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- (54) Benævnelse: **CARBONFIBERFORSTÆRKNINGSPOLYMER OG TILSVARENDE ANVENDELSESTEKNIK TIL FORSTÆRKNING AF BETONSTRUKTURER**
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DESCRIPTION

Technical field

[0001] The present application describes a carbon fiber reinforced polymer laminate and the respective technique for the strengthening of concrete structures.

Prior art

[0002] In several cases of projects in the strengthening of reinforced concrete (RC) structures, the need for the flexural strengthening requires additional measures in the shear reinforcement in order to avoid the occurrence of this type of brittle failure mode which is fragile, that, in general, occurs without signs of its occurrence. Thus, for these cases the rehabilitation practice undergoes the application of two reinforcement systems, one for the flexural and another for the shear. A similar situation also happens for slabs, where sometimes the need for flexural strengthening for negative bending moments requires punching strengthening.

[0003] The two inventors, Prof. Joaquim Barros from Universidade do Minho, and Eng. Filipe Dourado, CEO of Clever Reinforcement Iberica - Materiais de Construção Lda., have intense collaboration on the investigation on the area of carbon fiber reinforcement polymers (CFRP - Carbon Fiber Reinforcement Polymer) applied according to the Near Surface Mounted (NSM) technique, and which in Portuguese can be designated as "Instalação proximo da superficie". Since the beginning of the current century, Eng. Filipe Dourado has collaborated with the ongoing research carried out by Prof. Joaquim Barros on the use of CFRP laminates applied according to the NSM technique for the strengthening of concrete, masonry and timber structures. The efficiency of this technique for the flexural strengthening of RC beams and slabs has been evaluated [1-3], for the shear strengthening of RC beams [4,5], as well as for the simultaneous increase of the flexural and energy dissipation capacity of RC columns, where these CFRP laminates are used with strips (hoops) of wet layup CFRP sheets for shear strengthening and concrete confinement [6], have been demonstrated. The bond conditions of the applied CFRP laminates according to the NSM technique have been properly investigated [7]. Recently, the joint use of CFRP systems for the flexural and shear strengthening was explored by experimental [8] and numerical [9] research, which has demonstrated the interest for the concept of CFRP laminate intended to develop under the present project. The extraordinary efficiency on the shear strengthening provided by rods that were inserted in holes executed in the section of RC beams was recently assessed, having been demonstrated that it is possible to convert shear brittle failure mode into ductile flexural failure mode [10].

[0004] The knowledge heritage acquired by the inventors in the past fifteen years in the scope of the strengthening of structures with composite materials has allowed a deep understanding of the advantages and debilities of the current systems. The disadvantages of the

strengthening techniques based on the use Fiber-Reinforced Polymers (FRP) are mainly their premature detachment, especially when using the externally bonded reinforcement (EBR) technique, as well as its susceptibility to high temperatures and acts of vandalism. When applied according to the NSM technique, the strengthening capacity of CFRP laminates is not fully exploited, due to the premature rip-off of the concrete cover that includes these laminates, or by sliding alongside the substrate.

[0005] Document JP2003003674 discloses a reinforcing system comprising a sheet-shaped part, equipped with a plurality of extending portions extending outward from each of the four corners of the sheet portion. This invention is a sheet made of fibers that is applied on the surface of three faces of a beam.

[0006] Document JP2012207387 discloses a reinforcement structure for wood that includes an aramid fiber rod of which one end is bent and a wood with a hole and a groove extending from the hole along the front face, and the one end of the aramid fiber rod is inserted into the hole and the aramid fiber rod extends from one end to the other end and is fitted to the groove.

General Description

[0007] The present invention describes a carbon fiber reinforcement polymer (CFRP) laminate according to claim 1, a use thereof according to claim 5 and a method for the strengthening of a concrete beam or slab according to claim 3. A CFRP laminate with a clip shape (not according to the invention) is formed by three straight segments and two transition zones, or cane, constituted by two rectilinear segments and a transition zone (elbow), in which the extremity branches ensure shear strengthening in beams or punching in slabs, while the remaining part of the laminate ensures flexural reinforcement. This product is meant to be applied in the construction area.

[0008] Analytical studies and advanced numerical simulations, and the parametric studies performed with these models provided privileged information that are the ground for the CFRP laminate now being presented. In fact, the developed laminate results from the transformation of a laminate currently produced by Clever Reinforcement Iberica - Materiais de Construção Lda in its Elvas factory, where a developed mechanism allows to execute the transition zones (elbows) which grants the laminate with the clip (not according to the invention) or cane shape configurations.

[0009] These configurations assure to the laminate the ability for strengthening, simultaneously, in flexural and shear RC beams, in flexural and punching RC slabs, and in flexural with anchoring in the case of columns, balconies, cantilevers and related elements. The original CFRP laminate has a constant cross section, with a width that can vary between 10 to 20 mm, and a thickness of 1.4 mm.

