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Shear strengthening effectiveness with CFF strips

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Abstract

The present work deals with shear performance of reinforced concrete (RC) beams with rectangular section. The RC beams are designed with shear deficiencies and strengthened by externally bonded carbon fibre fabrics. Four different configurations of externally bonded carbon fibre fabric strips are used to strengthen the reinforced concrete beams in shear. The carbon fibre fabric, is a dry bi-directional impregnated (epoxy resin) on site, supplied and installed by Freyssinet (TFC®). The experimental programme consists of two control beams and eight strengthened RC beams. The reinforced concrete beams are strengthened with carbon fibre fabric vertical strips and 45° inclined strips in the form of U-wrap or in the form of a ring. The objectives of this study are to investigate the influence of parameters like carbon fibre fabric span and wrapping manners on the shear capacity of strengthened RC beams. A mechanical formula is used to predict the contribution of carbon fibre fabric to shear capacity of strengthened RC beams. The results obtained by using the mechanical formula have been compared with theses obtained by test.

Keywords: Carbon fibre fabric; Upgrading; Shear strengthening; Reinforced concrete beam

1. Introduction

The studies carried out by researchers on the repair and strengthening of structural reinforced concrete members show that the more strength in flexure increases, the more shear failure increases. The strengthening techniques have been widely used in recent years in civil infrastructures such as columns, beams or slabs since their first application in the 1960s [1]. Many studies [2–5] have been conducted to investigate the flexural behaviour of strengthened reinforced concrete structures by externally bonded steel plates or fibre reinforced polymer (FRP) sheets. However, it is more difficult to study the behaviour of strengthened shear reinforced concrete (RC) beams, because the behaviour and ultimate strength of shear upgraded reinforced concrete structures depends on many factors such as: concrete compressive strength, composite material strength, steel yield stress, longitudinal steel bar cross-section in flexural region, internal vertical steel cross-section, stirrup spacing, strengthening area, shear span to effective depth ratio, thickness of the composite material and strengthening technique [6–10].

Shear strengthening of RC beams is possible to attempt by bonded externally lateral carbon fibre fabric (CFF) strips. Four wrapping manners was used: CFF strips in the form of a U-shape and as closed rings, vertical or 45° inclined CFF.

The objectives of this work are to study the shear strengthening effectiveness with CFF strips and shear behaviour of rectangular section reinforced concrete beams with shear deficiencies after strengthening. This work deals also with the influence of the longitudinal spacing of carbon fibre fabric strips, the CFF strip orientation (90 or 45°) in comparison with the longitudinal direction and the wrapping method (U-shape or closed rings). The behaviour of the shear strengthened reinforced concrete beams is analysed by measuring the strains and displacement with the help of strain gauges and a linear voltage differential transducer (LVDT). The analytical investigation is made in order to estimate the contribution of CFF reinforcement to the shear capacity of strengthening RC beams.

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2. Experimental program

2.1. Materials

In this experimental programme, a concrete mix consisting of Portland cement and maximum aggregate size of 15 mm in diameter is used. The average compressive strength for all beams tested is 38 ± 2 MPa. The elastic modulus obtained by the test was 35 GPa. The yield strengths of the steel bars and internal steel stirrups are 550 and 240 MPa, respectively. The elastic modulus of steel is 210 GPa. The epoxy resin used consists of two components: an epoxy resin and a hardener. The mechanical properties of the epoxy resin are an ultimate tensile strength of 29.3 MPa and an elastic modulus 2.3 GPa (Table 1).

The carbon fibre fabric used was TFC® from Freyssinet International which consists of carbon fibres set at 90° in the warp and in the weft so as to obtain a flexible weave that can match various shapes of backings. TFC® is a high quality (there are 70% of the fibres in the direction of the warp and 30% in the direction of the weft). This fact implies that only wrap 70% of the fibres are really used in the tests, the remaining 30% protects the wrap direction from an early failure because of excessive transverse shear to the strip (shear resistance of carbon fibre is low). For the wrap direction the mechanical properties are:

- Thickness of the carbon fibre fabric is 0.43 mm and its width is 40 mm.
- Guaranteed ultimate tensile stress is 1400 MPa and the elastic modulus is 105 GPa.

2.2. Configuration of test beams

In this experimental programme, ten reinforced concrete and shear strengthened reinforced concrete beams are tested. The beams were designed with a total span of 2200 mm and a rectangular cross-section of 130 mm width and 450 mm depth, as shown in Fig. 1. The longitudinal reinforcement used in this investigation consisted of two 16 mm diameter and two 14 mm diameter high yield steel bars at the bottom and two 8 mm diameter high yield steel bars in the top of the beam's section. The web reinforcement consisted of 6 mm diameter closed stirrups spaced by 300 mm centre to centre throughout the beam span. All specimens are tested as simple span beams subjected to a three point loading as illustrated in Fig. 1. The load is monotonically increased. The RC beams are designed to have a much higher flexure capacity; thus, shear failure is the dominant mode of failure.

