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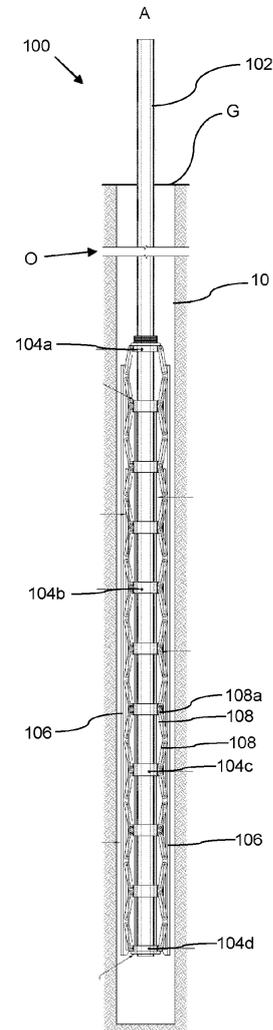
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(54) **PILE OR GROUND ANCHOR FOR A STRUCTURE**

(57) A pile or ground anchor (100, 200, 300) for a building or structure, comprising an elongate shaft (102, 202, 302) having a longitudinal axis (A) for positioning in a borehole (10, 20, 30), two or more sidewalls (106, 206, 306) defining a substantially tubular structure surrounding a length of the elongate shaft for engaging the borehole, one or more connectors (104, 204, 304) disposed along the elongate shaft, connecting the sidewalls to the elongate shaft, at least some of the one or more connectors being moveable relative to or along the elongate shaft for moving the sidewalls, the sidewalls being moveable or extendible from i) a retracted configuration in which the sidewalls are disposed proximate to the shaft, the diameter of the tubular structure being suitable for insertion into the borehole, to ii) a deployed configuration in which the sidewalls are radially spaced from the longitudinal axis of the shaft, relative to the retracted configuration, in use the two or more sidewalls bearing against and substantially radially expanding a corresponding length of the borehole by movement into the deployed configuration, such that the diameter of the tubular structure in the deployed configuration is greater than the original diameter of the borehole.

**Figure 1**



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**Description****PILE OR GROUND ANCHOR FOR A STRUCTURE**

**[0001]** The present invention relates to a pile or ground anchor for a building or structure, and to methods for assembly and installation of the same.

**BACKGROUND TO THE INVENTION**

**[0002]** When constructing a new building or structure, such as a house or a tower block, it is generally necessary to first construct a suitable foundation in the ground to support the building. Similar considerations apply for other heavy structures such as wind turbines, or any other structure where the ground needs to be sturdy enough to support the structure without giving way.

**[0003]** In some cases, a deep foundation may be installed so that the subsoil bears the load of a structure. This may be necessary to support the expected load from a large building like a skyscraper, and/or due to poor ground structure or soil at shallow depths, for example.

**[0004]** A pile (or piling) is a structural element of a deep foundation system. A pile may be prefabricated and driven into the ground using a pile driver, or alternatively a borehole is drilled and the pile can be formed in situ, e.g. by pouring in concrete. A reinforcing cage or casing can be provided in the borehole. The 'drilled pile' option can be advantageous because it is not necessary to transport large, heavy piles to a construction site.

**[0005]** The length of a pile can vary from around 6m to around 50m or more. The length of the pile(s) used depends on the structure being supported, the loads expected to be applied, and the ground quality of the ground surrounding the pile. Whilst longer piles can confer the necessary strength to a deep foundation, they are more expensive to construct and install.

**[0006]** Different types of drilled piles are available. For example, an under-reamed pile which is an inverted conical shape has a larger base diameter than a straight-sided pile, allowing it to provide extra support, but only in certain types of ground. An augercast pile can be installed relatively quietly compared to other piles.. Helical piles anchor into the ground by relying on either the shear of the soil in tension, or direct bearing in compression. Other types of pile are available, and may be selected according to the ground or soil conditions available at a particular site.

**[0007]** In some cases, a ground anchor may be suitable to provide support for a structure. Soil anchors and rock anchors are both types of ground anchor. A ground anchor can be driven into the ground or simply buried. The soil over the anchor secures it in place. A ground anchor is typically conical or frustoconical in shape, so that upward soil compression from lifting forces enhances resistance against movement of the ground anchor.

**[0008]** Typically a ground anchor is suitable for a structure like a retaining wall, a temporary structure such as

an excavation pit, a radio tower, a telephone pole and other smaller structures where a deep foundation is unnecessary. The capacity of a ground anchor to resist tension and compression is generally quite limited, relative to a deep foundation, and is affected by the ground conditions of the ground it is installed in.

**[0009]** It is an object of the present invention to reduce or substantially obviate the aforementioned problems.

**10 STATEMENT OF INVENTION**

**[0010]** According to a first aspect of the present invention, there is provided a pile or ground anchor for a building or other structure, the pile or ground anchor comprising:

an elongate shaft having a longitudinal axis for positioning in a borehole,  
two or more sidewalls defining a substantially tubular structure surrounding a length of the elongate shaft for engaging the borehole for generating skin friction, one or more connectors disposed along the elongate shaft, connecting the sidewalls to the elongate shaft, at least some of the one or more connectors being moveable relative to or along the elongate shaft for moving the sidewalls,  
the sidewalls being moveable or extendible from i) a retracted configuration in which the sidewalls are disposed proximate to the shaft, the diameter of the tubular structure being suitable for insertion into the borehole, to ii) a deployed configuration in which the sidewalls are radially spaced from the longitudinal axis of the shaft, relative to the retracted configuration, in use the two or more sidewalls bearing against and substantially radially expanding a corresponding length of the borehole by movement into the deployed configuration, such that the diameter of the tubular structure in the deployed configuration is greater than the original diameter of the borehole.

**[0011]** This provides a revolutionary type of deep foundation system, which can carry both compressive and tensile loads. The depth at which the apparatus (whether as pile or ground anchor) needs to be installed or embedded in the ground is significantly reduced compared to conventional piles, saving on time and cost. The number of piles required for a particular foundation can also be reduced. This is because the outer wall of the apparatus is designed to substantially expand when inside the bore hole, when suitable force is applied (typically via a tensioning action), thereby expanding the borehole itself and anchoring the apparatus onto the borehole wall. This can be done to a predetermined (or designed) compression stress.

**[0012]** The expansion of the system onto the borehole wall augments the natural occurring soil pressures, providing a significant increase in skin friction compared to conventional skin friction piles. It has been found that a

pile of the present invention can provide an enhancement of up to 5 times greater skin friction than a conventional pile. A ground anchor of the present invention has enhanced skin friction for most types of ground conditions found in clays, granular substrates and rocks.

**[0013]** The increased compression stress significantly increases the skin friction, due the increase in the mobilised stress in the soil by a factor  $F_{PILE}$  depending on the soil and stress applied varying from  $F_{PILE} = 1/K_a$  (roughly an increase of two to three times that of conventional piles) to  $F_{PILE} = 1/K_p$  (increase five or more times that of conventional piles).

**[0014]** Skin friction can be calculated in a conventional manner, so the load bearing capacity of the pile or ground anchor can be estimated prior to installation.

**[0015]** For example, it has been found that on a 10.0m embedment into granular substrate, a 600mm diameter embodiment of a pile according to the present invention will generate three times the skin friction of a conventional PFA pile of the same diameter.

**[0016]** If installed in firm clays, the skin friction enhancement can vary from between two to five times the skin friction of that of a conventional CFA pile of the same diameter.

**[0017]** If installed in rocks or rocky ground, a pile or ground anchor according to the invention has significantly increased skin friction compared to the recommended values for conventional rock sockets by Rosenberg & Journeaux or Williams & Pell and/or others. The increase is directly proportional to the applied torque (when tensioning during installation) and the generated friction increase to conventional rock sockets can be from two to five times greater.

**[0018]** The pile or ground anchor of the present invention is suitable for use in most soil and rock formations. However, it is not recommended for a) areas where liquefaction is likely, even if the bore has been concreted or grouted due to the possibility of loss of tension; and b) in very weak soils or soil depths with standard penetration test values lower than 5.

**[0019]** The pile or ground anchor of the present invention is unsuitable for use where the required tensile actions when tensioning the pile or ground anchor exceed the shear capacity generated from a) the overburden stress of the sidewalls against the borehole wall, together with b) any shear strength in the soil.

**[0020]** A pile or ground anchor according to the present invention can be used in any conventional piling application. It has enhanced capacity relative to all existing friction based piling systems, and significantly higher tensile capacity generation relative to existing ground anchor systems.

**[0021]** Examples of possible applications include use for: a building foundation; stabilising a retaining wall or temporary structure; a wind farm tower; and high tensile load applications (as a ground anchor).

**[0022]** The present invention may be used to reduce tensile stresses in reinforced concrete buildings from the

effects of wind gusts and/or earthquakes. This can be done by tying pre-stressing reinforcement from the pile or ground anchor into the main structure of the building. The present invention may be used to substitute helical piles which have limited capacity in lightweight anchoring applications.

**[0023]** Some embodiments of the pile or ground anchor may be used for underpinning application as the apparatus can be tensioned at an angle or even eccentrically.

**[0024]** Some embodiments of the pile or ground anchor can have continuity pre-stressing into the substructure or main supports in a building or other structure (e.g. a wind turbine or tower) for reducing dynamic loading impact effects.

**[0025]** The pile or ground anchor of the present invention may be considered to be modular. That is, the pile or ground anchor can be fabricated at a length which includes only the number of modules required to support the structure it is intended for. The length of the expansion system can be selected such that the shaft does not distort during tensioning, that is when the sidewalls of the pile are being moved outwards from the shaft.

**[0026]** The substantially tubular structure may provide a substantially cylindrical area for maximising friction between the sidewall and the borehole.

**[0027]** This allows for even distribution of forces around the apparatus. This enables suitable calculations regarding skin friction and thus the required size of apparatus for a particular application.

**[0028]** Note that whilst the apparatus includes two or more sidewalls, the sidewalls collectively form an outer wall of the pile or ground anchor. Two or more sidewalls are used to enable the sidewalls to move apart into the deployed configuration, whilst generating bearing forces against the borehole wall.

**[0029]** The sidewalls may each have an external curvature which substantially matches the internal curvature of the borehole wall (or a relevant portion thereof). This provides a more uniform application and distribution of stress during and application deployment of the sidewalls against the borehole wall.

**[0030]** The one or more connectors may include one or more collars. Each collar may comprise a plurality of bosses. The bosses may be arranged around the exterior of the collar(s). A plurality of spokes may be pivotably connected to the plurality of bosses. The sidewalls may each comprise a plurality of pile walls for each collar. The plurality of spokes may be pivotably connected to the plurality of pile walls.

**[0031]** This provides a mechanism where the bossed collars can move along the shaft, with the spokes pivoting to radial positions as the collars move. The pile walls thus move radially outwards from the shaft, and expand the borehole when using suitable force.

**[0032]** It will be appreciated that the pile walls may or may not be in contact with each other in the retracted configuration. In some embodiments, the pile walls may be spaced from each other in the deployed configuration,

whilst still having an overall arrangement which is cylindrical.

**[0033]** Each spoke may be a slat. If additional stiffness and/or buckling resistance is required, each spoke may include one or more recesses or channels, for example having a rectangular or square cross-section along the length of the spoke (terminating prior to ends of the spoke which are for connection to a connector or pile wall).

**[0034]** Each pile wall may be connected to an outer end of a spoke. The connection may be provided by a pin or locking pin. The pins may be a rod clevis type pin, with a groove at one end and secured with a circlip. Other clevis type pins, e.g. threaded at one end, or bolts with a washer and nuts, may be used if suitable for the size of the apparatus.

**[0035]** Each pile wall may be adapted to grip into the soil or rock. The pile walls generate the required skin friction of the apparatus once deployed in the borehole. The level of skin friction generated is affected by the force or torque applied and the extent to which the sidewalls are deployed.

**[0036]** Each pile wall may have a curved or convex outer side for matching the curvature of the interior borehole wall. Each pile wall may be curved relative to a longitudinal axis of the shaft.

**[0037]** A cable may be provided through the elongate shaft. At least some of the connectors may include a cable gripping portion engaged with the cable. A cable locking element may be connected or connectable to the cable for securing the cable in tension after deployment of the sidewalls.

**[0038]** This enables deployment of the sidewalls by tensioning the cable. This is preferably done by hydraulic means. Pulling the cable upwards in an axial direction causes the sidewalls to move outwards in a radial direction (relative to the shaft). The cable grips interconnect the connectors so that they can move substantially in concert along (or up) the cable as tension is applied to the cable. Deployment typically requires cable tensioning by hydraulic means.

**[0039]** An elongate sleeve may be connected or connectable to the uppermost connector on the elongate shaft. During installation, one of the elongate shaft and sleeve may be adapted to be moveable by rotation or translation relative to the other of the elongate shaft and sleeve. The other of the elongate shaft and sleeve may be securable against the corresponding rotation or translation.

**[0040]** The sleeve is intended to be connected to the pile after it has been placed in the borehole, although it can be connected at any suitable stage. Since the uppermost connector is disposed below the surface of the ground, typically by at least a few metres, the sleeve is long enough to connect to it and also extend sufficiently towards or above the ground surface for applying force to the sleeve for pile installation (either to move the sleeve whilst the shaft is kept in place, or to keep the sleeve in place whilst the shaft is moved).

**[0041]** A split gear or other securing means may be provided on the sleeve for securing the sleeve against movement. A second gear may be provided on the shaft for use in rotating the shaft to deploy the sidewalls. A locking nut may be provided on the shaft for locking the shaft against rotation after deployment of the sidewalls. That is, to prevent the loss of tension which has been applied. The connectors may each have a threaded connection to the shaft, such that rotation of the shaft causes movement of the connectors along or relative to the shaft.

**[0042]** This enables deployment of the sidewalls by rotation of the shaft relative to the sleeve. In other words, rotating the shaft about its longitudinal axis causes movement of the side walls radially outwards from the shaft.

This is due to movement of the one or more connectors along (up or down) the shaft as it rotates. The method of installation is similar to that of a bored pile, typically requiring relatively high torque to turn the shaft.

**[0043]** A split collar or other securing means may be provided on the shaft for securing the shaft against movement. Ribs or other engagement means may be provided at an upper end of the sleeve for use in moving the sleeve to deploy the sidewalls.

**[0044]** This enables deployment of the sidewalls by translation of the shaft relative to the sleeve. In other words, pulling (or pushing) the sleeve relative to the shaft causes movement of the side walls radially outwards from the shaft. This is due to movement of the connectors which are interconnected for transferring the applied force or torque, e.g. by the spoke arrangement. Deployment typically requires a pulling or pushing the sleeve using hydraulic means.

**[0045]** The elongate shaft may include a plurality of apertures arranged around the shaft. A clutch or locking means may be provided for securing the sidewalls against movement.

**[0046]** This allows the connectors to be locked in place after sidewall deployment (whether by cable, by shaft rotation, by pulling the sleeve upwards, or by other means) below the surface of the ground. It is not necessary to also apply a locking means at the top of the shaft or sleeve, because the connectors are engaged with the shaft further down.

**[0047]** The clutch (or locking means) may include a plurality of locking elements disposed around the shaft for engaging the apertures in the shaft. The clutch or locking means may include a mechanism or biasing arrangement for moving the locking elements into engagement with the apertures of the elongate shaft, when the locking elements are aligned with the apertures in the shaft. A clutch may be provided on one, some or all of the connectors.

**[0048]** The clutch may engage the shaft apertures once the predetermined tension or compression stress has been applied. The shaft apertures may be provided along the length of the shaft, or in one or more positions which correspond to the position the connector(s) will be once the predetermined tension or compression stress

has been reached during installation.

**[0049]** A plurality of placeholder elements may occupy the plurality of apertures. The elongate shaft may be hollow. An elongate rod may be provided within the hollow elongate shaft for preventing displacement of the placeholder elements from the apertures.

**[0050]** When the locking elements are aligned with the apertures in the shaft during installation of the pile or ground anchor in a borehole, the clutch or locking means may be configured to move the locking elements into the apertures. This may simultaneously displace the placeholder elements when the elongate rod is (being) removed from the shaft, for locking the sidewalls in the deployed configuration.

**[0051]** Using a rod or secondary shaft within the main shaft prevents, in combination with the sacrificial placeholder units, the clutch from engaging the shaft before the sidewalls have been deployed to the desired extent. The rod or secondary shaft needs to have an external diameter which is close to the internal diameter of the main shaft to prevent the placeholder elements being partially displaced and the clutch partially engaging the shaft apertures.

**[0052]** The rod should be elongate enough to extend along the inside of all of the through apertures in the shaft containing the placeholder elements which are expected to be displaced by the clutch.