[0010] The extremities of the CFRP laminate are introduced in holes opened into the section of

the element to be strengthened, similarly to the Embedded Trough Section (ETS) technique, which demonstrated an extraordinary efficiency on the shear strengthening of concrete beams [10]. The inclination and length of the extremities of the laminate depend on the type of strengthening to be executed, whereby they are data of the strengthening project. The largest and most complete experimental program performed to date regarding the use of CFRP laminates for the shear strengthening of RC beams according to the NSM technique [4] has demonstrated that the efficiency of this technique depends significantly on the inclination of the laminates, the quality of the surrounding concrete, the percentage of existing steel stirrups on the beam to be strengthened, and the stiffness of the strengthening systems. On the other hand, the results on the efficiency evaluation tests of the ETS technique for the shear strengthening of beams have demonstrated that due to the fact that the strengthening reinforcement elements are introduced into the section, a far superior level of efficiency is guaranteed when compared with the NSM and EBR techniques. This is justified by the greater confinement offered by concrete surrounding these reinforcement elements when using the ETS technique, as well as the larger fracture surface that is developed during the pullout process of the reinforcement elements crossed by the shear cracks. These conclusions were also confirmed by the presented parametric studies [5].

[0011] To evaluate the potential of the new type of laminate, standard CFRP laminates were manually transformed, in order to be with the intended configuration, namely clip (not according to the invention) or cane, and a preliminary experimental exploratory program consisting of RC beams and slabs was carried out, from which it was verified the greater efficiency of these new laminates and its respective strengthening technique, when compared to traditional laminates and techniques, as it is shown in Figures 7 and 8. In fact the CFRP laminates with a clip (not according to the invention) or cane configuration with the extremity(ies) inserted into the section are very efficient on the shear and punching strengthening. Such is due to the high confinement provided by the surrounding concrete to the laminate, the larger surface resisting to the concrete fracture that is mobilized during the pullout process of a laminate crossed by a potential shear crack, and the anchoring effect provided by the center part of the laminate used for the flexural strengthening. In turn, the efficiency for the flexural strengthening is far superior to the one achieved with standard CFRP laminates applied according to the NSM technique, since the extremities of the new laminate, when introduced into holes executed inside the section, assure an extraordinary anchoring effect to the middle part of the laminate used for the flexural strengthening. Therefore, the transition between the three segments, two in the cane laminate, that form this new laminate are the critical zones. These zones are made through a mechanism designed to ensure the proper inclination without loss of stiffness and strength. These zones are thermo-mechanically treated, keeping a plait configuration, and being jacketed with a fiber sleeve.

[0012] Thus, the results of the experimental, analytical and numerical research, along with the already performed exploratory results, show that the proposed laminate has a superior efficiency when compared to what is assured by the existing nowadays. The extremities of this new type of laminate, being inserted into the section of the element to be strengthened, are more protected against the detrimental effect of high temperatures, when compared with the

current marketed FRP systems. Therefore, even under fire, the new types of laminates work like tendons, in which the anchoring is assured by the extremities zones of the laminate that are embedded in the concrete according to the ETS technique. This type of laminate can also be used on the flexural strengthening of columns and cantilevers/consols (balcony types and related), with full mobilization of the CFRP laminate tensile capacity. In this case, the laminate extremities are inserted, with the intended anchorage inclination and length, into holes executed on the elements connected to the columns or into the elements connected to the cantilevers or consols.

[0013] The present CFRP laminate has the ability of, simultaneously, serve as a reinforcement for the flexural and shear strengthening of RC beams, and for the flexural and punching strengthening of RC slabs. It can also be applied on the flexural strengthening of RC columns, balconies and cantilevers, by anchoring the inclined extremity of the new CFRP laminate, designated in this case as sticker laminate, into is holes executed in concrete elements connected to the elements to be strengthened. The strengthening ability of this laminate is higher than any other FRP system currently in the market, since the maximum tensile strain possible to be mobilized is close to the its ultimate tensile strain, as was observed in the exploratory experimental programs already executed, as well as through performed numerical simulations. The technique for the application of this new type of laminate also contributed to its biggest strengthening efficiency, given that beyond the benefits derived from a good laminate anchoring, its extremities are protected from the detrimental effect of high temperatures, whereby the laminate, even under fire, develops a reinforcement ability, as if it is a tendon, much larger than any existing FRP system. The epoxy (S&P 55) adhesive used for bonding the extremities of the laminate to the surrounding concrete, fills by its own weigh the space between the laminate and the substrate into the holes due to its high fluidity, allowing a more complete and quick filling than the currently existing bonding systems.

[0014] Throughout this request it is considered that an elevated fluidity equals a viscosity between 850 e 1150 mPa*s.

[0015] The nature of this new type of laminate and the strengthening technique is based on the accumulation of solid knowledge supported by experimental, numerical and analytical research performed during the last 15 years on the use of FRP for the structural strengthening. This investigation allowed to demonstrate that the CFRP laminates of rectangular cross section, when applied according to the NSM technique, are more effective on the flexural strengthening than the systems applied according to the EBR technique. This comes from the fact that the laminate is confined within a groove executed in the concrete cover, therefore the premature debond observed on systems applied according to the EBR technique is not registered on the laminates applied according to the NSM technique. Beyond this, the analytical and numerical models have shown that the bigger is the ratio between the perimeter of the laminate and its cross sectional, the larger is its fixation capacity to the concrete substrate [2]. However, the high stress concentration on the extremities of the CFRP laminates applied according to the NSM technique leads to detachment of the concrete cover that starts in those areas and progresses throughout almost the entire laminate [3]. This limits the

potential strengthening of the laminate since the maximum mobilized tensile strain can be significantly smaller than the ultimate tensile strain of the laminate. Thus, by having folded extremities on the laminate, inserted into holes executed into the section of the structure to be strengthened, the premature detachment is avoided, and the critical parts of the laminate are protected against the detrimental effect of high temperatures typical of a fire.

