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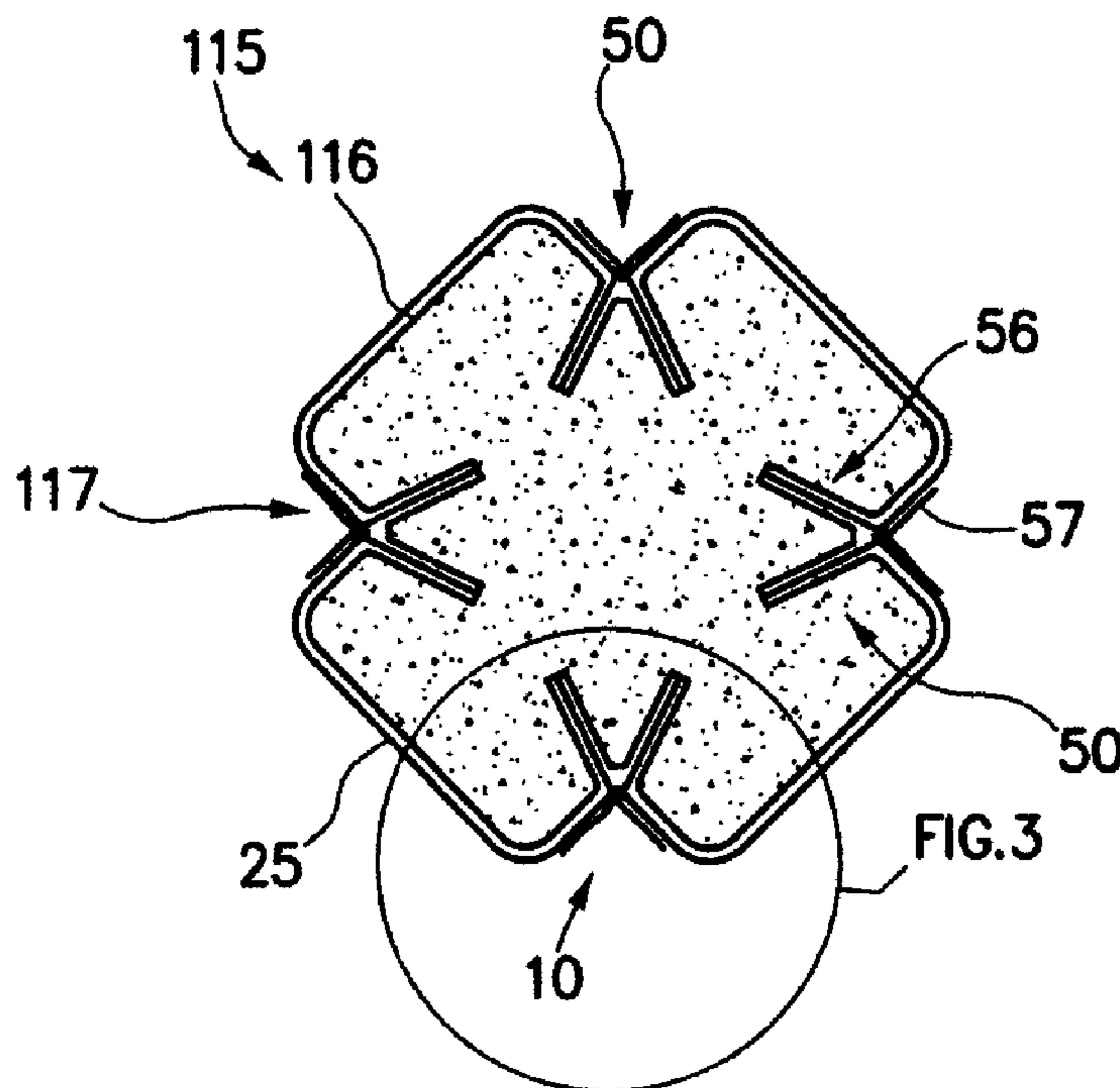
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(54) **Titre : SYSTEME ET METHODE DE RENFORCEMENT DE COLONNES FORMEES**

(54) **Title: SYSTEM AND METHOD OF REINFORCING SHAPED COLUMNS**



(57) **Abrégé/Abstract:**

Reinforcing system (10) for reinforcing structures with irregular surfaces, such as columns (115) with cruciform cross-section. Fiber-reinforced plastic sheathing (25) is wrapped around or over the surface to be reinforced and fiber anchors (50) are installed at high stress areas, such as re-entrant corners (117). Cover strip (30) spreads force among fiber anchors (50) and provides a smooth finish.