**[0053]** It is envisaged that the clutch might be operable by other means, without using a rod or placeholder elements. For example, a motor may be used to move the clutch into engagement with the shaft once signalled to do so, or there may be a catch or similar device in the biased clutch that can be released on demand, when the clutch is in position. However, such options are envisaged to be more costly and potentially less reliable than the rod and sacrificial / placeholder elements, which is why the rod and placeholder elements are generally preferred.

**[0054]** An expandable liner may be provided around the substantially tubular structure. For example, a UV-cured GRP liner or resin liner may be provided. However, other kinds of expandable liners may be used in other cases.

**[0055]** The liner helps to prevent soil collapse through gaps between the pile walls when the pile walls have been moved outwards into the second configuration in the borehole. In some embodiments, it may be possible to provide liner elements between the pile walls, and as the pile walls become separated during deployment the liner elements fill gaps between the pile walls.

**[0056]** According to a second aspect of the present invention, there is provided a method of manufacturing a pile or ground anchor for a building or other structure (particularly a pile or ground anchor according to the first aspect of the invention). The method comprises the steps of:

- a) providing an elongate shaft having a longitudinal

axis;

- b) connecting one or more connectors to the elongate shaft, the one or more connectors being movable relative to or along the elongate shaft once connected;

- c) connecting two or more sidewalls to the one or more connectors such that the sidewalls define a substantially tubular structure surrounding a length of the elongate shaft for engaging a borehole, and the two or more sidewalls are moveable or extendible from i) a retracted configuration in which the sidewalls are disposed proximate to the elongate shaft, the substantially tubular structure having a first diameter in the retracted configuration, to ii) a deployed configuration in which the sidewalls are radially spaced from the longitudinal axis of the elongate shaft, relative to the retracted configuration, the substantially tubular structure having a second larger diameter in the deployed configuration; and

- d) optionally, releasably securing or locking the two or more sidewalls in the retracted configuration.

**[0057]** This provides a prefabricated pile which is ready for installation in a pre-drilled (or excavated) borehole. It is significantly lighter for transport than a conventional prefabricated pile which would be driven into the ground. There are also similar advantages to the first aspect of the invention.

**[0058]** The length of the shaft and the number of connectors used can advantageously be selected based on the intended application, including expected structure load, ground conditions and suitable tolerances. Thus the apparatus can be constructed more or less in a modular manner, where the shaft length and corresponding number of connectors are customised for a particular installation, whilst the general principle on which the apparatus operates remains the same.

**[0059]** According to a third aspect of the present invention, there is provided a method of installing, in a borehole, a pile or ground anchor for a building or other structure. The method comprises the steps of:

- a) providing a pile or ground anchor according to the first aspect of the invention, in which the two or more sidewalls are in the retracted configuration, or providing a pile or ground anchor manufactured by the method of the second aspect of the invention;

- b) positioning the pile or ground anchor in the borehole, the borehole being wider than the diameter of the substantially tubular structure when the two or more sidewalls are in the retracted configuration; and

- c) applying a force or torque to the pile or ground anchor to move or extend the two or more sidewalls

outwards from the elongate shaft, from the retracted configuration to the deployed configuration, the force or torque being sufficient to cause the sidewalls to bear against and substantially radially expand a corresponding length of the borehole.

**[0060]** The advantages are similar to the first aspect of the invention. If a borehole has not been drilled or otherwise excavated in advance, it may be created in the course of the installation of the apparatus. The borehole should be around 10-20% wider than the diameter of the pile or ground anchor with its sidewalls in the retracted configuration

**[0061]** If the sidewalls are secured in the retracted configuration prior to installation, whatever securing means has been used may be removed or released before the pile or ground anchor is positioned in the borehole.

**[0062]** Alternatively, if a frangible device or similar has been used, then the force or torque applied during installation may be sufficient to overcome the securing force during deployment, but it should be ensured that this does not damage the sidewalls or adversely affect concerted deployment of the sidewalls.

**[0063]** Once the pile or ground anchor has had its sidewalls deployed, it can be grouted for securing the apparatus in place. This may be done through the middle of the shaft, or via the inside of the connector(s), or from the sides (e.g. if the shaft is perforated) if appropriate.

**[0064]** The apparatus may in some cases include reinforcement elements for enhancing its moment capabilities. For example, individual reinforcement bars may be pushed through gaps in the spokes. The spokes provide some shear capacity, but at higher levels a conventional reinforcement cage with shear reinforcement can be lapped to bars finishing above the top connectors to provide additional strength.

**[0065]** The apparatus may in some cases be lapped or joined with a separate tensile system in order to provide continuous tensile capacity above ground level. The tensile system may be in the form of strands, bars or cables which extend into the building or structure.

**[0066]** According to a fourth aspect of the present invention, there is provided a pile or ground anchor for a building or structure, comprising:

an elongate shaft for positioning in a borehole, including a plurality of apertures around the shaft;  
two or more sidewalls connected to the shaft;  
means for moving the sidewalls outwardly from the shaft for engaging the borehole, such as: one or more connectors disposed along the elongate shaft, connecting the sidewalls to the elongate shaft, at least some of the one or more connectors being moveable relative to or along the elongate shaft for moving the sidewalls outwardly from the shaft for engaging the borehole; and  
a clutch or locking means for securing the sidewalls against movement, the clutch or locking means be-

ing connected to the means for moving the sidewalls, and including a plurality of locking elements disposed around the shaft, and a mechanism or biasing arrangement for moving the locking elements into engagement with the apertures of the elongate shaft when the locking elements are aligned with the apertures in the shaft.

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**[0067]** The apparatus has similar advantages to the first aspect of the invention, particularly in terms of the clutch which latches into the shaft once a suitable tension or compression stress has been reached during installation. That is, the clutch (or clutches) engage with the shaft at the required depth to maintain the desired tensioning.

**[0068]** The shaft may be a hollow elongate shaft. A plurality of placeholder elements may occupy the plurality of apertures. An elongate rod may be disposed within the shaft for substantially preventing displacement of the placeholder elements.

**[0069]** In use, when the locking elements are aligned with the apertures in the shaft, the clutch system may be configured to displace the placeholder elements by moving the locking elements into the apertures upon or following removal of the elongate rod from the hollow elongate shaft.

**[0070]** According to a fifth aspect of the present invention, there is provided a method of manufacturing a pile or ground anchor for a building or structure (particularly a pile or ground anchor according to the fourth aspect of the invention). The method comprises the steps of:

a) providing an elongate shaft which includes a plurality of apertures around the shaft;

b) connecting one or more connectors to the elongate shaft, the one or more connectors being movable relative to or along the elongate shaft once connected;

c) providing a clutch or locking means around the elongate shaft, the clutch or locking means including a plurality of locking elements disposed around the shaft, and a mechanism or biasing arrangement for moving the locking elements into engagement with the apertures of the elongate shaft when the locking elements are aligned with the apertures in the shaft;

d) connecting two or more sidewalls to the one or more connectors, such that movement of the one or more connectors causes movement of the sidewalls outwardly from the elongate shaft for engaging a borehole; and

e) optionally, releasably securing or locking the two or more sidewalls against movement.

**[0071]** The advantages are similar to those of the sec-

ond and fourth aspects of the invention.

**[0072]** According to a sixth aspect of the present invention, there is provided a method of installing, in a borehole, a pile or ground anchor for a building or structure, the method comprising the steps of:

a) providing a pile or ground anchor according to the fourth aspect of the invention, or a pile or ground anchor manufactured according to the fifth aspect of the invention;

b) positioning the pile or ground anchor in the borehole;

c) applying a force or torque to the pile or ground anchor to move or extend the two or more sidewalls outwards from the elongate shaft; and

d) engaging the locking elements of the clutch or locking means with the apertures in the elongate shaft to secure the sidewalls against movement.

**[0073]** The advantages and features (whether or optional) are similar to the fourth and sixth aspects of the invention.

**[0074]** Any feature or features presented with respect to one aspect of the invention may be provided in any other aspect of the invention, unless explicitly indicated otherwise.

**[0075]** Note that any common boring technique, equipment and/or augering plant or device can be used to dig the required borehole(s) for receiving each pile or ground anchor according to the invention. The required borehole(s) can be determined by a conventional ground investigation and the recommendations of a competent geotechnical engineer based on their findings.

**[0076]** Where required, any of a bentonite clay slurry, Fuller's earth or a polymer slurry may be used in unstable strata, depending on the required expansion, until the pile or ground anchor has had tension applied and/or been concreted.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0077]** For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made by way of example only to the accompanying drawings, in which:

Figure 1 shows a cross-sectional side view of a first embodiment of a pile (or ground anchor) in a retracted configuration in a borehole;

Figure 1A shows an enlarged partial cross-sectional view of an upper end of the pile (or ground anchor) of Figure 1;

Figure 1B shows an enlarged partial cross-sectional

view of a mid-portion of the pile (or ground anchor) of Figure 1;

Figure 1C shows an enlarged partial cross-sectional view of a lower end of the pile (or ground anchor) of Figure 1;

Figure 1D shows a cross-sectional plan view of the pile (or ground anchor) of Figure 1 partway along the shaft, omitting certain elements for clarity;

Figure 2 shows a cross-sectional side view of the pile (or ground anchor) of Figure 1, which has been expanded into a deployed configuration in the borehole;

Figure 2A shows an enlarged partial cross-sectional view of an upper end of the pile (or ground anchor) of Figure 2;

Figure 2B shows an enlarged partial cross-sectional view of a mid-portion of the pile (or ground anchor) of Figure 2;

Figure 2C shows an enlarged partial cross-sectional view of a lower end of the pile (or ground anchor) of Figure 2;

Figure 2D shows a cross-sectional plan view of the pile (or ground anchor) of Figure 2 partway along the shaft, omitting certain elements for clarity;

Figure 3 shows a perspective view of a first type of collar of the pile (or ground anchor) of Figure 1;

Figure 4 shows a perspective view of a first type of threaded pinion of the pile (or ground anchor) of Figure 1;

Figure 5 shows a perspective view of a second type of collar of the pile (or ground anchor) of Figure 1;

Figure 6 shows a perspective view of a second type of threaded pinion of the pile (or ground anchor) of Figure 1;

Figure 7 shows a perspective side view of a sleeve for use in deploying the pile (or ground anchor) of Figure 1;

Figure 8 shows a perspective view of a first spur gear for use in deploying the pile (or ground anchor) of Figure 1;

Figure 9 shows a perspective view of a second spur gear for use in deploying the pile (or ground anchor) of Figure 1;

Figure 10 shows a cross-sectional side view of a second embodiment of a pile (or ground anchor) in a retracted configuration in a borehole;

Figure 10A shows an enlarged partial cross-sectional view of an upper end of the pile (or ground anchor) of Figure 10; 5

Figure 10B shows an enlarged partial cross-sectional view of a mid-portion of the pile (or ground anchor) of Figure 10; 10

Figure 10C shows an enlarged partial cross-sectional view of a lower end of the pile (or ground anchor) of Figure 10; 15

Figure 10D shows a cross-sectional plan view of the pile (or ground anchor) of Figure 10 partway along the shaft, omitting certain elements for clarity; 20

Figure 11 shows a cross-sectional side view of the pile (or ground anchor) of Figure 10, which has been expanded into a deployed configuration in the borehole; 25

Figure 11A shows an enlarged partial cross-sectional view of an upper end of the pile (or ground anchor) of Figure 11;

Figure 11B shows an enlarged partial cross-sectional view of a mid-portion of the pile (or ground anchor) of Figure 11; 30

Figure 11C shows an enlarged partial cross-sectional view of a lower end of the pile (or ground anchor) of Figure 11; 35

Figure 11D shows a cross-sectional plan view of the pile (or ground anchor) of Figure 11 partway along the shaft, omitting certain elements for clarity; 40

Figure 12 shows a perspective view of a first type of collar of the pile (or ground anchor) of Figure 10;

Figure 13 shows a perspective view of a second type of collar of the pile (or ground anchor) of Figure 10; 45

Figure 14 shows an enlarged partial cross-sectional view of a portion of Figure 11B; 50

Figure 15 shows a cross-sectional side view of a third embodiment of a pile (or ground anchor) in a retracted configuration in a borehole; 55

Figure 15A shows an enlarged partial cross-sectional view of an upper end of the pile (or ground anchor) of Figure 15;

Figure 15B shows an enlarged partial cross-sectional view of a mid-portion of the pile (or ground anchor) of Figure 15;

Figure 15C shows an enlarged partial cross-sectional view of a lower end of the pile (or ground anchor) of Figure 15;

Figure 15D shows a cross-sectional plan view of the pile (or ground anchor) of Figure 15 partway along the shaft, omitting certain elements for clarity;

Figure 16 shows a cross-sectional side view of the pile (or ground anchor) of Figure 15, which has been expanded into a deployed configuration in the borehole;

Figure 16A shows an enlarged partial cross-sectional view of an upper end of the pile (or ground anchor) of Figure 16;

Figure 16B shows an enlarged partial cross-sectional view of a mid-portion of the pile (or ground anchor) of Figure 16;

Figure 16C shows an enlarged partial cross-sectional view of a lower end of the pile (or ground anchor) of Figure 16;

Figure 16D shows a cross-sectional plan view of the pile (or ground anchor) of Figure 16 partway along the shaft, omitting certain elements for clarity;

Figure 17 shows a perspective side view of a perforated shaft of the pile (or ground anchor) of Figure 15;

Figure 18 shows an exploded perspective view of a first type of collar of the pile (or ground anchor) of Figure 15;

Figure 19 shows a perspective view of a second type of collar of the pile (or ground anchor) of Figure 15;

Figure 20 shows a perspective view of a third type of collar of the pile (or ground anchor) of Figure 15;

Figure 21 shows a perspective view of a fourth type of collar of the pile (or ground anchor) of Figure 15;

Figure 21A shows a perspective view of a clutch mechanism of the collar of Figure 21;

Figure 22 shows a perspective view of a sleeve for use in deploying the pile (or ground anchor) of Figure 15;

Figure 23 shows a perspective view of a split collar for use in deploying the pile (or ground anchor) of Figure 15;

Figure 24A shows an enlarged partial cross-sectional side view of the collar of Figure 21 in a first position depicted in the pile (or ground anchor) of Figure 15; and

Figure 24B shows an enlarged partial cross-sectional side view of the collar of Figure 21 in a second position depicted in the pile (or ground anchor) of Figure 16.

## DESCRIPTION OF PREFERRED EMBODIMENTS

**[0078]** The present invention can be implemented in a variety of different ways, based on the general principle of expanding the pile or ground anchor within a borehole to generate skin friction and secure the apparatus in the borehole. Three exemplary embodiments are described below and illustrated in the Figures, including:

a) a 'mechanical' embodiment, where a tapped bar is screwed from above with torque using manual or hydraulic techniques similar to a helical pile, until desired movement or torque is reached and the apparatus is locked in place;

b) a 'pre-stressed' embodiment, with collars being pulled on a tubular sleeve until the required stress or full stress is achieved, at which stage the apparatus is locked in place; and

c) a second 'mechanical' embodiment, with a tapped bar at the bottom and ribs for gripping at the top, where a sleeve is screwed onto the top of the system and pulled up (or pushed down as the case may be) until desired movement or stress is reached and a clutch engages the main shaft.

**[0079]** The embodiments described below each include a shaft (also referred to as a rod, tube or bar) as a central element, a number of floating and/or fixed connectors, spokes connected or pinned to bosses on the connectors, and pile walls on the other ends of the spokes.

**[0080]** The general principle of the apparatus operation is that the floating connectors can move relative to the fixed connectors over or along the shaft when suitable force/torque is applied to the relevant part(s) of the apparatus. The movement of the floating connectors relative to the fixed connectors results in the flattening of the spoke angles and consequential expansion of the side-walls outwards from the shaft.

**[0081]** Where steel is used for the fabrication of parts such as a shaft or sleeve, the steel should generally be grade S275J0 steel or better, conform to EN 10025-

P2:2004, and have yield strength appropriate for the required installation. Stainless steel or GRP may be used in place of steel.

**[0082]** Where steel is used for the fabrication of plated members, the steel should conform to EN 1090-1 :2009 Class II.

**[0083]** Where lock pins are used, the lock pins should have mechanical properties in accordance with EN ISO 898-1.

**[0084]** Fabrication of the pile or ground anchor should be done in accordance with EN 1090-2:2008.

**[0085]** Structural steelwork should be grade S275J0 or better, conform to EN 10025-P2:2004, and have yield strength appropriate for the required installation.

**[0086]** Where welding is carried out, the welding consumable(s) should be at a minimum class 42 to BS 5950-P2.

**[0087]** The following embodiments are described as piles for brevity, but it will be appreciated that the term ground anchor is also applicable.

### Embodiment 1 - Structure

**[0088]** Figures 1 to 1D show a first embodiment of an apparatus for use as a pile or ground anchor in a retracted configuration, indicated generally at 100. The apparatus 100 is shown positioned in a borehole 10. The diameter of the borehole 10 is slightly wider than the maximum diameter of the apparatus 100 in its retracted state. The borehole 10 is created in the ground in a known manner. The borehole 10 is initially substantially cylindrical as shown in Figure 1.

