



(11) **EP 3 168 384 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
17.05.2017 Bulletin 2017/20

(51) Int Cl.:
E04C 5/12 (2006.01) E04C 5/08 (2006.01)

(21) Application number: **15754011.3**

(86) International application number:
PCT/IB2015/055208

(22) Date of filing: **09.07.2015**

(87) International publication number:
WO 2016/005941 (14.01.2016 Gazette 2016/02)

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA ME
Designated Validation States:
MA

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(30) Priority: **09.07.2014 PT 10775514**

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**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL RO RS SE SI SK SM TR**

(54) **STRUCTURAL STRENGTHENING SYSTEM WITH INTERNALLY ANCHORED
REINFORCEMENTS BY ADHERENCE**

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(57) A strengthening system with post-installed reinforcement is described, the reinforcement having a profile with maximum eccentricity in the regions with higher tensions. This strengthening reinforcement is anchored by adherence inside the structural element along a straight segment, which is located after the transition curve between this straight section and the surface of the element.

The application of this strengthening system comprises drilling holes for the anchorage of the strengthening reinforcement in the core of the element to be strengthened; arranging the transition curves between the holes and the surface in order to allow the transition of the strengthening reinforcement into the anchorage zone; applying the adherence agent inside the holes, and arranging the strengthening reinforcement.

This system can be used in the strengthening of structures, making it possible to change the installed force when using active reinforcement.

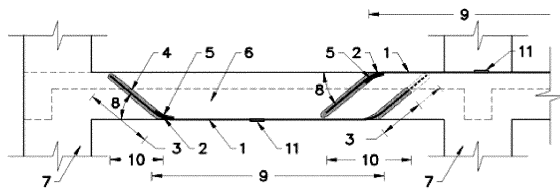


Fig. 1

Description

Technical field

[0001] A system to strengthen structural elements is described, where reinforcement is applied to them, these structural elements being footings, caisson foundation, pile foundations, beam foundations, raft foundations, columns, beams, arches, vaults, slabs, cantilevers, corbels, or walls.

Background

[0002] Nowadays there are some solutions for structural strengthening.

[0003] One of the solutions to strengthen structural elements is based on the addition of reinforcement to the elements to be strengthened, either by applying post-tensioning or not, the former being the so-called "active strengthening" and the latter the "passive strengthening". The application of active strengthening makes it possible to take advantage of the materials capabilities and dramatically improve the behavior of the strengthened element under service conditions by reducing its deformations. When the element to be strengthened is in reinforced concrete, for example, the application of active strengthening also decreases the opening of cracks.

[0004] The application of active strengthening with post-tensioned reinforcement consists of fixing the strengthening reinforcement to the element to be strengthened, by tensioning it and thus introducing compressive forces in the element. The use of active strengthening requires the use of strengthening reinforcement with high tensile strength, low relaxation and preferably linear elastic behavior. In this type of strengthening it is common to use high strength steel (prestressing steel) or carbon-fiber laminated reinforcement. The application of the active strengthening is usually performed in two ways: with adherent post-tensioned active reinforcement (i) or unbonded post-tensioned active reinforcement (ii).

[0005] In the case (i) the implementation procedure generally comprises the surface preparation of the element in order to improve the adhesion of the adherence agent; the application of the adherence agent along the surface; and the application of pre-tensioned strengthening reinforcement with the aid of anchorages. After the adherence agent cure, with this strengthening procedure, the transfer of forces between the structural element and the strengthening reinforcement occurs via the adherence agent essentially by shear forces.

[0006] In the application (i) the transfer of forces between the strengthening reinforcement and the structural element to be strengthened is carried out continuously and transmitted through an adherence agent, whereas in the active strengthening with unbonded post-tensioning (ii) the forces are occasionally transmitted to the anchorages and deviators. The adherent post-tensioned active

strengthening (i) is usually externally bonded to the faces of the structural element to be strengthened or within an additional layer applied to it. In both cases, (i) or (ii), the success of the solution depends on the ability of the strengthening reinforcement to transmit the forces to the structural element. It is, therefore, essential that the strengthening reinforcement is properly anchored to the structural element in order to avoid losses of prestressing, which are more likely to happen in (ii).

[0007] The application of passive strengthening reinforcement for strengthening in bending flat and linear structural elements such as columns, beams and slabs is usually carried out in two ways: i) externally bonded to the element or ii) near-surface mounted to the structural element, this surface being also called cover in case of reinforced concrete elements. These two application procedures of reinforcement have been widely applied and well accepted in the strengthening and repair of structures.

[0008] In the case (i), application of externally bonded reinforcement to the element (i), the application procedure generally comprises the preparation of the surface of the element to be strengthened in order to improve the adhesive bonding; the application of the adhesive along the surface; and the application of strengthening reinforcement. With this strengthening procedure the transfer of forces between the structural element and the strengthening reinforcement occurs through the adhesive essentially by shear forces.

[0009] For the near-surface mounted reinforcement technique (ii), the application procedure begins with the cutting of grooves into the surface layer of the structural element to be strengthened (with appropriate dimensions for the strengthening reinforcement); next, the grooves are partially filled with adhesive and the strengthening reinforcement is introduced; finally, the grooves are completely filled with adhesive. With this strengthening solution the transfer of forces between the structural element and the strengthening reinforcement occurs also through the adhesive. However, the strengthening reinforcement has the advantage of being partially embedded in the element, allowing the forces transmitted to the strengthened element to occur inside it, what does not happen with the externally bonded reinforcement.

[0010] The strengthening with near-surface mounted reinforcement has shown better results than the application of the externally bonded reinforcement. Still, both of the strengthening procedures previously mentioned present ruptures, mostly in the interface of the strengthening reinforcement with the structural element to be strengthened.

In both cases it is difficult to mobilize the ultimate tensile strength of strengthening reinforcement, so it is not taken full advantage of its maximum tensile capacity. Therefore, these ruptures are usually called "premature" and produce some concerns related to the strengthening with the use of post-installed reinforcement. In order to improve the behavior of strengthened structural elements

with externally bonded reinforcement - mainly their behavior in rupture -, it is common to apply mechanical or adhesive anchors to anchor the strengthening reinforcement to the structural element.

[0011] Mechanical anchorage are usually performed by introducing mechanical or chemical anchors in the element to be strengthened in order to have a compressive force in the normal direction to the surface of the strengthening reinforcement. In this way, and with suitable design, it is possible to mobilize the maximum tensile capacity of the strengthening reinforcement.

[0012] The other way to improve the behavior of strengthened elements with the addition of reinforcement is to increase the anchoring area in the zones of potential risk of premature rupture, particularly at the ends and in zones where concentrated loads are applied. For this purpose, reinforcement is applied in the transverse direction of the strengthening reinforcement and, whenever possible, partially or completely surrounding the cross-section of the structural element. This solution is often used when the intention is to strengthen the structural element simultaneously in bending and shear, and it improves the strengthening behavior in the ultimate limit state.

[0013] The introduction of the strengthening in the cover of the structural elements is documented in the document EP 0803020. This document deals with externally bonded reinforcement and consists in inserting at least one of the ends of the strengthening reinforcement into an open cavity in the surface of the element, which is considered the anchorage zone. The strengthening reinforcement on this anchorage zone has an arched shape and is anchored using an adhesive agent which fills the cavity and thus allows that anchoring.

[0014] The document DE2510262 shows a strengthening procedure consisting, as the previous one, in grooves which are opened on the element to be strengthened and filled, in this case, with binder or epoxy resin reinforced with fibers. This document also considers the prior inclusion of fibers on the grooves and subsequent filling with resins or other binder materials. In the latter procedure it is also contemplated the possibility of introducing fibers at the tops of the element between the grooves, improving this way the bearing capacity of the anchorage zone of the fibers. The opening of grooves conditions the application of this disclosure in elements whose reinforcement, or fibers, cannot be cut, such as reinforced concrete elements with reinforcement perpendicular to the direction of the strengthening reinforcement in the anchorage zone.

[0015] It is also described in EP 1016767 a procedure for anchoring the ends of fiber-reinforced polymer laminates where the resin matrix is previously removed in order to adapt the fibers to the support; then the resin is placed again. This additional step increases the costs and time spent in the process.

[0016] The patent document US 6389775 describes a way of anchoring the ends of the externally bonded re-

inforcement via anchoring straps. In this invention the anchoring straps - two for each end -, are used and can either or not have a slot to accommodate the end of the strengthening reinforcement, on which an increased thickness and / or width is performed by adding the binder matrix and moving away the fibers and / or overlapping the layers of the strengthening reinforcement. The anchoring of the strengthening reinforcement to the anchor plates is performed with adhesive material, and the fastening of the anchor plates to the element is done via high strength securing screws traversing the two plates. By fixing the plates with screws, the compressions on the strengthening reinforcement increase, which improves the performance of the anchorage.

[0017] The patent document, publication number US 20110036029, presents a strengthening process where the thermosetting polymer matrix of the reinforcement fibers is removed by heating or chemical exposure in order to facilitate the rearrangement of the fibers in the anchorage zone. This way, it is possible to adjust the reinforcement fibers in these areas, being the matrix later put back by impregnation.

[0018] US 20110197540 presents an anchorage device for elongated reinforcement, such as fiber-reinforced polymers, and polymers reinforced with metallic bars or cables. This device, in its different variations, consists of a block with a hole where the strengthening reinforcement and at least two fastening devices are introduced. These fastening devices allow the introduction of compression in the strengthening reinforcement by contracting the perimeter of the hole, which is achieved by the existence of a slot traversing the anchorage device from the hole to the lateral surface. This anchorage device can be fixed to the structure via screws.

[0019] The patent document No. EP2083133 describes a mechanical device which is applied outside the element to be strengthened and uses mechanical anchors to transmit shear forces between the device and the element to be strengthened. To anchor the reinforcement to the device the invention uses two curved metal pieces outside the element in a perpendicular plane to the face of the element, being the reinforcement introduced between the two curved metal pieces and later tightened via screws.

[0020] In PT 103785 a post-tensioning system with anchorage by adherence for concrete structures is presented. The system consists in installing prestress anchored by adherence, the prestressing steel being tensioned with the aid of provisional anchors. After the adhesive cure, the prestress is released from the temporary anchors and transferred to the concrete. In this system the anchorage is performed after tensioning the strengthening reinforcement, thus not allowing further changes in the value of the installed force in the strengthening reinforcement.

[0021] These facts are put forward to illustrate the technical problem that the present disclosure solves.

General description

[0022] The present disclosure describes a strengthening system which solves the problem of premature failure that normally occurs in structural elements strengthened with post-installed reinforcement, with no need to change geometrically the strengthening reinforcement, or to apply additional devices in the anchorage zones, therefore allowing the mobilization of the ultimate tensile strength of the strengthening reinforcement and providing greater confidence in the use of strengthening with post-installed reinforcement. It can be applied to elements with reinforcement or fibers perpendicular to the direction of the strengthening reinforcement in the anchorage zone. In addition the proposed system also makes it possible to change the value of the installed force in the strengthening reinforcement, when using active strengthening.

[0023] The present disclosure describes a structural strengthening system comprising at least one post-installed strengthening reinforcement (1), whose profile has maximum eccentricity in the regions with higher tension, anchored at its core by a adherence agent placed along a straight section (3) with an inclination that can range between 0.5° and 100° (8) and is located after the transition curve (2) that exists between this straight section (3) and the surface of the element.

[0024] The application method comprises the steps of opening holes (3) for anchoring the strengthening reinforcement in the core of the element to be strengthened; implementation of the transition curve (2) between the hole and the surface of the element to be strengthened; application of a adherence agent into the anchorage hole and application of the strengthening reinforcement (1); and, if an active system is intended, changing the value of force installed in the strengthening reinforcement (1). The holes may be previously drilled mechanically with the shapes and dimensions of the cross sections, which are dependent on the dimensions and shapes of the strengthening reinforcement and with the minimum depth conditioned to the anchorage length (3) required for the transfer of force by adherence to the structural element, and they can pass completely through the element (12). The holes may be formed during the manufacturing process of the structural element or in tubular devices (16) applied to it, whenever the element for physical, mechanical or geometric reasons, does not allow the opening of the holes.