System and Method of Reinforcing Shaped Columns

ABSTRACT OF THE INVENTION

Reinforcing system (10) for reinforcing structures with irregular surfaces, such as columns (115)
5 with cruciform cross-section. Fiber-reinforced plastic sheathing (25) is wrapped around or over
the surface to be reinforced and fiber anchors (50) are installed at high stress areas, such as re-
entrant corners (117). Cover strip (30) spreads force among fiber anchors (50) and provides a
smooth finish.

System and Method of Reinforcing Shaped Columns

FIELD OF THE INVENTION

This invention relates in general to reinforcing a structure, and more particularly to
5 reinforcement of a support column of complex shape.

BACKGROUND OF THE INVENTION

Structures such as buildings and bridges have traditionally been designed to support their own
weight plus that of expected loads from people, vehicles, furnishings, etc. Buildings and other
structures for supporting weight have long been expected to be very strong under vertical
10 compression. Concrete is a favorite material for weight-bearing structures because it is
inexpensive and has exceptional compressive strength.

However, many existing commercial and public structures are not strong enough to survive
having one or more support columns destroyed by an explosion, earthquake, or impact. These
existing structures need to be reinforced in order to meet current standards of safety. The related
15 applications listed in the Cross-Reference section, above, disclose various methods for
reinforcing the attachment among various components of a structure, such as beams, decks,
walls, and columns in order to increase the structure's strength and safety.

In some cases, reinforcement of support columns themselves, in addition to connection of
20 components, is necessary to provide sufficient safety. In other cases, reinforcement of support
columns alone is sufficient to make the structure safe.

Conventional methods of reinforcing support columns can be broadly described as adding one or
more additional layers to the column: pouring additional concrete around the column; welding
25 metal supports, such as panels or bands, around the column; or wrapping the column in fiber-
reinforced plastic sheathing. The purpose of adding more material is to allow the column to sway
and deform, such as in an earthquake or hurricane, without the internal steel rods or bars

buckling and possibly rupturing the column. The columns of many existing structures were designed without sufficient constraint of the internal steel.

Fiber-reinforced plastic (FRP) wrapping is a preferred method because it can be installed quickly with little disruption to the use of the structure. FRP material can be viewed as either a fabric that is saturated with polymer resin, or plastic that includes embedded fabric. The fabric is typically woven or knitted from fibers with high tensile strength, such as graphite carbon or high-strength glass.

FRP may be applied to a column while the resin is “wet”, i.e., not yet cross-linked and containing solvents, or when the resin is gelled and has little solvent, but not yet cross-linked. FRP may also be created in situ by wrapping the column with fabric then saturating the fabric by applying resin with a roller, sprayer, or brush.

The FRP sheathing has low mass, so it can be installed on upper floors of a building without increasing the load on lower floors. FRP sheathing is relatively thin and can conform to the original contours of the building. FRP sheathing increases the apparent ductility of the column so that it is more resistant to forces other than vertical compression. Also, if the reinforced column does fail under catastrophic forces, the failure will typically be more gradual than that of a column reinforced with concrete or metal, allowing occupants time to escape the building or even time for emergency repairs to be performed.

FRP sheathing has been widely accepted as an effective method of reinforcing standard columns of rectangular and cylindrical cross-section. However, some existing buildings have columns of more complex shape in cross-section, including concavities or re-entrant corners. Conventional FRP sheathing is considered less effective for these types of columns because of the potential for adhesive failure on complex surfaces. However, steel or concrete jacketing are undesirable because they destroy the aesthetic effect of the shaped columns. As the state of Washington Dept. of Transportation says about one of their bridges, “The bridge has cruciform “+” shaped columns that make it architecturally unique as well as a challenge to strengthen against

earthquakes using steel column jackets.”

There is thus a need for a method of reinforcing support columns of complex shape that will preserve the many benefits and advantages of FRP sheathing, including retention of historic or
5 aesthetic features, while overcoming the potential shortcoming of possible adhesive failure.

SUMMARY OF THE INVENTION

The present invention is an improved system for sheathing columns with fiber-reinforced plastic (FRP) to strengthen the columns. Some columns have concavities such as fluting, vertical
10 notches, or re-entrant corners and require special methods for sheathing.

A first layer of FRP sheathing is wrapped around the column and attached to it with adhesive. A line of ductile fiber anchors is installed through the first layer of sheathing, along the deepest part of the notch or fluting. The free ends of the fiber anchors are splayed over the first layer of sheathing and attached with adhesive. A second layer of FRP sheathing is typically attached over
15 the first layer and the free ends of the fiber anchors.

Additionally, a cover strip of FRP is attached along the notch or fluting. Preferably, the FRP sheathing is installed with the grain (direction of greatest strength) oriented horizontally but the cover strip is oriented vertically.

The invention will now be described in more particular detail with respect to the accompanying
20 drawings, in which like reference numerals refer to like parts throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a front elevation view of a prior art support structure for a bridge.

