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(54) DEVICE AND METHOD FOR REINFORCING STRUCTURES WITH PRE-STRESSED FIBRE-REINFORCED-POLYMER LAMINATES

(57) This invention discloses a pre-stressing system for retrofitting of reinforced concrete members with externally bonded fibre-reinforced-polymer (FRP) laminates in bending. An FRP pre-stressing system includes a clamping unit (1), a light frame for hydraulic jack (2) and anchoring plates (3). The novel clamping unit (1) comprises tempered steel grips with corrugated gripping surfaces (4) which are tightened with high strength bolts (5) in a steel frame (6). This invention also discloses using the epoxy adhesive (8) on both upper and lower corrugated contact surfaces of the grips (4) and the FRP laminate (7) surface parts being clamped by said grips (4). The result is more effective clamping with very low slipping possibility. This invention provides retrofitting and reinforcement solutions for concrete slabs, wide beams, and also smaller beams, by using the threaded rods (10) and additional steel plates (11) instead of anchor bolts (9).

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Description

TECHNICAL FIELD

[0001] This invention relates to the field of structural and material engineering and can be used for reinforcing the existing structural elements. More specifically, it discloses reinforcing means and a method for retrofitting concrete structures with externally bonded pre-stressed fibre-reinforced-polymer laminates.

BACKGROUND ART

[0002] There are many buildings, bridges, and other structures worldwide in bad or even critical conditions. Such conditions can be caused by aging, poor maintenance, and corrosion of structural elements, also design and constructional mistakes. Therefore, the strengthening of such structures is often required. Fibre-reinforced-polymers (FRPs), due to their corrosion resistance and high strength-to-weight ratio, have established themselves in the construction market as an appropriate material for retrofitting concrete structures, thus replacing other materials for this use, such as concrete jackets and steel plates. Fibre-reinforced polymers are expensive high strength materials. The pre-stressing of FRP reinforcements is a solution for using the full potential of these high tensile strength materials. Other benefits of using the pre-stressed FRPs are reduced deflection, control of cracks, improved cracking and yield loads of the retrofitted structures.

[0003] The main problem of pre-stressing FRP materials is to have a reliable anchorage and clamping system to prevent or minimize slipping of the contacting surfaces of the concrete structure and FRP reinforcement and prevent debonding the FRP reinforcement from the concrete structure.

[0004] Chinese patent CN208578344U provides a clamping piece and hinge-type anchor device for fibre reinforced composite (FRP) panel. The front end of its clamping piece type plush copper anchor is the curved surface to the evagination, and the middle part of a side of preceding spill anchoring block, spill sliding block is the curved surface to the indent, and the concave curved surface of the outer convex surface of plush copper anchor and preceding spill anchoring block and spill sliding block mates each other and constitutes the face contact and form the hinge connection. The main disadvantage of this system that it is not bonded to the surface of concrete and holds only on the anchors that is quite risky and can end up with an accident if slipping would occur between the contacting surfaces of FRP panel and the anchors. Moreover, during pre-stressing, the clamping unit is in tension while using this method central alignment of the laminate is very important, even small eccentricities can cause longitudinal cracks in the FRP laminate with following tensile failure. In addition, the anchors are made of copper, which makes the whole system much more expensive as the price of copper is approximately 13 times higher than steel.

[0005] Another Chinese patent application CN104895251A provides a wraparound type waveform anchor for fibre sheets and pre-tensioning method thereof. The method comprises that both ends of the FRP sheet are clamped and fixedly anchored through the wraparound type waveform anchor and one end of the wraparound type waveform anchor is pulled so as to achieve the longitudinal tension of the FRP sheet. The main disadvantage of this and similar systems, they could be used only for FRP sheets as FRP laminate would break while trying to clamp it with a curved/wavy surface. Besides, it also has similar disadvantages to the above-described system.

[0006] One more Chinese patent application CN1699710A provides a pre-stressed fibre-reinforced plastic plate anchoring device and tensioning tow knee coordinated therewith. The main idea of this invention is to use a wedge type clamping unit in a tension frame. Disadvantages: a tension frame takes a lot of space and can be difficult to use on a site for strengthening. Also, other disadvantages of the above-mentioned systems are valid, only the current system has a higher risk of critical eccentricities due to the absence of the hinge element.

[0007] European patent application EP2631392A1 provides a commercially available device for the application of force to tension members from fibre-reinforced plastic plates. The device has a clamping element made of soft- and hard layers. The clamping element comprises a structure without a wedge taper or a wedge-shaped or conical structure, where a cross-section reduction of the wedge runs against a tension direction of a tension element. A sleeve has an interior shape for retaining the clamping element and for exerting clamping pressure. Disadvantages: The clamping unit is in tension, it means that the system will take place outside the end of the laminate and even small eccentricities can cause longitudinal cracks in the laminate with the following tensile failure. Also, the end of the laminate will be moved away from the support, such a reduced ratio of the laminate and concrete element lengths can lead to the end debonding failure mode, especially for shorter concrete elements. Besides, this device requires additional damage to the concrete for using it in EBR strengthening systems. In real structure, longitudinal and transverse reinforcements won't let to make such a groove on a concrete surface. Without a groove for the clamping unit, the laminate will be too far from the concrete surface to bond it.