The details and dimensions of the ten RC beams are illustrated in Fig. 2. Two RC beams are not strengthened as control specimens, whereas eight beams are strengthened with externally bonded CFF strips in various manners. The specimens are grouped into two series, designated PU and PC depending on the strengthening schemes. Group PU consists of four reinforced concrete beams that are strengthened with externally bonded CFF fabrics in the form of a U-shape. Two RC beam specimens are strengthened with vertical CFF strips and the spacing of CFF strips is 200 and 250 mm. Two other specimens are strengthened with 45° CFF strips and the spacing of CFF strips is 300 mm and 350 mm. Group PC consists of four reinforced concrete beams that are strengthened with externally bonded CFF fabrics in the form of a closed ring. Two RC beam specimens are strengthened with vertical CFF strips and the spacing of CFF strips is 200 and 250 mm. Two other specimens are strengthened with inclined CFF strips and the spacing of CFF strips is 300 and 350 mm.

The use of 40 mm strips and large spacing was imposed by maximal load capacity of the testing equipment and to avoid the a flexure failure mode of strengthened beams.

Table 1
Materials' properties

Materials		Modulus of elasticity (MPa)	Strength (MPa)
Concrete		35,000	$R_{c28}{}^{a}$=40
Steel	Transversal	210,000	$R_e{}^{b}$=240
	Longitudinal		$R_e{}^{b}$=550
Resin epoxy		2300	$R_t{}^{c}$=92
Carbon fibre fabric		105,000	$R_t{}^{c}$=1400

[a] R_c: Compressive strength of concrete
[b] R_e: Yield point
[c] R_t: Tensile strength

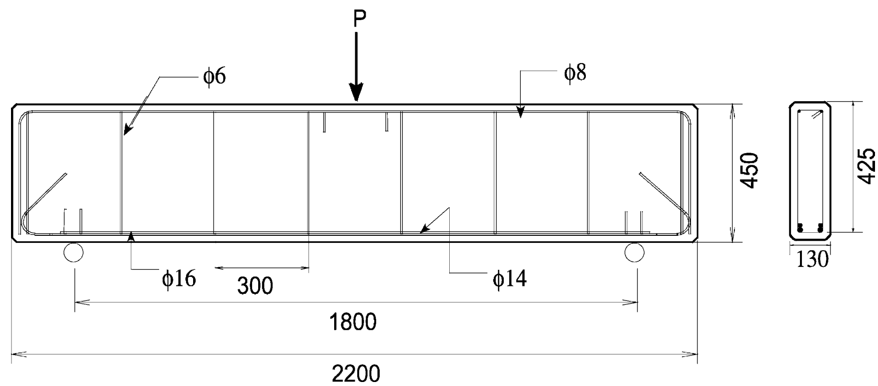

Fig. 1. Configuration and detail of RC beam.