Figure 2 is a sectional view of a support pier of the bridge of figure 1, taken along line 2- -2 of
25 Figure 4 and showing the reinforcement system of the present invention in partly exploded view.

Figure 3 is an enlarged detail view of the circled area of figure 2.

Figure 4 is a perspective view, partly cut away, of an exemplary bridge support column similar to the Prior Art support of Figure 1, shown with the reinforcement system of the present invention.

5 DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a front elevation view of an exemplary PRIOR ART structure 100, such as support pier 110 for a bridge. Support pier 110 includes a pair of shaped columns 115 joined at their tops. Shaped columns 115 each include re-entrant corners 117, that is, vertically elongate concavities.

Looking now at Figure 4, shown is a perspective view of a portion of a shaped column 115 similar to those of Figure 1 with one re-entrant corner 117 shown. Re-entrant corner 117 is a dihedral angle with a generally vertical line of intersection 118.

Column 115 of figure 4 is shown with the reinforcement system 10 of the present invention installed and partly cut away, both for clarity and to demonstrate the steps of the method of practicing the invention.

Figure 2 is a sectional view taken along line 2- -2 of Figure 4 and showing the reinforcement system 10 of the present invention in partly exploded view.

Figure 3 is an enlarged detail view of one corner of column 115 as shown in area 3 of figure 2, with reinforcement system 10 shown in partly exploded view.

As best seen in figure 2, exemplary shaped column 115 is overall generally square in horizontal cross-section, but with a notch, or “re-entrant corner” 117 removed from what would have been the four corners of the square. Column 115 thus has four “external” faces 116 and four re-entrant corners 117.

As best seen in Figure 1, shaped columns 115 may taper in width such that the cross-sectional area changes with height. The complex shape of columns 115 results in less intimidating bulk for

people passing below bridge 100, provides protected niches for conduits, and offers a distinctive appearance even from a distance.

Reinforcing shaped columns 115 with conventional concrete or steel jackets would probably destroy this aspect of bridge 100's design. An attempt to create concrete or steel jackets
 5 mimicking the cruciform shape of shaped columns 115 would be extremely expensive and would likely be only partially successful. Because of the added bulk, any historical value of the design would be lost or diminished and surrounding infrastructure would have to be modified, for example, adjacent roads might be narrowed, trees removed, or private property condemned.

Simple wrapping with FRP panels 25 as is known in the art would tend to peel or pop loose from
 10 re-entrant corner 117 if column 115 is deflected such as by a large earthquake. The present reinforcement system 10 has been found in simulation and mechanical testing to be far more ductile and resistant to delamination of the FRP panels 25 from shaped column 115 than conventional reinforcement by wrapping with FRP panels 25 alone.

Column 115 is prepared for installation of reinforcement system 10 by drilling boreholes 55 on
 15 or next to dihedral intersection 118, as seen in the upper portion of Figure 4. Debris and dirt are removed from boreholes 55 and external surfaces of column 115 by brushing, vacuuming, compressed air, steam, or other cleaning processes as needed. An adhesion primer (not shown) may be applied to all surfaces if needed. Also, radius means 60, such as pasty epoxy 65, is preferably applied to dihedral intersection 118 to create a rounded corner, typically of half an
 20 inch radius or greater.

A first layer of FRP 25 is wrapped around column 115, allowing sufficient slack that FRP 25 can be pressed fully into re-entrant corner 117. FRP 25 is preferably laid up such that the edges overlap slightly over one of external faces 116.

FRP 25 is composed of a woven or knitted fabric made of high-strength yarns such as of graphite
 25 carbon or glass, saturated with a polymer resin such as polyurethane or epoxy. The fabric may be of a single type of fiber or may be blended, so as to provide the strength and ductility characteristics required. FRP 25 can be prepared *in situ* by dipping strips of suitable fabric into

liquid resin and spreading the fabric immediately around column 115, or FRP 25 can be prepared beforehand by saturating fabric with resin then allowing the resin to gel. The resulting flexible panels of FRP 25 can be cut and handled easily, but the gelled resin will still affix FRP 25 strongly to column 115 upon curing.

- 5 The attached FRP 25 is pressed into re-entrant corners 117 so that it encases column 115 snugly and holes (not shown) are slit or punched through FRP 25 over each borehole 55 that was previously drilled. A ductile fiber anchor 50 (described below) is inserted into each borehole 55.

Ductile fiber anchors are known in the art and described in US Patent 7207149, which issued in 2007. They are often used to reinforce the attachment among structural elements such as beams,
10 columns, roofs, and floors. A ductile fiber anchor 50 typically comprises a length of roving composed of filaments of high tensile strength fibrous materials such as graphite carbon, glass, or a mixture of carbon and glass. A portion of fiber anchor 50 is typically pre-saturated with adhesive means such as gelled epoxy, polyurethane, or acrylic resin. One end of fiber anchor 50 is left uncoated so that free ends 57 of the filaments remain individual and fully flexible.