**[0089]** The apparatus 100 includes a central elongate shaft 102. Figure 1A shows the top of the shaft 102 above the pile cut-off level (or ground level (G)) in more detail. A mid-section of the shaft is omitted from Figure 1 so that the rest of the apparatus 100 fits on the page, but it will be appreciated that the omitted portion (O) of the elongate shaft 102 is substantially similar to the neighbouring portions of the shaft 102 which are depicted just above and below the omitted section. The shaft 102 is externally-threaded in this embodiment. The shaft 102 may be solid or hollow. The shaft 102 extends out of the open (upper) end of the borehole 10 when the apparatus 100 is in the borehole 10. A lower end of the apparatus 100 is spaced from the closed (lower) end of the borehole 10.

**[0090]** In this embodiment, the shaft 102 is tubular and made from CHS steel. It is tapped on the outside for pinions to screw on. In other embodiments, particularly for smaller pile diameters, the shaft may be made from a proprietary solid bar like a Macalloy post-tensioning bar.

**[0091]** A plurality of connectors 104 are threaded onto the shaft 102. In this embodiment, there are eleven connectors 104. The uppermost connector, indicated at 104a, is described in further detail in Figure 3. Intermediate connectors, examples of which are indicated at 104b and 104c, are described in further detail in Figures 4 and 5 respectively. The lowermost connector, indicated

at 104d, is described in further detail in Figure 6.

**[0092]** The apparatus 100 includes a plurality of pile walls (or ground anchor walls), indicated generally at 106. The walls 106 may be considered to be a plurality of sidewalls of the apparatus. The sidewalls 106 are together arranged to provide substantially cylindrical or tubular structure in the retracted configuration, although it will be appreciated that there may be spaces between the pile walls in some embodiments.

**[0093]** A subset of the sidewalls 106 is connected to each connector 104. The pile walls 106 are spaced around each connector. In this embodiment, there are sixteen pile walls 106 equidistantly spaced around each connector 104. Each pile wall 106 has a curved outer surface for matching the internal curvature of the borehole 10. The curved surface is a curved section of a sidewall of a cylinder. The surface is substantially uniform for equal distribution of force.

**[0094]** It will be appreciated that the length of the arc of the curved surface around the inside of the borehole may depend on the number of pile walls and the extent to which the pile wall moves from the retracted configuration to the deployed configuration. The pile walls may also be sized according to the soil type and the size of the apparatus 100. The curved pile walls are shown to be in side-by-side engagement in the retracted configuration (see Figure 1D).

**[0095]** Each side wall 106 is connected to its respective connector 104 by a spoke or a slat 108. Each spoke or slat 108 is pivotably (or adjustably) connected at one end to a particular side wall 106, and pivotably (or adjustably) connected at the other end to a particular connector 104. Locking pins 108a are used to secure the spokes 108 at each of their ends.

**[0096]** The spokes 108 are provided in a radial arrangement relative to a longitudinal axis (A) of the central shaft 102 (see Figures 1D and 2D).

**[0097]** A UV-cured GRP liner 110 can be provided around the exterior of the pile walls 106. The liner is shown in Figures 1D and 2D. The liner may be substantially cylindrical when disposed around the pile walls. In some other embodiments, the liner may be provided on an interior surface of the borehole 10 instead. When the apparatus 100 is expanded into the deployed configuration, the liner expands as the pile walls 106 are deployed and prevents soil collapse between the pile walls 106 as the borehole is expanded by the apparatus 100.

**[0098]** Figure 1B shows the connectors 104 on the shaft in more detail. The top connector 104a is a collar (or boss collar) which is illustrated in Figure 3. The top collar 104a includes a cylindrical portion with an external thread for receiving a sleeve with a corresponding internal thread. The collar includes a plurality of bosses or apertured flanges 112 which are spaced apart around the collar for a subset of the spokes 108 to connect to.

**[0099]** The collar can be fabricated by welding a tapped collar to a circular hollow section. A capping plate is fabricated from a flat plate and welded on top of the circular

hollow section. Brackets are fabricated from flat plates and holes drilled in the required positions. The brackets are then welded equidistantly around the circular hollow section.

**[0100]** Intermediate connectors 104 are shown in Figures 4 and 5. The connector 104b in Figure 4 has a cylindrical body 114 with an internal thread 116. The connector 104b is an internally-threaded pinion. A plurality of bosses or apertured flanges 118 are spaced around the exterior of the pinion 104b. The flanges 118 each include two apertures for connection to respective pairs of spokes 108 via a locking pin 108a. A plurality of further apertures 120 are provided on one or both sides of the pinion 104b for receiving spacer elements or struts 122, e.g. see Figure 1B.

**[0101]** Note that a plurality of apertures may similarly be provided on the underside of the top connector 104a for receiving spacer elements or struts. Such apertures are depicted in Figure 1D. The struts 122 are indicated in Figure 1, and are secured in place between the connectors 104. For example, the struts may be welded in place.

**[0102]** The pinion 104b can be fabricated by casting a circular hollow section which is then internally tapped to correspond to the thread on the shaft 102. The openings 120 are formed during casting for receiving the spacer struts. A plurality of brackets are fabricated from flat plates and pairs of holes then drilled in the required positions. The brackets can then be welded to the circular hollow section.

**[0103]** The connector 104c in Figure 5 is substantially similar to the connector 104b in Figure 4, but it is a collar (or boss collar) which does not include an internal thread within its cylindrical body.

**[0104]** In this embodiment, for the intermediate connectors, there will be  $n$  collars (of the type shown in Figure 5) and  $n+1$  pinions (of the type shown in Figure 4), plus the top collar and end pinion. This may be applied more generally to other embodiments as well. The two types of intermediate connectors 104b, 104c may be provided in an alternating arrangement along the shaft 102.

**[0105]** Figure 1C shows the lower end of the apparatus 100 in more detail. Some of the connectors 104 shown are the connectors of Figures 4 and 5. However, the lowermost connector 104d is that of Figure 6. The lowermost connector 104d is a pinion which includes a cylindrical body 124 with an internal thread for connection to the shaft 102. The pinion includes a plurality of bosses or apertured flanges 126 which are spaced apart around the collar for a subset of the spokes 108 to be connected to. A plurality of further apertures 128 are provided on the pinion 104d for receiving spacer elements or struts 122.

**[0106]** The pinion 104d can be fabricated by casting a circular hollow section and then internally tapping it to correspond to the thread on the shaft 102. A capping plate can be fabricated from a flat plate and welded on top of the circular hollow section. Brackets can be fabri-

cated from flat plates and holes then drilled in the required positions. The brackets can then be welded around the circular hollow section.

**[0107]** It will be appreciated from Figures 1 and 1B that for intermediate connectors 104 which are disposed between the first and last connectors 104 on the shaft 102, a given pair of spokes 108 may be connected to the same pile wall 106 but connected to different (typically adjacent) connectors 104. A given pair of laterally-adjacent spokes 108 connected to the same connector 104 may be connected to different (typically laterally-adjacent) pile walls 106. A given pair of vertically-adjacent spokes 108 connected to the same connector 104 may be connected to different (typically vertically-adjacent) pile walls 106.

**[0108]** Figures 2 to 2D show the apparatus 100 of Figure 1 in a deployed configuration, indicated generally at 100'. The sidewalls 106 have been moved outwards such that the spokes 108 are now horizontal and parallel to each other, rather than in a zig-zag arrangement. The pile walls 106 have, due to the application of suitable force or torque, caused outward deformation of the borehole to provide an expanded borehole 10'. The walls of the borehole 10' are compressed and there is a predetermined skin friction between the apparatus sidewalls 106 and the borehole 10'.

**[0109]** Note that the angled sides of the borehole wall are illustrative of the difference in borehole diameter between initial and expanded states, rather than being strictly determinative of the way that the borehole 10' will be structured.

**[0110]** Figure 2A shows the top of the shaft 102 above the pile cut-off level (G) in more detail. A sleeve (or tube) 130 has been screwed onto the external thread of the uppermost connector 104a. The sleeve 130 is coaxial with the shaft 102. A mid-section of the sleeve 130 is omitted from Figure 2 so that the rest of the apparatus 100 fits on the page. However, the sleeve 130 is shown in Figure 7, having a substantially cylindrical elongate body. The sleeve 130 includes an internal thread 130a at one end, for connection to the thread on the uppermost connector. The sleeve 130 also includes a plurality of holes or perforations 130b at its other end. In this embodiment there are sixteen holes 130b arranged in four columns running parallel to the longitudinal axis of the sleeve 130, and spaced equidistantly around the sleeve sidewall.

**[0111]** The sleeve 130 can be fabricated from a circular hollow section. It can then be internally tapped at its bottom end to correspond to the external thread of the top connector 104a. Perforations are then provided at or near the other end for connection to a split spur gear (see below). Note that the number of perforations can be selected according to the torque which will need to be applied during installation of the apparatus 100.

**[0112]** A split spur gear 132 is shown engaged with the upper end of the sleeve 130 in Figures 2 and 2A. The split spur gear 132 is shown in two halves in Figure 9. The gear 132 includes a first half-cylindrical portion 134

and a second half-cylindrical portion 136 which are shaped to together surround the upper end of the sleeve 130. The split spur gear includes a plurality of spurs or elongate ridges and troughs 132b provided at its external sidewall. Each portion 134, 136 has eight protrusions or pins 138 (some of which are visible and some of which are not) which correspond to the apertures 130b in the sleeve 130. There are two columns of four protrusions 138 on each portion 134, 136 in this embodiment. It will be appreciated that the exact location on the concave surface of the portions 134, 136 is not critical, but the columns are located approximately one quarter and three quarters of the way round the interior surface of the relevant portion 134, 136.

**[0113]** The two halves of the split spur gear 132 can be fabricated by casting. This allows it to be detached from the sleeve 130 without losing tension in the apparatus once the apparatus 100 is taut, i.e. once deployed to the extent required within the borehole 10. However, it is not essential to provide a split or detachable spur gear, or even a device which is separate from the sleeve 130, as long as the upper end of the sleeve is adapted for receiving or being engaged by means which can assist in holding the sleeve against movement or rotation.

**[0114]** A locking nut 140 is threaded onto the shaft 102 at a position above the split spur gear 132. The locking nut 140 is shown spaced from the split spur gear 132. In this embodiment, the nut 140 comprises a hexagon nut and locking nut, but any suitable locking nut may be used.

**[0115]** A spur gear 142 is threaded onto the shaft 102 just above the locking nut 140. The spur gear 142 can be fabricated by casting. The spur gear 142 can be locked by the locking nut 140 when screwed onto the shaft.

**[0116]** The spur gear 142 is shown in more detail in Figure 8. The spur gear 142 includes a substantially cylindrical body 142a which has an internal thread, and a plurality of spurs or elongate ridges and troughs 142b provided at its external sidewall. The spur gear 142 is used to apply torque (by any suitable means) to the shaft 102 and turn the shaft 102 to deploy the sidewalls 106, thereby expanding the borehole.

**[0117]** Figure 2B illustrates a deployed section of the apparatus 100' which approximately corresponds to the retracted section of Figure 1B. The sidewalls 106 are spaced from the shaft 102 and in engagement with the sides of the borehole 10'. The borehole 10' has been expanded at the sidewalls 106 to approximately 150-160% of its initial diameter. Rotation of the threaded shaft 102 has caused the connectors 104 to thread further along the shaft, in this case in an upwards direction. It will be appreciated that the lower end of the shaft 102 has migrated downwards, closer to the base of the borehole (compare Figures 2C and 1C).

**[0118]** Rotation of the shaft 102 has reduced the relative distance or separation between the uppermost connector 104a and the directly adjacent connector 104. Struts 122 are not provided between these two connectors to allow for this, but the struts 122 are provided be-

tween the other connectors 104 to help to transfer force between them for concerted threading along the shaft 102.

**[0119]** Note that the degree of borehole expansion is in general related to the length of the spokes and the degree to which the shaft 102 is rotated (and so the degree to which the spokes 108 approach the horizontal), and to the tension or compression stress being applied. The embodiments are generally designed such that maximum capacity is reached when the spokes are horizontal, since the side walls cannot be deployed further. The ratio of the retracted diameter to the deployed diameter of the apparatus is related to the maximum capacity, and can be selected according to the tension or compression stress required for a particular application.

**[0120]** Figure 2D depicts the deployed configuration of the apparatus 100' from above. There are now gaps between the sidewalls 106, but the liner 110 prevents soil collapse through the gaps during/after deployment of the sidewalls 106. Note that the spur gears 132, 142 and sleeve 130 are omitted from Figure 2D for clarity. The spokes 108 for the uppermost connector 104a are visible in Figure 2D but the spokes for subsequent connectors are hidden for clarity (or alternatively lie directly in line with but below the spokes 108 shown, although this is not essential).

#### Embodiment 1 - Assembly

**[0121]** To assemble the apparatus 100 in the configuration shown in Figure 1, the following steps can be carried out (assuming the relevant parts have been obtained or fabricated, either as indicated above or by other suitable means).

**[0122]** First, the required length of shaft 102 is selected according to the planned depth of the borehole. The uppermost collar 104a is pushed or threaded to the required position along the shaft, following by the required number of pinions 104b and boss collars 104c in turn. Spokes 108 are then pinned via lock pins around each of the collars, and then pinned to respective pile walls 106.

**[0123]** Spacer struts 122 are provided between the pinions 104b and boss collars 104c, either as the collars and pinions are being threaded on or afterwards via minor adjustments to the positions of the respective parts. The end pinion 104d is then threaded onto the shaft 102. The bottom ends of the remaining struts 122 are welded to the end pinion 104d.

**[0124]** The apparatus 100 is then fully retracted, such that the spokes lie near parallel to the longitudinal axis of the shaft 102 and the sidewalls 106 are proximate to the shaft 102, and taped securely.

#### Embodiment 1 - Installation

**[0125]** To install the apparatus 100 in the borehole, the borehole 10 needs to be about 10% to 20% greater in diameter than the apparatus 100 in its retracted config-

uration. The borehole 10 should also be about 100mm longer than the length of the apparatus 100, where needed for providing room for downwards movement of the shaft 102.

**[0126]** When the borehole 10 has been prepared, the apparatus 100 is pushed into the borehole 10. The sleeve 130 is then aligned with the longitudinal axis of the shaft 102, lowered over the shaft and screwed onto the top collar 104a. The split spur gear 132 is engaged with the sleeve 130. The locking nut 140 is provided on the shaft above the split spur gear 132, at a suitable position to allow full deployment of the sidewalls 106. The spur gear 142 is then threaded onto the shaft above the locking nut 140, until it reaches the locking nut 140.

**[0127]** Note that, in other embodiments, the above steps may feasibly be carried out before insertion of the apparatus 100 into the borehole 10.

**[0128]** Before deploying the apparatus 100, the split spur gear 132 needs to be pinned to prevent the apparatus 100 from spinning. This may be accomplished by any suitable means. Then, torque may be applied manually or hydraulically to refusal, or to a predetermined torque value, by suitable means while preventing rotation of the apparatus 100. This causes the shaft 102 to translate downwards whilst the sidewalls move radially outwards from the shaft 102, expanding the liner 110, and engaging and expanding the borehole wall.

**[0129]** Note that conventional methods and equipment for generating torque for a helical pile can be used for this embodiment.

**[0130]** Once the apparatus has been deployed, the spur gear 142 and split spur gear 132 are released, and the locking nut 140 is installed at the top of the sleeve 130 to secure the apparatus 100 in the deployed configuration.

**[0131]** Note that the gear 132 is split so that it can be removed without losing tension. The nut 140 needs to be in place first because once the split spur gear 132 is removed the nut 140 is screwed down to lock the apparatus in the deployed arrangement, while the spur gear 142 is used to maintain the apparatus taut.

**[0132]** Concrete can then be poured into the borehole and/or apparatus 100.

#### Embodiment 2 - Structure

**[0133]** In this second embodiment, some features are similar or identical to features which have already been described for the first embodiment. The following disclosure will focus on those features which differ to the first embodiment, generally using like reference numerals for like features where possible.

**[0134]** Figures 10 to 10D show a second embodiment of an apparatus for use as a pile or ground anchor in a retracted configuration, indicated generally at 200. The apparatus 200 is shown positioned in a borehole 20, which has the same features as the first borehole 10.

**[0135]** The apparatus 200 includes a central elongate

shaft 202. Figure 10A shows the top of the shaft 202 above the pile cut-off level (G) in more detail. As with the first embodiment, a mid-section of the shaft 202 is omitted from Figure 10A so that the rest of the apparatus 200 fits on the page, but it will be appreciated that the omitted portion of the elongate shaft 202 is substantially similar to the neighbouring portions of the shaft 202 which are depicted just above and below the omitted section.