[0008] European patent EP2088259B1 provides a commercially available device for pre-tensioning reinforcement elements on structures. The method involves producing pre-tensioning between a building and a clamping shoe attached

at a reinforcement laminate-end by using a hydraulic cylinder-piston unit that is utilized in a device for tensioning. Pre-tensioning is maintained by driving a setscrew between a tensioning device and the clamping shoe. The piston unit is removed under retention of the pre-tensioning held by the screw. The tensioning device and the shoe are removed from a building after hardening of an adhesive. The shoe is provided for clamping of the laminate-ends and a box-type metal body. The main disadvantage is still a risk of slipping in the contacting surfaces of the reinforcement laminate and the plane of aluminum bloc clamping the laminate.

[0009] In order to eliminate the above disadvantages, the present invention provides an advantageous clamping device and a method for pre-stressing of reinforcing FRP laminates.

SUMMARY OF THE INVENTION

[0010] The current invention discloses a pre-stressing device for retrofitting of reinforced concrete members with externally bonded CFRP laminates in bending.

[0011] The pre-stressing system includes a clamping unit, a light frame for hydraulic jack and anchoring plates. The novel clamping unit consists of tempered steel grips with a corrugated surface, which are tightened with high strength bolts in a steel frame. Usually, the result of using corrugated surface steel grips would be fractured laminate, therefore plane surfaces were used in all pre-stressing systems mentioned in the previous section (patent No. CN208578344U provides a wavy shape of the clamping unit to bend the FRP material, what is unacceptable for laminates, but the surface itself is still plane). The catch of this invention is to add epoxy adhesive on both upper and lower contact surfaces of the grips and the laminate and tighten with high strength bolts in the steel frame. The result after one day of hardening is more effective clamping unit with very low slip potential. Such units can be attached on both sides of the laminate one day before strengthening outside the construction site, this way strengthening time is not higher than using any other existing method. If one day does not make any difference, the clamping unit can be attached on one side of the laminate and the other end can be anchored to concrete with riffled surface steel plates, epoxy adhesives must be added onto concrete-laminate, laminate-steel plate contact surfaces and the plates must be tightened to concrete with anchor bolts at once. Anchoring with plane surface plates as proposed in the prior art would not withstand similar loads, even bonded with epoxy adhesive one day before the tensioning.

[0012] The current invention provides retrofitting solutions not only for concrete slabs and wide beams as it does previously mentioned systems but also for smaller beams by using the steel clamps instead of direct fixing to concrete.

[0013] The main working principle of the system is that hydraulic jack in steel frame pushes the clamping unit through the hinge while the other side of the laminate is anchored. This way precise central alignment of the laminate is far less important as in tensile systems (e.g. patents No. CN208578344U, CN104895251A, CN1699710A, EP2631392A1). The anchoring plates are added by the same principle described above between the clamping unit and the frame of hydraulic jack. Next, the applied force is transmitted from the jack into the frame through bolts and the jack can be removed. After full hardening of the adhesive, the hydraulic jack is returned to the frame and a force of the same magnitude is added to the clamping unit. The bolts are released and the force is slowly removed, transferring pre-stressing force into the anchors and concrete-laminate joint. The process is similar to the one provided in European patent No. EP2088259A1, but the improved anchors and clamping unit reduce the risk of the FRP laminate slipping in the clamping unit and the anchors and thus the failure of the concrete-laminate joint. Moreover, the frame of the clamping unit has attached rollers that can move through rail holding the clamping unit attached to the ceiling, this way the effect of friction between surfaces is lower than it is in European patent No. EP2088259B1. In the case of smaller beams, the rollers can be added on the other side of the beam.

DESCRIPTION OF DRAWINGS

[0014] To understand the FRP laminate clamping solution and appreciate its practical applications, the following pictures are provided and referenced hereafter. Figures are given as examples only and in no way should limit the scope of the invention.

Fig. 1 Pre-stressing of CFRP laminate on wide concrete beams and slabs while both ends of the laminate are clamped (time-saving on construction site);

Fig. 2 Pre-stressing of CFRP laminate on wide concrete beams and slabs while one end of the laminate is clamped and the other one is anchored;

Fig. 3 Pre-stressing of CFRP laminate on smaller concrete beams while one end of the laminate is clamped and the other one - anchored;

Fig. 4 View of the pre-stressing system from the bottom of the beam;

Fig. 5 Clamping unit of the laminate;

Fig. 6 Bonding laminate to the grips;

Fig. 7 Tightening of the clamping unit;
Fig. 8 Bonding of anchoring plates;
Fig. 9 Dimensions of the tested beams;
Fig. 10 Surface corrugation options (a) surface corrugated with linear grooves, (b) surface corrugated with peaks.