- 15 A ductile fiber anchor 50 is inserted into each borehole 55 through the slit or hole (not shown) created in FRP panel 25. Free ends 57 are splayed apart and attached to the exterior surface of FRP 25 sheathing covering the surface of re-entrant corner 117, such as the dihedral surface opposing the surface in which borehole 55 was drilled. Free ends 57 are attached to FRP 25 with suitable adhesive means 60 such as backfill adhesive (not shown) which is typically an epoxy,
20 urethane, or acrylic resin. Additional backfill adhesive (not shown) is inserted to fill borehole 55, such as by injection. When cured, backfill adhesive anchors fiber anchor 50 securely in borehole 55 and to FRP panel 115.

Fiber anchors 50 tie FRP sheathing 25 strongly to re-entrant corners 117 such that deflection of column 115 in an earthquake will not pop or peel FRP 25 loose from re-entrant corner 117. The
25 purpose of radiusing the interior angle with pasty epoxy 65 is to ensure that no unattached gap is formed at dihedral intersection 118.

Figure 4 is a perspective view, partly cut away, of a preferred installation of fiber anchors 50 in

re-entrant corner 117. Boreholes 55 are drilled in pairs into opposing faces of re-entrant corner 117 preferably on either side of the fillet of radius epoxy 65. Two such pairs of boreholes 55 are shown in the upper portion of Figure 4.

After FRP panel 25 is wrapped around column 115, as in the middle portion of Figure 4, a fiber anchor 50 is inserted into each borehole 55 with free end 57 protruding through a slit or hole provided in FRP 25. Free end 57 is splayed apart and attached to the exterior surface of panel 25, preferably lapping onto the face of re-entrant corner 117 opposite from the face in which its borehole 55 is located.

Fiber anchors 50 thus anchor FRP sheathing 25 into re-entrant corner 117, which is an area of high tensile and peeling forces on FRP 25 when column 115 deflects laterally. Fiber anchors 50 prevent FRP 25 from peeling or popping away from re-entrant corner 117 under stress.

An additional strip of fabric, such as cover strip 30, such as a strip of FRP with vertical grain 35, is optionally attached with suitable adhesive means (not shown) along the length of re-entrant corner 117 to cover fiber anchors 50. Cover strip 30 is shown in Figure 3 and in the lower portion of Figure 4. The yarns embedded in cover strip 30 may be the same material as FRP sheathing 25, or may be different, depending upon the application. As described above regarding the attachment of FRP 25, adhesive means is typically an epoxy, which may be either a liquid or gelled resin. Cover strip 30 provides a smooth external surface in re-entrant corner 117 and helps spread forces among fiber anchors 50.

In some cases, it is desirable to include a second layer of FRP 25 sheathing (not shown). This second layer is applied much the same as the first layer, described above, but without being pierced by fiber anchors 50. The second layer may be installed either directly over fiber anchors 50, with cover strip 30 attached over the second layer of FRP 25, or may be installed after and on top of cover strip 30. Because FRP 25 is quite thin, even two layers of FRP sheathing 25 plus cover strip 30 add only about half an inch to the profile of column 115. Except for the slight radiusing of dihedral intersection 118 by radius epoxy 65, surface features and dimensions of the original shaped column 115 are substantially retained. Reinforcement system 10 is translucent and allows the original surface to show through. If desired, a decorative finish coat such as paint

may be applied.

Although the reinforcement system 10 of the present invention is described and depicted herein as reinforcing a vertical column 115 with square re-entrant corners 117, other sorts of structural elements may be equally well reinforced by system 10, such as horizontal beams with re-entrant
5 corners, or structural elements having concavities other than re-entrant corners, such as elongate semi-circular grooves; or other sorts of high peeling stress regions such as ridges, beading, or non-elongate depressions. It will be obvious to one of skill in the art that the specific method of installation and design details of reinforcement system 10 may be adapted to many applications that are similar in the stress loading to the exemplary bridge support 110.

10 Mechanical testing has shown that reinforcement system 10 meets or exceeds current standards for seismic safety, yet is less expensive and faster to install than conventional concrete or steel jackets. Because the original dimensions are retained, public acceptance of the retrofitting project is far greater than for jacketing type reinforcement that often requires a long period of disruption during installation, may encroach into existing roads or private property, and forever changes the
15 appearance of the structure .