**[0136]** The shaft 202 may be considered to be a tube or sleeve (which is a permanent part of the apparatus 200). The shaft may include a number of shaft sections which are lapped together at the base of the shaft to extend the shaft by the required length (i.e. in a modular fashion). The shaft can be made from hot rolled or cold formed CHS. The shaft 202 extends out of the open (upper) end of the borehole 20 when the apparatus 200 is in the borehole 20. A lower end of the apparatus 200 is spaced from the closed (lower) end of the borehole 20.

**[0137]** In this embodiment, the shaft 202 is hollow for receiving a cable or strand of wire 244. The cable 244 extends to the bottom of the apparatus 200, and is long enough to extend out of the top of the apparatus 200 above ground during installation. The cable 244 may include one or more low relaxation wire strands which conform to EN 10138 with a minimum strength of 1725MPa. The properties of the strands of the cable 244 depend on the number of strands (i.e. whether it is mono-strand or has multiple wire strands, or several wire strands or mono-strands) and relates to the size of the apparatus 200 and the post-tensioning force required for deploying it.

**[0138]** A plurality of connectors 204 is provided on the shaft 202. In this embodiment, there are eleven connectors 204. The uppermost connector and some of the intermediate connectors, indicated at 204a, are described in further detail in Figure 12. Other intermediate connectors and the terminal connector, indicated at 204b, are described in further detail in Figures 13 and 14. Note that the top collar 204a is provided in a fixed position on the shaft 202, e.g. it may be welded in place.

**[0139]** The apparatus 200 includes a plurality of pile walls (or ground anchor walls), indicated generally at 206. The walls 206 may be considered to be a plurality of sidewalls of the apparatus. The sidewalls 206 are together arranged to provide substantially cylindrical or tubular structure in the retracted configuration, although it will be appreciated that there may be spaces between the pile walls in some embodiments.

**[0140]** A subset of the sidewalls 206 is connected to each connector 204 using spokes 208 and locking pins as described for the first embodiment. The features of and options for the sidewalls 206 and the spokes 208 are the same as the first embodiment. An expandable liner 210 is also provided in a similar manner to the first embodiment.

**[0141]** In Figure 12, the connector 204a is a collar which includes a cylindrical body. The collar also includes a plurality of bosses or apertured flanges 212 which are

spaced apart around the collar for a subset of the spokes 208 to connect to. The flanges 212 each include two apertures for connection to respective pairs of spokes 208 via a locking pin. The upper set of apertures are not necessary for the topmost connector 204. Note that the upper collar is permanent in this pre-stressed system.

**[0142]** The connector 204a can be fabricated by casting a circular hollow section, which has a central aperture for fitting the shaft 202. Brackets can be fabricated from flat plates and then holes drilled in the required positions in the brackets, which are then welded around the circular hollow section.

**[0143]** The internally-coned connector 204b in Figure 13 has similar features to the first connector 204a and can be fabricated in a similar manner, but with a conical (rather than cylindrical) central aperture. Note that the internally-coned collar 204b is also grooved to grip the cable. In this embodiment, a split barrel gripper 246 or other suitable cable grip is provided in the conical section (see the cross-section in Figure 14), configured to match the cable and cone diameter.

**[0144]** Note that the fixings at the top can include conventional industry wedge sitting locking mechanisms.

**[0145]** In this embodiment, for the intermediate connectors, there will be  $n$  collars (of the type shown in Figure 12) and  $n+2$  collars (of the type shown in Figure 13), plus the top collar. This may be applied more generally to other embodiments as well. The two types of connectors 204a, 204b may be provided in an alternating arrangement along the shaft 202, but the end collar 204 should be an internally-coned collar 204b (which may be a second internally-coned collar in a row, i.e. the end may not be part of the alternating pattern).

**[0146]** Figure 10C shows the lower end of the apparatus 200 in more detail. The lowermost connector 204b is internally-coned and is connected to the cable 244 by a cable grip. The same applies to the connector above the lowermost connector 204b.

**[0147]** Figures 11 to 11D show the apparatus 200 of Figure 10 in a deployed configuration, indicated generally at 200'. Similarly to the first embodiment, the sidewalls 206 have been moved outwards such that the spokes 208 are now horizontal and parallel to each other, rather than in a zig-zag arrangement, and the pile walls 206 have caused outward deformation of the borehole to provide an expanded borehole 20'. The walls of the borehole 20' are compressed and there is a predetermined skin friction between the apparatus sidewalls 206 and the borehole 20'.

**[0148]** Figure 11A shows the top of the shaft 202 above the pile cut-off level (G) in more detail. A cable locking element (or wedge type locking end for the cable) 248 is provided at the top of the shaft 202, in engagement with the cable 244. The cable locking element 248 allows passage of the cable upwards through the locking element 248, but not in the reverse direction. There is an inverted cone inside the element 248. For example, a post-tensioning wedged locking block such as CCL International-

al's brifen barrel and wedges or similar may be used.

**[0149]** Figure 11B illustrates a deployed section of the apparatus 200' which approximately corresponds to the retracted section of Figure 10B. The sidewalls 206 are spaced from the shaft 202 and in engagement with the sides of the borehole 20'. The borehole 20' has been expanded at the sidewalls 206 to approximately 150-160% of its initial diameter. Axial displacement of the shaft 202 has caused the connectors 204 to move upwards. It will be appreciated that the lower end of the shaft 202 has migrated upwards, away from the base of the borehole (compare Figures 11C and 10C), due to the pulling force, typically generated by hydraulic means, applied to the cable 244 for deploying the sidewalls 206.

**[0150]** In this embodiment, pulling the cable 244 has led to a reduced distance or separation between the uppermost connector 204a (fixed in place) and the directly adjacent connector 204b. The other connectors 204 are free to move along the shaft 202 during deployment.

**[0151]** Figure 11D depicts the deployed configuration of the apparatus 200' from above. Similarly to the first embodiment, there are now gaps between the sidewalls 206 but the liner 210 prevents soil collapse through the gaps during/after deployment of the sidewalls 206. Note that the cable locking element 248 is not shown for clarity.

#### Embodiment 2 - Assembly

**[0152]** To assemble the apparatus 200 in the configuration shown in Figure 10, the following steps can be carried out (assuming the relevant parts have been obtained or fabricated, either as indicated above or by other suitable means).

**[0153]** First, the required length of shaft 202 is selected according to the planned depth of the borehole. The uppermost collar 204a is pushed to the required position along the shaft, and then welded in place at the top and bottom of the collar. The cable strand (or stranded wire) 244 is threaded through the shaft 202.

**[0154]** If the shaft is being constructed in a modular fashion (rather than having an integrally-formed shaft at the full required length *ab initio*), a shaft section is pushed into and lapped with the bottom of the main shaft 202. Then, an internally-coned collar 204b with a cable gripper is pushed into position. Additional shaft sections and either non-coned connectors 204a or coned connectors 204b are connected in place in an alternating pattern (coned/non-coned), terminating with a final coned collar 204b.

**[0155]** Spokes 208 are then pinned via lock pins around each of the collars, followed by pinning to the respective pile walls 206, which bridge adjacent connectors as in the first embodiment.

**[0156]** The apparatus 200 is then fully retracted, such that the spokes lie near parallel to the longitudinal axis of the shaft 202 and the sidewalls 206 are proximate to the shaft 202, and taped securely.

#### Embodiment 2 - Installation

**[0157]** To install the apparatus 200 in the borehole, the borehole 20 should again be about 10% to 20% greater in diameter than the apparatus 200 in its retracted configuration. The borehole 20 does not need to be substantially longer than the apparatus because the shaft is intended to be pulled upwards during installation, although it may be 100mm or so longer than the apparatus as for the first embodiment. If a variant employed a rigid rod instead of a cable and was to be pushed downwards for installation, a suitable gap at the bottom of the borehole is envisaged to accommodate the expected movement of the apparatus. The rod could of course be pulled upwards like the cable in other embodiments.

**[0158]** When the borehole 20 has been prepared, the apparatus 200 is pushed into the borehole 10. The cable locking element 248 is then installed on the cable 248 and pushed to around ground level.

**[0159]** A hydraulic tensioning apparatus (or other means of pulling the cable) is connected to the cable 248. Force is then applied to refusal, or to a predetermined stress value, pulling the cable 248 through the locking element 248. This causes the shaft 202 to translate upwards whilst the sidewalls move radially outwards from the shaft 202, expanding the liner 210, and engaging and expanding the borehole wall.

**[0160]** Note that conventional methods and hydraulic equipment for pre-stressing a beam can be used for this embodiment.

**[0161]** Once the apparatus has been deployed, the cable is locked in place by the locking element 248. Concrete can then be poured into the borehole and/or apparatus 200.

#### Embodiment 3 - Structure

**[0162]** In this third embodiment, some features are similar or identical to features which have already been described for the first embodiment. The following disclosure will focus on those features which differ to the first embodiment, generally using like reference numerals for like features where possible.

**[0163]** Figures 15 to 15D show a third embodiment of an apparatus for use as a pile or ground anchor in a retracted configuration, indicated generally at 300. The apparatus 300 is shown positioned in a borehole 30, which has the same features as the first borehole 10.

**[0164]** The apparatus 300 includes a central elongate shaft 302, as shown in Figure 18. Figure 15A shows the top of the shaft 302 above the pile cut-off level (G) in more detail. As with the first embodiment, a mid-section of the shaft 302 is omitted from Figure 15A so that the rest of the apparatus 300 fits on the page, but it will be appreciated that the omitted portion of the elongate shaft 302 is substantially similar to the neighbouring portions of the shaft 302 which are depicted just above and below the omitted section.

**[0165]** The shaft 302 may be considered to be a tube or hollow bar (which is a permanent part of the apparatus 200). The shaft can be made from hot rolled or cold formed CHS, which is perforated for receiving one or more clutch elements. Figure 17 shows that perforations or apertures 302a are provided along the length of the shaft 302, but the number and spacing of the apertures 302a may be varied as needed. There are four columns of apertures equidistantly spaced around the shaft 302 in this embodiment.

**[0166]** The shaft 302 can also be grooved 302b to ensure precise movement of elements (particularly collars) along the shaft 302. The grooves 302b may be correspond to or be aligned with the apertures 302a, or may be offset from the apertures 302a.

**[0167]** The shaft 302 extends out of the open (upper) end of the borehole 30 when the apparatus 300 is in the borehole 30. A lower end of the apparatus 300 is spaced from the closed (lower) end of the borehole 30.

**[0168]** In this embodiment, the shaft 302 is hollow for receiving an elongate rod 350. The rod 350 extends along at least part of the shaft, and preferably along most/all of it. The rod 350 has an external diameter which is about the same as the internal diameter of the hollow shaft 302, but with sufficient tolerance for easy removal of the rod from the shaft 302. The rod 350 is long enough to extend out of the top of the apparatus 300 above ground during installation.

**[0169]** Placeholder elements, or sacrificial dowels, are located in the perforations and indicated generally at 350a. The placeholder elements 350a are prevented from displacement into the middle of the shaft 302 whilst the rod 350 is in position within the shaft 302. Each placeholder element 350a may be approximately ovoid in shape. Each placeholder element 350a may be forged from steel or from rolled bars with rounded ends, and machine ground to fit the apertures in the shaft 302.

**[0170]** A plurality of connectors 304 is provided on the shaft 302. In this embodiment, there are eleven connectors 304. The uppermost connector, indicated at 304a, is described in further detail in Figure 18. The second connector 304b, adjacent to the uppermost connector 304a, is described in further detail in Figure 19. The remaining connectors, examples of which are indicated at 304c and 304d, are described in further detail in Figures 20 and 21-21A respectively.

**[0171]** The apparatus 300 includes a plurality of pile walls (or ground anchor walls), indicated generally at 306. The walls 306 may be considered to be a plurality of sidewalls of the apparatus. The sidewalls 306 are together arranged to provide substantially cylindrical or tubular structure in the retracted configuration, although it will be appreciated that there may be spaces between the pile walls in some embodiments.

**[0172]** A subset of the sidewalls 306 is connected to each connector 304, similarly to the first embodiment, and each side wall 306 is connected to its respective connector 304 by a spoke 308 and locking pins. The fea-

tures of the sidewalls 306 and spokes 308 are the same as the first embodiment. An expandable liner 310 is also provided in a similar manner to the first embodiment.

**[0173]** Figure 15B shows the connectors 304 on the shaft 302 in more detail. The top connector 304a is a floating collar (or boss collar) which is illustrated in Figure 18. The top collar 304a includes a cylindrical portion 304aa with an external thread for receiving a sleeve with a corresponding internal thread. The collar 304a also includes an apertured disc 304ab which has notches or chases 304ac spaced around an internal side of the aperture for spacer ties or struts 322 to slot through. The spacer ties serve a similar purpose to the struts in the first embodiment, but are adapted to fit between the clutch mechanisms (discussed below). In this case, the spacer ties or struts may be welded to the floating collars (collars 304d discussed below), but not to the fixed collars (collars 304c discussed below).

**[0174]** The collar 304a can be made from hot rolled or cold formed CHS and tapped as required to provide the external thread. The bottom portion can be cast with the chases 304ac, and the cylindrical portion welded to the disc.

**[0175]** Figure 19 shows the second connector 304b, which may be fixed in place on the shaft 302, e.g. by welding. The collar 304b includes a cylindrical body 304ba with a central aperture 304bb. The collar 304b has an internal thread for connection to the shaft. A plurality of bosses or apertured flanges 318 are spaced around the exterior of the collar 304b. The flanges 318 each include an aperture for connection to a spoke 308 via a locking pin.

**[0176]** The collar 304b can be cast with notches or chases 304bc for spacer ties to slot through, similar to the top collar 304a. A capping plate can be fabricated from a flat plate and then welded on top of a circular hollow section. Brackets are fabricated from flat plates and holes drilled in the required positions. The brackets are then welded equidistantly around the circular hollow section.

**[0177]** Leaving aside the top two connectors 304a, 304b, in this embodiment there are  $n$  collars of the type shown in Figure 20, and  $n+1$  collars of the type shown in Figure 21. This may be applied more generally to other embodiments as well. The two types of collars in Figures 20-21 may be provided in an alternating arrangement along the shaft 302, preferably terminating at the base end of the apparatus 300 with one or two collars each of which has a clutch mechanism.

**[0178]** The first type of remaining connector 304c is shown in Figure 20, which may be fixed in place on the shaft 302, e.g. by welding. The connector 304c has an apertured cylindrical body 304ca with longitudinal notches or grooves 304cb spaced around the interior of the aperture. A plurality of bosses or apertured flanges 318 are spaced around the exterior of the collar 304c. The flanges 318 each include two apertures for connection to respective pairs of spokes 308 via locking pins. The

connector 304c can be constructed similarly to the second connector 304b, but without a capping plate and using doubly apertured brackets instead of singly-apertured brackets.

**[0179]** The connector 304d in Figure 21 is substantially similar to the connector 304c in Figure 20, but also includes a clutch arrangement or locking mechanism on the top or bottom, indicated generally at 352. The connector 304d is a floating collar.

**[0180]** The clutch mechanism 352 includes a cylindrical section 352a on top of the apertured cylindrical body 304da. Longitudinal notches or grooves 352b are provided around the interior of the cylindrical section and these notches 352b line up with the corresponding notches/grooves 304db in the lower cylindrical section. Each collar 304d also includes one or more protrusions or cogs (not shown) which fit into the grooves on the shaft 302. This ensures that the clutch(es) 352 do not rotate relative to the shaft 302, at which point it would be unable to engage the shaft apertures.

**[0181]** Four clutches 354 are spaced at ninety degree intervals around the cylindrical section 352a. One of the clutches is shown in more detail in Figure 21A. Each clutch 354 includes two side walls 354a (typically made of steel plate, one of which is shown in Figure 21A), a fixed rear plate 354b, and a sliding front plate 354c. The front plate 354c is guided via a circular protrusion 356 (one shown) on two recessed grooves or runners 358 (one shown) in the side walls 354a. A spring system with two springs 360 is mounted on blocks or protrusions 362 between the rear of the sliding front plate 354c and the front of the fixed rear plate 354b.

**[0182]** A lock bullet 364 is provided on the sliding plate 354c for insertion into one of the apertures in the shaft 302. The lock bullet 364 has a similar size and shape to the placeholder elements 350a, and is configured to displace one of the placeholder elements 350a and engage an aperture in the shaft 350a when aligned with the aperture. The rod 350 must first be removed to allow the lock bullet to displace the sacrificial element 350a.

**[0183]** Figures 24A and 24B illustrate the operation of the clutch mechanism 352. In Figure 24A, the lock bullets 364 on either side of the shaft 302 cannot occupy the apertures they are aligned with. This is because the sacrificial dowels 350a are occupying the apertures, and the rod 350 in the shaft 350 is blocking the dowels from exiting the apertures.