DRAWINGS - Reference Numerals

[0015]

1 clamping unit;
2 light frame for hydraulic jack;
3 anchoring plates;
4 steel grips with a corrugated surface;
5 high strength bolts;
6 steel frame;
7 laminate;
8 epoxy adhesive;
9 anchor bolts
10 threaded rods;
11 additional steel plates;
12 hydraulic jack;
13 steel rails;
14 dynamometer;
15 hinge;
16 force transfer plate;
17 threaded rods;
18 rollers;
19 nuts;
20 wider rollers;
21 brackets;
22 concrete element.

DETAILED DESCRIPTION OF THE INVENTION

[0016] The pre-stressing system (presented in Figures 1 to 4) includes three main items: a clamping unit (1), a light frame for hydraulic jack (2) and anchoring plates (3).

[0017] The novel clamping unit (1) consists of tempered steel grips with the corrugated surface (4), which are tightened with high strength bolts (5) in the steel frame (6). The shape of the grips (4) was specially made to bend the laminate (7) with a low angle, in order to get a better anchorage but not to break the laminate (7) at the same time (see Fig. 5). The assembly process of the clamping unit (1) starts from adding epoxy adhesive (8) onto the corrugated surfaces of the grips (4) and closing the CFRP laminate (7) inside between the grips (4) (see Fig. 6). Next, the grips (4) with the laminate (7) and epoxy adhesive (8) inside are tightened in a steel frame (6) with high strength bolts (5) (see Fig. 7).

[0018] The light steel frame (2) is mounted onto a concrete surface with anchor bolts (9), or with threaded rods (10) and additional steel plates (11) in case of smaller beams (Fig. 1 to 4). The purpose of this frame is to hold hydraulic jack (12), serve as a support to it and take over the pre-stressing force while the adhesive hardens.

[0019] The third component of the pre-stressing system is the anchoring plates (3) with the corrugated surface for additional anchoring the laminate (7) to concrete element (22) (presented in Fig. 8). If the clamping unit (1) is assembled on the construction site one day or more before strengthening, then the laminate (7) with the clamping unit (1) on one end can be mounted to the concrete beam/slab (22), while bonding another end to the concrete beam/slab (22) is done with anchoring plates (3).

[0020] The process of anchoring the FRP laminate (7) to the concrete beam/slab (22) is as follows:

Step 1: the epoxy adhesive (8) is added onto the concrete beam/slab (22) or the laminate (7), and the end of the laminate (7) is bonded to the beam/slab (22).

Step 2: afterward, the epoxy adhesive (8) is added onto the anchoring plate (3) (see Fig. 8) and the anchoring plate (3) is bonded onto the laminate (7) and concrete beam/slab (22).

Step 3: next, the anchoring plate (3) is tightened to the concrete beam/slab (22) with anchor bolts (9) or threaded rods (10), and additional steel plates (11). This way, the anchoring plates (3) turn on to work from the start of pre-stressing.

[0021] The situation is different when both ends of the laminate (7) are clamped. In this case, the anchoring plates (3) are added on the same day as the pre-stressing process takes place and fully turn on to work only when adhesive (8) hardens and force transfer frame (2) is removed.

[0022] The general steps of the pre-stressing process are described below (in the case, when both ends of the laminate (7) are clamped, as presented in Fig. 1).

[0023] First step: the surface of the concrete beam/slab (22) is grinded and cleaned with the cleaner.

[0024] Second step: the laminate (7) is cleaned the same way as the concrete object (22), the epoxy adhesive (8) is added onto the corrugated surfaces of the grips (4) and the CFRP laminate (7) is closed inside between the grips (4) (see Fig. 6). Next, the grips (4) with the laminate (7) and epoxy adhesive (8) inside are tightened in a steel frame (6) with high strength bolts (5) (see Fig. 7).

[0025] Third step: the steel rails (13) are mounted, they will hold the clamping units (1).

[0026] Fourth step: on the next day, the laminate (7) is bonded to the concrete with epoxy adhesive (8), the clamping units (1) are hanged behind the steel rails (13).

[0027] Fifth step: the epoxy adhesive (8) is added onto the anchoring plates (3) (see Fig. 8) and the anchoring plates (3) are hanged on anchor bolts (9), but not tightened.

[0028] Sixth step: mounting of a force transfer frame (2) for a hydraulic jack (12) onto a concrete surface with anchor bolts (9).

[0029] Seventh step: fixing the hydraulic jack (12) with brackets (21) screwed to the frame (2) and fixing dynamometer (14) with brackets (21) screwed to the anchoring plate (3), the hinge (15) is added between the dynamometer (14) and force transfer plate (16).

[0030] Eighth step: the hydraulic jack pushes the force transfer plate (16), which moves on the threaded rods (17).

[0031] Ninth step: the tensile force is transferred into the clamping unit (1) through dynamometer (14) and the hinge (15).

[0032] Tenth step: the rollers (18) attached to the clamping unit (1) move on the steel rails (13) and this way force is transferred to the laminate (7).

[0033] Eleventh step: when the designed tensile force is achieved, nuts (19) on the threaded rods (17) and the bolts (9) of the anchoring plates (3) are tightened.