Although particular embodiments of the invention have been illustrated and described, various changes may be made in the form, composition, construction, and arrangement of the parts herein without sacrificing any of its advantages. For example, although the exemplary embodiment described herein is reinforcement of a cruciform column, the system and method
20 can also be applied with the same benefits to many other structures with niches, fluting, banding, or similar surface features. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

System and Method of Reinforcing Shaped Columns

I claim:

1. A system for reinforcing a column that includes an elongate concavity having a deepest part,
 2 including:
 a fabric sheathing layer wrapped around the column and attached by suitable adhesive
 4 means;
 at least one ductile fiber anchor inserted through said fabric sheathing layer and disposed
 6 within a borehole drilled in or adjacent to the deepest part of the concavity; said ductile fiber
 anchor including:
 8 a free end attached to said fabric sheathing layer by adhesive means; and
 a cover strip attached over said fiber anchors and attached to said fabric sheathing layer
 10 and said free ends by suitable adhesive means.

2. A reinforcement system for protecting a vertically elongate concrete structure against seismic
 2 and other lateral forces; including:
 a fabric sheathing layer attached to the structure by suitable adhesive means;
 4 at least one ductile fastener additionally connecting said sheathing layer to an area in
 which said fabric sheathing will be exposed to high tensile or peeling forces if the elongate
 6 structure deflects substantially; and
 a cover strip covering said at least one ductile fastener and attached to said fabric
 8 sheathing layer by suitable adhesive means.

3. The reinforcement system of claim 2, further including:
 2 a second fabric sheathing layer attached by adhesive means over said at least one ductile
 fastener and below said cover strip.

4. The reinforcement system of claim 2, further including:
 2 a second fabric sheathing layer attached by adhesive means over said cover strip.

5. A reinforcement system for columns having re-entrant corners, including:

2 a first FRP panel wrapped around the perimeter of the column and substantially covering
the height of the column; said first FRP panel attached by adhesive means;

4 a plurality of ductile fasteners disposed along the interior angle of each re-entrant corner
to reinforce the attachment of said first FRP panel to each re-entrant corner.

6. The reinforcement system of claim 5, said first FRP panel being disposed such that the grain
2 is substantially perpendicular to the longitudinal axis of the column.

7. The reinforcement system of claim 5, further including:

2 a cover strip attached over said ductile fasteners, disposed such that the grain of said
cover strip is substantially parallel to the longitudinal axis of the column.

8. The reinforcement system of claim 5, the column further including a series of boreholes on or
2 beside the dihedral intersection of the re-entrant corner and said ductile fasteners comprising:
fiber anchors disposed in the boreholes; said first FRP panel including a plurality of holes; each
4 said hole disposed over one borehole; and each said fiber anchor including:

a free end passing through and protruding from one said hole in said FRP panel; said free
6 end attached by adhesive means to said first FRP panel.

9. The reinforcement system of claim 5, further including:

2 a second FRP panel wrapped around the perimeter of the column and covering said
ductile fasteners; said second FRP panel attached by adhesive means.

10. A method for reinforcing a column; including the steps of:

2 creating at least one borehole on or adjacent a geometric discontinuity in the surface of
the column;

4 conformably wrapping the column in a first layer of fabric sheathing and attaching the
sheathing to the column with a suitable adhesive;

- 6 creating an opening in the fabric sheathing over the borehole;
 inserting a fiber anchor through the opening and into the borehole;
- 8 splaying apart the free end of the fiber anchor and attaching the splayed apart free end to
 an adjacent surface of the fabric sheathing with a suitable adhesive;
- 10 inserting backfill adhesive into the borehole to embed the fiber anchor and retain it in the
 borehole; and
- 12 attaching a fabric cover strip over the installed fiber anchor with suitable adhesive means.