**[0184]** In Figure 24B, the collar 304d has migrated up the shaft 302 and the rod 350 has been removed, such that the lock bullets 364 were able to displace the relevant sacrificial dowels 350a. The springs in the clutch 354 provide a biasing arrangement that leads to the clutch automatically engaging the shaft 302, as the rod is being removed or immediately afterwards. If the clutch 354 is not quite aligned with the apertures once the sidewalls have been deployed, then slight adjustment of the tensioning force may be required in order to allow the clutch to be aligned and engaged.

**[0185]** Figure 15C shows the lower end of the apparatus 300 in more detail. The lowermost connector 304d is that of Figure 21. The lowermost collar includes one of the clutch mechanisms 352, as does the collar which is immediately above the lowermost collar.

**[0186]** Figures 16 to 16D show the apparatus 300 of Figure 15 in a deployed configuration, indicated generally at 300'. The sidewalls 306 have been moved outwards in a similar fashion as that described for the first embodiment, but using different means to achieve it, as detailed below.

**[0187]** Figure 16A shows the top of the shaft 302 above the pile cut-off level (G) in more detail. A sleeve (or tube) 330 has been screwed onto the external thread of the uppermost connector 304a. The sleeve 330 is coaxial with the shaft 302. A mid-section of the sleeve 330 is omitted from Figure 16 so that the rest of the apparatus 300 fits on the page. However, the sleeve 330 is shown in Figure 22, having a substantially cylindrical elongate body. The sleeve 330 includes an internal thread 330a at its lower end for connection to the external thread on the uppermost connector 304a. The sleeve 330 includes external ribs 330b at its top end, for connection to another device which can pull or push the sleeve during installation.

**[0188]** The sleeve 330 can be fabricated from a circular hollow section. It can then be internally tapped at its bottom end to correspond to the external thread of the top connector 304a. The ribs 330b can then be welded on the top end for gripping it and securing it when it is being pulled. Note that the number of ribs can be selected according to the force which will need to be applied during installation of the apparatus 300.

**[0189]** A split collar 332 is shown engaged with the upper end of the shaft 302 in Figures 16 and 16A. The split collar 332 is shown in two halves in Figure 23. The split collar 332 includes a first half-cylindrical portion 334 and a second half-cylindrical portion 336 which are shaped to together surround the upper end of the shaft 302. Each portion 334, 336 has a plurality of ribs 335 on its outside (concave) side.

**[0190]** Each portion 334, 336 also has fourteen protrusions or pins 338 (some of which are visible and some of which are not) which correspond to some of the perforations 302a in the shaft 302. There are two columns of seven protrusions 338 on each portion 334, 336 in this embodiment. It will be appreciated that the exact location on the concave surface of the portions 334, 336 is not critical, but the columns are located approximately one quarter and three quarters of the way round the interior surface of the relevant portion 334, 336.

**[0191]** The two halves of the split spur gear 132 can be fabricated from circular hollow sections split in half. This allows it to be detached from the shaft 302 without losing tension in the apparatus once the apparatus 300 is taut, i.e. once deployed to the extent required within the borehole 30.

**[0192]** Figure 16B illustrates a deployed section of the

apparatus 300' which approximately corresponds to the retracted section of Figure 15B. The sidewalls 306 are spaced from the shaft 302 and in engagement with the sides of the borehole 30'. The borehole 30' has been expanded at the sidewalls 306 to approximately 150-160% of its initial diameter. The shaft 302 has not been displaced in this embodiment, but rather the clutch collars 304d are displaced by pulling or pushing the sleeve 330 in order to deploy the sidewalls 306. Displacement of the connectors 304 has reduced the relative distance or separation between the second connector 304b and the adjacent connector 304d directly below it.

**[0193]** Figure 16D depicts the deployed configuration of the apparatus 300' from above. Similarly to the first embodiment, there are now gaps between the sidewalls 306 but the liner 310 prevents soil collapse through the gaps during/after deployment of the sidewalls 306. Note that the sleeve 330 and split ribbed collar 332 are not shown for clarity.

#### Embodiment 3 - Assembly

**[0194]** To assemble the apparatus 300 in the configuration shown in Figure 15, the following steps can be carried out (assuming the relevant parts have been obtained or fabricated, either as indicated above or by other suitable means).

**[0195]** First, the required length of shaft 302 is selected according to the planned depth of the borehole, and having suitable perforations along it. The rod 350 is then inserted through the shaft 350. The second collar 304b is pushed to the required position along the shaft, and then welded in place at the top and bottom of the collar. The top collar 304a is then fitted from the top next to the second collar 304b.

**[0196]** The remaining collars 304c, 304d are then fitted onto the perforated shaft 302 in turn from the bottom end, in an alternating pattern, welding the fixed collars 304c in place on the shaft 302. Sacrificial dowels 350a are placed into each of the perforations in the shaft 302 as the collars are being fitted, particularly in the regions which correspond to perforations where the clutches are expected to latch following sidewall 306 deployment.

**[0197]** Spokes 308 are then pinned via lock pins around each of the collars 304, followed by pinning to the respective pile walls 306, which bridge adjacent connectors as in the first embodiment. The collars 304 are spaced apart by the inclusion of struts 322 which are welded to the floating collars 304a, 304d but remain free to pass through the fixed collars 304b, 304c. The struts 322 are welded to the bottommost floating collar 304d too, once it has been fitted.

**[0198]** The apparatus 300 is then fully retracted, such that the spokes lie near parallel to the longitudinal axis of the shaft 302 and the sidewalls 306 are proximate to the shaft 302, and taped securely.

#### Embodiment 3 - Installation

**[0199]** To install the apparatus 300 in the borehole, the borehole 30 should be about 10% to 20% greater in diameter than the apparatus 300 in its retracted configuration. The borehole 30 should also be about 100mm longer than the length of the apparatus 300, although because the shaft 302 does not substantially move the additional length may not be needed.

**[0200]** When the borehole 30 has been prepared, the apparatus 300 is pushed into the borehole 30. The sleeve 330 is then aligned with the longitudinal axis of the shaft 302, lowered over the shaft and screwed onto the top collar 304a.

**[0201]** Before deploying the apparatus 300, the split collar 332 is engaged with the shaft 302 to prevent it from moving, in conjunction with any suitable equipment which is engaged with the ribs on the split collar 332. Then, a pulling or pushing force may be applied hydraulically (or by other suitable means) to refusal, or to a predetermined stress value, while preventing displacement of the shaft 302. This causes the sleeve 330 to translate upwards or downwards whilst the sidewalls move radially outwards from the shaft 302, expanding the liner 310, and engaging and expanding the borehole wall.

**[0202]** Note that conventional methods and equipment for generating a force or torque for a helical pile can be used for this embodiment.

**[0203]** Once the apparatus has been deployed, the rod 350 can be removed from within the shaft 302. The pulling/pushing force may be incremented slightly to line up the clutches 354 with the shaft apertures, and the clutches 354 then displace the sacrificial dowels and engage the shaft 302, securing the collars 304 against further movement along the shaft 302. The split collar 332 can be removed and the sleeve 330 can be unscrewed from the collar 304a. Concrete can then be poured into the borehole and/or apparatus 300.

**[0204]** Any feature or combination of features presented in the specific description above is intended to be available as a feature in isolation of the other features presented in the embodiment. That is, features from different embodiments are intended to be freely combined in any suitable combination (whether or not explicitly disclosed) within the scope of the claims.

**[0205]** It will be appreciated that whilst the embodiments described above each comprise multiple 'modules' along the respective shafts, other embodiments are contemplated which include a greater or lesser number of such modules. This includes some embodiments where there is a single collar and set of pile walls which expand a borehole, if such an arrangement provides a suitable foundation for a given structure.

**[0206]** The length of the shaft, and the number of collars and pinions on the shaft, can be selected as needed for a particular embodiment to achieve the required skin friction. Generally, there will be a greater number of collars and pinions with increasing shaft length, but the exact

relationship depends on spoke length, shaft diameter and borehole size.

**[0207]** It will also be appreciated that whilst the embodiments shown all depict 'full' deployment of the sidewalls, such that the sidewalls are at the maximum radial extent from the shaft, this is not necessarily required for every application. If the predetermined tension or compression stress is reached without the sidewalls being at maximum distance from the shaft, then the apparatus can still be locked in that partially deployed configuration.

**[0208]** It will be appreciated that the standards presented above are for guidance only and are not intended to limit the scope of protection in any way. Standards may vary between countries and so the materials used in any particular embodiment may adhere to local standards (which may be more or less stringent than those presented above).

**[0209]** The embodiments described above are provided by way of example only, and various changes and modifications will be apparent to persons skilled in the art without departing from the scope of the present invention as defined by the appended claims. In particular, any feature or combination of features presented in the detailed description may be provided in another embodiment.

#### Claims

1. A pile or ground anchor (100, 200, 300) for a building or structure, comprising

an elongate shaft (102, 202, 302) having a longitudinal axis (A) for positioning in a borehole (10, 20, 30),

two or more sidewalls (106, 206, 306) defining a substantially tubular structure surrounding a length of the elongate shaft for engaging the borehole,

one or more connectors (104, 204, 304) disposed along the elongate shaft, connecting the sidewalls to the elongate shaft, at least some of the one or more connectors being moveable relative to or along the elongate shaft for moving the sidewalls,

the sidewalls being moveable or extendible from i) a retracted configuration in which the sidewalls are disposed proximate to the shaft, the diameter of the tubular structure being suitable for insertion into the borehole, to ii) a deployed configuration in which the sidewalls are radially spaced from the longitudinal axis of the shaft, relative to the retracted configuration, in use the two or more sidewalls bearing against and substantially radially expanding a corresponding length of the borehole by movement into the deployed configuration, such that the diameter of the tubular structure in the deployed configura-

tion is greater than the original diameter of the borehole.

2. A pile or ground anchor (100, 200, 300) as claimed in claim 1, in which the substantially tubular structure provides a substantially cylindrical area for maximising friction between the sidewall and the borehole.
3. A pile or ground anchor (100, 200, 300) as claimed in claim 1 or claim 2, in which the one or more connectors include one or more collars (104abcd, 204ab, 304abcd), each of which comprises a plurality of bosses arranged around its exterior; a plurality of spokes (108, 208, 308) are pivotably connected to the plurality of bosses; and the sidewalls comprise a plurality of pile walls for each collar, the plurality of spokes being pivotably connected to the plurality of pile walls.
4. A pile or ground anchor (100, 200, 300) as claimed in any preceding claim, in which a cable (244) is provided through the elongate shaft, and at least some of the one or more connectors include a cable gripping portion (246) engaged with the cable, optionally in which a cable locking element (248) is connected or connectable to the cable for securing the cable after deployment of the sidewalls.
5. A pile or ground anchor (100, 200, 300) as claimed in any preceding claim, in which an elongate sleeve (130, 330) is connected or connectable to the uppermost connector (104a, 304a) on the elongate shaft, wherein during installation one of the elongate shaft and sleeve is adapted to be moveable by rotation or translation relative to the other of the elongate shaft and sleeve, and the other of the elongate shaft and sleeve is securable against the corresponding rotation or translation.
6. A pile or ground anchor (100, 200, 300) as claimed in claim 5, in which a split gear (132) or other securing means is provided on the sleeve for securing the sleeve against movement, and a second gear (142) is provided on the shaft for use in rotating the shaft to deploy the sidewalls, optionally in which a locking nut (140) is provided on the shaft for locking the shaft against rotation after deployment of the sidewalls.
7. A pile or ground anchor (100, 200, 300) as claimed in claim 5, in which a split collar (332) or other securing means is provided on the shaft for securing the shaft against movement, and ribs (330b) or other engagement means are provided at an upper end of the sleeve for use in pulling the sleeve upwards to deploy the sidewalls.
8. A pile or ground anchor (100, 200, 300) as claimed in any preceding claim, in which the elongate shaft

includes a plurality of apertures (302a) arranged around the shaft, and a clutch or locking means (352) is provided for securing the sidewalls against movement, the clutch or locking means including: a plurality of locking elements (364) disposed around the shaft for engaging the apertures in the shaft, and a mechanism or biasing arrangement (360) for moving the locking elements into engagement with the apertures of the elongate shaft when the locking elements are aligned with the apertures in the shaft.

9. A pile or ground anchor (100, 200, 300) as claimed in claim 8, in which a plurality of placeholder elements (350a) occupy the plurality of apertures; the elongate shaft is hollow and an elongate rod (350) is provided within the hollow elongate shaft for preventing displacement of the placeholder elements from the apertures; and, when aligned with the apertures in the shaft during installation, the locking elements are configured to move into the apertures and displace the placeholder elements upon or following removal of the elongate rod from the shaft for locking the sidewalls in the deployed configuration.

10. A pile or ground anchor (100, 200, 300) as claimed in any preceding claim, in which an expandable liner (110, 210, 310) is provided around the substantially tubular structure, such as a UV-cured GRP liner.

11. A method of manufacturing a pile or ground anchor (100, 200, 300) for a building or structure, the method comprising the steps of:

- a) providing an elongate shaft (102, 202, 302) having a longitudinal axis (A);
- b) connecting one or more connectors (104, 204, 304) to the elongate shaft, the one or more connectors being movable relative to or along the elongate shaft once connected; and
- c) connecting two or more sidewalls (106, 206, 306) to the one or more connectors such that the sidewalls define a substantially tubular structure surrounding a length of the elongate shaft for engaging a borehole (10, 20, 30), and the two or more sidewalls are moveable or extendible from i) a retracted configuration in which the sidewalls are disposed proximate to the elongate shaft, the substantially tubular structure having a first diameter in the retracted configuration, to ii) a deployed configuration in which the sidewalls are radially spaced from the longitudinal axis of the elongate shaft, relative to the retracted configuration, the substantially tubular structure having a second larger diameter in the deployed configuration.

12. A method of installing, in a borehole (10, 20, 30), a pile or ground anchor (100, 200, 300) for a building

or structure, the method comprising the steps of:

- a) providing a pile or ground anchor as claimed in any of claims 1 to 10, in which the two or more sidewalls are in the retracted configuration, or providing a pile or ground anchor manufactured by the method of claim 11;
- b) positioning the pile or ground anchor in the borehole, the borehole being wider than the diameter of the substantially tubular structure when the two or more sidewalls are in the retracted configuration; and
- c) applying a force or torque to the pile or ground anchor to move or extend the two or more sidewalls outwards from the elongate shaft, from the retracted configuration to the deployed configuration, the force or torque being sufficient to cause the sidewalls to bear against and substantially radially expand a corresponding length of the borehole.

13. A pile or ground anchor (300) for a building or structure, comprising

- an elongate shaft (302) for positioning in a borehole (30), including a plurality of apertures (302a) around the shaft,
- two or more sidewalls (306) connected to the shaft,
- one or more connectors (304) disposed along the elongate shaft, connecting the sidewalls to the elongate shaft, at least some of the one or more connectors being moveable relative to or along the elongate shaft for moving the sidewalls outwardly from the shaft for engaging the borehole, and
- one or more clutch or locking means (352) for securing the sidewalls against movement, the clutch or locking means connected to the one or more connectors and including a plurality of locking elements (364) disposed around the shaft, and a mechanism or biasing arrangement (360) for moving the locking elements into engagement with the apertures of the elongate shaft when the locking elements are aligned with the apertures in the shaft.

14. A method of manufacturing a pile or ground anchor (300) for a building or structure, the method comprising the steps of:

- a) providing an elongate shaft (302) which includes a plurality of apertures around the shaft;
- b) connecting one or more connectors (304) to the elongate shaft, the one or more connectors being movable relative to or along the elongate shaft once connected;
- c) providing one or more clutch or locking means

(352) around the elongate shaft, the clutch or locking means including a plurality of locking elements (364) disposed around the shaft, and a mechanism or biasing arrangement (360) for moving the locking elements into engagement with the apertures of the elongate shaft when the locking elements are aligned with the apertures in the shaft; and

d) connecting two or more sidewalls (306) to the one or more connectors, such that movement of the one or more connectors causes movement of the sidewalls outwardly from the elongate shaft for engaging a borehole 15. A method of installing, in a borehole (30), a pile or ground anchor (300) for a building or structure, the method comprising the steps of:

- a) providing a pile or ground anchor as claimed in claim 13, or a pile or ground anchor manufactured by the method of claim 14;
- b) positioning the pile or ground anchor in the borehole;
- c) applying a force or torque to the pile or ground anchor to move or extend the two or more sidewalls outwards from the elongate shaft; and
- d) engaging the locking elements of the clutch or locking means with the apertures in the elongate shaft to secure the sidewalls against movement.