[0025] The anchorage zone (3) corresponds to the area where the transfer of stresses between the strengthening reinforcement and the core of the structural element (6) to be strengthened occur. To perform this anchorage zone a hole is drilled in the core of the structural element (6) and the adherence agent (4), and the strengthening reinforcement (1) is applied within the hole (3). Whenever the structural element (6), for physical, mechanical or geometric reasons, does not allow the opening of the holes, tubular devices (16) are used for this purpose.

[0026] The change in the alignment of the strengthening reinforcement can be made via a transition curve (2) performed directly on the element to be strengthened, with the opening of a slot or by placing a prefabricated deviator device (5) with the same shape of the curve as if it were deviation saddles or metal profiles, but not being limited to these. The deviation angle, as well as the shape of the curve, may vary depending on the materials of the strengthening reinforcement, of the adherence agent and of the characteristics of the materials of the structural elements to be strengthened. It varies between 0.5° and 100° , and the shape may be of a semicircle, an ellipse, a parabola, a hyperbola, a clothoid or any other shape derived or composed by these ones.

[0027] A preferred embodiment of this strengthening system, and whenever it is necessary to ensure a proper fit of the reinforcement to the shape of the curve, is to use prefabricated deviator devices (5) applied to the transition curve zone.

[0028] This structural strengthening system uses a adherence agent (4), also called adhesive, to anchor and protect the strengthening reinforcement inside the element, an adhesive which is compatible with the materials of the structural element, as well as with the strengthening reinforcement. It consists of a material identical to the one of the structural element to be strengthened or another material with better characteristics of adhesion, of resistance to environmental agents and of physical and chemical protection of the strengthened element.

[0029] The adherence agent used can be either natural or synthetic, among which are cement mortars and polymeric resins or other materials.

[0030] In accordance with another preferred embodiment, this strengthening system may also comprise the step of applying drains and injection tubes (23) in the holes, sealing them, in case adherence agents with low viscosity are used.

[0031] This strengthening system uses strengthening reinforcement in bars, strands, wires, strips, sheets, laminates or others with linear, straight or curved development, which can be bonded to the surface of the element or inserted in its cover, or even use other forms of application that already exist or may come into existence.

[0032] The materials of the strengthening reinforcement include the following constitutions: steel; fabrics or composite laminates reinforced with carbon-fibers, glass, basalt, graphene or aramid; shape memory alloys; metallic strengthening materials, polymeric, composites, mixed or even other materials that may come into existence.

[0033] Preferably the profile of the strengthening reinforcement has maximum eccentricity in the regions of higher tensions.

[0034] This structural strengthening system may also comprise an initial step of surface preparation, in case of externally bonded reinforcement; a step of opening the grooves in case of near-surface mounted reinforcement, or a step of application of prefabricated deviator

devices (5) when the unbonded reinforcement is applied.

[0035] According to a further preferred embodiment, the structural strengthening system may also comprise the step of applying a temporary support for the strengthening reinforcement when the strengthening is not carried out on the upper surface of the element. This temporary support may be either a mechanical device fixed to the element, a propping system (20), among others.

[0036] This structural strengthening system is characterized by its ability to strengthen structures and structural elements in bending and shear. These structural elements can be linear, flat or curved, such as slabs, cantilevers, corbels, beams, columns, shear walls, footings, caisson foundation, pile foundations, beam foundations, raft foundations, arches and vaults, walls or others, and are made of masonry, wood, concrete, metal, composites, mixed, or other materials.

[0037] The system presented comprises at least one structural element, one strengthening reinforcement, one anchorage zone with a hole (3) in order to anchor the strengthening reinforcement to the structural element to be strengthened, one transition curve (2) between the hole and the surface which allows the transition of the strengthening reinforcement to the anchorage zone, one adherence agent inside the hole or on its surface (4) and one strengthening reinforcement (1) whose profile has maximum eccentricity in the region of higher tensions. The anchorage zone is geometrically delimited by the free surfaces of the structural element and by half the distance to the nearest strengthening reinforcement or, in case it exists, by the outer surface of the tubular device (16).

[0038] The operating principle of the system consists in anchoring by adherence the strengthening reinforcement inside the element, with the possibility of changing the installed force, after the cure of the adherence agent in one of the anchorage zones, whenever an active strengthening is intended. The anchorage of the reinforcement inside the element is carried out after the change of its alignment and the drilling of holes in the structural element to be strengthened. It becomes effective after the application and cure of the adherence agent in the anchorage zone. The transition curve may be performed directly on the element to be strengthened, or by placing an additional component with the shape of the curve. By using this strengthening system, and as long as it has the appropriate anchorage length, it is possible to mobilize the ultimate tensile strength of the strengthening reinforcement, except for the cases when the ruptures occur by crushing in the compression zone of the section or by shear. Thus, the failure modes in the interface strengthening reinforcement-structural element (premature) do not occur, and what happens is the classical rupture of the structural elements or of the strengthening, in particular the failure by compression or shear of the structural element, or the rupture of strengthening reinforcement by tension.

[0039] The procedure to use the presented structural

strengthening system may include, depending on the application, the following different procedures:

- Surface preparation in case of externally bonded reinforcement;
- Opening of the grooves in case of near-surface mounted reinforcement;
- Drilling of at least one hole (3) in the anchorage zone of the strengthening reinforcement;
- Performing of at least one transition curve (2) between the hole and the surface of the element to be strengthened or between the hole and the grooves on the surface of the element to be strengthened. The transition curve may be performed with the opening of a slot or by applying a prefabricated deviator device with the shape of the curve;
- Cleaning and dedusting of holes, surfaces or grooves;
- Application, in case passive strengthening is intended, of the adhesive or adherence agent on the surface or in the grooves;
- Application of strengthening reinforcement (1);
- Application of drains and injection tubes in the holes, as well as their sealing (23 and 24);
- Filling of all the grooves with the adherence agent, if passive strengthening with near-surface mounted reinforcement is intended;
- Application of the temporary support of strengthening reinforcement (20, 21 and 22, or combination);
- Injecting or pouring the adherence agent in the holes;
- Removal of the temporary supports of the reinforcement;
- Installing the device that allows to change the value of the installed force in the strengthening reinforcement, if active strengthening is intended;
- Application - when active strengthening is intended - of the adhesive or adherence agent on the surface or in grooves, followed by the change of the installed stress in the strengthening reinforcement, after the cure of the adherence agent in the anchorage zones;
- Filling of all the grooves with the adherence agent, whenever active strengthening is intended and whenever the reinforcement is near-surface mounted.

[0040] The above procedure can be modified to adapt to the characteristics of the structural element to be strengthened, in particular the adherence agent, the strengthening reinforcement or the anchorage zone characteristics. For example, when high viscosity adherence agents are used to anchor the strengthening reinforcement inside the holes or in case externally bonded reinforcement is applied, the application of drains and injection tubes in the holes, as well as their sealing, can be left out, and the injection of the adherence agent is performed directly in the anchorage hole from the inside to the outside (Figure 16). When the proposed strengthening system in this disclosure cannot be implemented

in structural elements due to their physical, geometrical or mechanical characteristics, they should be previously prepared. This preparation may consist, for example, in the injection of resins to improve the mechanical characteristics of the element, the application of a tubular device (Figure 8), the partial replacement of the material of the element or the application of a prefabricated or cast in situ concrete block (Figure 9), suitably secured to the element to be strengthened in order to accommodate the anchorage zones.

[0041] The transition curve (2) aims primarily to deviate the strengthening reinforcement into the element to be strengthened. It can have different geometric shapes: semicircular, elliptic, parabolic, hyperbolic, spiral, or other, and may even be composed of more than one geometric shape. The choice of the shape for the transition curve is subject to the material of the strengthening reinforcement, the material of the element to be strengthened, the level of stress produced by the strengthening reinforcement on the intrados of the curve and the adherence agent characteristics. The development of the transition curve is geometrically conditioned by its shape, and by the straight alignments of strengthening reinforcement, since the beginning and the end must be tangent to these alignments. Depending on the material of the strengthening reinforcement and on the element to be strengthened, the transition curve can be performed directly on the element to be strengthened by opening of a slot, or by placing an additional component with the shape of the curve (5). In both cases, fillers and / or auxiliary devices may either or not be placed in order to ensure a proper fit of the strengthening reinforcement to the shape of the curve.

[0042] The adherence agent may be any material whose properties guarantee the transmission by adhesion of the forces between the strengthening reinforcement and the structural element. Among the various currently available materials it should be mentioned the polymeric resins (epoxy based, methacrylate or urethane), mortars (cement or polymeric), and other materials with similar characteristics, that already exist or may come into existence. In addition to the transmission of forces, the adherence agent should provide physical and chemical protection to the strengthening and be compatible with the material of the element to be strengthened.

[0043] The reinforcement temporary support system includes any procedure that allows the reinforcement to sustain itself until the adherence agent acquires strength. Among the temporary supports is included the application of mechanical devices fixed to the element (21, 22), propping systems (20), and others.

[0044] The holes for the anchorage of the strengthening reinforcement may have any shape and size, being, however, dependent on the shape and size of the cross sections of the strengthening reinforcement. The minimum depth of the holes is subject to the anchorage length required for the transfer of the force by adherence and can pass completely through the structural elements. The

holes can be mechanically or manually opened, leaving a negative in the element during the manufacturing process, or by placing a tubular device fixed to the element within which the strengthening reinforcement is anchored via an adherence agent (4).

[0045] The strengthening reinforcement can be installed continuously, passing completely through the structural elements (12), thereby allowing the strengthening reinforcement to follow the profile of the bending moment diagrams. Preferably, and whenever possible, the reinforcement profile has a maximum eccentricity in the regions of higher tensions.

[0046] The anchorage zones are crucial for the success of strengthening and, if performed according to the present invention, they allow the following, among others:

- enhanced corrosion resistance;
- enhanced fire resistance;
- lower risks of small defects in the preparation or application of the strengthening reinforcement in the anchorage zone.

[0047] The anchorage of the strengthening reinforcement inside the structural elements allows greater corrosion protection in the anchorage zones, reducing or even eliminating the need to apply anticorrosion protection systems in the strengthening reinforcement in these areas.

[0048] As the strengthening reinforcement is anchored inside the strengthened element, resistance to fire is improved when compared to the traditional externally bonded reinforcement solutions and near-surface mounted reinforcement. Using strengthening reinforcement and adherence agents with high performance at high temperatures, it is possible to strengthen structural elements which may be subject to fire situations, thereby reducing the passive protection system of the strengthening reinforcement.

[0049] With the presented strengthening system, small defects of preparation at the anchorage zone no longer have influence. For example, irregularities on the bonding surface (in the case of externally bonded reinforcement), or improper geometry of the slots (in the case of near-surface mounted reinforcement), because the anchorage zones are made within the strengthened element via holes filled with the adherence agent, thus providing a greater force transfer surface and consequently lower installed stresses.

[0050] Using this system as active strengthening enables the change of force in the strengthening reinforcement after the cure of the adherence agent in the anchorage zone. So, mechanical anchors at the ends can be left out and using only a device intercalated between the transition curves.

[0051] The introduction of strengthening reinforcement to the structural elements in regions subjected to shear forces also increases the shear strength of these zones (Figure 33 and Figure 34).

[0052] The presented system can be used in the strengthening of linear elements, either flat or curved, such as footings, caisson foundation, pile foundations, beam foundations, raft foundations, columns, beams, arches, vaults, slabs, cantilevers, corbels or walls; in concrete (single, reinforced, pre- or post-stressed, composite, with fibers), wood (solid, glued laminated, particle board), masonry (stone, adobe, rammed earth, brick, cement mortar), steel or polymers (plastics) or any other structural material where it is possible to carry out the anchorage by adherence of the strengthening reinforcement.