FIG. 1
PRIOR ART

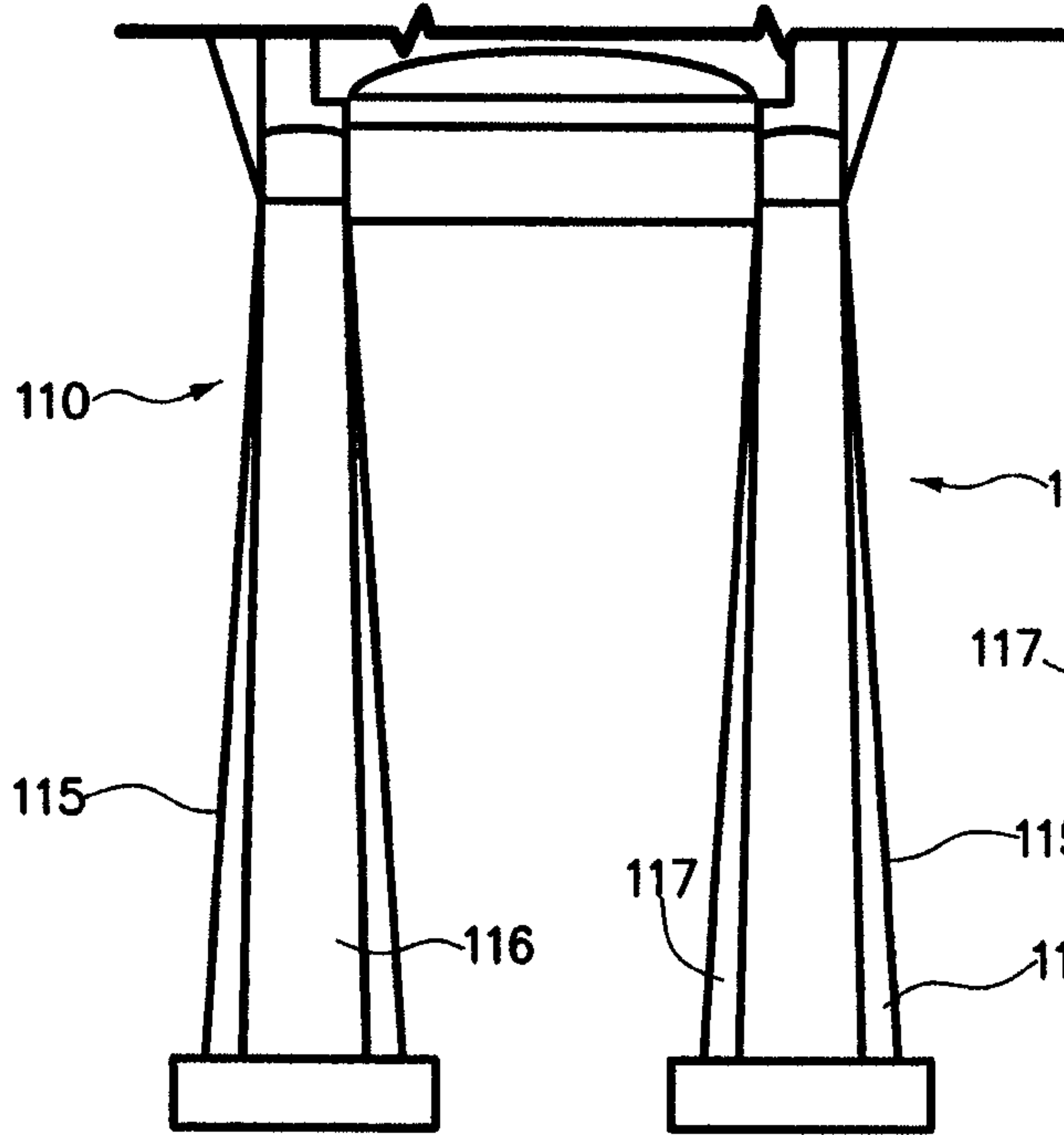


FIG. 2