[0034] Twelfth step: the tensile force is released from the hydraulic jack (12), which now can be removed.

[0035] Thirteenth step: after full hardening of epoxy adhesive (8), the hydraulic jack (12) is returned into the frame (2) and a force of the same magnitude is added into the system.

[0036] Fourteenth step: the nuts (19) are released.

[0037] Fifteenth step: release the force from the hydraulic jack (12) and remove the dynamometer (14).

[0038] Sixteenth step: cut the laminate (7) close to the clamping unit (1), remove rails (13), the clamping unit (1) and the force transfer frame (2). If both ends of the laminate (7) were with clamping units (1), then repeat the actions from the Thirteenth step on the other end of the laminate (7).

[0039] In case of smaller beams, when the threaded rods (10) and additional steel plates (11) are used instead of anchor bolts (9), the rollers (18) can be removed from the clamping unit (1) and wider rollers (20) can be added from the other side of the beam and pressed with the steel plates (11) (see Fig. 3). This way rollers get support and the bending moment acting on them is removed.

[0040] It should be noted, that the pre-stressing level of the FRP laminate (7) should be additionally controlled with strain gauges, not shown in the drawings, but still electromechanical indicators (LVDT's) with a sensor base of 25 mm are recommended for measuring the elongation of the laminate on the intermediate section of the element (22). If the concrete element (22) is not cracked, then the measurement base should not make any difference, but if the strengthened member (22) is cracked, then the strain gauge should be mounted on the most widely opened crack with the recommended measurement base of 50 mm. Also, depending on the length of the laminate (7), for better performance, it is advisable to add additional anchoring plates (3) on intermediate sections, not only on the ends of the laminate (7).

[0041] The prototype of the pre-stressing system was made and tested on the series of reinforced concrete beams on courtesy of Vilnius Gediminas Technical University. Eighteen full-scale beams were cast and tested at the local laboratory. Half of them were strengthened under external load action (a common situation in practice). Pre-stressing force varied from 20 % to 75 % of a nominal load-carrying capacity of the laminate (7), i.e. the force transmitted to the tensioning system varied from 30 kN to 125 kN. Dimensions of the beams and reinforcements are presented in Fig. 9 and material properties in the table below:

f_{cm} (MPa)	$f_{y.s1}$ (MPa)	E_{s1} (GPa)	$f_{y.s2}$ (MPa)	E_{S2} (GPa)	f_{fu} (MPa)	E_f (GPa)	P (kN)
48.98	568.5	199.75	537.68	195.55	2800	170	0÷125

where: f_{cm} - mean compressive strength of concrete cylinders; $f_{y.s1}$ - yield strength of tensile steel reinforcements; E_{s1} - modulus of elasticity of tensile steel reinforcements; $f_{y.s2}$ - yield strength of compressive steel reinforcements; E_{s2} - modulus of elasticity of compressive steel reinforcements; f_{fu} - tensile strength of CFRP laminate; E_f - modulus of elasticity of CFRP laminate; P - pre-stressing force.

[0042] During the research program, different angles of bending FRP in a clamping unit were tested and 7° was found as an optimal safe angle of bending the laminate (7). There is a high risk of breaking the laminate (7) with bending angles higher than 10°. The best result of preventing slipping in contact surfaces of the laminate (7) and the grips (4) is obtained when the surface of the grips (4) is corrugated with peaks (Fig. 10 b), though for anchoring plates (3) surface corrugation with linear grooves (Fig. 10 a) is more acceptable. Considering the laminate (7) is composed of fibre and a polymeric matrix, and it's surface slip properties will be similar to those of other fibres in the polymeric matrixes, it becomes obvious that the present invention can be used with other FRP laminates.

Claims

1. A pre-stressing device for retrofitting reinforced concrete members in bending with externally bonded fibre-reinforced-polymer (FRP) laminates, the device comprising at least

   - clamping unit (1),
   - light frame for hydraulic jack (2),
   - anchoring plates (3),

   characterized in that
   the clamping unit (1) comprises tempered steel grips with a corrugated surface (4) and epoxy adhesive (8) covered onto both upper and lower contact surfaces of the grips (4) and the FRP laminate (7) surface parts being clamped by said grips (4).

2. The pre-stressing device according to claim 1, **characterized in that** the anchoring plates (3) comprise a corrugated surface covered with epoxy adhesive for gripping the FRP laminate (7) surface parts being anchored.

3. The pre-stressing device according to claim 1, **characterized in that** the clamping unit (1) is tightened with high strength bolts (5) in a steel frame (6).

4. The pre-stressing device according to claim 1, **characterized in that** the shape of the grips (4) is made to bend the FRP laminate (7) with an angle of 0 to 10 degrees in order to get the better anchorage.

5. The pre-stressing device according to claim 4, **characterized in that** the FRP laminate (7) bending angle is sufficiently low not to break the FRP laminate (7) during the pre-stressing.

6. The pre-stressing device according to claims 1 to 5, **characterized in that** clamping unit (1) and anchoring plates (3) are fully operational after one day of hardening of the epoxy adhesive (8).