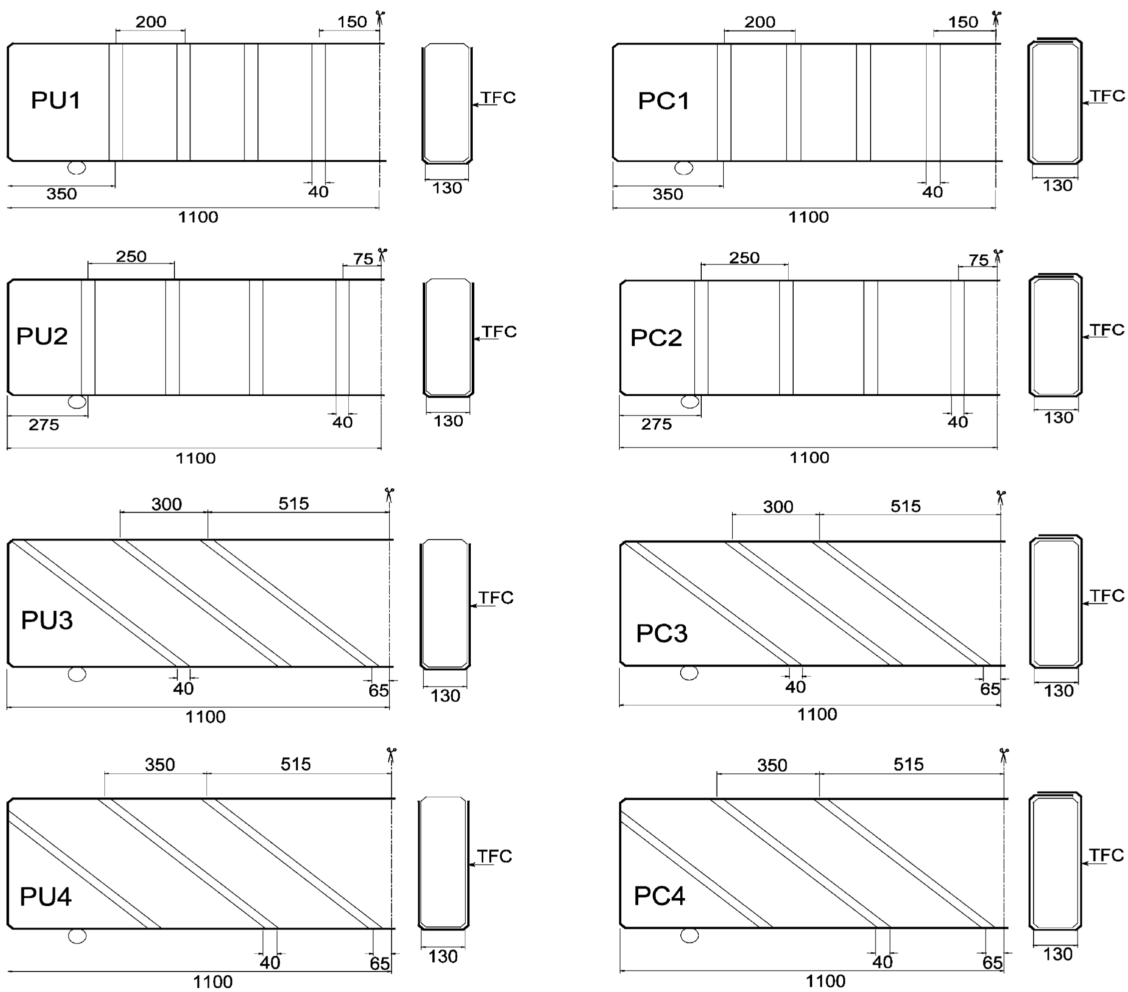

Fig. 2. Configuration and details of the RC beams strengthened by bonding CFF strips.

2.3. Instrumentation

For each reinforced concrete beam specimen, strain gauges are mounted on the longitudinal steel bar surface at mid-span of the specimen (J_1), on the vertical steel stirrups (J_2, J_3 and J_4) and carbon fibre fabric strips (J_5, J_6, J_7 and J_8) as illustrated in Fig. 3. A linear voltage differential transducer (LVDT) is also used for each test to monitor the maximum vertical displacement during loading. The beam is incrementally loaded up to failure under load control. For each increment of the load, the strains in the tensile steel bar, in the vertical steel stirrups

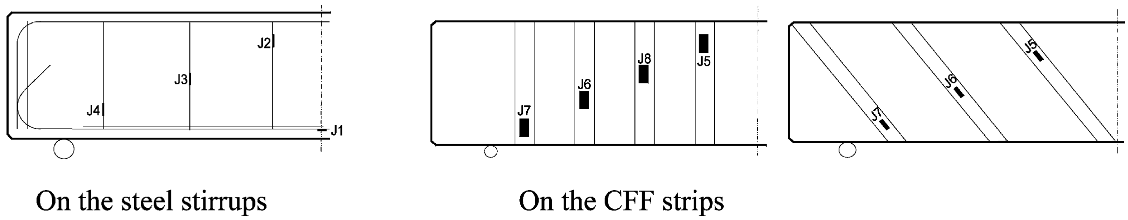

Fig. 3. Location of the guages.

and in the CFF strips and the load point deflection were recorded by means of an automatic data acquisition system.

3. Experimental results and discussions

3.1. Ultimate force of beams

Table 2 shows the values of the ultimate force of the beams and the contribution of the carbon fibre fabrics to the ultimate force. Beams P_0 and $P_{0\text{-bis}}$ are the control RC beams. Beams PU_1, PU_2, PU_3 and PU_4 are the RC beams strengthened by the composite fabrics in the form of U-wrap. Beams PC_1, PC_2, PC_3 and PC_4 are the RC beams strengthened by the composite fabrics in the form of ring.

It can be seen from Table 2 that the ultimate forces of two control specimens are the same: 220 kN. It is interesting to show that the ultimate forces of two control specimens are perfectly identical. This result allows analysing the strengthening effectiveness in a good condition.

The obtained experimental results show that:

- The contribution of the carbon fibre fabrics to the ultimate force of beam varies with the spacing of CFF strips and the plating pattern.
- The gain obtained in ultimate force of strengthening the RC beam is considerable in comparison with the control specimen. The ultimate capacity gain increases as the strips' spacing reduces. In the case of strengthened strips in vertical, the ultimate force increases more than 50% for a spacing of 200 mm (PU_1) in comparison with a spacing of 250 mm (PU_2).
- For the RC beams strengthened in vertical by CFF strips, the form of a ring is more interesting than the form of U-wrap. The contribution of the carbon fibre fabrics in form of a ring (PC_1 and PC_2) to the ultimate force of the beam is twice more than that in the form of U-wrap (PU_1 and PU_2).
- In the case of RC beams strengthened with CFF strip at 45°, the contribution of the carbon fibre fabrics in the form of a closed ring (PC_3 and PC_4) to the ultimate force is less important than that in the form of a U-shape (PU_3 and PU_4) which is at first sight surprising. For the beam specimen PC_4, the contribution of the CFF fabrics to the ultimate force of the beam is two times less than the beam PU_4. In this case, the advantage of high tensile strength of CFF is not used, the CFF strips of the beams PC_3 and PC_4 are subjected to a twist force in the compressive region of the beams. This twist force weakens the strengthening gain effect.
- However, for the RC beams strengthened with CFF strips in the form of a U-shape, the contribution of the carbon fibre fabric strip inclined at 45° to the ultimate force of the beam is more important than that in vertical even if the spacing of CFF strips is greater—350 mm in the case of the beam PU_4 against 200 mm in the case of the beam PU_1. These results show that for the beams strengthened with CFF strips

