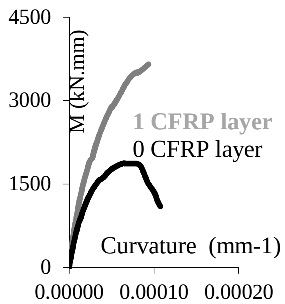

Figure 8 *M-1/r* responses for $\lambda = 65$

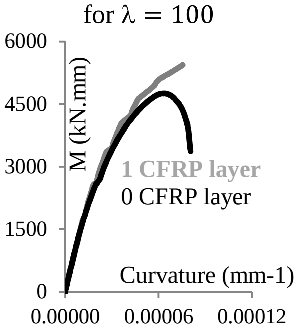

Figure 9 *M-1/r* responses for $\lambda = 55$

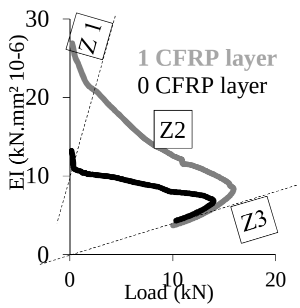

Figure 10 *N-EI* responses for $\lambda = 100$

Figure 10 shows the rigidity EI of the columns with slenderness $\lambda = 100$ as a function of the axial load N; its non-uniformity and the loss of rigidity when the load N intensity increases is clearly noticed. Confinement considerably slowed down the damage to the reinforced concrete, in pre-peak this slowing was reflected in a stiffness contribution visible in Figure 10, where it is easy to see the difference between the rigidity of the unconfined columns and that of the confined column. This difference decreases with increasing load; in zone 3 in post-peak, the difference becomes insignificant. The distance separating the curves represents the rigidity contribution of the confinement; the increase passes from 100% to 47% between the beginning and the end of the branch of zone 2, the location of cracking under tension. Here we demonstrate that confinement slows compressed concrete expansion, and increases its resistance and consequently that of the column. The confinement made increase the curvature in ultimate state $1/\mathrm{r_u}$ of the slenderness $\lambda = 100$ column from 44%, while, the effect is unimportant on the two other slenderness.

4. Conclusions

We show that the confinement of a column under eccentric compression is really effective only when the slenderness is high (here λ = 100). The confinement had only limited effectiveness for slenderness λ = 55 and λ = 65. This can be explained by the following facts: (a) In all our experiments, we used a constant confinement rate represented by one layer of CFRP, while the volume of concrete treated decreased with increasing slenderness; indeed, compared to the column of slenderness λ = 100, it is respectively 2.4 and 3.3 times higher for slenderness 65 and 55. We know that the confined concrete strength is inversely proportional to the transverse dimension (4) (5) (6) and therefore to the confined volume, thus the effect of confinement is reduced by increasing the slenderness. (b) The critical section of the columns is subject to compound bending, and the high values for the slenderness of the columns studied are the source of large eccentricities that are added to the initial eccentricity (7) of the load. Therefore, the area of compressed concrete is reduced, reducing the confinement action area, contrary to the confined columns which are entirely compressed, where the confinement action zone is at its maximum. (c) It is therefore necessary to confine all slender columns.

5. References

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