7. The pre-stressing device according to claims 1 to 6, **characterized in that** the permanent parts (anchoring plates (3)) and temporary parts (light frame for hydraulic jack (2), steel rails (13)) are tightened to the concrete beam/slab (22) with anchor bolts (9) or threaded rods (10), and additional steel plates (11) in case of smaller beams.

8. A method for reinforcing by externally bonded pre-stressed fibre-reinforced-polymer (FRP) laminates comprising steps at least of:

   (a) clamping the FRP laminate (7) by the clamping unit (1) having tempered steel grips with a corrugated surface (4),
   (b) mounting the clamp unit (1) with the anchoring plates (3) and light frame for hydraulic jack (2) onto the concrete structure (22) being reinforced,

(c) pre-stressing the FRP laminate (7) with the hydraulic jack,
(d) fixing the pre-stressed FRP laminate (7) to the concrete structure (22),

characterized in that in step (a):

- the corrugated surface of tempered steel grips (4) and the FRP laminate (7) surfaces to be clamped by said grips (4) are covered with epoxy adhesive (8);
- the clamping unit (1) is tightened with high strength bolts (5) in a steel frame (6);
- that clamping unit (1) is left for one day of hardening of the epoxy adhesive (8).

9. The method according to claim 8, **characterized in that** the step (b) temporary parts: steel rails (13) for a clamping unit and a light frame for hydraulic jack (2) are tightened to the concrete element (22), but clamping unit (1) itself and anchoring plates (3) - not.

10. The method according to claim 8, **characterized in that** step (c) employs rollers (18) and wider rollers (20) (in case of smaller beams) in order to reduce friction and pre-stress losses.

11. The method according to claim 8, **characterized in that** the step (d) comprises tightening of anchoring plates (3) to the concrete element (22) with anchor bolts (9) or threaded rods (10), and additional steel plates (11) (in case of smaller beams) after design pre-stressing force is achieved. Also, step (d) comprises a full hardening of the epoxy adhesive (8), afterward, temporary parts can be removed.