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50

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Figure 1

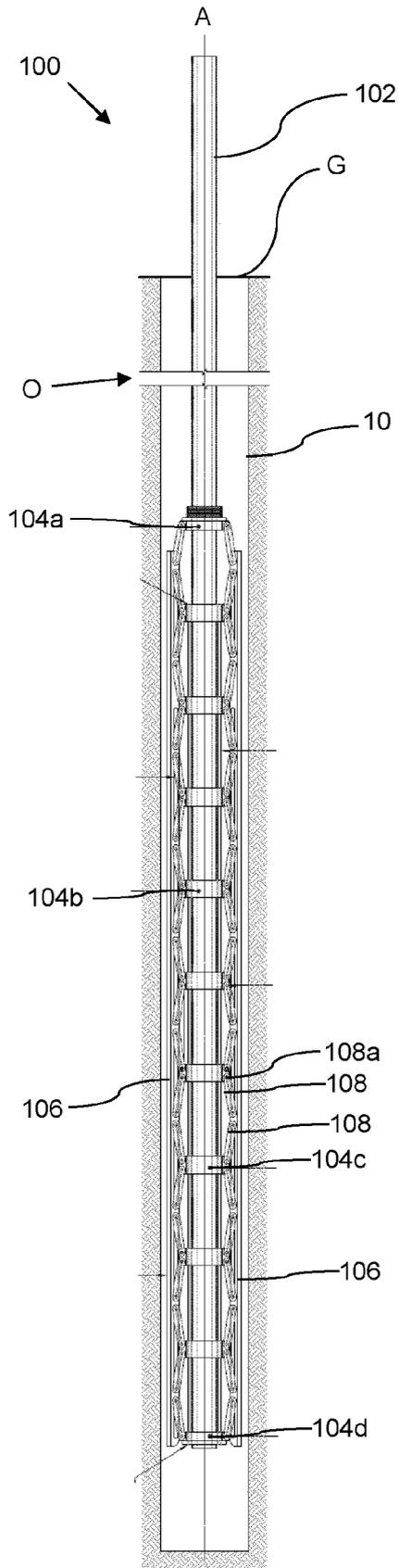
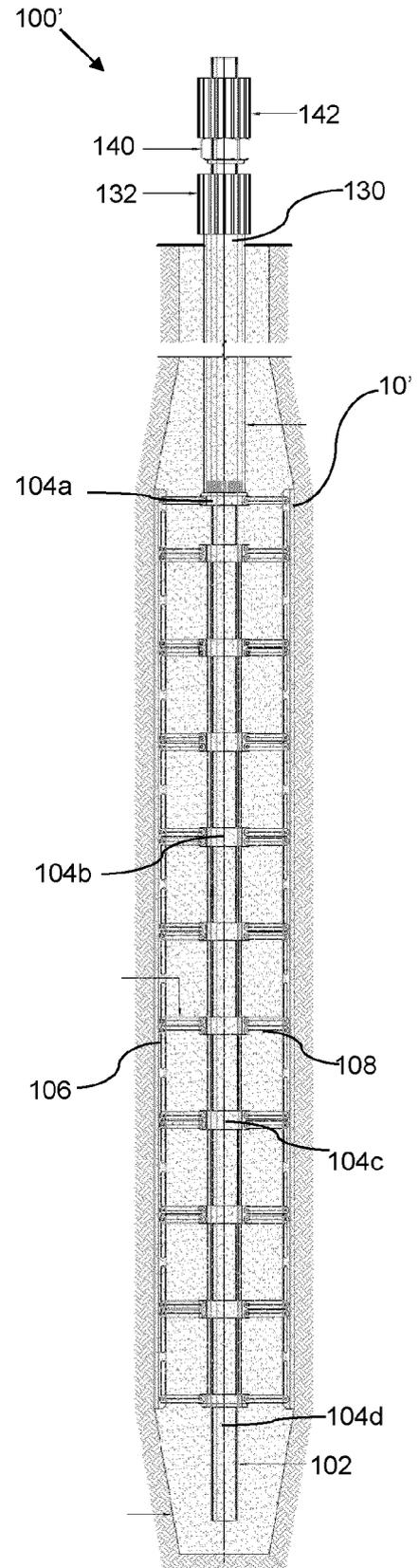
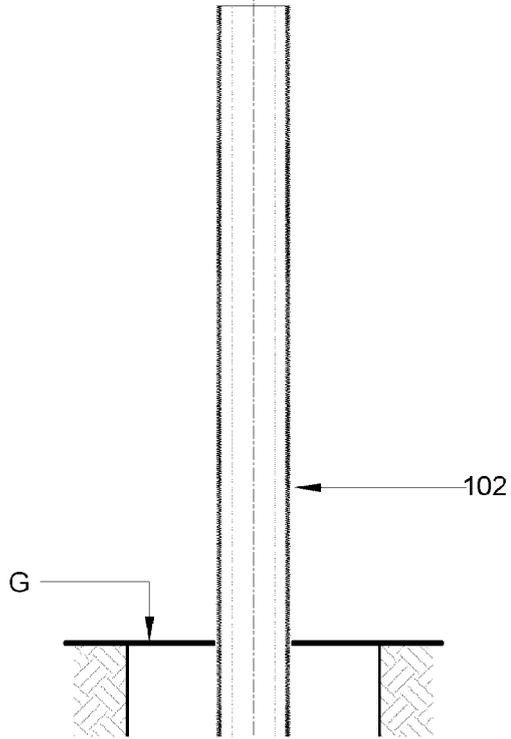


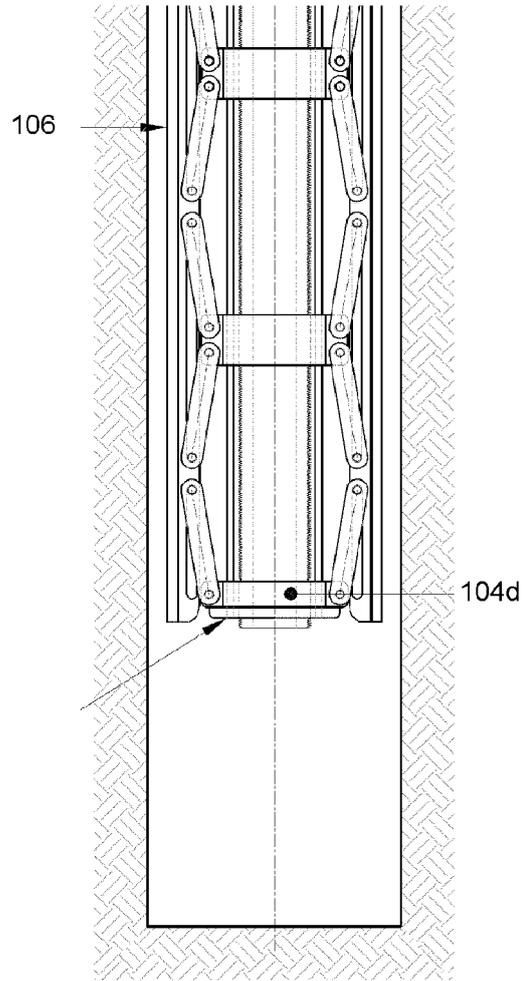
Figure 2



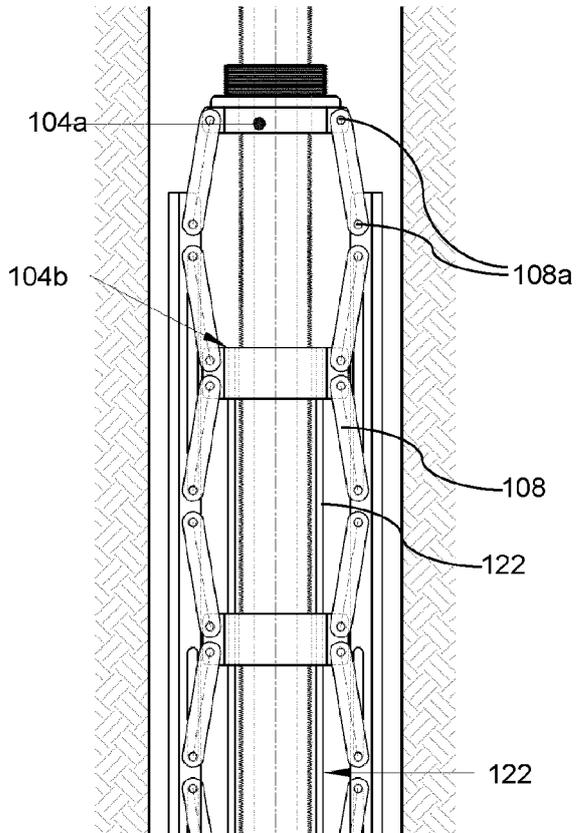
**Figure 1A**



**Figure 1C**



**Figure 1B**



**Figure 1D**

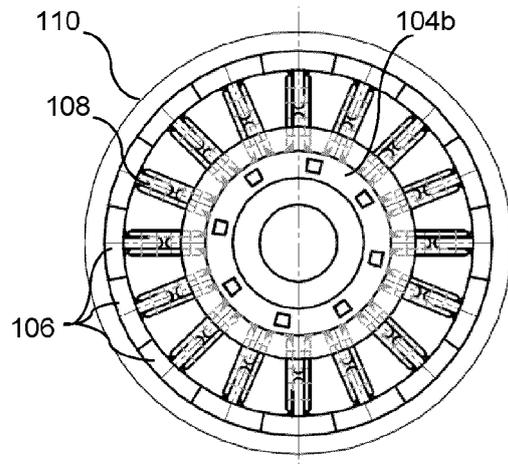


Figure 2A

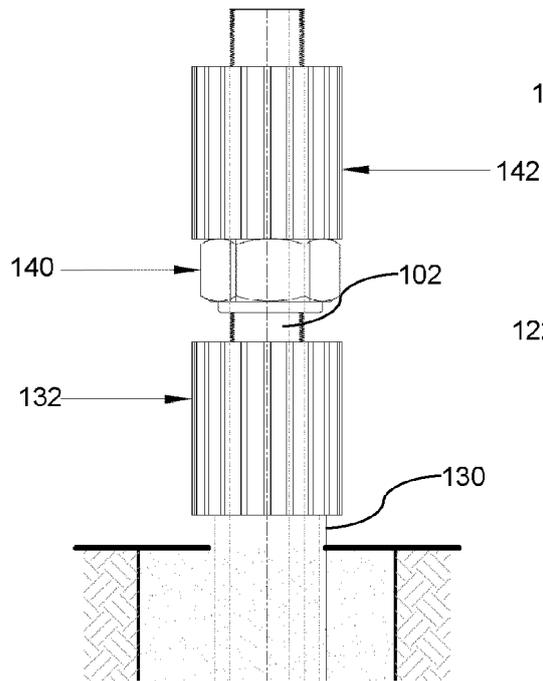


Figure 2C

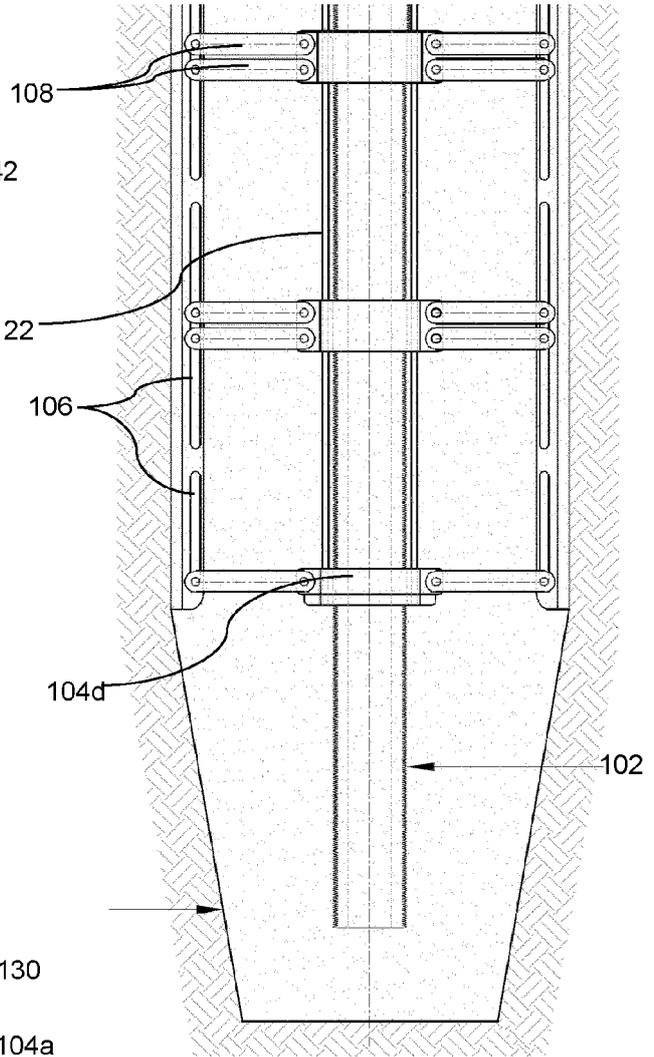


Figure 2B

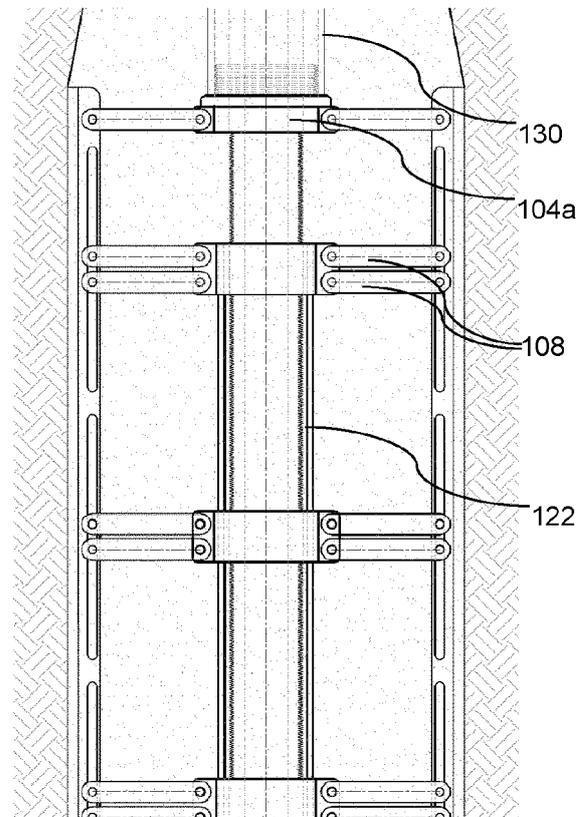
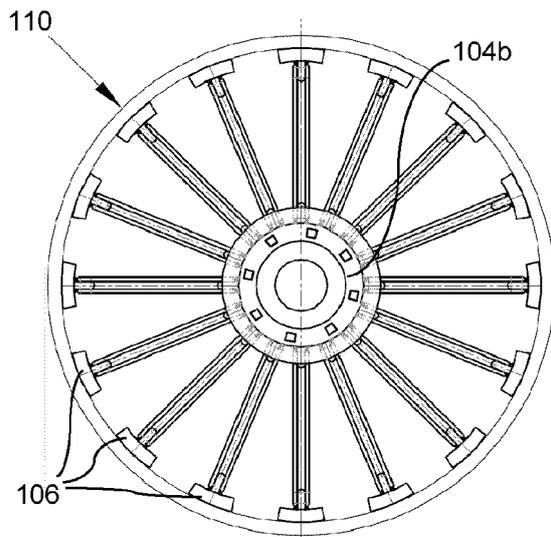
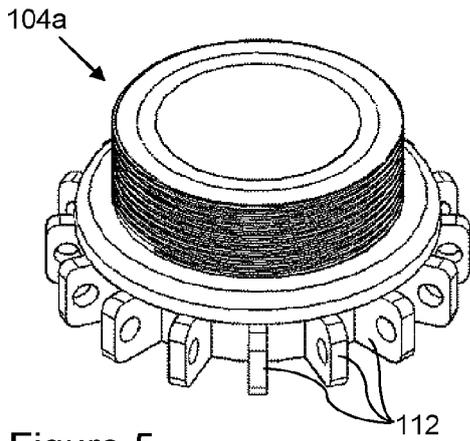