[0053] Different materials can be used for the strengthening reinforcement: steel reinforcement, fiber-reinforced polymers with carbon, glass, basalt, graphene, aramid, steel or any other composite or mixed materials with strengthening purpose and whose behavior is similar to the aforementioned.

[0054] The presented system is not limited to strengthening solutions with externally bonded reinforcement or near-surface mounted reinforcement. It can also be used in strengthening situations with addition of reinforcement wherever anchorage is crucial for successful strengthening.

[0055] As the anchorage of the strengthening reinforcement is carried out inside the strengthened elements or in post-installed blocks, the use of this system is a solution to the problem of premature failure of the strengthening reinforcement due to debonding in situations of load increase, fire, among others.

[0056] When the anchorage of strengthening reinforcement is performed in regions with high shear forces, for example close to beam-column joints (10), it is possible to achieve a dramatic increase of the shear strength of the structural element (Figures 33 and 34), gaining an extra advantage with this strengthening procedure.

[0057] With this system, the use of strengthening reinforcement in sheets, fabrics, strips, bars, strands or wires is generally only conditioned by the deformation capacity of the strengthening reinforcement to adapt to the curvature of the transition curve without significant loss of its strength properties. In the particular case of the strengthening of reinforced concrete elements, it is also necessary to limit the size of the strengthening reinforcement to the spacing of the existing reinforcement.

[0058] This structural strengthening system may be used together with other ways of anchoring the strengthening reinforcement, thus allowing a very versatile use. It is also possible to anchor one end of the reinforcement following the procedure in the present invention and use another system or technique to anchor the other end.

[0059] The present structural strengthening system may comprise at least one structural element (6), one post-installed strengthening reinforcement (1) whose profile has maximum eccentricity in the zones with higher tensions, one anchorage zone (3) in the core of the structural element (6), one adherence agent (4), one straight section with an inclination which can vary between 0.50

and 100° (8), and a transition curve (2) located between this straight section and the surface of the element. The system now disclosed may further comprise, in the case of the application of non-adherent strengthening, deviator devices.

[0060] In a preferred embodiment, the anchorage zone (3) of the structural strengthening system may be located in tubular devices (16) applied on the structural element (6).

[0061] In a preferred embodiment, the transition curve can have an additional component with the shape of the curve, in particular deviation saddles, deviator saddles, hot-rolled profiles or cold-rolled profiles.

[0062] In one embodiment, the angle (8) of the transition curve (2), as well as its shape, may vary depending on the material of the strengthening reinforcement (1), of the adherence agent (4), and of the characteristics of the material of the elements to be strengthened.

[0063] In one embodiment, the shape of the transition curve can be a semicircle, an ellipse, a parabola, a hyperbola, a clothoid or any other shape derived or composed by these ones.

[0064] In one embodiment, the structural strengthening system may further comprise prefabricated deviator devices (5) in the transition curve zone (2) when it is necessary to ensure a proper adjustment of the reinforcement to the shape of the curve.

[0065] In one embodiment, this structural strengthening system may further comprise an adherence agent in a material similar to the one of the element to be strengthened or even in another material with better characteristics of adherence, of resistance to environmental agents and of physical and chemical protection of the strengthening reinforcement and of the strengthened element.

[0066] In one embodiment, the structural strengthening system may further comprise natural or synthetic adherence agents such as cement mortars, polymer resins or others.

[0067] In one embodiment, the structural strengthening system may have reinforcement in bars, strands, wires, strips, laminates or others with linear, straight or curved development.

[0068] In one embodiment, the structural strengthening system can have strengthening reinforcement (1) bonded to the surface of the element, inserted in the cover of the element or using another existing form of application.

[0069] In one embodiment, the structural strengthening system can have strengthening reinforcement (1) in materials such as, for example, steel, laminated composites reinforced with carbon fiber, glass, basalt, graphene or aramid, shape memory alloys, metallic, polymeric, or other composites strengthening materials.

[0070] In one embodiment, the structural strengthening system can modify the installed force in the strengthening reinforcement, after the adherence agent cure in the anchorage zone.

[0071] In one embodiment, the structural strengthen-

ing system can strengthen to bending and shear structures and structural elements.

[0072] In one embodiment, the structural strengthening system may strengthen linear structural elements, flat or curved, such as slabs, beams, columns, shear walls, footings, caisson foundation, arches and vaults, walls or others. The structural strengthening system may also strengthen structural elements of masonry, wood, concrete, metal, composites, mixed, or others.

[0073] The present disclosure also relates to a method for installing a structural strengthening system comprising the following steps:

- Opening at least one hole with an inclination which can vary between 0.5° and 100° to the anchorage (3) of at least one strengthening reinforcement (1), post-installed at the core of at least one structural element (6) whose layout has maximum eccentricity in the areas of higher tensions;
- Perform the transition curve (2) between the hole and the surface of the structural element (6) to be strengthened;
- Applying an adherence agent (4) inside the anchorage hole (3);
- Applying the strengthening reinforcement (1) connecting the anchorage zones.

[0074] In one embodiment, the method described above may further comprise an initial step of surface preparation, in case of externally bonded reinforcement application, and / or an initial step of grooving opening in case of near-surface mounted reinforcement on the surface of the element, and / or an initial step of the deviator devices application, when applying the non-adhered strengthening, and / or a temporary support for the strengthening reinforcement, in case the strengthening reinforcement is not applied in the top surface of the element.

[0075] In one embodiment, the method described may further comprise the temporary support to the strengthening reinforcement with a device fixed to the element (21, 22), one propping system (20), among others.

[0076] In one embodiment, the method described may further comprise the step of applying drains and injection tubes in the holes, with their sealing, in case of using low viscosity adherence agents.

[0077] In one embodiment, the holes performed with the aforementioned method may be previously carried out by mechanically drilling systems and additionally; the holes may have shapes and dimensions of the cross sections, depending on the dimensions and shapes of the strengthening reinforcement; the previously drilled holes may have a minimum depth conditioned by the anchorage length (3) required for the transfer of force by adherence and can pass completely through the section (12).

[0078] In one embodiment, when the structural element (6) for physical, mechanical or geometric reasons, does not allow the drilling of holes, they can be moulded

during the manufacturing process of the element or in tubular devices (16) applied to the structural element (6).

[0079] In one embodiment, the transition curve (2) can be made directly in the structural element (6) to be strengthened, through the opening of a slot.

[0080] In one embodiment, the transition curve can be performed by placing an additional component with the shape of the curve, as if it were, but not limited to, deviator saddles, hot-rolled profiles or cold-rolled profiles.

[0081] In one embodiment, the angle (8) of the transition curve (2), as well as its shape, may vary depending on the materials of the strengthening reinforcement (1), on the adherence agent (4), and on the characteristics of the materials of the elements to be strengthened. The angle (8) of the transition curve may vary between 0.5° and 100°.

[0082] In one embodiment, an adherence agent (4), also called adhesive, is used to anchor and protect the strengthening reinforcement inside the element, compatible with the materials of the structural element and with the strengthening reinforcement.

[0083] In one embodiment, structures and structural elements are strengthened in bending and shear.

[0084] In one embodiment, linear structural elements - flat or curved - are strengthened, among which are slabs, beams, columns, shear walls, footings, caisson foundation, arches and vaults, walls or others.

[0085] In one embodiment, structural elements in masonry, wood, concrete, metal, composites, mixed, or others, are strengthened.

Brief Description of the Drawings

[0086] For a better understanding of the strengthening solution, the figures are attached. They represent its preferred embodiments, but do not intend to restrict the object of the present disclosure.

Figure 1 shows a structural element (6) corresponding to the end span of a continuous reinforced concrete beam, with the columns (7), also in reinforced concrete, strengthened in bending (9) and shear (10) with post-installed reinforcement (1). It is also possible to observe the representation of the anchorage (3) of the ends of the strengthening reinforcement in holes filled with adherence agent (4), with a certain depth to ensure the transfer of forces by adherence. The transition curve (2), which allows the deviation of strengthening reinforcement into the beam, with a deviation angle (8), is also represented, as well as the prefabricated deviator (5) with the shape of the curve and the devices which allows the variation of the force in the strengthening reinforcement (11).

Figure 2 represents a structural element (6) corresponding to the end span of a continuous reinforced concrete beam, with the columns (7) of the same material, strengthened in bending (9) and shear (10) with continuous post-installed reinforcement (1) that

pass completely through the section (12) using the present system. It is also possible to observe in this figure the anchorage (3) of the ends of the strengthening reinforcement in holes filled with adherence agent (4) to ensure the transfer of force by adherence and the transition curve (2) which allows the deviation of the strengthening reinforcement into the beam with the respective deviation angle (8). Figure 2 also represents the devices that allow the variation of the installed stresses in the strengthening reinforcement (11).

Figures 3 and 4 illustrate, in a longitudinal cross-section, vertical and horizontal respectively, the use of this system to give continuity to the strengthening reinforcement (1) in a structural element (6) subject to bending stresses. It is possible to observe a lap zone (13) which ensures the level of strengthening along the structural element, the transition curve (2), the anchorage zone (3), the adherence agent (4) and the deviation angle (8).

Figure 5 represents the application of the invention in the strengthening of a structural element (6) corresponding to a reinforced concrete slab. This figure shows, in a vertical longitudinal cross-section, the end and the mid span of a continuous slab supported on beams and these on columns (7). This structural element (6) is strengthened with addition of post-installed reinforcement (1) and the continuity of this reinforcement allows the strengthening of the element to positive bending moments in the end span and to negative bending moments in the support area (9). In this case, the anchorage holes pass completely through the section (12), so it can be assumed that they play a double role: to anchor the strengthening reinforcement (1); and to pass through the section in order to allow its continuity. The holes in the ends only need to ensure the anchorage of the reinforcement, but they can also pass completely through the section. Again, in this application, and after the deviation given by the transition curves (2), the anchorage of the strengthening reinforcement (1) is carried out inside the element using the adherence agent (4) inside the holes. The change of the value of the force in the strengthening reinforcement (1), after the cure of the adherence agent (4) in the anchorage zone (3), is achieved with the installation of the devices represented in figure as 11.

Figure 6 shows the application of the system for the anchorage of the strengthening reinforcement (1) embedded in the cover in a structural element (6) corresponding to a reinforced concrete beam that supports the slab (14). It is also possible to observe the anchorage (3) of the post-installed strengthening reinforcement (1) inside the element after the transition curve (2).

Figure 7 represents the system application in the strengthening of a structural element (6) corresponding to a wood beam strengthened with post-installed

externally bonded reinforcement. It is also depicted in this figure the anchorage (3) of the strengthening reinforcement in the structural element (6) after the transition curve (2) and anchorage of the strengthening reinforcement (1) with adherence agent (4) in the anchorage hole.

Figure 8 illustrates the application of the system for strengthening in bending (9) of a structural element (6) corresponding to a steel beam, supported by columns (7). In this figure the anchorage (3) of the post-installed strengthening reinforcement (1) is carried out within a tubular device (16) welded or mechanically fixed to the beam web. Again, in this case the strengthening reinforcement is anchored to the tubular device with the adherence agent (4). It is also possible to observe the extension of the tubular device along the transition curve (2) passing through the flange of the beam (17), which is aimed at providing an appropriate shape to the respective curve. The application of strengthening in the beam web (15) aimed at preventing local web buckling due to stress concentration in the intrados of the transition curve is also depicted, as well as the device application (11) that allows the change of the value installed in the strengthening reinforcement (1).