Table 2
Test results

Beams	Spacing of CFF strips (mm)	Angle of CFF strips (°)	Applied load at ultimate P_u (kN)	Contribution of CFF reinforcement to the shear capacity $\Delta P = Pn - P_0$ (kN)
P_0	0	0	220	0
$P_{0\text{-bis}}$	0	0	220	0
PU_1	200	90	285	65
PU_2	250	90	260	40
PU_3	300	45	309	89
PU_4	350	45	300	80
PC_1	200	90	355	135
PC_2	250	90	310	90
PC_3	300	45	291	71
PC_4	350	45	264	44

inclined at 45° in the form of U-wrap, the strips are not subjected to a twist force in the compressive region of the beams.

3.2. Cracking and failure mode

At the time of the test, all beam specimens failed in shear but in a different manner. For the RC beams strengthened in shear by carbon fibre fabric strips in the form of U-wrap, failure did not occur in the CFF strips. Debonding of two or three CFF strips (with a layer of concrete adherent to them) over the main shear crack is observed. The debonding is initiated at the main shear crack and progress to the extremity. This kind of debonding does not allow the carbon fibre fabric to be solicited at its ultimate tensile strength. It must be indicated that at the moment of debonding of CFF strips, the strengthening RC beam fails immediately by widening of main shear crack.

For the RC beams strengthened by externally bonded CFF strips in the form of a closed ring, it can be observed that the CFF strips over the main shear crack are broken off in the compressive region. Before the strip failure in tension, the strip debonds, progressing from the crack to the extremities, the debonded area cannot progress through the section's angles. This type of break occurs at the passage of the main shear crack.

If one considers only the strengthening of RC beams by externally bonded CFF strip in the form of U-wrap whatever the orientation and the spacing of CFF strips, one observes that the CFF strips inclined at 45° have a greater contribution on ultimate shear strength of the strengthening RC beam. The photos of failure modes of tested beams are illustrated as Fig. 4.

Fig. 5 shows development of cracks following loading in the control RC beam (unstrengthened). Up to an applied load of 90 kN, only flexural cracks start at the centre of the beam. As the load increases, these cracks start to develop, widen and propagate. After the load of 90 kN, shear cracks begin to occur. As the load increases, between 130 and 200 kN, the shear cracks develop and propagate quickly. Then the failure occurs after a load of 200 kN with a great opening of shear cracks.

On account of symmetry, Fig. 6 shows only development of cracks of half of strengthening beams PC_2 and PU_4 following loading. It can be observed from this figure that the flexural cracks start to occur at an applied load of 100 kN to the beam PC_2 and 120 kN to the beam PU_4. As the load increases, shear cracks begin to occur, propagate and widen, leading to the shear failure of the beams.

These results show that the shear strengthening in of the RC beam by externally bonded CFF strips do not allow to sew the cracks, but to delay apparition and propagation of the cracks.

3.3. Behaviour of strengthened RC beam

3.3.1. Deflection

Fig. 7 shows the experimental results in terms of applied load vs mid span deflection for the control beam P0 and the strengthened beams PU_3, PU_4, PC_3 and PC_4. Five curves show three successive phases. The first phase is the linear elastic phase (without crack in concrete). The second phase corresponds to appearance and propagation of cracks in concrete due to flexural moment. During this phase, the applied load is taken by longitudinal steel bars. The third phase is characterised by the propagation of flexural cracks, the appearance of shear cracks and the start of the yielding of the steel bar. The applied load begins to be taken by internal reinforced steel stirrups and external CFF strips until the failure of the beam.

It can be observed from Fig. 7 that the value of the applied load, at the moment of the appearance of initial flexural cracks in concrete, is about 50 kN to the control specimen and 62 kN to the strengthened specimens. The strengthening effect can be observed from the start of loading. However, the strengthening orientation and form have an effect on the strength of beam before the appearance of first flexural cracks in concrete.

These curves show also that as the spacing of the carbon fibre fabric strips decreases, the stiffness of the beam increases. It can also be seen from these curves that at the moment of yielding of internal steel, in the case of inclined strips and the same strips' spacing, the deflection of RC beams strengthened by CFF strips in the form of U-wrap is greater than that of RC beams strengthened by CFF strips in the form of a closed ring. These results lead us to conclude that the strengthening by CFF strips in the form of U-shape is more interesting.

3.3.2. Longitudinal steel bars strain

Fig. 8 shows the development of strain in longitudinal steel bar in the tensile region of the control beam and of the strengthened beams PU_3, PC_3 and PC_4. The experimental result in terms of applied load vs mid span strain in a longitudinal steel bar for the tested strengthened beam PU_4 is not shown in Fig. 8, for the strain gauge does not function.