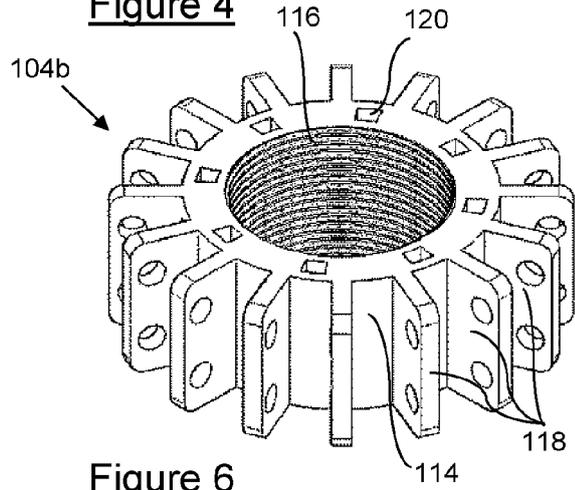
Figure 2D



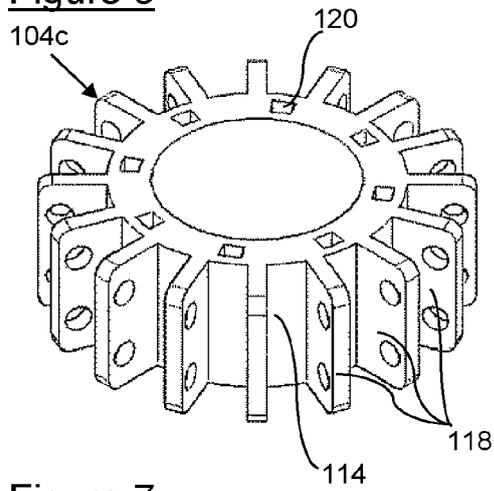
**Figure 3**



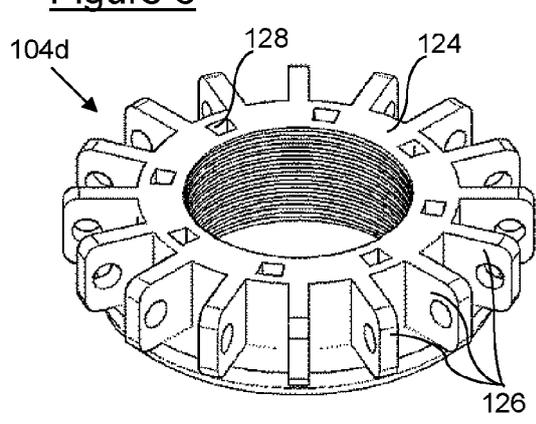
**Figure 4**



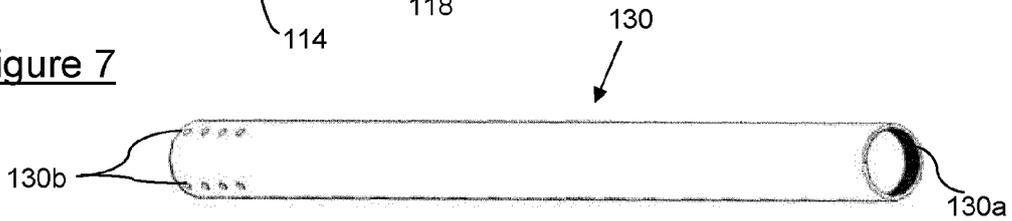
**Figure 5**



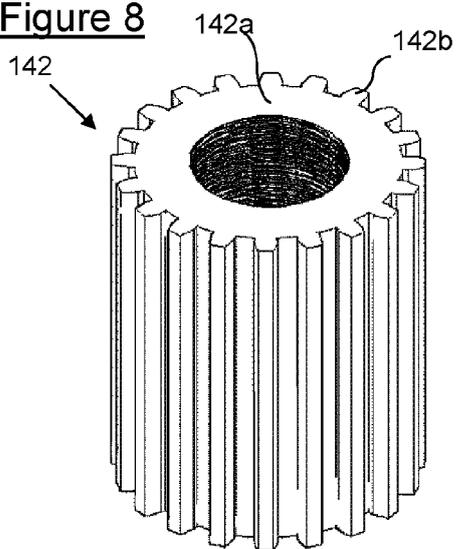
**Figure 6**



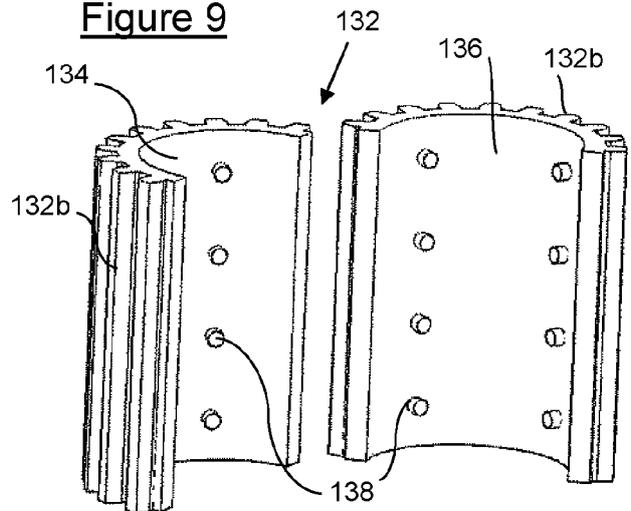
**Figure 7**



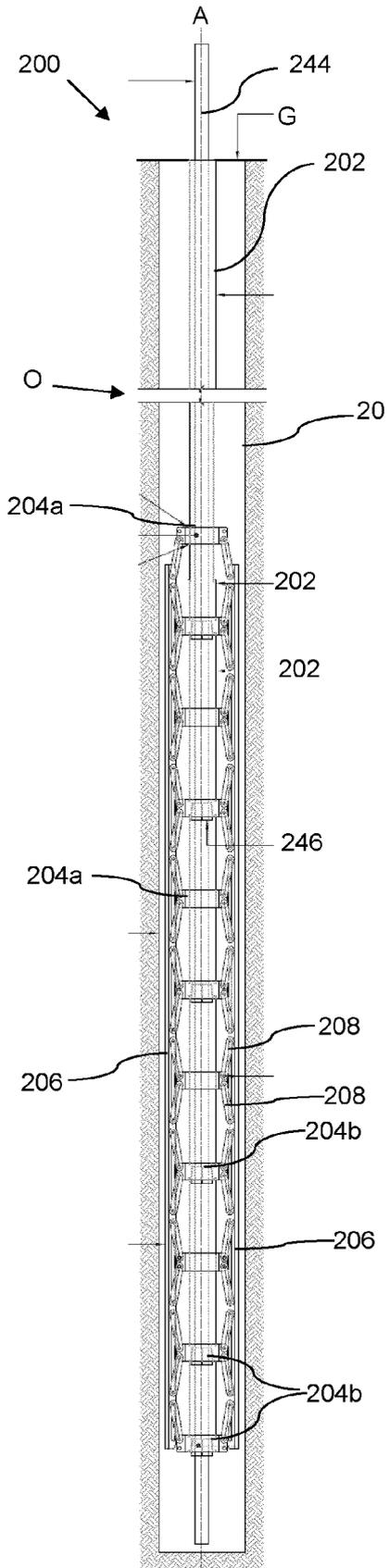
**Figure 8**



**Figure 9**



**Figure 10**



**Figure 11**

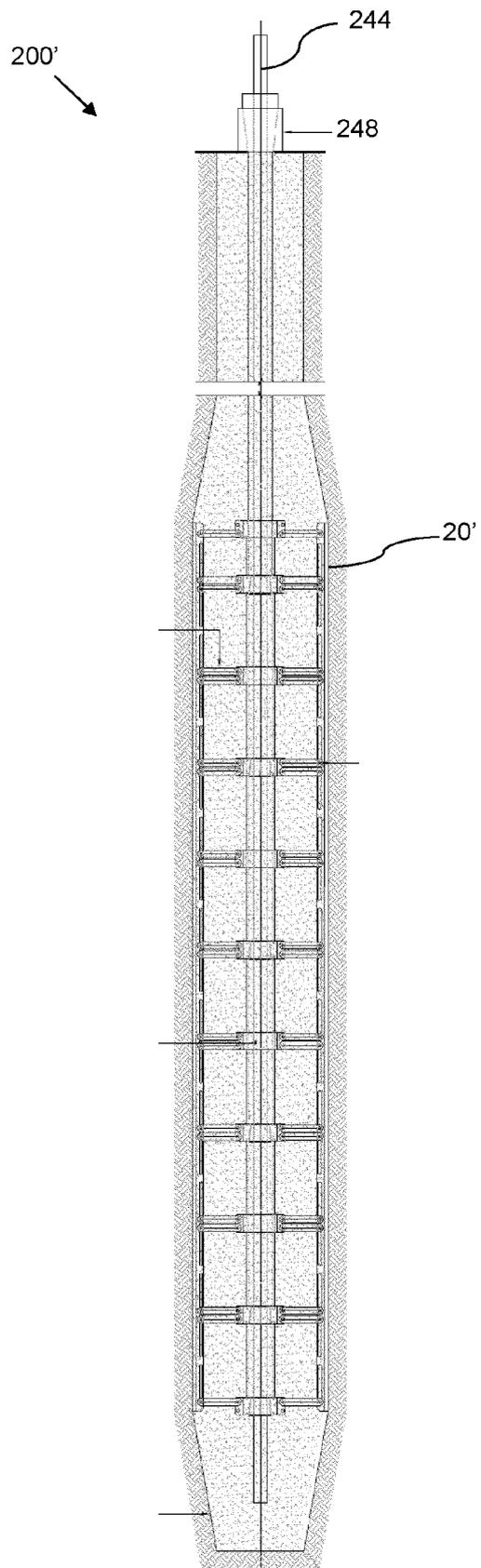


Figure 10A

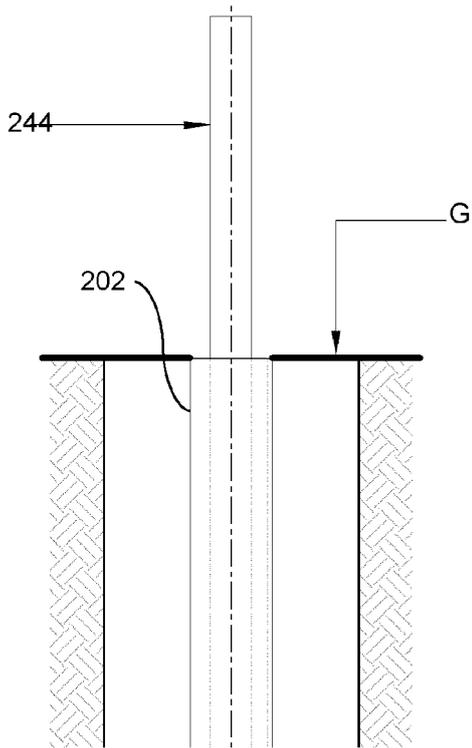


Figure 10C

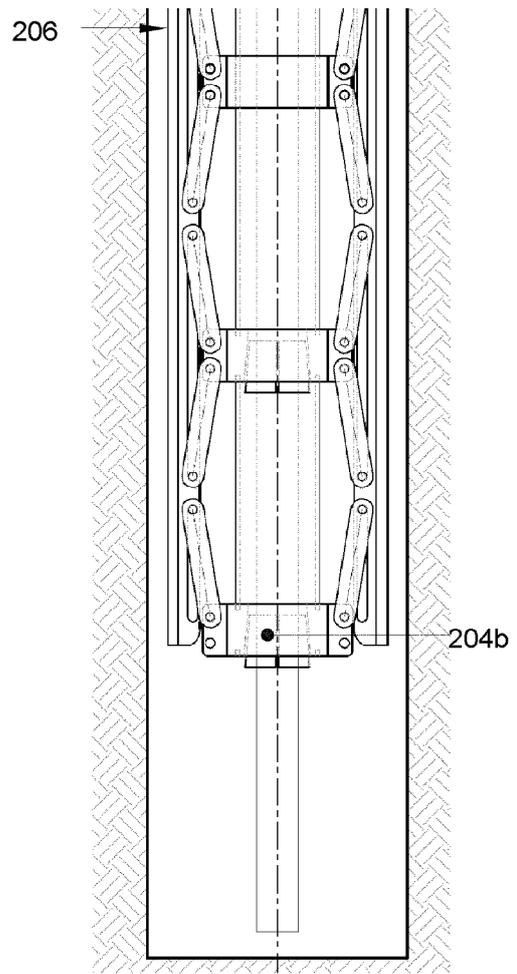


Figure 10B

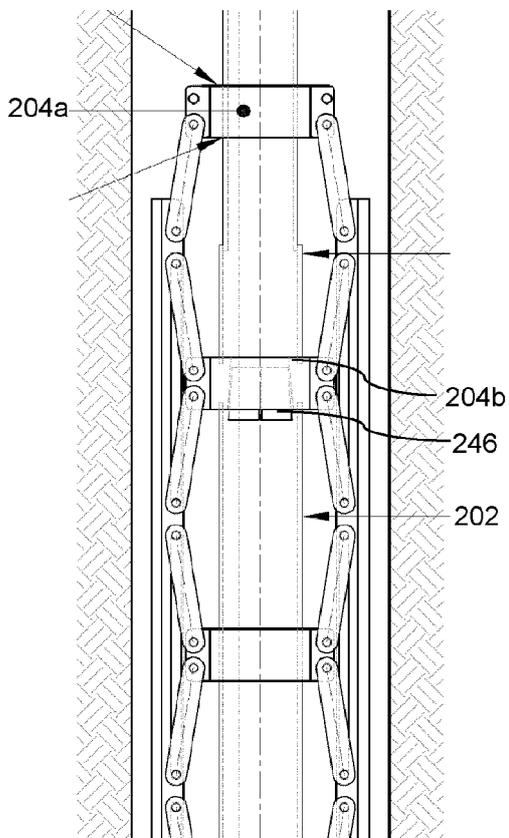
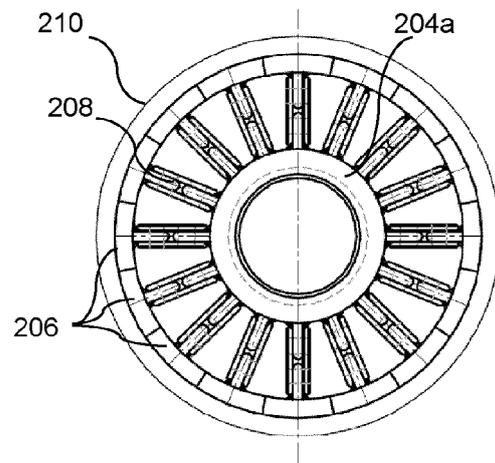
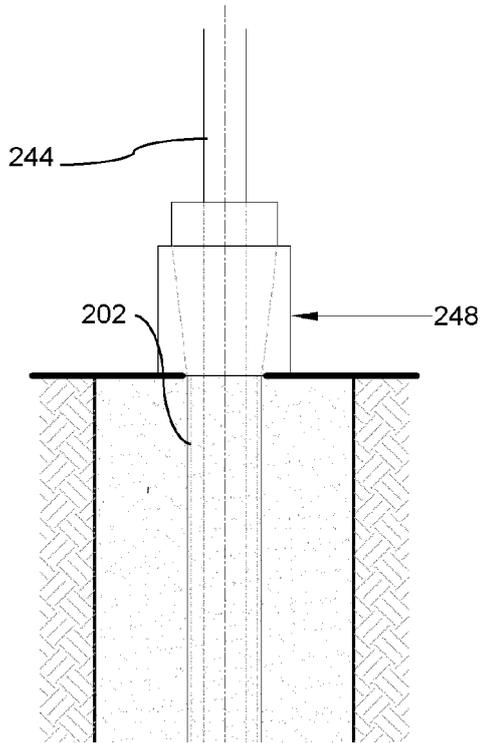