Figure 9 illustrates the strengthening in bending (9) of a structural element (6) corresponding to a steel beam, supported by columns (7), in which the anchorage of the strengthening reinforcement (1) is held inside a concrete block (18) previously placed - in this case by concreting in situ -, to the implementation of the anchorage holes. This concrete block (18) can be prefabricated, and the anchorage holes previously drilled. In both situations the anchorage (3) is performed in the holes using adherence agents (4) after the transition curve (2), which passes through the flange of the beam (17). The installation of the device (11) allows the change of the value of the stresses in the strengthening reinforcement (1) after the cure of the adherence agent (4) in the anchorage zone (3).

Figure 10 depicts the application of the system for strengthening in bending (9) of a structural element (6) corresponding to a mixed steel-concrete composite beam with anchorage in the slab (14). In this case the anchorage (3) of the post-installed strengthening reinforcement (1) is performed in holes drilled in the slab (14) using an adherence agent (4). Again, here, the transition curve (2), which passes through the flange of the beam (17) makes use of a prefabricated deviator device (5) to deviate the reinforcement to the anchorage zone with a certain angle (8). The application of strengthening reinforcement (15) in the beam web aims at ensuring that the local web buckling does not occur and the application of the device (11) makes it possible to change the value of the installed force in the strengthening reinforcement.

Figure 11 represents the application of the system for strengthening in bending (9) of a structural element (6) corresponding to a continuous mixed steel-concrete composite beam with anchorage on the slab (14) and post-installed strengthening reinforcement (1). In this case the anchorage (3) of the strengthening reinforcement is performed in holes drilled on the slab (14), with adherence agent (4). The amount of force applied to the strengthening reinforcement (1) may be modified with a device (11) interposed between the anchorage zone (3) and the transition curve (2) - which passes through the flange of the beam (17) -, with the aid of a prefabricated deviator device (5), allows the deviation of the strengthening reinforcement to the anchorage zone with a certain angle (8). The application of strengthening reinforcement (15) in the beam web aims at ensuring that the local web buckling does not occur.

Figure 12 illustrates a structural strengthening reinforcement (6), corresponding to a masonry column using post-installed strengthening reinforcement (1) to confine the element. The strengthening reinforcement is anchored with the adherence agent (4) in the masonry elements (19), in an anchorage zone (3) whose hole was performed with a certain deviation angle (8) after the transition curve (2). The value of the force installed in the strengthening reinforcement (1) can be modified with a device (11), thus allowing to increase the confinement of the element.

Figure 13 depicts the application of active reinforcement in a structural element (6), corresponding to a masonry arch, with the application of strengthening reinforcement (1) post-installed on the extrados of the arch to confine the element. The reinforcement is anchored with the adherence agent (4) into the masonry elements (19) in an anchorage zone (3) whose hole was performed with a given deviation angle (8) after the transition curve (2). The value of the force installed in the strengthening reinforcement (1) can be modified with a device (11), thus allowing to increase the confinement of the element.

Figure 14 presents some possible solutions to support the post-installed strengthening reinforcement (1) during its application period and until the adherence agent is able to support it. In (20) it is possible to observe the temporary support - by propping up an element - on the opposite side of the strengthening reinforcement (1). In 21 and 22 it is shown the temporary support of the strengthening reinforcement, mechanically fixed to a device in the structural element (6) to be strengthened, thus allowing the temporary support of the strengthening reinforcement when it is not feasible with propping systems. In 21 the support device is fixed on the side where the strengthening reinforcement is applied and in 22 the device is fixed on the lateral side.

Figure 15 presents a solution for the injection of the anchorage holes into a structural element (6) in

which the adherence agent has low viscosity. The injection of the adherence agent into the holes is performed with the aid of two tubes (23) that are placed near the strengthening reinforcement (1). With this method it is necessary to seal the hole (24) close to the transition curve and leave the end of one of the tubes near the bottom end (25) of the anchorage hole and the other tube close to the upper end (26) of the anchorage hole. Thus, it is possible to inject the adherence agent into the tube near the bottom end (25) and purge the air through the upper end (26).

Figure 16 illustrates a solution for the injection of an adherence agent with some viscosity into the anchorage holes of a structural element (6). The adherence agent is injected into the anchorage hole before placing the strengthening reinforcement using a tube whose end should fill almost the entire cross section of the hole (27). In this case the injection starts from the final end to the initial end of the hole, leaving a section with no adherence agent at the beginning of the anchorage hole, which will be filled when the strengthening reinforcement (1) is introduced.

Figure 17 shows the test results of a set of beams strengthened with carbon-fibre reinforced polymers, using the same amount of strengthening reinforcement, using the traditional externally bonded reinforcement (29), the near-surface mounted reinforcement of the element (30) and the system presented in this disclosure (31). In this figure it is also possible to observe the unstrengthened beam (28), used as a reference, and from which the load and displacement values at yield were used to normalize the results. These results show the increased load capacity and ductility achieved with the present disclosure.

Figure 18 shows the test results of a set of beams strengthened with stainless steel reinforcement, with approximately the same amount of reinforcement, using the traditional externally bonded (33) and the near-surface mounted (34) reinforcement systems, and also the system presented in this disclosure (35). In this figure it is also possible to observe the unstrengthened beam (32), used as a reference, from which the load and displacement values at yield were used to normalize the results. The results show the increased load capacity and ductility achieved with the use of the present disclosure.

Figure 19 presents the test results of a set of beams strengthened with carbon-fibre reinforced polymers, in particular the measurement results of the strains in the shear reinforcement (vertical stirrup with two branches), which are apart from d movable support (being d the effective height of the beam), the beams strengthened with the system presented in this disclosure (39), with the traditional systems (37, 38). The test results of a similar unstrengthened beam (36) are indicated as well. In this figure it is clear the

strain reduction in the vertical shear reinforcement in the beams strengthened with the system presented in this disclosure (39) compared to the results of the unstrengthened beam (36) and of the beams strengthened with the traditional systems (37, 38). The strain reduction in the vertical shear reinforcement in the monitored zone indicates, for the same level of deformation, an increase in the shear strength capacity of the beam, which is a consequence of the use of the system shown in the present disclosure.

Figure 20 presents the test results of a set of beams strengthened with stainless steel reinforcement, in particular the measurement results of the strains in the shear reinforcement (vertical stirrup with two branches), which are apart from d movable support (being d the effective height of the beam), the beams strengthened with the system presented in this disclosure (43), with the traditional systems (41, 42). The test results of a similar unstrengthened beam (40) are also indicated in this figure. It is clear the strain reduction in the vertical shear reinforcement in the beams strengthened with the system presented in this disclosure (43) compared to the results of the unstrengthened beam (40) and of the beams strengthened with the traditional systems (42, 43). The strain reduction in the vertical shear reinforcement in the monitored zone, for the same level of deformation, indicates an increase in the shear strength capacity of the beam, which is a consequence of the use of the system shown in the present disclosure.

Detailed Description

[0087] The present invention is hereinafter explained in detail, without setting limits and as an example, via a preferred embodiment.

Example 1 - Experiments whose results are documented in Figures 17 to 20.

[0088] In order to evaluate the potential of the presented system, a set of full-scale tests were carried out on reinforced concrete beams with cross-section "T" using, for strengthening reinforcement, carbon-fibre reinforced polymers i) and stainless steel ii). For each group of beams, i) and ii), four-points bending tests were carried out: a) an unstrengthened beam; b) a beam strengthened with the traditional externally bonded reinforcement; c) a beam strengthened with near-surface mounted reinforcement; and d) a beam using the present disclosure with externally bonded reinforcement.

[0089] The testing setup used consists on simply supporting the sample on two supporting devices, a fixed and a movable support with dimensions of 200x200mm², and applying in the upper surface level of the flange and symmetrically to the mid-span, two concentrated loads

with a spacing of 1000mm. This system makes it possible to apply pure bending between the load application points and simple bending at the ends of the model.

[0090] During the tests the values of the applied loads were measured, as well as the displacement at mid span and stains in the shear reinforcement.

[0091] The beams from group i) were built with a total length of 3300mm, 3000mm between supports, a total height of 315mm, being 225mm of the web, a width of 400mm at flange level and a width of 150mm at the web level. The beams from group ii) were built with the same dimensions, except for the overall height, whose size was 300mm, 200mm of which correspond to the height of the web.

[0092] The concrete beams were longitudinally reinforced with three 12mm-diameter steel bars disposed close to the lower face of the web (tension area) and six 8-mm diameter steel bars arranged in the flange. To resist shear forces, beams were reinforced with two-branches of 6mm-diameter steel stirrups, which were longitudinally spaced at 150mm. The concrete cover of the reinforcement had 20 mm, except on the lower side of the beam webs from group i), which was 36mm-thick.

[0093] The concrete used in the beams from group i) had, after 28 days, an average strength to compression of 18.5MPa, which was obtained in tests with 150mm-diameter and 300mm-height cylindrical samples. The concrete used in the beams from group ii), after the same period of time, had an average strength to compression of 24.1MPa, which was obtained in tests with cubic samples with an edge of 150mm.

[0094] The mean values of yield strength (f_{ym}) and tensile strength (f_{um}) of the reinforcing steel used in beams from group i) are: $f_{ym}=568\text{MPa}$ and $f_{um}=721\text{MPa}$ for the 6mm-diameter bars; $f_{ym}=566\text{MPa}$ and $f_{um}=680\text{MPa}$ for the 8mm-diameter bars; and $f_{ym}=546\text{MPa}$ and $f_{um}=649\text{MPa}$ for the 12mm-diameter bars. The reinforcing steel of the beams from group ii) presented $f_{ym}=538\text{MPa}$ and $f_{um}=634\text{MPa}$ for the 6mm diameter bars, $f_{ym}=573\text{MPa}$ and $f_{um}=675\text{MPa}$ for the 8mm diameter bars and $f_{ym}=530\text{MPa}$ and $f_{um}=637\text{MPa}$ for the 12mm-diameter bars. The 6mm-diameter reinforcing steel used in beams from group i) and the 6mm-diameter reinforcing steel used in beams from group ii) is from A500ER class. The remaining ordinary reinforcing steel is from A500NR SD class.

[0095] The average maximum strain (ϵ_m) and the average elastic modulus (E_m) of the carbon-fiber-reinforced polymer laminates with cross-sections of 50x1.2mm² and 10x1.4mm² are respectively $\epsilon_m=1.05\%$, $E_m=170\text{GPa}$ and $\epsilon_m=1.03\%$, $E_m=159\text{GPa}$.

[0096] The stainless steel strengthening reinforcement in a 20x5mm² cross-section bar is EN1.4404 class and presents average values of the limit of proportionality at 0.2% equal to 259.8 MPa and tensile strength equal to 617.8 MPa. Stainless steel ribbed bar with a nominal size of 8 mm is EN1.4301 class and present an average value of limit the proportionality at 0.2% equal to

471.7MPa; and an average value of tensile strength equal to 1008.5MPa.

[0097] As adherence agents, two types of bi-component epoxy resins were used. Their mechanical characteristics were determined on 160x40x40 mm³ rectangular samples, using three-point bending tests. The average value of the elastic modulus (Emr), and the average value of the maximum strain (εmr) of resin r1 and resin r2 is respectively Emr=0.79GPa, εmr=3.65% and Emr=1.51GPa, εmr=2.28%. Resin r2 was used inside the anchorage holes of two carbon-fiber reinforced polymer laminates aimed at strengthening beam d) from group i). In all the remaining cases where an adherence agent was applied, r1 was used.

[0098] The dimensions and quantities of strengthening in the beams were analysed. In group i) the beam b) was strengthened with a laminate with a cross-section of 50x1.2mm² and a length of 2700mm applied over a 2mm-layer of resin r1 on the lower side of the beam web. The beam c) was strengthened with four laminates which were 2700mm-long and had a cross-section of 10x1.4mm², applied with resin r1 in four grooves with a 5x15mm² cross-section. The beam d) was strengthened with four laminates with a 10x1.4mm² cross-section and a length of 3700mm applied to the lower side of the beam web, over a length of 2035mm. This application was on a 1mm-thick resin layer r1 and anchored (3) at the ends inside 12mm-diameter holes over a length of 415mm with resin r1 and resin r2 (two laminates anchored with resin r1 and two anchored with resin r2), with a deviation angle of 33° (8) and a transition curve radius (2) of 300mm. Strengthening reinforcement was applied in a staggered manner, two for each side, 72mm off-centered from the mid-span of the beam.