[0016] On the other hand, the research carried out on the shear strengthening with CFRP laminates applied according to the NSM and ETS techniques has shown that the strengthening efficiency is higher when the ETS technique is used, given the higher confinement assured by the surrounding concrete [10]. By such fact, in the proposed laminate, its extremities are applied according to the ETS techniques, but now resorting to the rectangular section laminate due to the already stated fact of this geometry assures better bonding conditions than circular section reinforcement. Besides that, the adhesive to be applied on these zones, of high fluidity, will ensure a faster and more complete space filling between the laminate and the surrounding substrate.

Intervals and possible variations

[0017] The efficiency and profitability of the strengthening technique depends on the rigor assured for the required length and inclination of the laminate extremities, as well as on the quality and rigor on the execution of the transition zones (elbows). However, an error below 10% either in the inclination or in the length of the extremities does not affect significantly the performance of the new type of laminate and the respective strengthening technique, as well as in the time execution procedure of such technique. An equal error level is admitted for the diameter of the holes where the laminate extremities are inserted. These relatively high tolerances are justified by the adequate flexibility of the transition zones of the laminate, which allows some adjustment in job site regarding the inclination laminate extremities. The extremity inclination of the laminate ranges from 30 to 90 degrees with the beam axis (or the slab middle surface), and it should be as orthogonal as possible to the cracks due to shear (beams) or punching (slabs). Considering the shear and punching failure modes observed on reinforced concrete beams and slabs, respectively, the laminates extremities inclination should be close to 45 degrees, but a variation of +/- 15 degrees is perfectly acceptable (inclinations of 30 to 60 degrees), and the assumption of vertical extremities (orthogonal to the beam's axis or the slab's middle surface) can still be an effective alternative when difficulties on the execution of inclined holes are a considerable obstacle for technical/economic reasons. The length of each of the parts that compose the laminate, will be completely dependent on the conditions of the project for the structural strengthening, but a 10% error does not compromise its efficacy. However, the higher the length of the laminates embedded into the cross section of the RC element to be strengthened, the greater the efficiency of the shear/punching strengthening.

Brief description of figures

[0018] To better understand the technique, the figures are present in annex, which represent preferable embodiments which, however, are not intended to limit the object of the present invention, which is only defined and limited by the appended claims.

Figure 1 shows a clip type of CFRP laminate which does not form part of the present invention.

Figure 2 shows a cane type of CFRP laminate according to the invention.

Figure 3 shows a clip type laminate application for the simultaneous flexural and shear strengthening of reinforced concrete beams which does not form part of the invention.

Figure 4 shows a clip type laminate application for the simultaneous flexural and punching strengthening of reinforced concrete slabs which does not form part of the invention.

Figure 5 shows a clip type laminate application for the flexural strengthening of reinforced concrete columns with laminate extremities anchored which does not form part of the invention.

Figure 6 shows a cane type laminate application for the flexural strengthening to negative bending moments of cantilever type reinforced concrete structures like balconies according to the invention.

Figure 7 shows a strengthened beam.

Figure 8 shows an exploratory test on the use of the new types of laminates for the simultaneous flexural and punching strengthening of RC slabs: a) laminates' configuration; b) punching failure of the reference slab; c) flexural failure in the strengthened RC slab with a 30% increase on the load carrying capacity and 33% on the deflection ability, using a small percentage of the new laminates, executed by a manual process by transformation of Clever's laminates.

Description of the embodiments

[0019] Hereafter, some embodiments will be described in a more detailed manner, which however are not intended to limit the scope of the invention. The present application describes CFRP laminates as the ones shown on Figs. 1 and 2, as well as the strengthening technique for concrete structures using these laminates.

Types of laminates

[0020] The laminates shown in Figs. 1 and 2 are elaborated from $1.4 \times 10 \text{ mm}^2$ or $1.4 \times 20 \text{ mm}^2$ cross section laminates. The transformation, executed by an automatism, introduces the

transition zones (Tz), elbows, presented on the referred figures, being the laminate able to take a clip shape (Fig. 1) (not according to the invention) or a cane shape (Fig. 2). The transition zone is executed by a thermo-mechanical treatment, in which by temperature rise, with an oven existing in the mechanism, the adhesive becomes viscous, in a way that it becomes possible to assure the required inclination to the laminates extremity. This process is followed by application of a rotational movement to the part formed by the transition zone and its corresponding laminate extremity, while the other part of the laminate is kept clamped, which introduces a plait configuration to the transition zone. This transition zone is then dipped with adhesive and jacketed by a fiber sleeve in order to achieve the intended stiffness, being the process finalized by curing this zone.