The strain measured by strain gauge gives the local data that allows knowing the local behaviour of the tested beam during loading. It can be seen that the curves of applied load vs mid span strain in Fig. 8 are different from these in Fig. 7. The curves show that when the tensile stress of concrete reaches its ultimate strength, one or several cracks appear in concrete. The cracks due to flexural moment, perpendicular to the beam axis, are controlled by internal longitudinal steel bars and compressive region of concrete. The results show also that at the moment of appearance of initial cracks in concrete, the value of the applied load is of 50 kN for the control

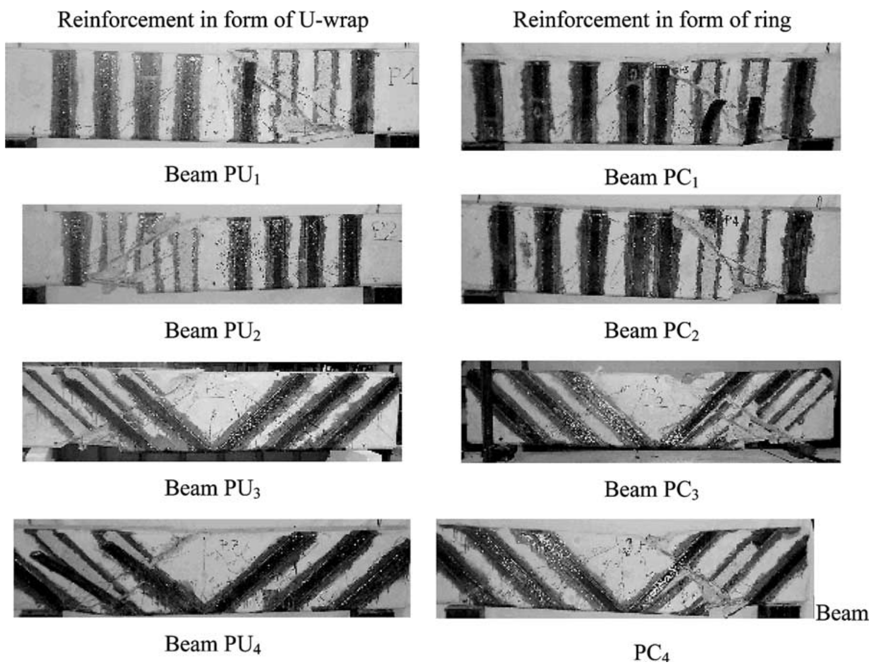

Fig. 4. Mode of failure.

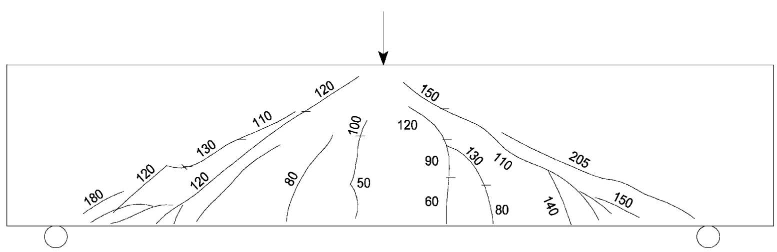

Fig. 5. Propagation of the cracks.

tested beam and of 62 kN for the strengthening RC beams. It can be observed from these curves that as the applied load increases, the strains of all strengthening RC beams develop with the same step.

3.3.3. *Steel stirrups and composite fabric strains*

The strains in the stirrup are measured in the vertical direction. The strains in the composite fabrics are measured in the warp direction of the fabrics. Fig. 9 shows the load-strain curves in the stirrup of the control RC beam P_0 and strengthened RC beams PU_1, PU_2, PU_3 and PU_4.

From this figure, it can be seen that the load, corresponding to the apparition of diagonal cracks in concrete, increases after strengthening from 100 kN for the control beam P_0, to 130 kN for the strengthened RC beams PU_1 and PU_2, then to 150 kN for the strengthened RC beam PU_4 and 165 kN for the strengthened RC beam PU_1. In comparison with control beam P_0, the value of the load increases 30% for beams PU_1 and PU_2, 50% for the beam PU_4 and 65% for the beam PU_1. The results clearly point out the strengthening effect. The bonded carbon fibre fabrics delay the appearance of diagonal cracks in the concrete and also reduce the development of diagonal cracks.

For the four strengthened RC beams, the internal steel stirrups, in the case of the two strengthened beams PU_1 and PU_2, resist the loading earlier than in the strengthened beams PU_3 and PU_4. This signifies that the strengthening by carbon fibre fabric inclined strips is more effective than that by CFF vertical strips, for CFF inclined strips participate early in resisting the loading.

The load-strain curves obtained by the strain gauge mounted on the composite fabric surfaces for the beams PU_1, PU_2 and PU_4 are shown in Fig. 10. It can be seen that the test results are similar compared to those of Fig. 9. However, in comparison with Fig. 9, it can also be seen that the strain value in composite fabrics is greater than that in the stirrups during the whole loading after the appearance of the diagonal cracks (debonding effect). That indicates that the composite fabrics resist the shear force more than the stirrup and the strain in composite fabrics develops faster than that in steel stirrups. The strengthening effect by the bonded composite fabrics is obvious.