[0099] In group ii) the beam b) was strengthened with two stainless steel bars with a cross-section of 20x5mm² and a length of 2750mm applied on a 1.5 mm resin layer r1 on the lower side of the beam web. The beam c) was strengthened with four ribbed bars with a cross-section of 48.1mm² and a length of 2750mm inserted with resin r1 in grooves with a cross-section of 12x12mm². The beam d) was strengthened with two stainless steel bars with cross-section 20x5mm² with a length of 3015mm resin bonded with r1 on the lower side of the beam web over a length of 2000mm and anchored (2) inside 25mm-diameter holes over a length of 332mm with resin r1, with a deviation angle of 33° (8) and a radius of the transition curve of 300mm.

[0100] The preparatory works to the application of the strengthening reinforcement are described below. In the beams strengthened with externally bonded reinforcement, beams b) and c) from both groups, the application surface was previously mechanically treated with a grinding wheel in order to remove the superficial layer of cement and expose the concrete aggregates.

[0101] The opening of the grooves on the surface layer of the concrete beams c) from both groups was carried out with a concrete cutting grinder equipped with a dia-

mond disk and cutting guide.

[0102] The holes for the anchorage of reinforcement in the beams d) from both groups were performed with a rotary hammer drill, aided by a guide device which ensured the drilling with the intended deviation angle (8).

[0103] The transition curves (2) were opened in slots with an electric hammer equipped with chisel.

[0104] In the beams b) the following steps were followed in the process for the implementation of the strengthening system: treating and cleaning the bonding surface; applying the adherence agent in a uniform layer over the surface; and applying the strengthening reinforcement pressing it down slightly to ensure contact between the strengthening reinforcement and the adherence agent.

[0105] In the beams c) the following steps were followed in the application of the strengthening system: marking the grooves on the surface; opening and cleaning the grooves; filling approximately half the depth of the grooves with adherence agent; applying the strengthening reinforcement on the adherence agent; and filling the grooves completely.

[0106] For the beams d) the following steps were followed in the application of the strengthening system: marking and opening the anchorage holes; treating the bonding surface; executing the transition curves; cleaning the holes, the transition curves and the bonding surface; applying the adherence agent inside the holes, on the transition curves and on the bonding surface; applying the strengthening reinforcement pressing it down slightly to ensure contact between the strengthening reinforcement and the adherence agent; applying temporary support to the strengthening reinforcement in the transition curves zone to ensure the contact between the strengthening and the adherence agent.

[0107] This embodiment is of course not in any way restricted and anyone with average knowledge in the field can provide many possibilities for modifying it without departing from the general idea as defined in the present disclosure.

[0108] The following claims represent further preferred embodiments of the present disclosure. They may be combinable among them.

Claims

1. Structural strengthening system with post-installed strengthening reinforcements internally anchored by adherence, for bending and shear strengthening of a structural element, comprising:

a structural element;
one or more longitudinal tension reinforcements;
wherein an end of the reinforcement or reinforcements is anchored by an adherence agent in an anchorage hole inside the structural ele-

- ment;
 wherein the structural element comprises, for each anchorage hole, a transition curve, on the structural element, for changing of the alignment of the reinforcement between the alignment of the surface of the structural element and the alignment of the anchorage hole;
 wherein each anchorage hole forms a deviation angle from the direction of the reinforcement into the structural element.
2. Structural strengthening system according to any of the preceding claims wherein each end of the reinforcement is anchored by an adherence agent in a hole in the core of the structural element.
 3. Structural strengthening system according to any of the preceding claims wherein the deviation angle is 0.5° - 100° .
 4. Structural strengthening system according to any of the preceding claims wherein each of the two ends of each reinforcement is anchored by an adherence agent in an anchorage hole inside the structural element.
 5. Structural strengthening system according to any of the preceding claims wherein the transition curve is a slot opened in the structural element.
 6. Structural strengthening system according to any of claims 1 - 4 wherein the transition curve is a prefabricated component with the intended shape of the curve, which is inserted into the structural element, in particular comprising a deviation saddle or a metal profile.
 7. Structural strengthening system according to any of claims 1 - 4 wherein the transition curve is obtained by placing the filling material in a slot of the structural element.
 8. Structural strengthening system according to any of the preceding claims wherein the beginning of the transition curve is tangent to the surface alignment of the structural element and the end of the transition curve is tangent to the alignment of the anchorage hole.
 9. Structural strengthening system according to any of the preceding claims wherein the shape of the transition curve is either of a semicircle, an elliptical arch, part of a parabola, part of a hyperbola, part of a clothoid, or their combinations.
 10. Structural strengthening system according to any of the preceding claims wherein the reinforcement or the reinforcements are arranged to strengthen the structural element to positive bending moments and to shear forces.
 11. Structural strengthening system according to any of the preceding claims wherein the reinforcement or the reinforcements are arranged to strengthen the structural element to negative bending moments and to shear forces.
 12. Structural strengthening system according to any of the preceding claims wherein the reinforcement or the reinforcements are arranged to strengthen the structural element to positive bending moments, to negative bending moments and to shear force.
 13. Structural strengthening system according to any of the preceding claims wherein the reinforcement or the reinforcements are arranged to increase the confinement of the structural element.
 14. Structural strengthening system according to any of the preceding claims wherein the holes are defined by tubes inserted in the structural element, in particular tubes mechanically inserted and fixed to the web of the structural element
 15. Structural strengthening system according to any of the preceding claims wherein the holes are moulded in the manufacturing process of the structural element.
 16. Structural strengthening system according to any of the preceding claims further comprising at least at one of the reinforcements an adjusting device for adjusting the installed stress on them.
 17. Structural strengthening system according to any of the preceding claims wherein the stress installed in the reinforcement was adjusted after the adherence agent cure in the hole or in the anchorage hole.
 18. Structural strengthening system according to any one of the preceding claims further comprising one or more reinforcements in the web of the structural element to prevent local web buckling of the structural element due to the stress concentration at the intrados of the transition curve.
 19. Structural strengthening system according to any of the preceding claims wherein the adherence agent for anchorage is cementitious mortar, polymer mortar, polymer resin, epoxy-based polymer resin, methacrylate polymer resin or urethane polymer resin.
 20. Structural strengthening system according to any of the preceding claims wherein the reinforcement or the reinforcements are bars, strands, wires, strips,

sheets, laminates, or combinations thereof.

21. Structural strengthening system according to any of the preceding claims wherein the reinforcement or the reinforcements are inserted in grooves cut in the structural element or are inserted in the surface layer cover of the structural element. 5
22. Structural strengthening system according to any one of the preceding claims wherein the reinforcement or the reinforcements are bonded to the structural element. 10
23. Structural strengthening system according to any of the preceding claims, wherein the reinforcement or the reinforcements are of steel, fiber-reinforced polymer, carbon-fiber reinforced polymer, glass-fiber reinforced polymer, basalt-fiber reinforced polymer, graphene-fiber reinforced polymer, aramid-fiber reinforced polymer, shape memory alloys, or combinations thereof. 15 20
24. Structural strengthening system according to any one of the preceding claims wherein the structural element is either a slab, a cantilever, a corbel, a beam, a column, a shear wall, a footing, a caisson foundation, a beam foundation, a raft foundation, an arch, a vault or a wall. 25
25. Structural strengthening system according to any one of the preceding claims wherein the structural element is of masonry, stone masonry, adobe masonry, rammed earth masonry, brickwork, cement mortar masonry, wood, solid wood, glued laminated wood, particle board wood, concrete, plain concrete, reinforced concrete, prestressed concrete, post-stressed concrete, composite concrete, concrete with steel fibers, composite concrete, steel, polymer, or combinations thereof. 30 35 40
26. Structural strengthening method with one or more longitudinal tension strengthening reinforcements internally anchored by adherence, for bending and shear strengthening of a structural element, comprising: 45
 - opening one or more anchorage holes inside the structural element;
 - arranging, for each anchorage hole, a transition curve, in the structural element, for changing of the reinforcement alignment between the surface alignment of the structural element and the alignment of the anchorage hole;
 - applying an adherence agent inside each anchorage hole;
 - arranging the reinforcement or reinforcements, wherein an end of the reinforcement or reinforcements is anchored by the adherence agent
- in an anchorage hole, wherein each anchorage hole forms a deviation angle from the direction of the reinforcement into the structural element; curing the adherence agent in the anchorage hole or holes.
27. Structural strengthening method according to the preceding claim, wherein the deviation angle is 0.5°-100°.
28. Structural strengthening method according to claim 26 or 27, wherein each end of the reinforcement or the reinforcements is anchored by an adherence agent in a hole in the core of the structural element.
29. Structural strengthening method according to any of claims 26 - 28, wherein each of the two ends of each reinforcement is anchored by an adherence agent in an anchorage hole inside the structural element.
30. Structural strengthening method according to any of claims 26 - 29 comprising opening a slot in the structural element to obtain the transition curve.
31. Structural strengthening method according to any of claims 26 - 29 comprising inserting a prefabricated component with the shape of the intended curve in the structural element to obtain the transition curve.
32. Structural strengthening method according to any of claims 26 - 29 comprising placing filler material in a slot of the structural element to obtain the transition curve.
33. Structural strengthening method according to any of claims 26 - 32, wherein the beginning of the transition curve is tangent to the alignment surface of the structural element and the end of the transition curve is tangent to the alignment of the anchorage hole.
34. Structural strengthening method according to any of claims 26 - 33 comprising applying a temporary support to the strengthening reinforcement until the cure of the anchorage with adherence in the anchorage hole or anchorage holes.
35. Structural strengthening method according to any of claims 26 - 34 comprising posterior adjustment of the installed stress in each reinforcement via a stress adjustment device mounted in the reinforcement.
36. Structural strengthening method according to any of claims 26 - 35 comprising adjusting the installed stress after the adherence agent cure in the anchorage hole or anchorage holes.
37. Structural strengthening method according to any of claims 26 - 36 comprising opening grooves in the

structural element to insert the reinforcement or the reinforcements.