[0021] In figure 1 it is precisely shown a representation of the CFRP laminate with a clip shape (not according to the invention) with its both extremities inclined, being able to have two different inclinations ($\Theta 1$ and $\Theta 2$). The laminate is formed with three branches: central with a length of L_b , which has the fundamental function of guaranteeing the flexural strengthening of the RC element to be strengthened; both extremities, whose length can be different, $LS1$ and $LS2$, which have as the main objective of providing the required shear strengthening. These branches are connected by a transition zone (TZ), that is formed by thermo-mechanical treatment complemented by fiber jacket in order to assure the required strength and stiffness to avoid premature failure due to the development of stress gradient caused by the variation on the orientation on the parts of the laminate and the existence of different anchoring conditions on the laminates parts.

[0022] In figure 2 a representation of a cane type CFRP laminate with a folded extremity is shown, being able to take the intended orientation. The laminate is formed by two branches, one with a L_b length for the flexural strengthening, and another with a L_s length which can serve for the shear strengthening and/or to assure an adequate anchoring to the part of flexural strengthening. These branches are connected by a transition area (TZ) .

Strengthening techniques

[0023] The strengthening technique consists of installing the laminate part destined to the flexural strengthening (L_b on Figs. 1 and 2) in a groove made on the concrete cover of the RC element to strengthen (zone with a $L1$ and $L2$ length as shown on Fig. 3a) and on the installation of the extremity (extremities) of the laminate into holes previously opened on the section of the element to be strengthened (Fig. 3a, 3e and 3f). After the execution of the groove and holes, they are cleaned by compressed air or an equivalent technique. The groove should have a width (a_g) between 4.5 and 5.5 mm (Fig. 3g) and a height (b_g) equal to the cross section height of the laminate plus 1.0 to 3.0 (Fig. 3g). On the other hand, the diameter of the hole should be equal to the largest dimension of the laminate cross section dimensions plus 1.0 to 3.0 mm (Fig. 3f). Before introducing the laminate in the groove and holes, the laminate is cleaned with a degreasing agent. The adhesive for fixing the L_b part of the laminate to the concrete, S&P 220, is produced according to the recommendations of the adhesives

manufacturer, although another adhesive can be used as long as it is demonstrated by pullout tests that equal or superior conditions of bonding the laminate to concrete are achieved. The adhesive is applied with spatula, collapsible tube or other nozzle mechanism in order to completely fill the groove with the adhesive throughout the length L_b and part of the transition zone for sealing the lower part of the holes. On the lateral faces of the laminate (10 or 20 mm wide), throughout the L_b length, a thin adhesive layer is applied, and the laminate is immediately introduced into the groove and respective holes. After the laminates have been applied, and while assuring a curing period for the adhesive of at least 24 hours, a high fluidity adhesive is introduced by gravity, on the top of the holes, in order to bond the laminate extremities to the surrounding concrete (Fig. 3e, 3f and 3h). The curing period for the two types of used adhesives should be the one stated by the manufacturer of such adhesives.

[0024] The clip shaped laminates (not according to the invention) are especially suited for the simultaneous flexural and shear strengthening of beams. In the example shown on Fig. 3a, a beam with a T cross section is strengthened for positive bending moments and shear forces by using a clip laminate (L_1) disposed along the longitudinal symmetry plane of the beam, as shown on Fig. 3c, and by two clip laminates (L_2) disposed along the beam, near the beam lateral faces, as shown on Fig. 3b. Throughout the L_1 length, the beam is flexurally strengthened with 3 laminates, as shown on Fig. 3a and 3d, while on the L_2 length the beam has only 2 laminates for the flexural strengthening, as shown on Fig. 3a and 3c. The central part of the laminates (L_b) assures flexural strengthening, and offers resistance against the propagation of flexural cracks (Cr_f), while the extremity parts of the laminates (L_s) assure shear strengthening and offer resistance to the opening and sliding of the shear cracks (Cr_s). The side parts of the laminate, while inclined, are inserted into opened holes on the beam's cross section, with a diameter equal to the bigger side of the laminate's cross section, b_f , plus approximately 2 mm, as shown on Fig. 3e. After the laminate is installed, the hole is filled with high fluidity adhesive in order to fill by gravity the existing spaces between the laminate and the hole's wall, as shown in Fig. 3h and 3f.

[0025] The clip laminates (not according to the invention), as shown in Figure 4, are also proposed for the simultaneous flexural and punching strengthening of RC slabs. The central parts of the laminates are used for the flexural strengthening, as well as to assure anchoring conditions to the extremity parts of the laminate. Such extremity parts have the main function of assuring the punching strengthening and providing suitable anchoring conditions to the central part of the laminate dedicated for the flexural strengthening. The central part of the laminate offers resistance to the propagation of flexural cracks (CR_f), while the extremity branches offer resistance to the opening and sliding of shear cracks (CR_s).

[0026] The clip (not according to the invention) or cane laminates, as shown on figure 5, can also be used for the flexural strengthening of columns, where the non-inclined part has the function of assuring the required flexural strengthening, and the extremity(extremities) to assure the needed anchoring conditions for an effective flexural strengthening by avoiding a premature detachment of the laminate.

[0027] The cane laminates, as shown on figure 6, are indicated particularly for increasing flexural capacity for the negative bending moment in cantilever type structures, such is the case of the balconies shown in the figure. The horizontal part of the laminate assures the intended flexural strengthening, while the La length assures the intended laminate anchoring conditions.

[0028] Figure 7 shows the strengthening configuration of RC beams adopted in the ongoing experimental program.