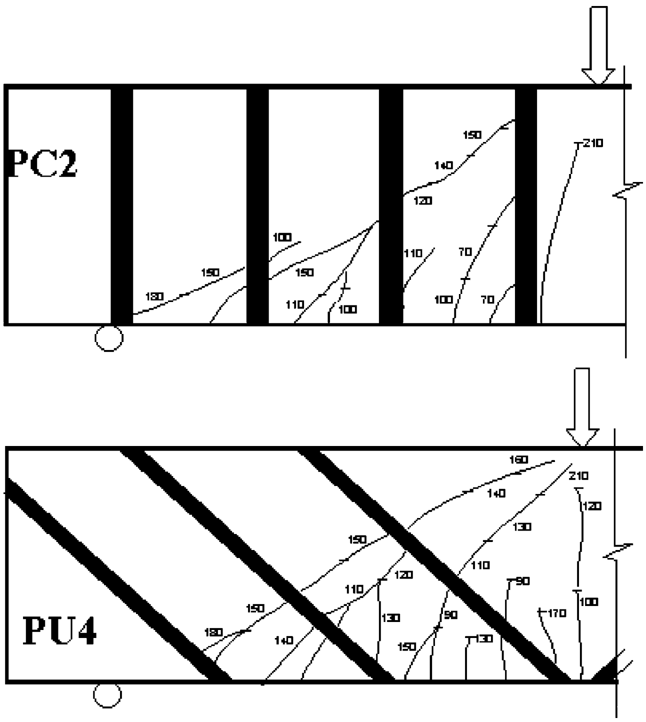

Fig. 6. Development of the cracks.

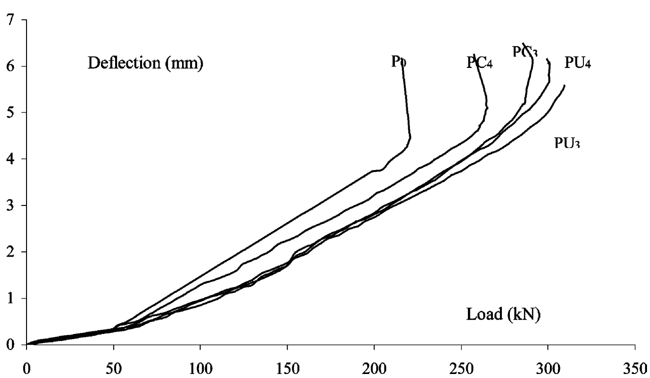

Fig. 7. Applied load–mid-span deflection curves for the beams P_0, PC_3, PC_4, PU_3 and PU_4.

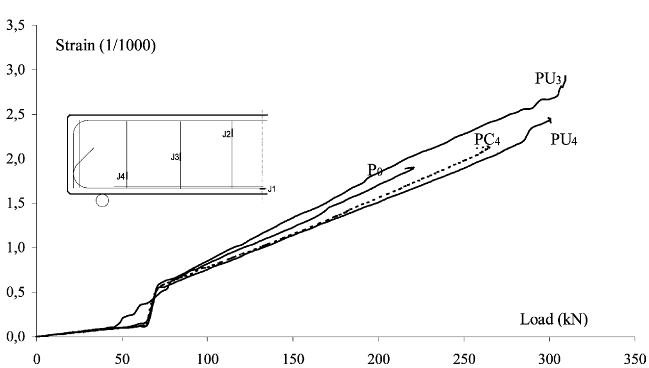

Fig. 8. Applied load–strain (J_1) curves for the beams P_0, PC_4, PU_3 and PU_4.

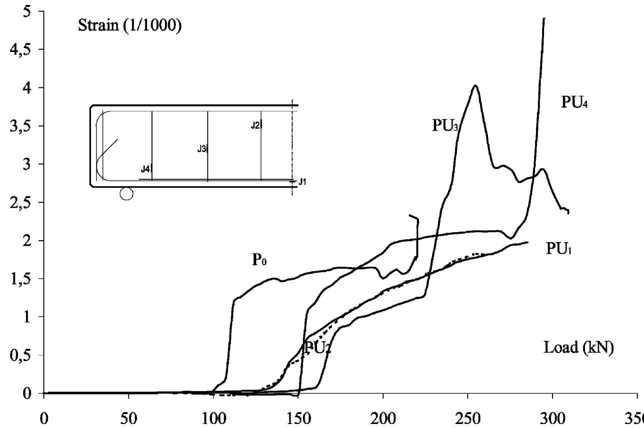

Fig. 9. Applied load–strain (J_3) in the internal steel stirrup curves for the beams P_0 and PU_n.

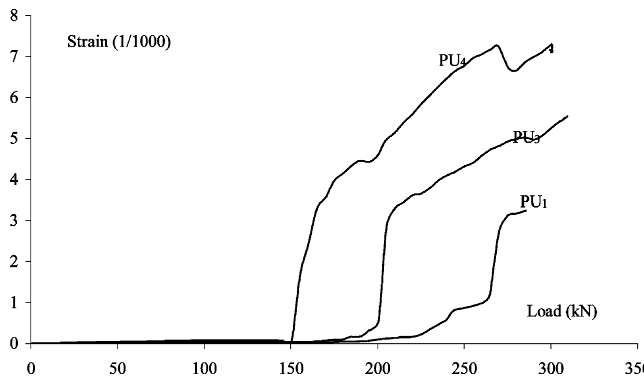

Fig. 10. Applied load–strain (J_6) in the CFF strip curves for the beams PU_1, PU_2 and PU_3.