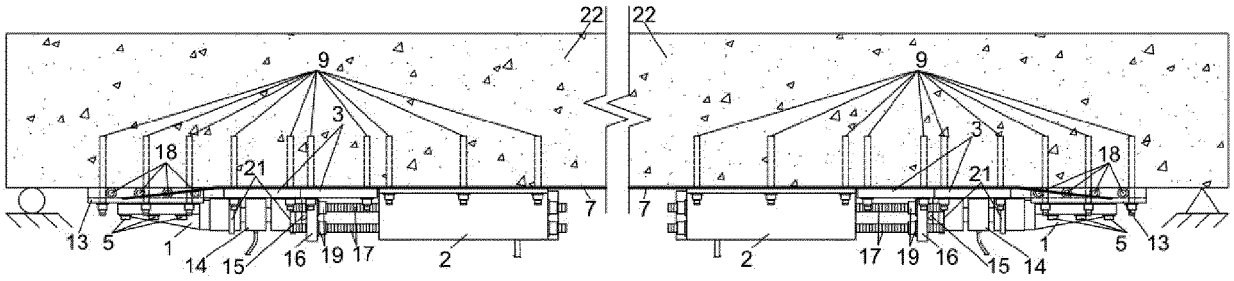


Fig. 1

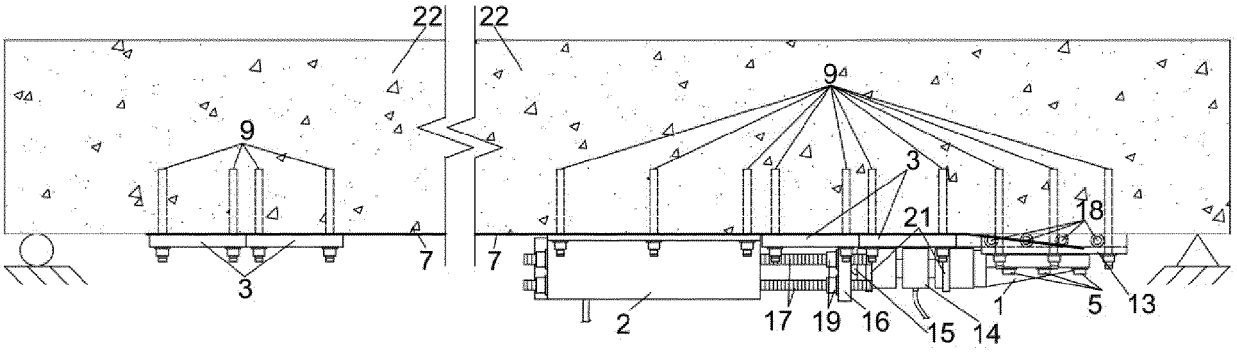


Fig. 2

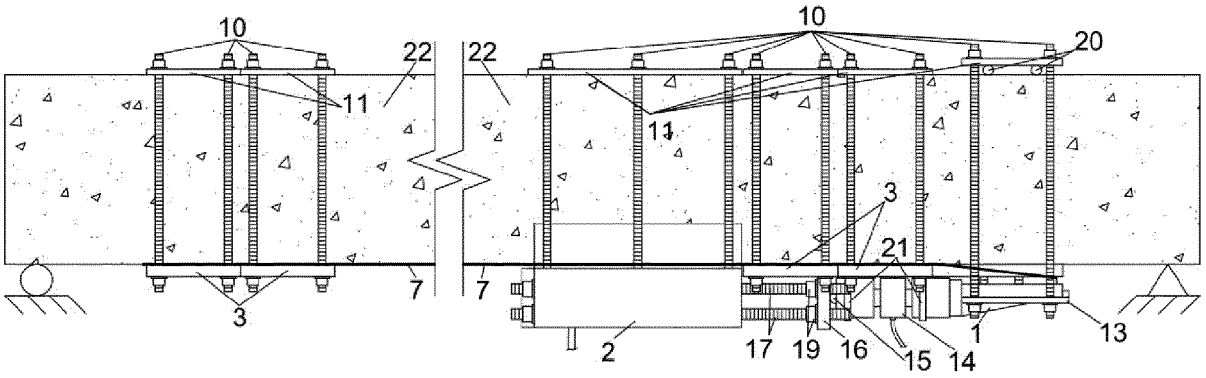


Fig. 3

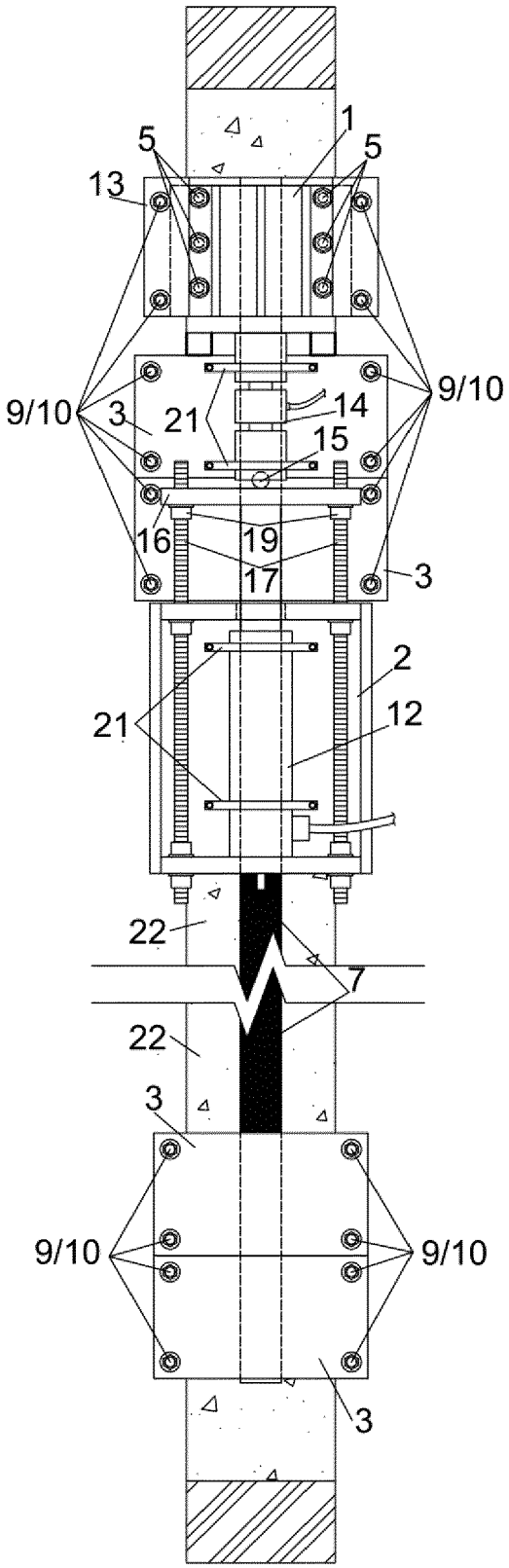


Fig. 4

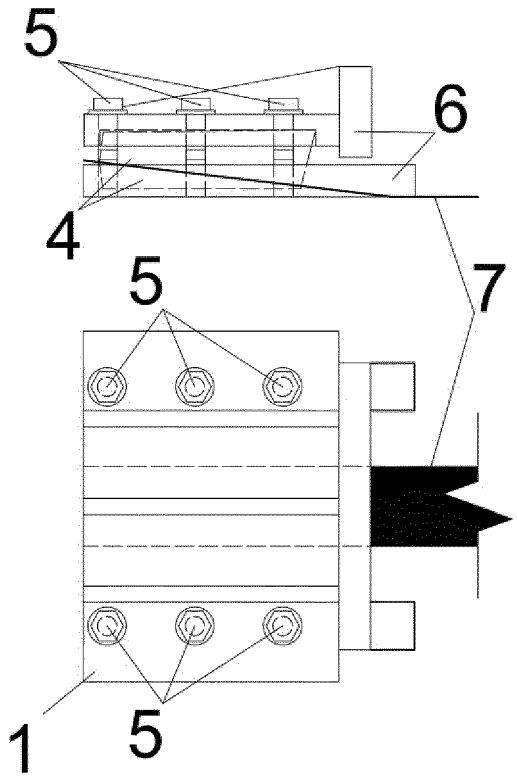


Fig. 5

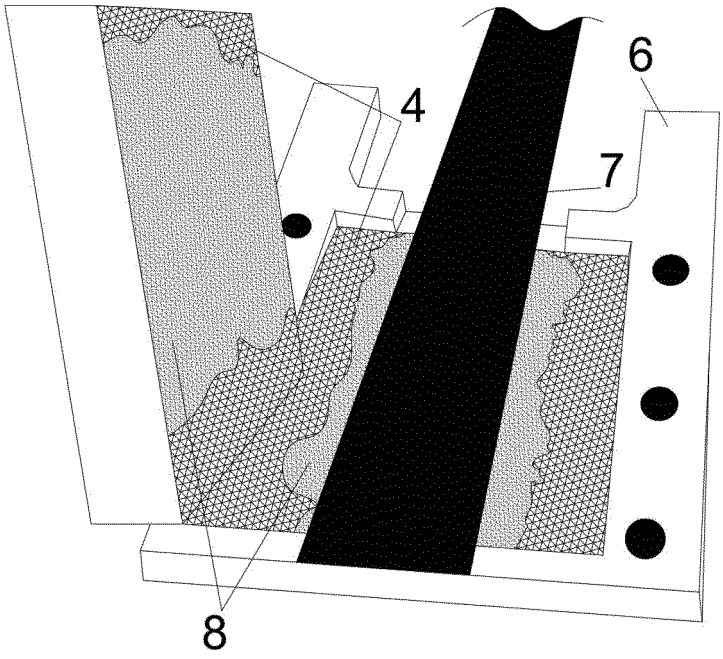


Fig. 6

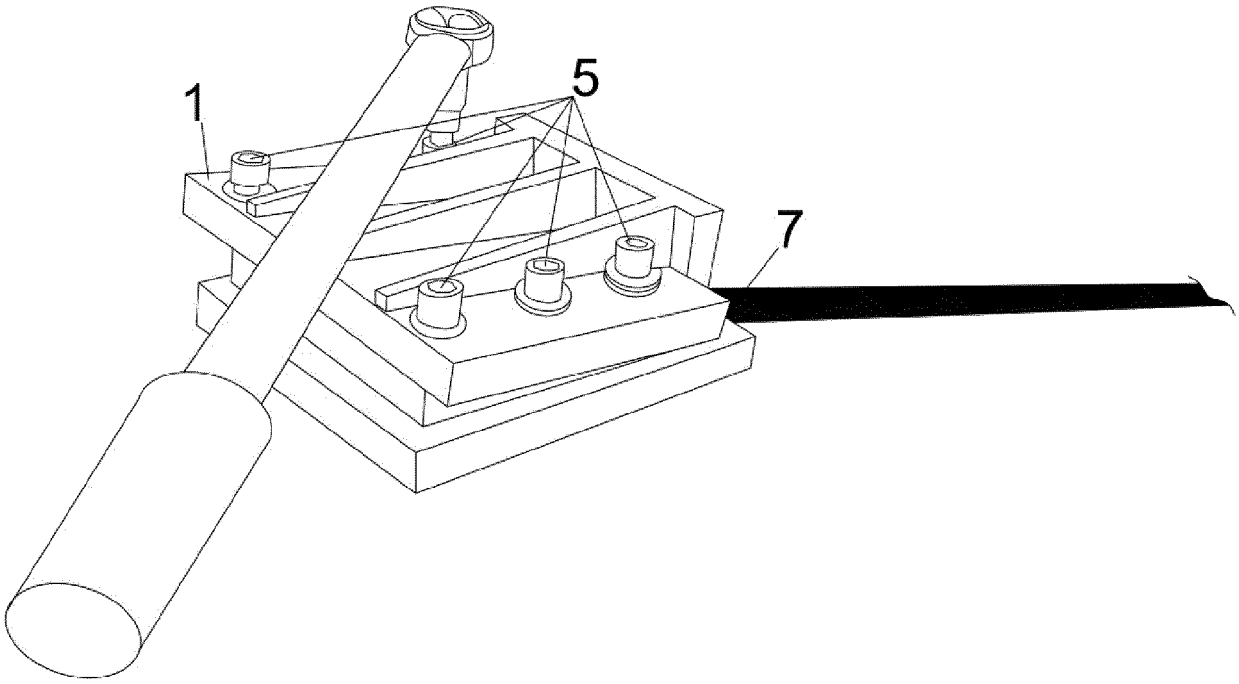