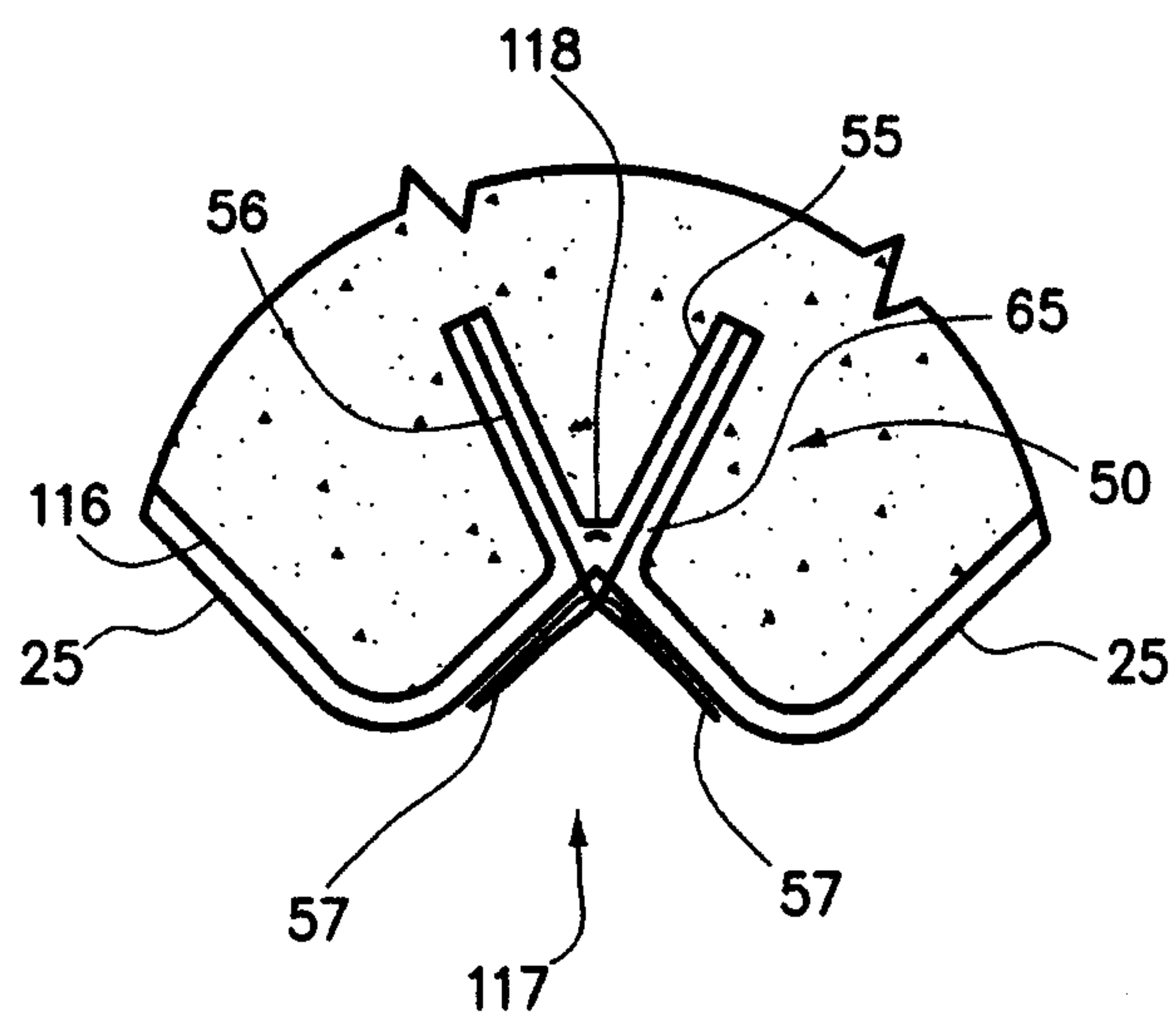
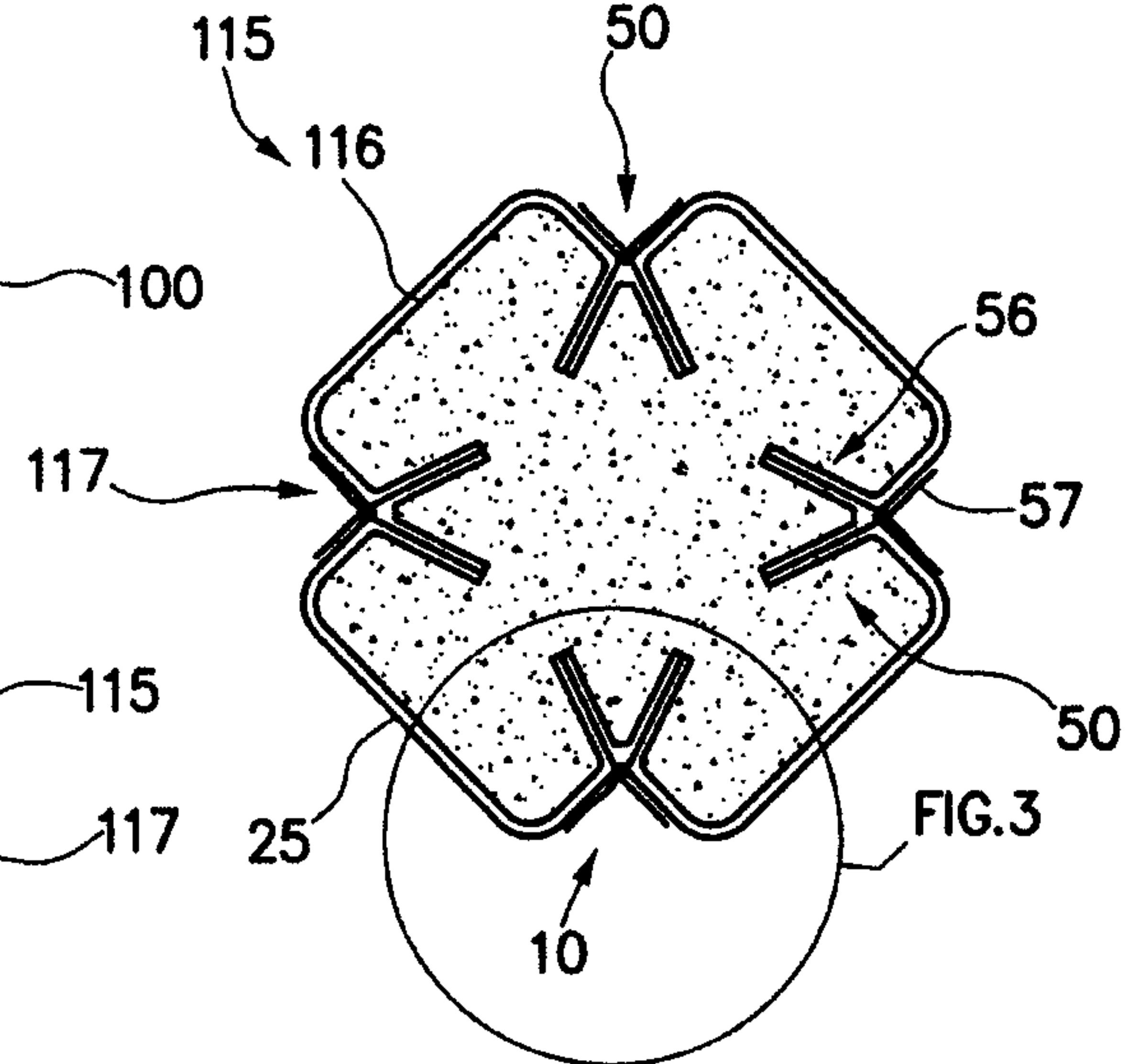