- 38.** Structural strengthening method according to any of claims 26 - 36 comprising bonding the reinforcement or the reinforcements to the structural element. 5

- 39.** Structural strengthening method according to any of the preceding claims wherein the structural element is a slab, a cantilever, a corbel, a beam, a column, a shear wall, a footing, a caisson foundation, a beam foundation, a raft foundation, an arch, a vault or a wall. 10

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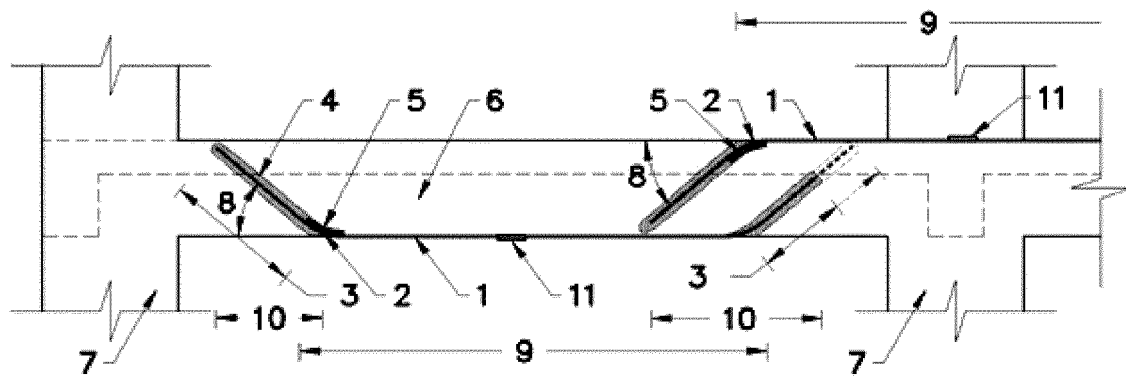