[0029] Figure 8 shows the strengthening configuration of RC slabs adopted in the current experimental program - Fig. 8a, brittle punching brittle failure mode registered in the reference slab, as shown on Fig. 8b, and flexural ductile failure mode observed in the RC slab strengthened with the new types of CFRP laminates, as shown on Fig. 8c.

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[0030]

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[0031] The present technology is not, naturally, in any way restricted to the embodiments described in this document and a person skilled in the art could predict many technology modification possibilities without departing from the scope of the invention which is only defined by the appended claims.

[0032] The following claims define the invention and its preferred embodiments.

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**CARBONFIBERFORSTÆRKNINGSPOLYMER OG TILSVARENDE
ANVENDELSESTEKNIK TIL FORSTÆRKNING AF
BETONSTRUKTURER**

5 PATENTKRAV

1. Carbonfiberforstærket polymerlaminat med en rørform til forstærkning af en armeret betonbjælke med en akse eller betonplade med et pladeplan, hvor bjælken eller pladen har bjælkebøjleindlejring ind i det indre og en betonafdækning, hvor
10 bjælken eller pladen omfatter riller og huller til indføring af det carbonfiberforstærkede polymerlaminat og klæbemateriale med høj flydeevne, hvor rørformen omfatter to retlinjede segmenter (Ls, Lb) og én overgangszone (Tz), der forbinder de to retlinjede segmenter (Ls, Lb), hvor det udvendige segment (Ls) danner en ende af det carbonfiberforstærkede polymerlaminats rørform, hvor i
15 anvendelse hældningen på enden ligger mellem 30 til 90 grader i forhold til bjælkeaksen eller pladeplanet for henholdsvis den armerede betonbjælke eller betonplade, der skal forstærkes.

2. Carbonfiberforstærket polymerlaminat ifølge det foregående krav, der her et
20 konstant tværsnit med en bredde på mellem 10 og 20 mm og en tykkelse på 1,4 mm.

3. Forstærkningsfremgangsmåde til forstærkning af en betonbjælke eller betonplade ved hjælp af det carbonfiberforstærkede polymerlaminat ifølge et
25 hvilket som helst af de foregående krav, omfattende følgende trin:

- åbning af en rille på betonafdækningen af den armerede betonbjælke eller betonplade, der skal forstærkes;
- åbning af et hul med en diameter svarende til maksimummålet på laminatets tværsnit plus 1,0 til 3,0 mm;
- 30 - rensning af rillen og hullet B5 med trykluft;
- rensning af laminatet med et affedtningsmiddel;

- anvendelse af klæbemidlet og påføring heraf over hele rillens længde, og påføring af et tyndt lag klæbemiddel på sidefladerne af ét af laminatets retlinjede segmenter;
 - indføring af det retlinjede segment (Lb) til forstærkning af bøjningsstyrke i rillen, og indføring af det andet af de retlinjede segmenter (Ls) af laminatet, der danner enden, i hullet;
- 5
- efter hærkning af klæbemidlet påført det retlinjede segment (Lb), fyldning, med klæbemiddel med høj flydeevne, af rummet mellem det andet retlinjede segment, der danner enden (Ls) af laminatet og hullets væg.
- 10
- 4.** Forstærkningsfremgangsmåde ifølge det foregående krav, hvor bredden på rillen åbnet på betonaafdækningen ligger mellem 4,5 og 5,5 mm.
- 5.** Anvendelse af det carbonfiberforstærkede polymerlaminat ifølge et hvilket som helst af kravene 1 til 2 til forstærkning af en armeret betonbjælke eller betonplade.