FIG. 3

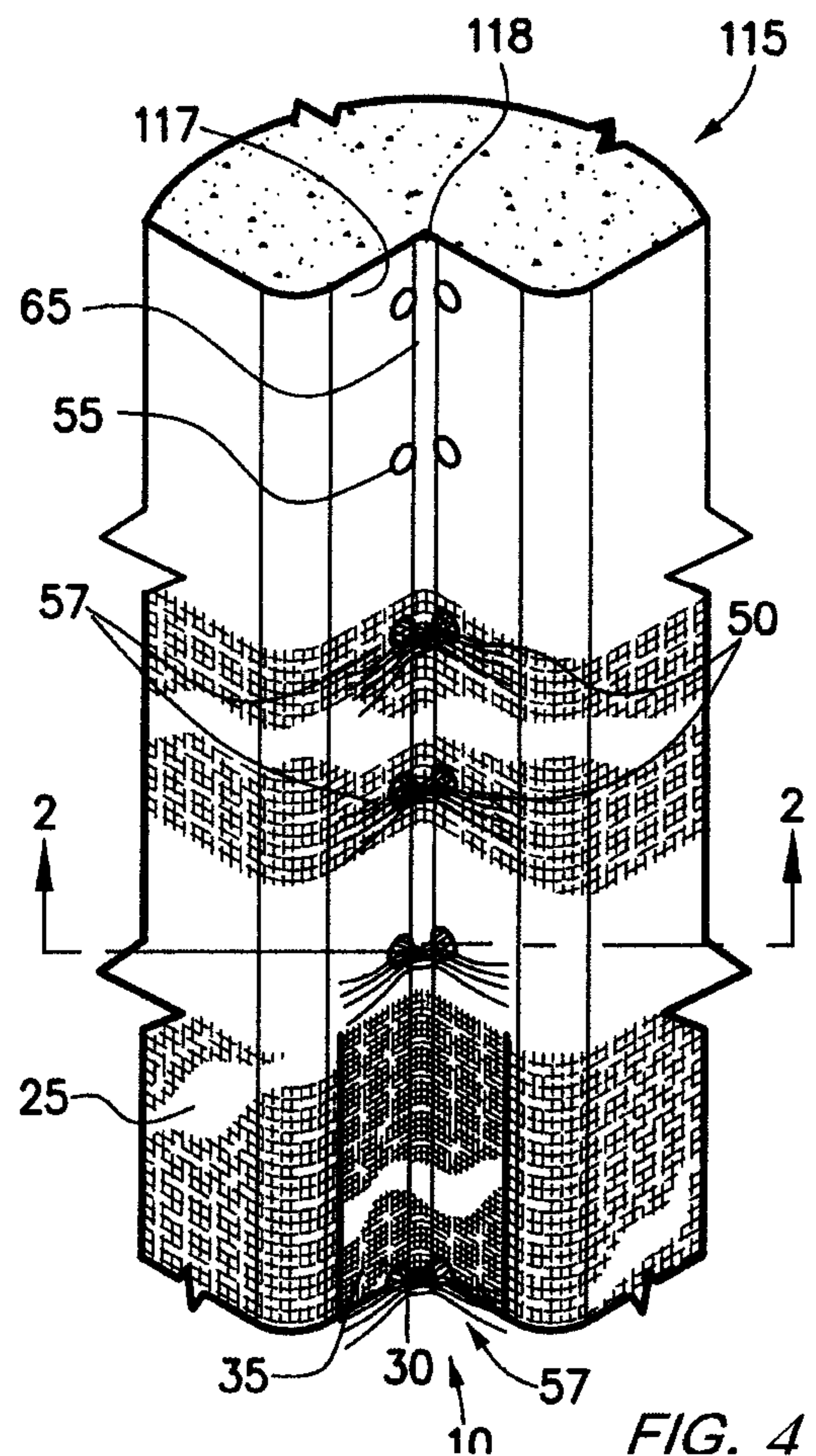


FIG. 4