Fig. 7

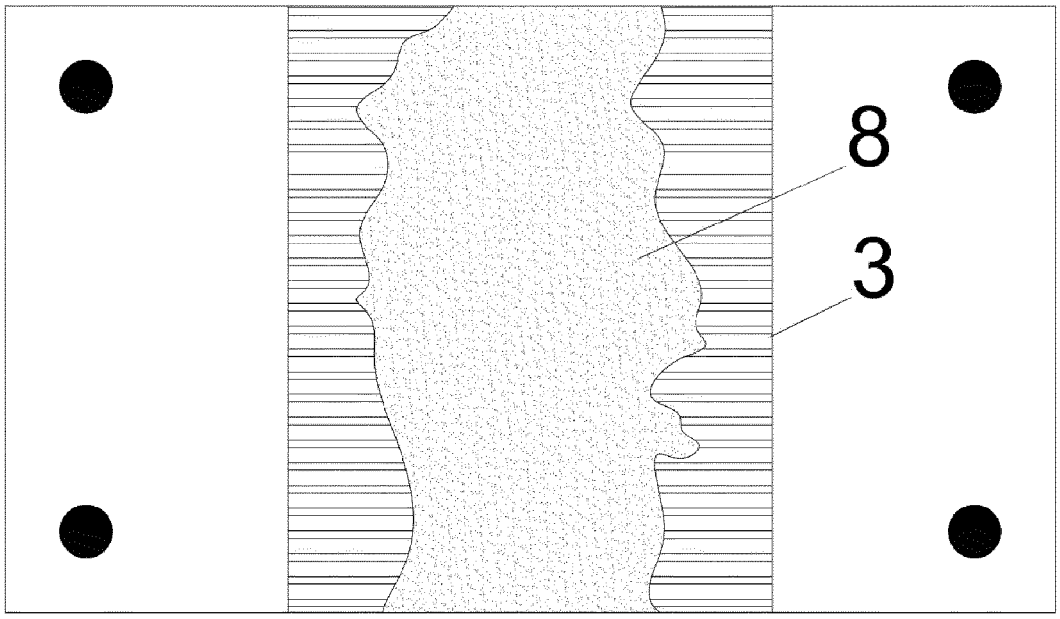
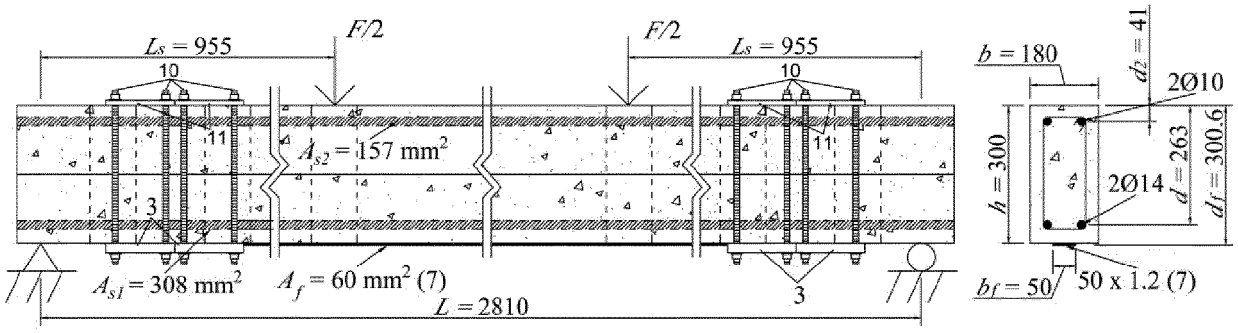


Fig. 8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10
10
11
11
3
3
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Af = 60 mm2 (7)
L = 2810
b = 180
d2 = 41
2Ø10
h = 300
2Ø14
d = 263
df = 300.6
bf = 50
50 x 1.2 (7)

Fig. 9