DRAWINGS

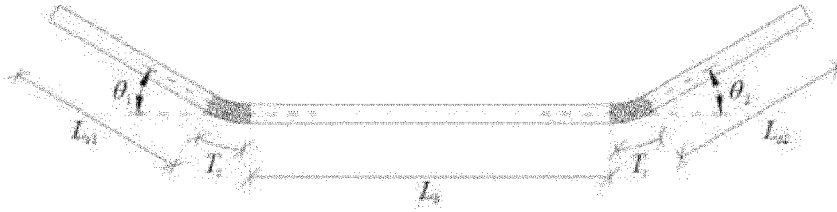


Fig. 1

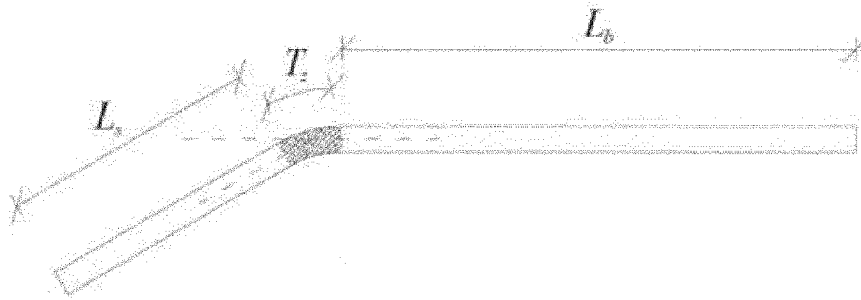


Fig. 2

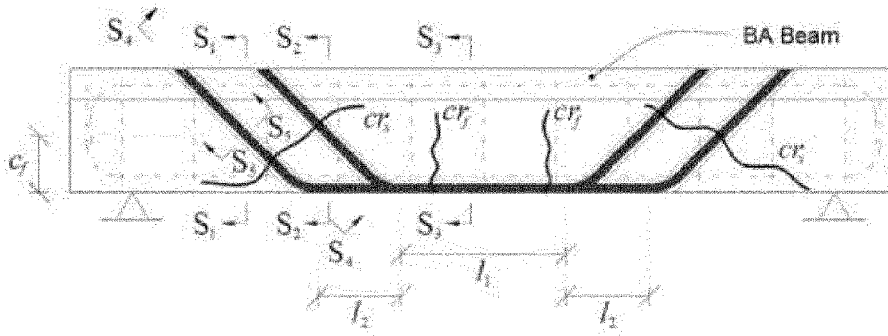
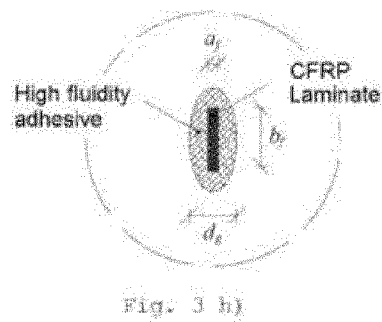
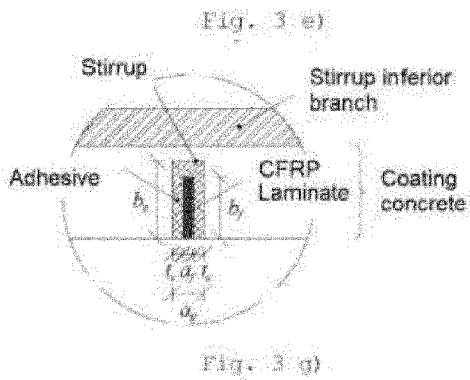
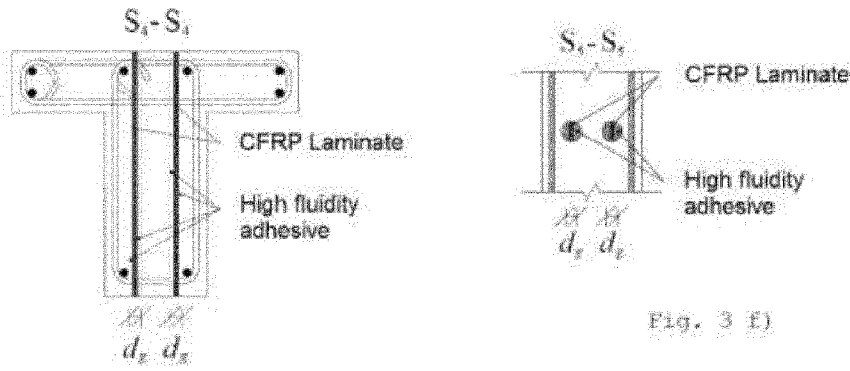
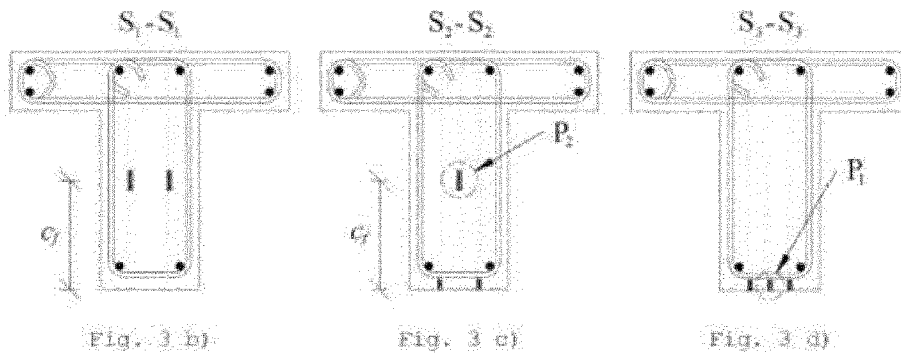


Fig. 3 a)