Figs. 11 and 12 show the load-strain curves measured by the strain gauge mounted on the steel stirrup and the composite fabrics surfaces of the beams PC_1, PC_2, PC_3 and PC_4.

From Fig. 11, it can be seen that the large diagonal

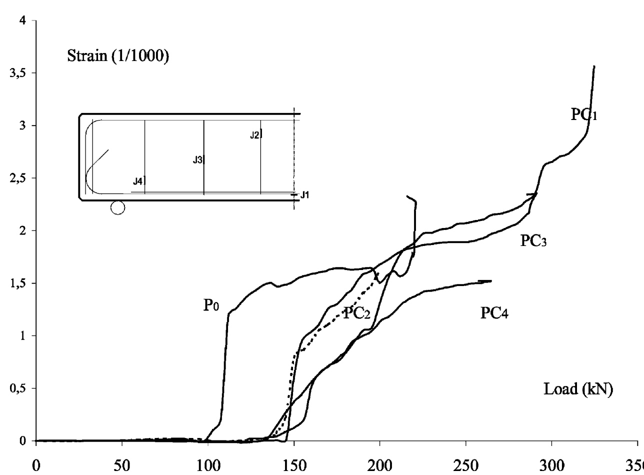

Fig. 11. Applied load–strain (J_3) in the internal steel stirrup curves for the beams P_0 and PC_n.

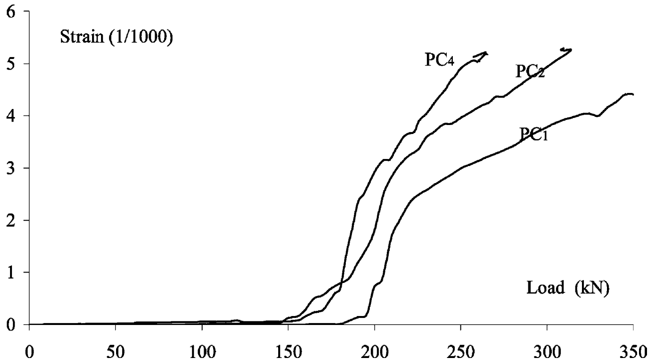

Fig. 12. Applied load–strain (J_6) in the CFF strip curves for the beams PC_1, PC_2 and PC_4.

shear crack is formed at a load of about 140 kN and propagates as the load increases in a similar manner to Fig. 9. In the post-cracking range, the strain increases at a greater rate and the strain value in composite fabrics is greater than that in the stirrup during the whole loading. With a decrease in the spacing of carbon fibre fabric strips, the strain in composite fabrics reduces. In comparison with the RC beam strengthened by vertical composite fabric strips, the level of strain in inclined composite fabric strips is improved. This means that the state of strain varies with the composite fabric pattern and the spacing of composite fabric strips. Comparing the beam strengthened by composite fabric strips in the form of a U-shape, the beam strengthened by composite fabric strips in the form of a closed ring is more interesting from a mechanical point of view, for the strain value in the composite fabric is reduced.

4. Estimation of contribution of CFF reinforcement to the shear capacity

To predict shear performance on an empirical basis, various theories have been developed and many design codes and guidelines have been established in America (ACI 440, 2001), Canada (CHBDC, 1996), Europe (Eurocrete, 1998) and Japan (JSCE, 1997) [11–14]. According to these design codes, for the RC beam strengthened with externally bonded composite material, the shear strength of a strengthening RC section (V_n) is expressed as follows:

$$V_n = V_c + V_s + V_f \quad (1)$$

where V_c is the shear strength of the concrete, V_s the shear strength of the steel reinforcement, and V_f is the shear contribution of the composite reinforcement.

Fig. 13 shows the internal forces in carbon fibre fabric strips and in steel stirrups. Note that the diagonal cracks are assumed to be inclined at an angle β. With reference to Fig. 13, the vertical component of the force in the steel transversal bars V_s can be estimated as

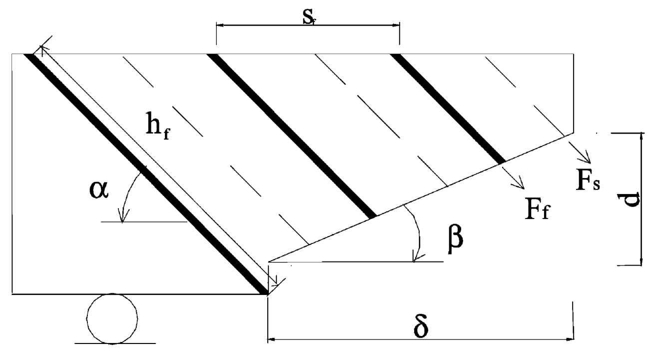

Fig. 13. Definition of the forces and the parameters.

$$V_s = n_s A_v f_y \sin\alpha \quad (2)$$

where A_v is vertical stirrup area, f_y is the yield strength of internal steel.