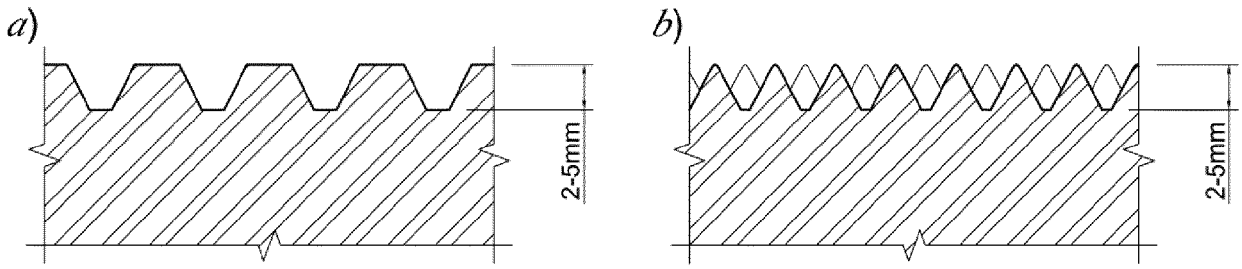
a)
2-5mm
b)
2-5mm

Fig. 10

Europäisches Patentamt
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EUROPEAN SEARCH REPORT

Application Number
EP 21 16 7213

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Place of search	Date of completion of the search	Examiner
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