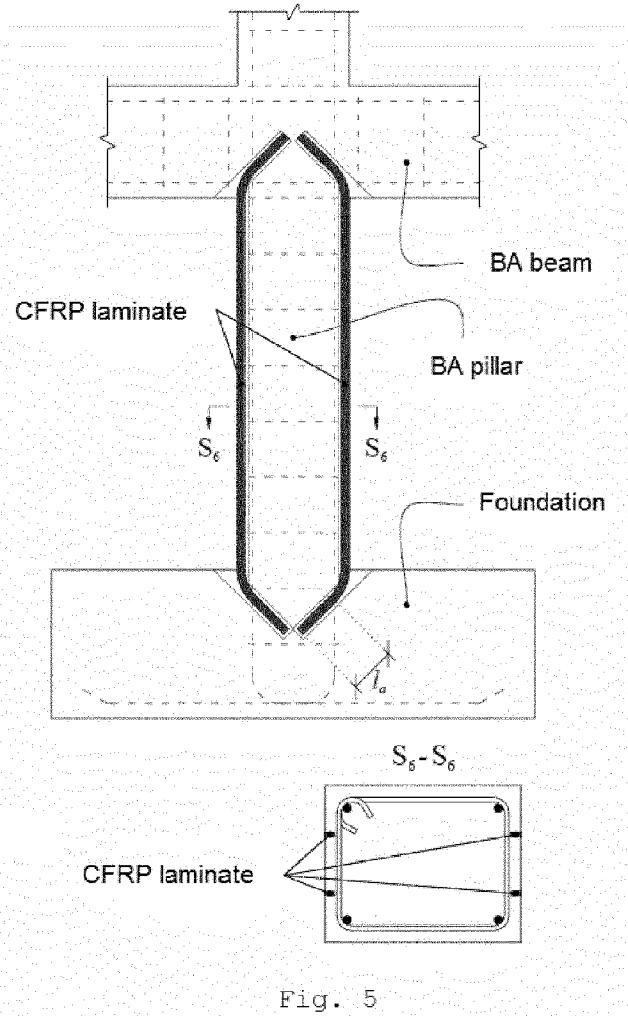


Fig. 5

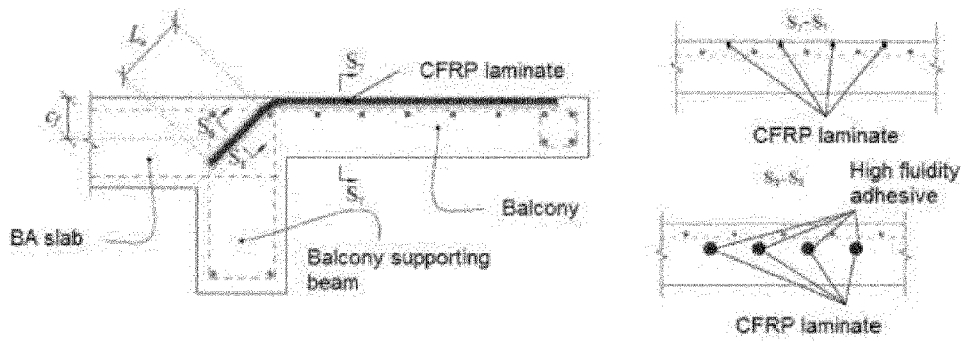
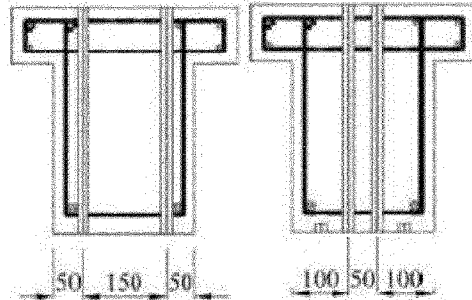
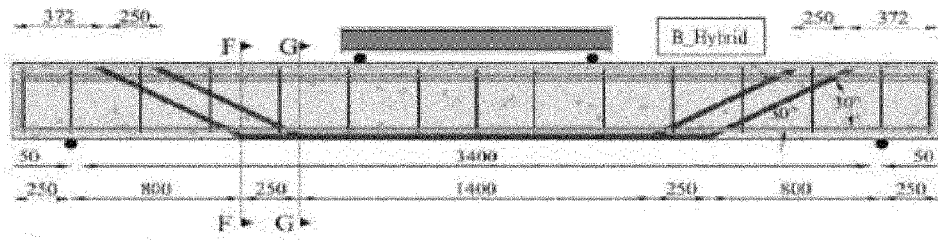