Fig. 1

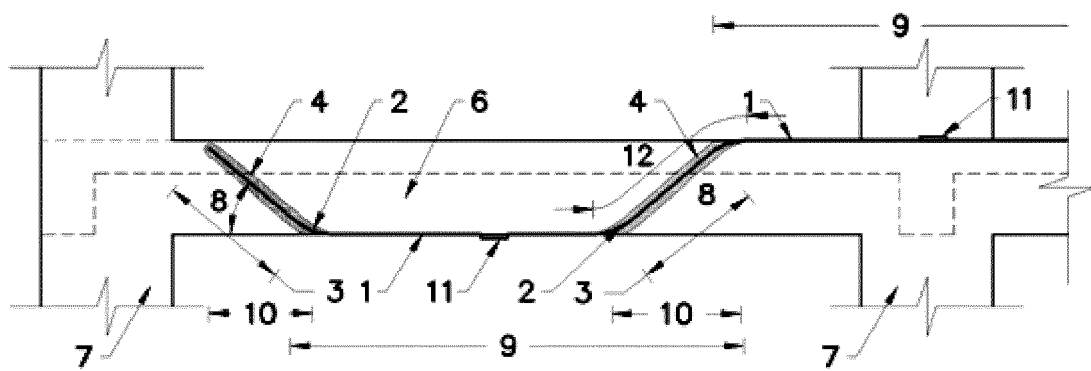


Fig. 2

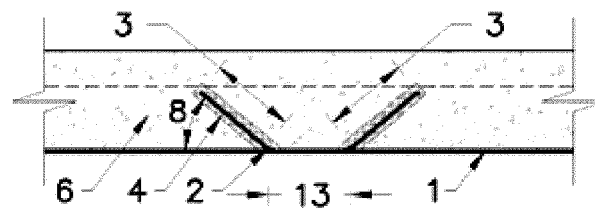


Fig. 3

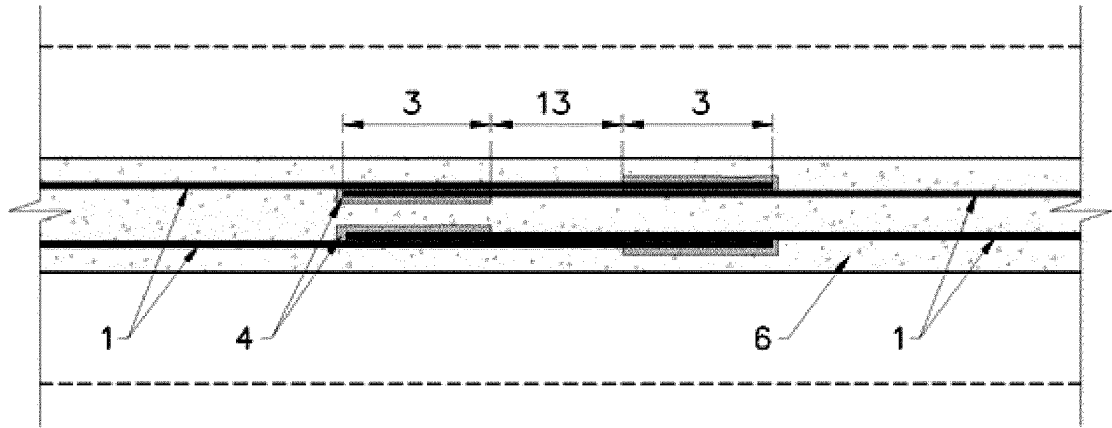


Fig. 4

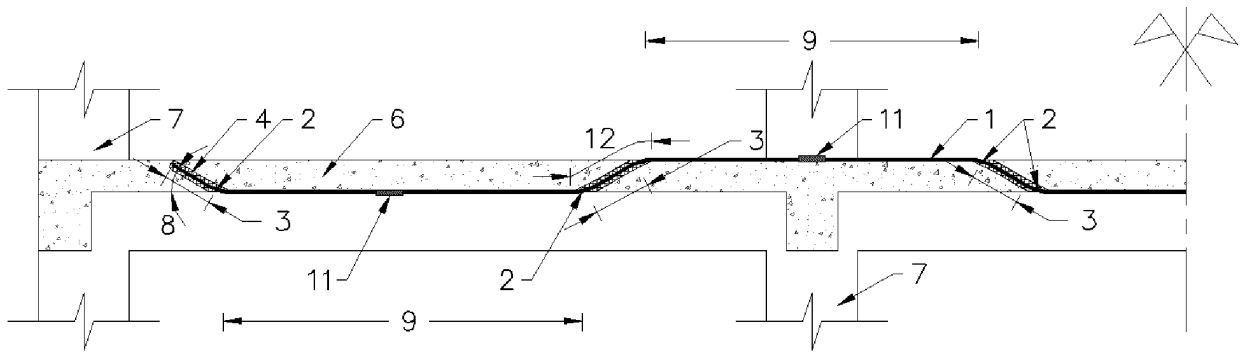


Fig. 5

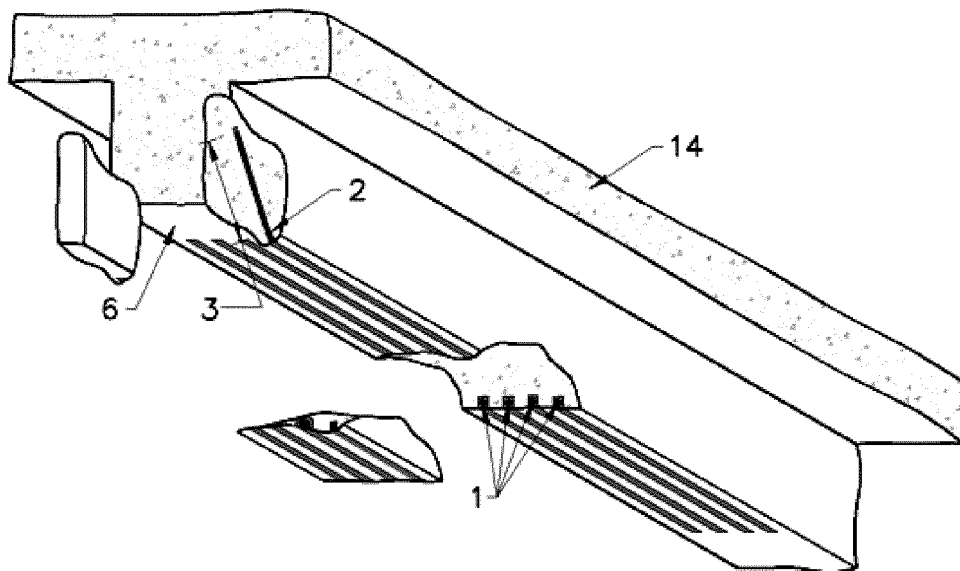


Fig. 6

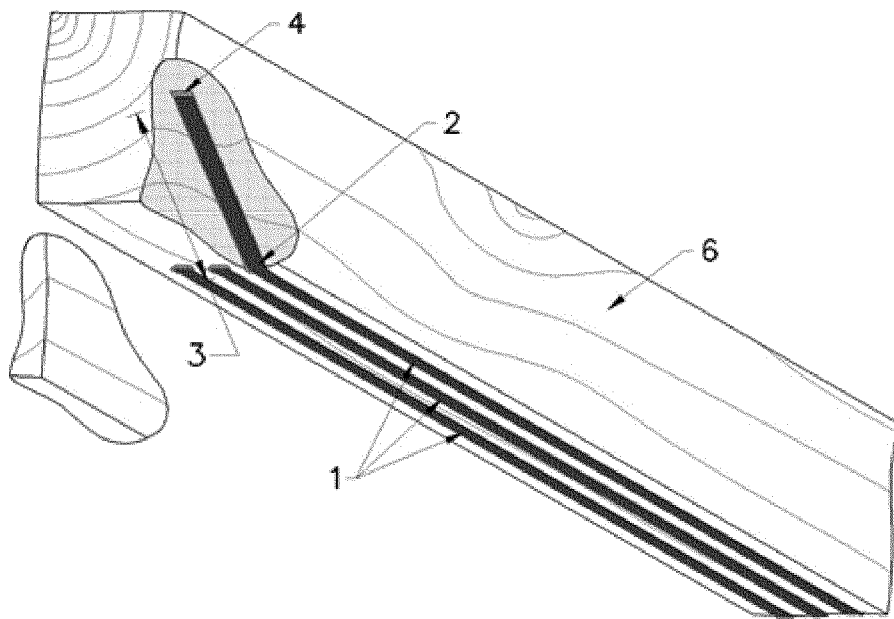


Fig. 7

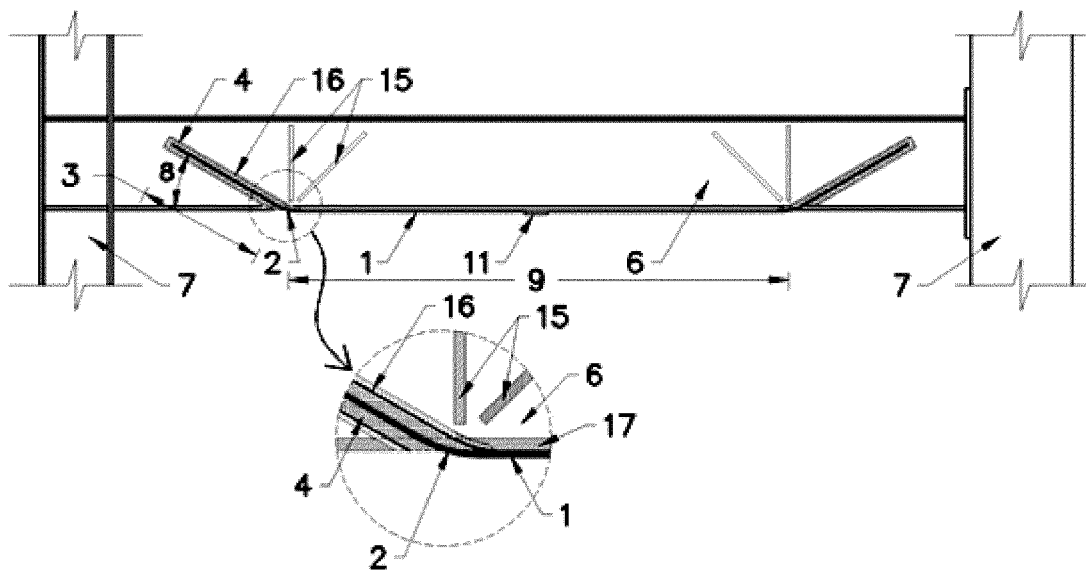


Fig. 8

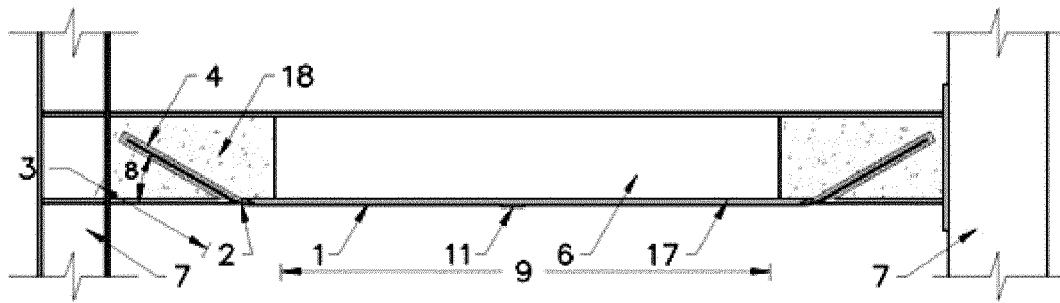


Fig. 9

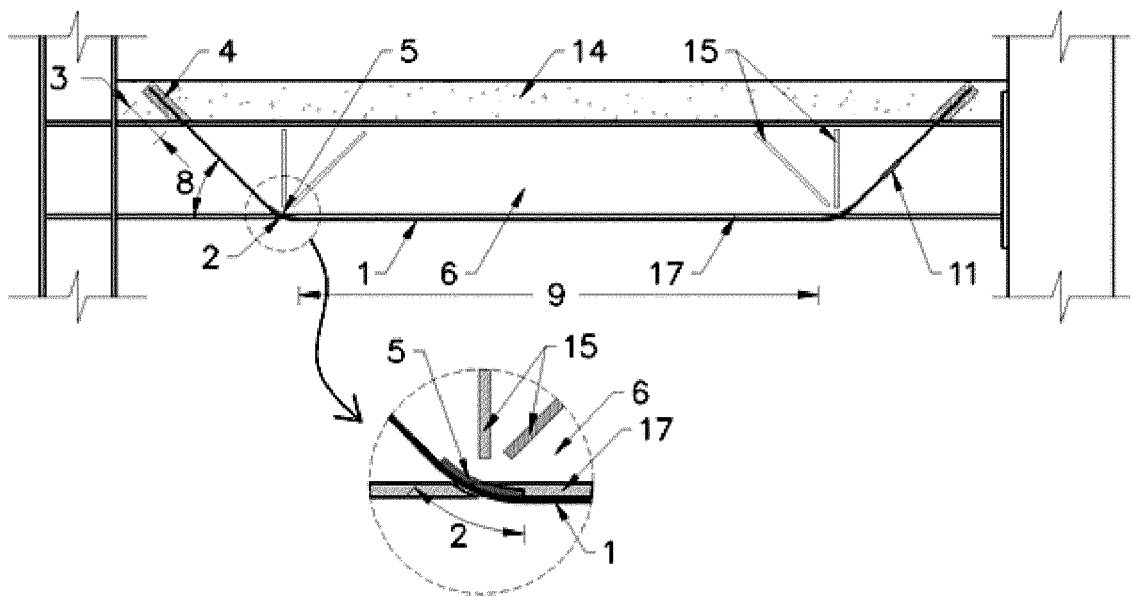


Fig. 10

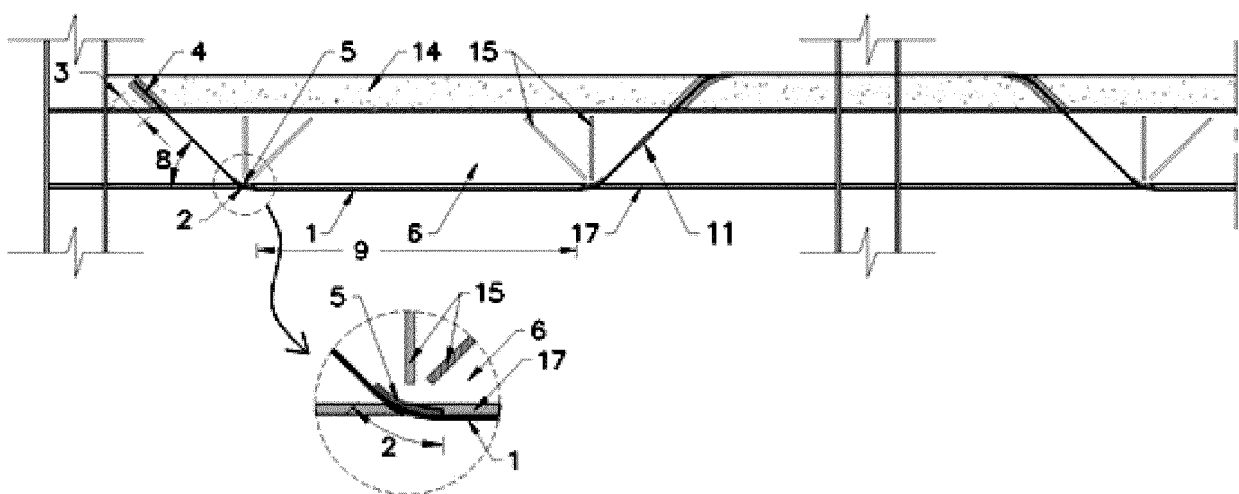


Fig. 11

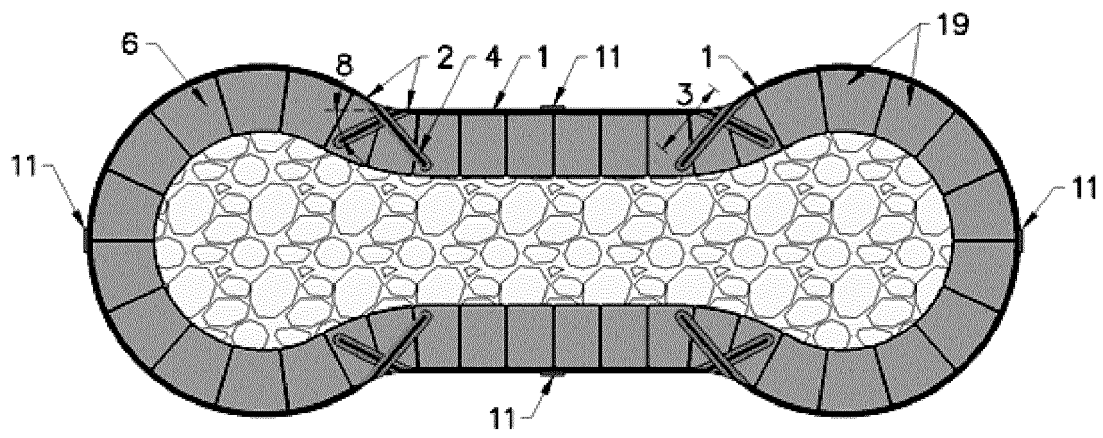


Fig. 12

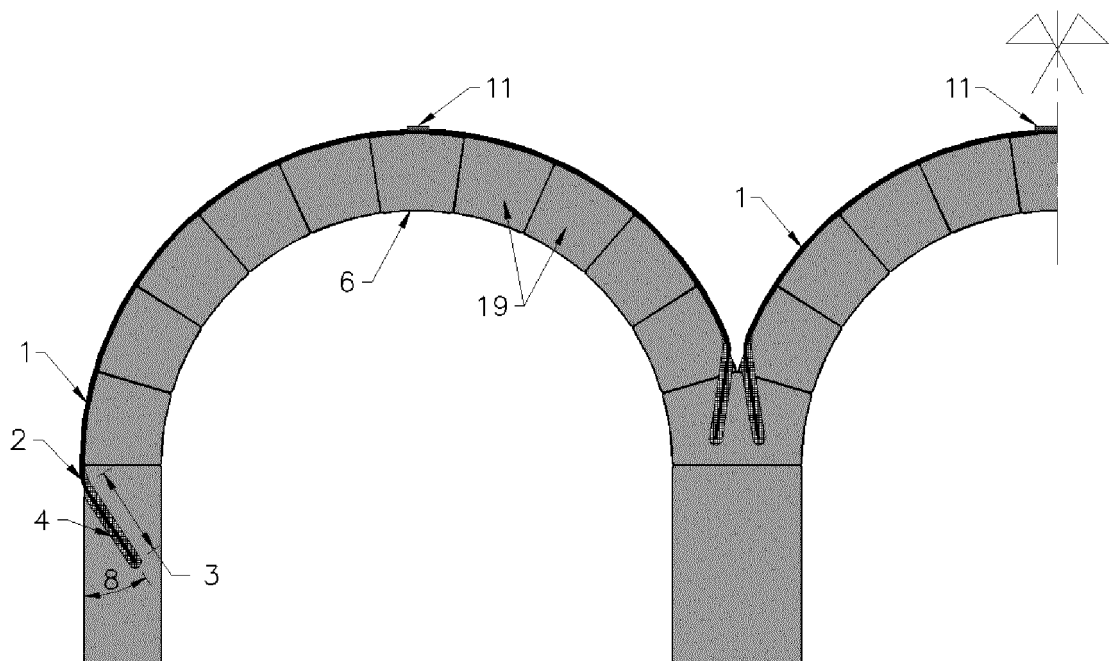


Fig. 13

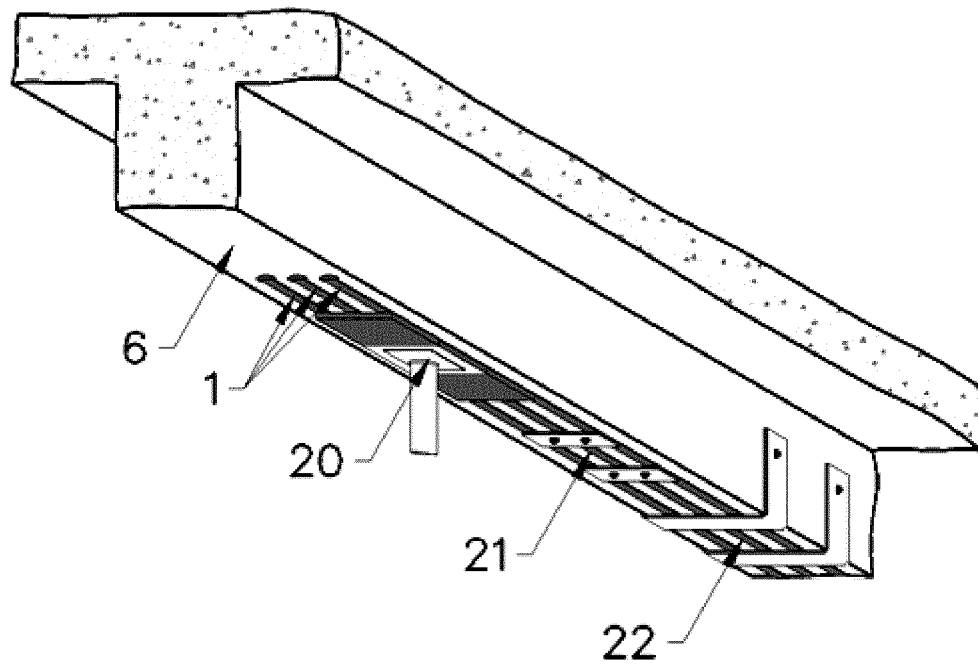


Fig. 14

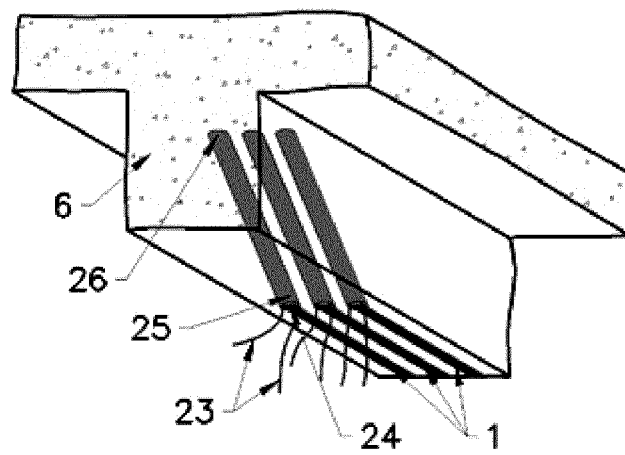


Fig. 15

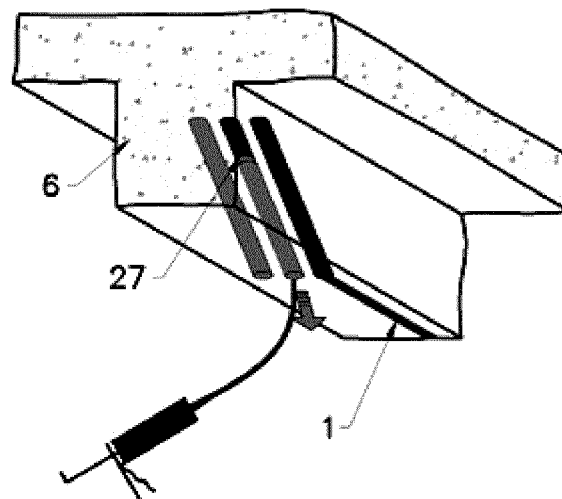


Fig. 16

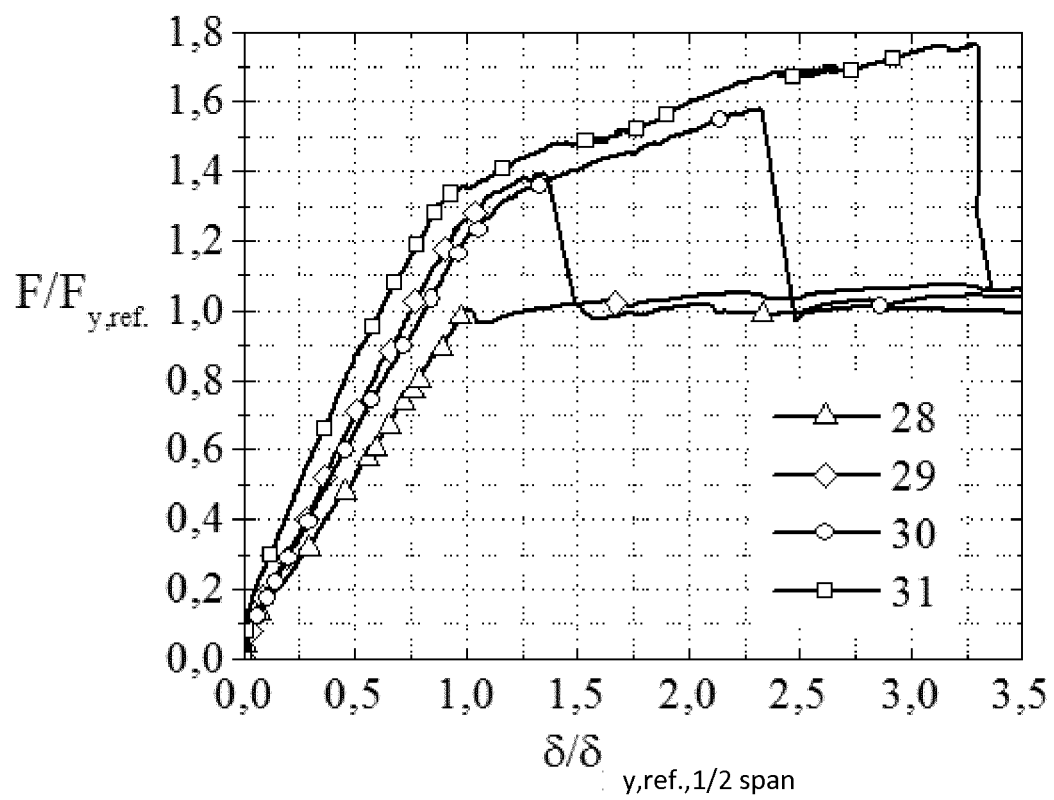


Fig. 17

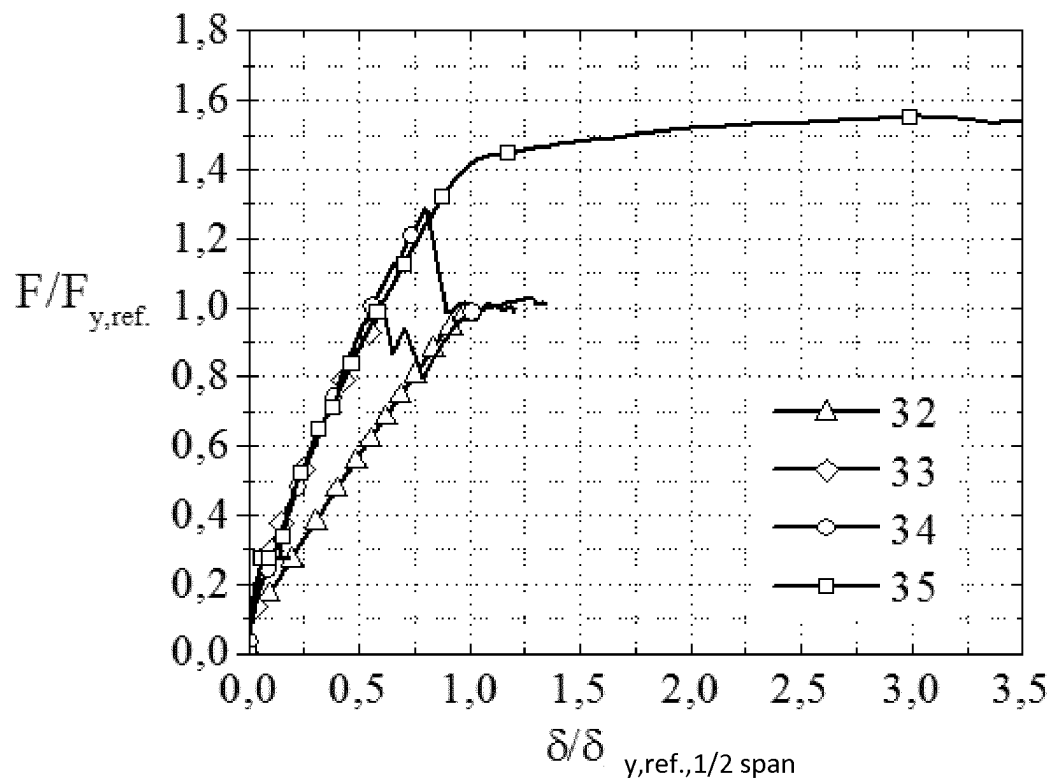


Fig. 18

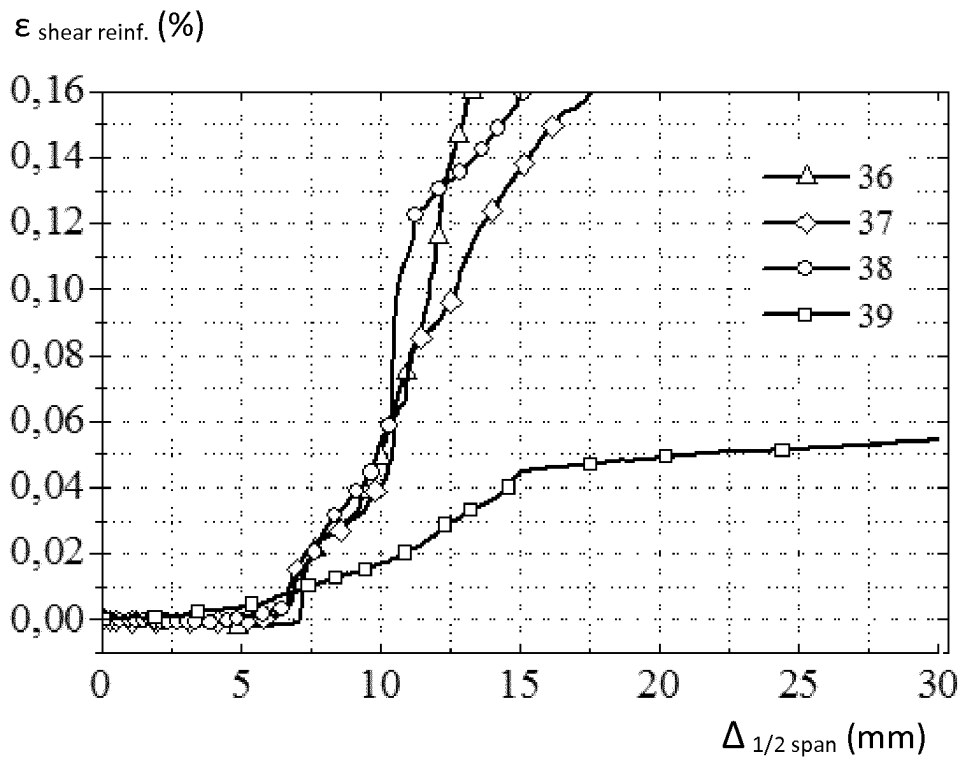


Fig. 19

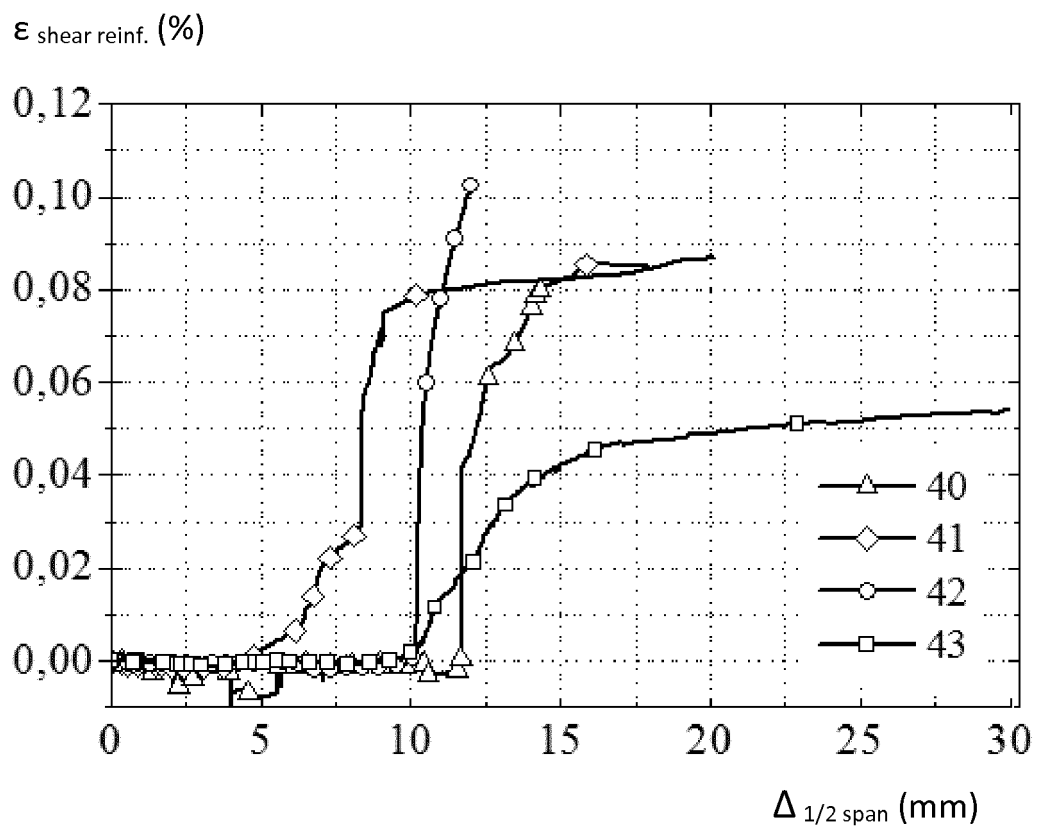


Fig. 20

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/055208

A. CLASSIFICATION OF SUBJECT MATTER

INV. E04C5/12 E04C5/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E04C E04G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 837 202 A1 (FREYSSINET INT STUP [FR]) 22 April 1998 (1998-04-22)	1-5, 7-13, 17-30, 33,37-39
A	column 1, line 37 - column 5, line 27; figures 2-3	6,14-16, 31,32, 34-36
X	DE 100 34 534 A1 (BRINKE ACHIM [DE]) 22 March 2001 (2001-03-22)	1-5, 7-13, 18-30, 33,37-39
	the whole document	
X	US 5 044 139 A (MILLS TYRONE T [US]) 3 September 1991 (1991-09-03) column 3, line 30 - column 5, line 38; figures 3,6	14-16, 31,32



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

3 November 2015

Date of mailing of the international search report

10/11/2015

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Authorized officer

Lopes, Claudia

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/055208

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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REFERENCES CITED IN THE DESCRIPTION

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