The expression used to estimate the shear contribution of CFF reinforcement is similar to that Eq. (2) for shear contribution of steel stirrups. The assumptions used in the expression (3) are as follows:

- Perfect bonding between the strengthening composite strips and concrete beam is assured and no slipping occurs under loading between the composite strips and the concrete beam.
- The composite fabric strips have elastic and linear behaviours. Hook's law is applicable to the composite fabric strips.
- Failure mode of strengthened RC beam is in shear.

Then, the shear contribution of carbon fibre fabric strips is calculated by Eq. (3) as follows:

$$V_f = n_f A_f \sigma_f \sin\alpha = A_f \sigma_f (\sin\alpha + \cos\alpha \tan\beta)(d_f / s_f). \quad (3)$$

In Eq. (3), n_f is the number of externally bonded carbon fibre fabric strip pairs. The cross-sectional area of CFF shear reinforcement, A_f, is the thickness of strip usually t_f times the width of the CFF strips b_f. σ_f is the nominal CFF strip strength. α is strengthening CFF strip inclination with respect to beam axis. β is shear crack inclination corresponding to V_f. d_f is the effective depth of the CFF reinforcement and s_f is the spacing of horizontal CFF strips.

In the case of the RC beam strengthened by CFF strips in form of U-wrap, the debonding failure occurs. The shear contribution of carbon fibre fabric strips depends also on the bonded surface configuration. For the CFF strip, the anchorage value is given as following

$$d_f = h_f - 120 \text{ (mm) to reinforcement in form of U} - \text{shape;}$$

$$d_f = h_f \text{ to reinforcement in form of ring,}$$

where h_f is the lateral length of CFF strip.

The results obtained by using Eq. (3) and the compari-

Table 3
Contribution of CFF strip to the shear capacity

Specimen	PU_1	PU_2	PU_3	PU_4	PC_1	PC_2	PC_3	PC_4
V_{fc}^{a}	66	53	85	69	123	98	105	85
V_{ft}^{b}	65	40	89	80	135	90	71	44
$(V_{fc}^{a}–V_{ft}^{b})/V_{ft}^{b}100$	1.5%	32.5%	−4.5%	−13.5%	−8.9%	8.9%	47.9%	93.2%

[a] V_{fc}: calculated value
[b] V_{ft}: test value

son between test values and calculated values are shown in Table 3. The measured CFF shear contribution to the shear capacity is obtained by subtracting the ultimate shear strength of the reference beam from the non-strengthened one. Table 3 shows that in comparison with experimental results, the calculated values for the five beams PU_1, PU_3, PU_4, PC_1 and PC_2 are acceptable. The difference between calculated value and tested value is less than 14%. However, for the another three beams, in particular for the beams PC3 and PC4, the calculated values and tested values are distant. This phenomenon can be explained by the fact that the internal flexure of the inclined CFF strips in the compressive region of the RC beam reduces the contribution of the carbon fibre fabric strip to the shear capacity.

5. Conclusions

The test results indicate that the shear strengthening effectiveness with carbon fibre fabric strips on the RC beams varies in function of the spacing of CFF strips, CFF plating pattern and CFF strip orientation. The test results confirm that the strengthening technique using external bonded CFF strips can be used to significantly increase the shear capacity of the RC beams with shear deficiencies. Among the eight RC beams strengthened in different ways, the more interesting beam is the beam strengthened by vertical CFF strips in the form of U-wrap (PC_1).

For the RC beams strengthened with vertical CFF strips, the shear reinforcement in the form of a closed ring is more interesting than that in the form of a U-shape. The contribution of CFF strips in the form of a ring on the shear ultimate capacity of the RC beam is two times greater than that in the form of U-wrap. The importance of anchorage length of the reinforcing material is obvious.

However, in the case of reinforcement with CFF strips inclined at 45°, the strengthening effectiveness in the form of a ring is less important than that in the form of U-wrap. This result can be explained by the fact that in the case of the reinforcement with inclined CFF strips in the form of a ring, there is a local flexure. This flexure provokes a local overload of border fibres of the CFF strips situated at the compressive region of the beam.

The load-strain curves obtained by the strain gauge indicate that the bonded composite fabrics in shear on the beam have a significant effect on beam ductility. In general, for a strengthened reinforced concrete beam, composite fabrics resist the loading rather than the internal steel stirrups. The strain in composite fabrics develops faster than that in steel stirrups.

The vertical CFF strips and the inclined CFF strips do not work in the same manner. The results show that the CFF strips near the applied load resist the loading well. However, the strain in the CFF strips near the end of the RC beam is very small.

The comparison between the experimental results and calculated values indicates that the used expression to estimate the contribution of CFF strips to the shear capacity of the RC beam is acceptable. It must be noted that the expression used in this work is only valuable in the case of the RC beam strengthened by the CFF strips in the form of U-wrap or in the form of a ring. The results indicate that the difference between the calculated value and the tested value is less than 14% for the beams PU_1, PU_3, PU_4, PC_1 and PC_2, 33% for the beam PU_2. This difference is important for the beam PC_3 (48%) and PC_4 (93%). It is clear that the present expression should be further developed in order to satisfy all the cases of the RC beam strengthened by composite material.

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