Fig. 6



Section F-F Section G-G

Fig. 7

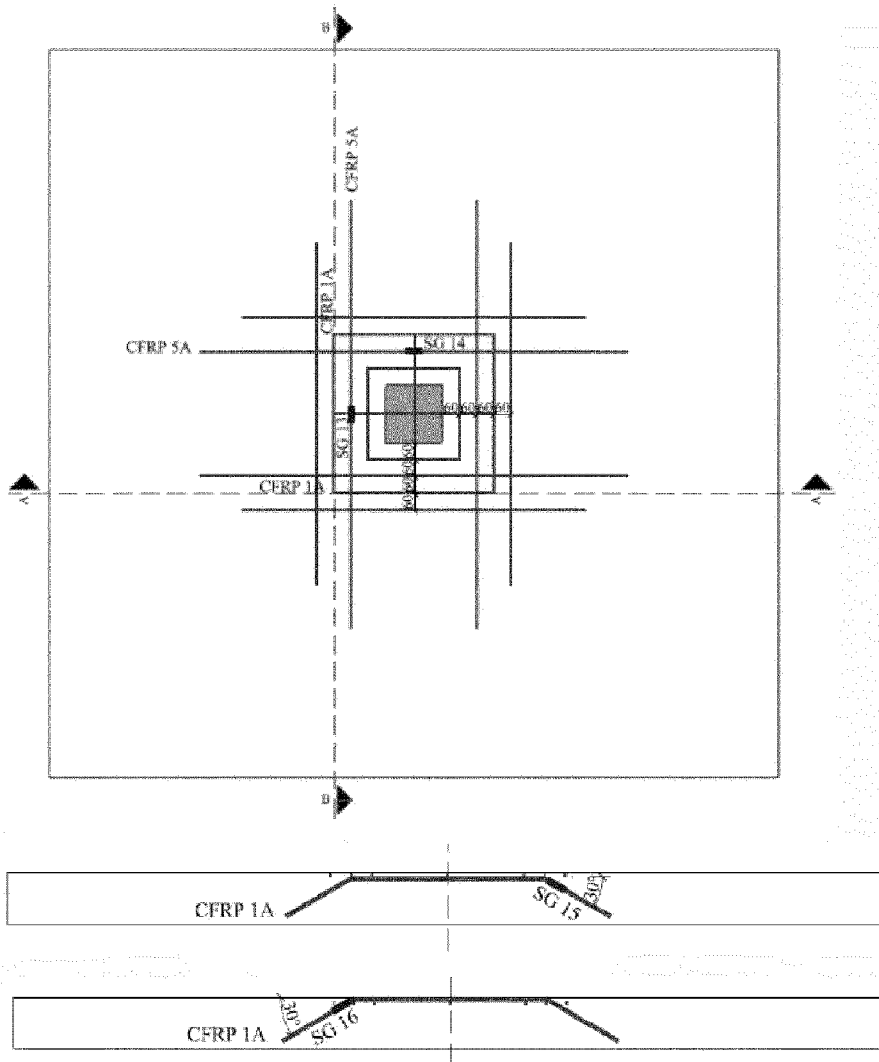


Fig. 8 a)

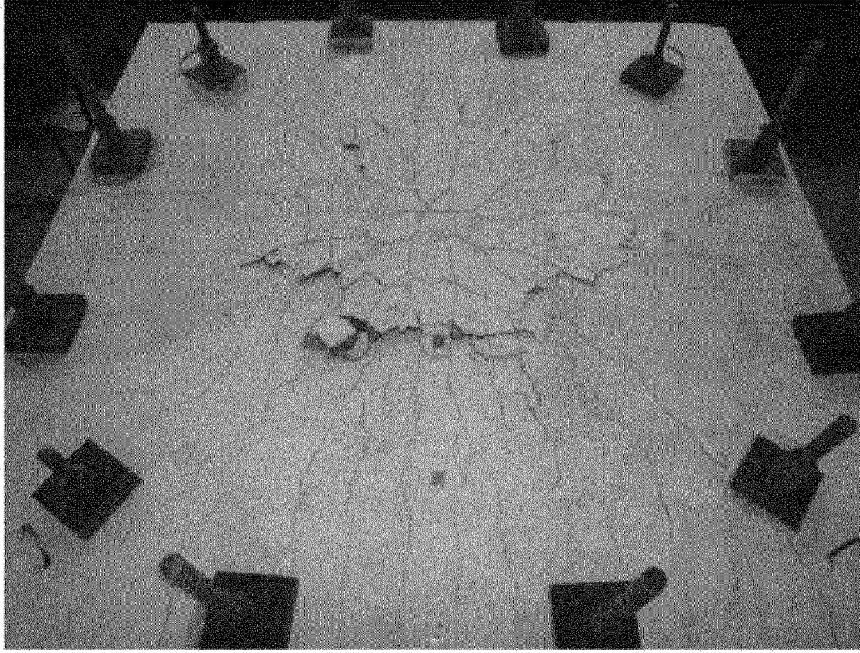


Fig. 8 b)

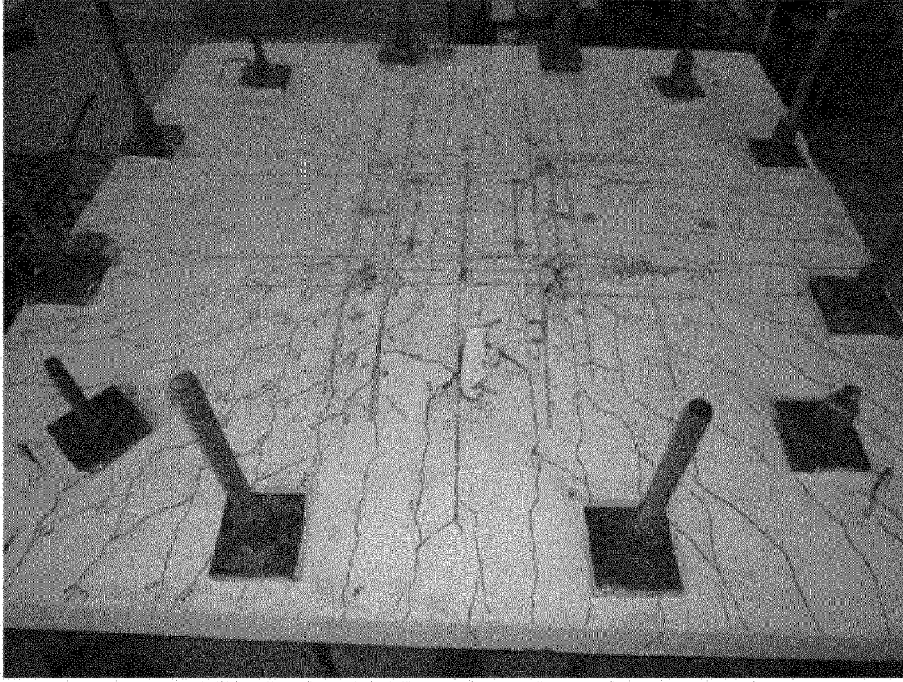


Fig. 8 c)