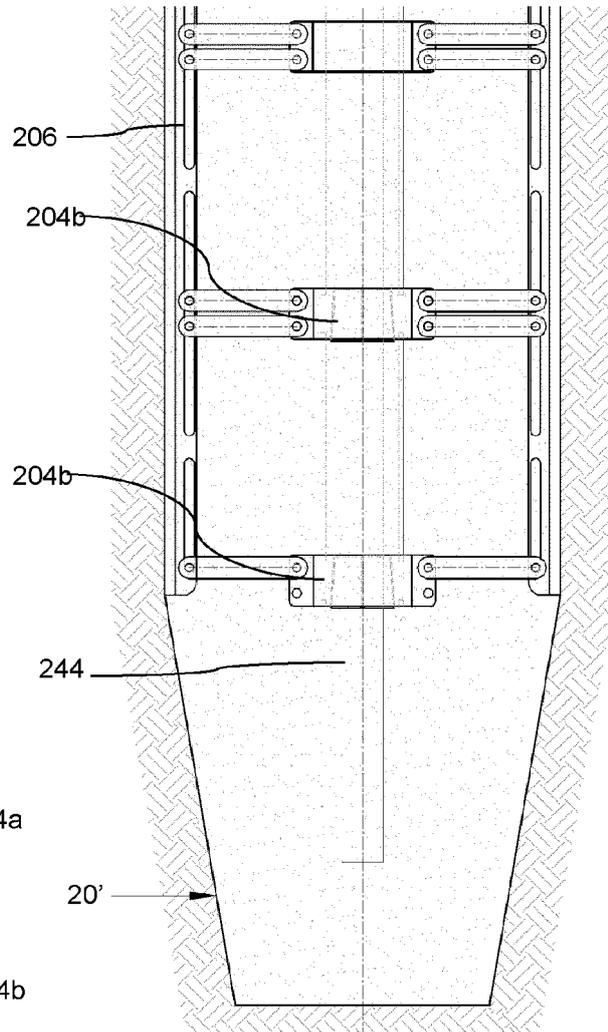
Figure 10D



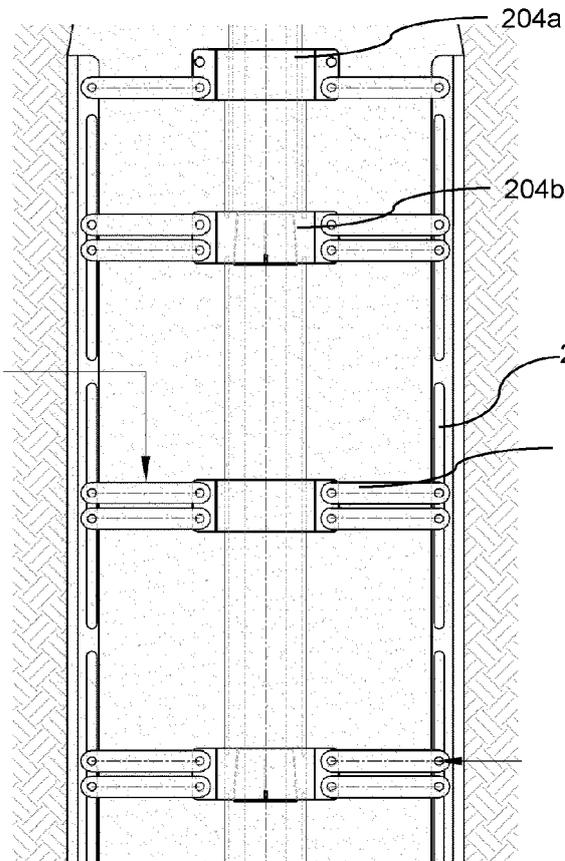
**Figure 11A**



**Figure 11C**



**Figure 11B**



**Figure 11D**

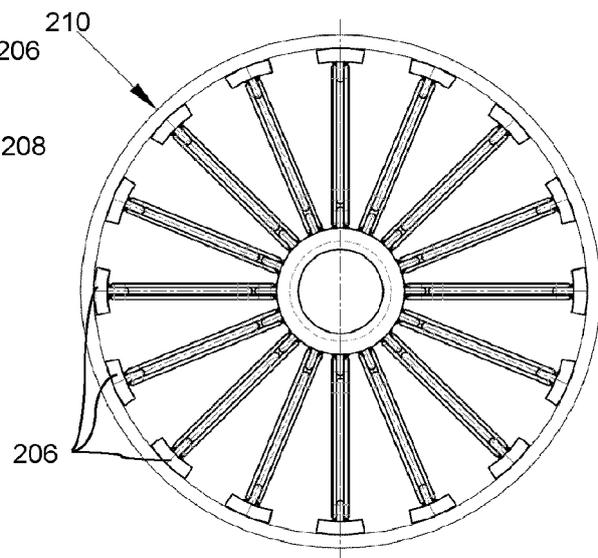


Figure 12

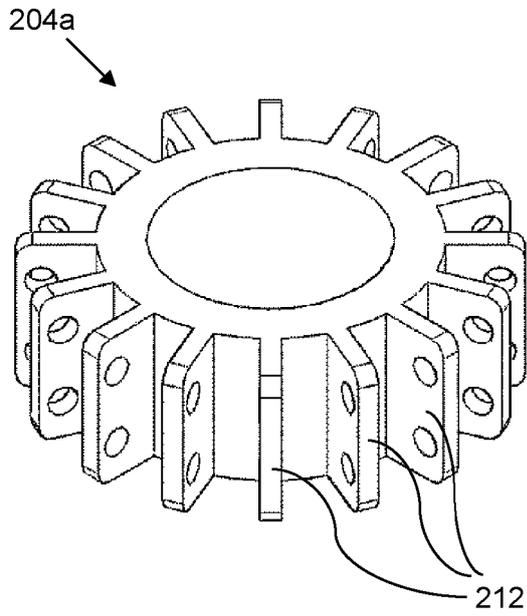


Figure 13

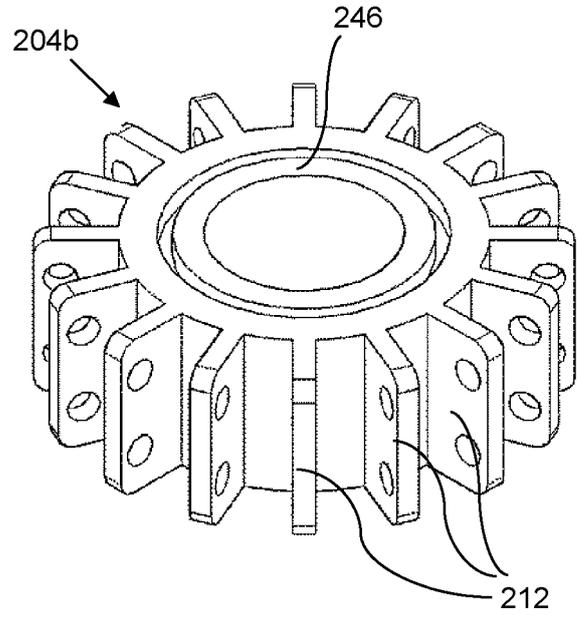


Figure 14

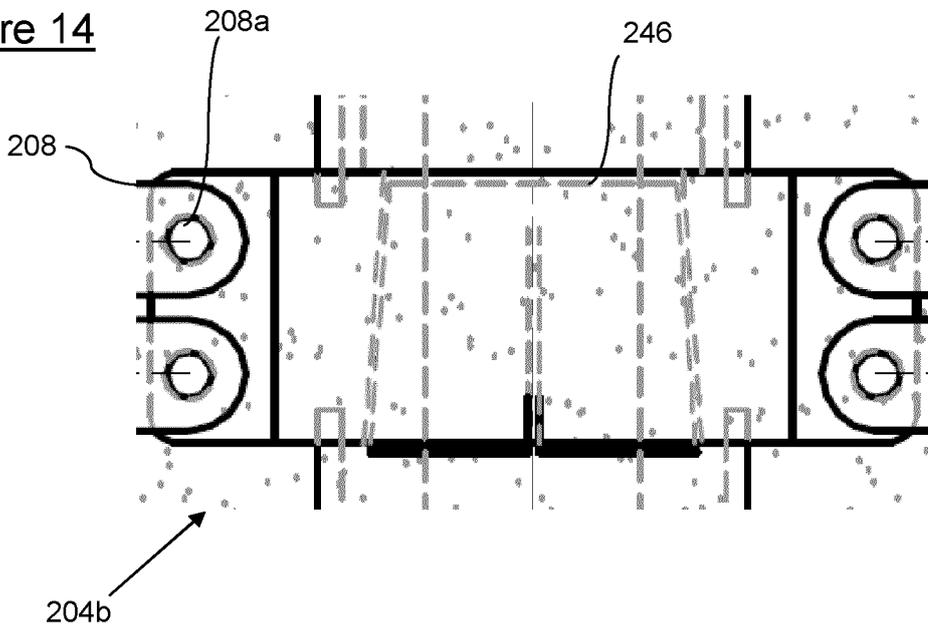


Figure 15

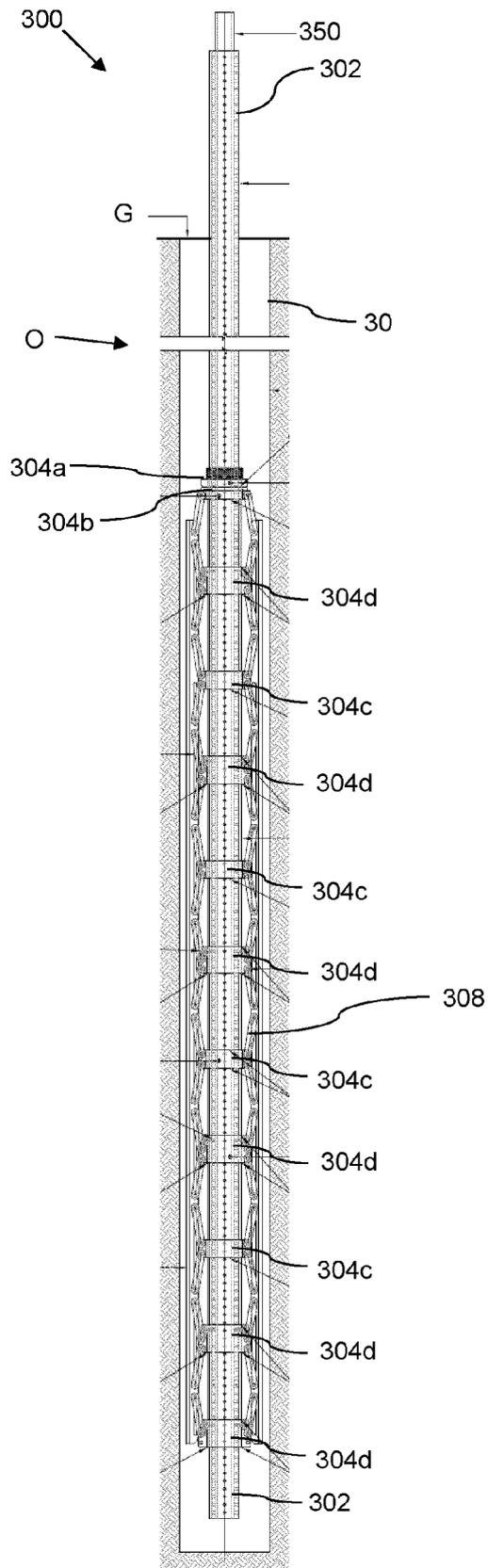
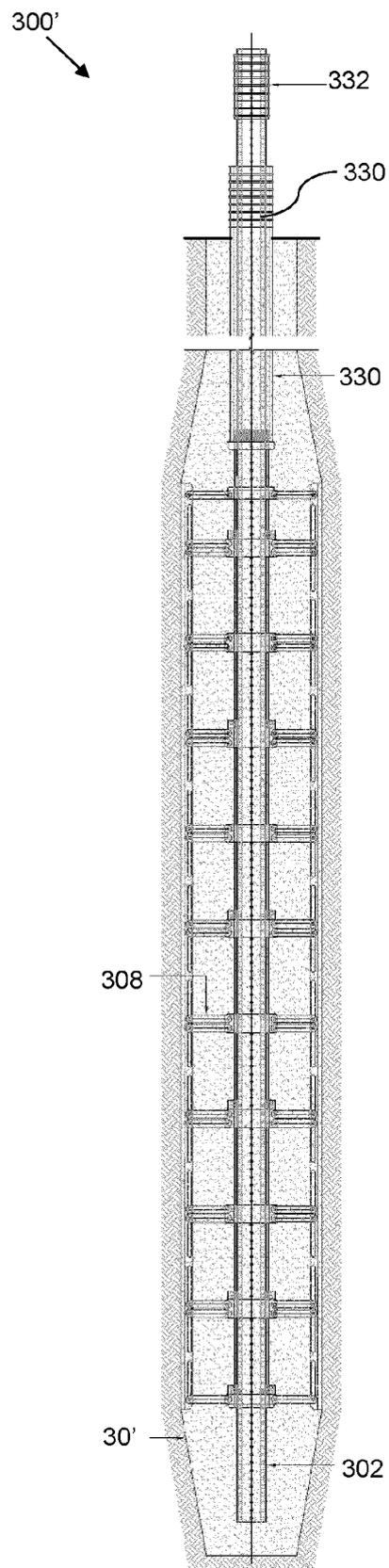
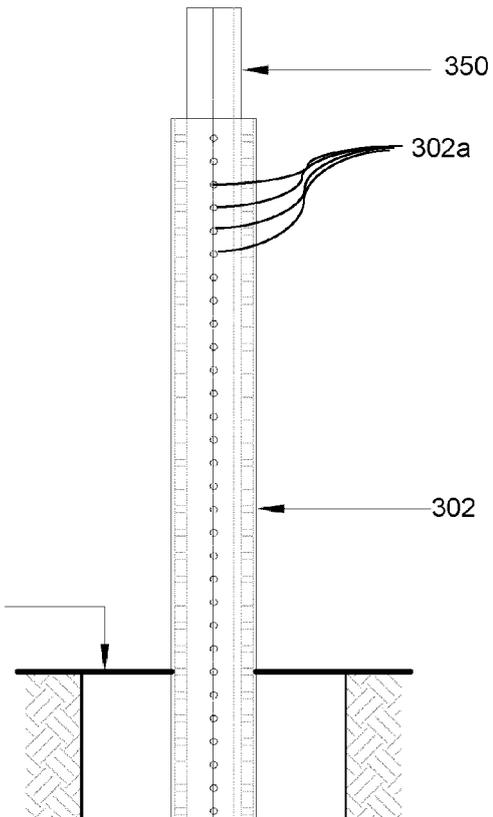


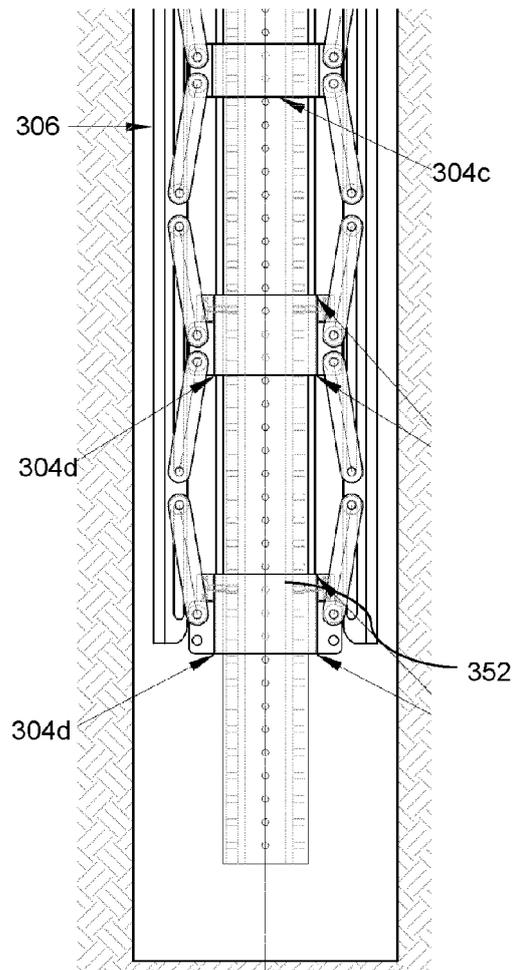
Figure 16



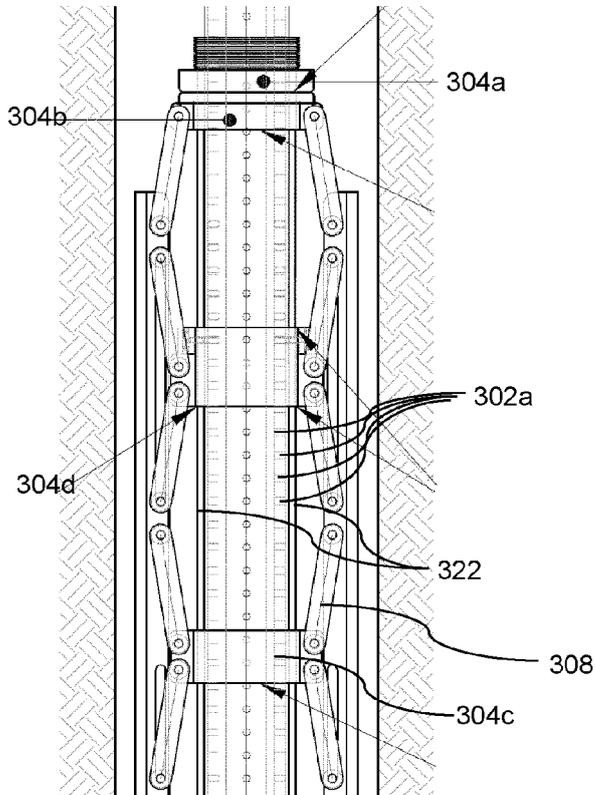
**Figure 15A**



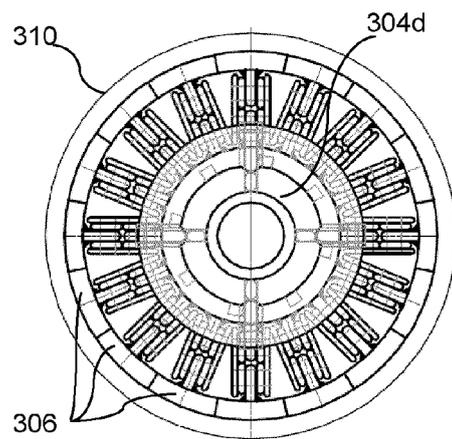
**Figure 15C**



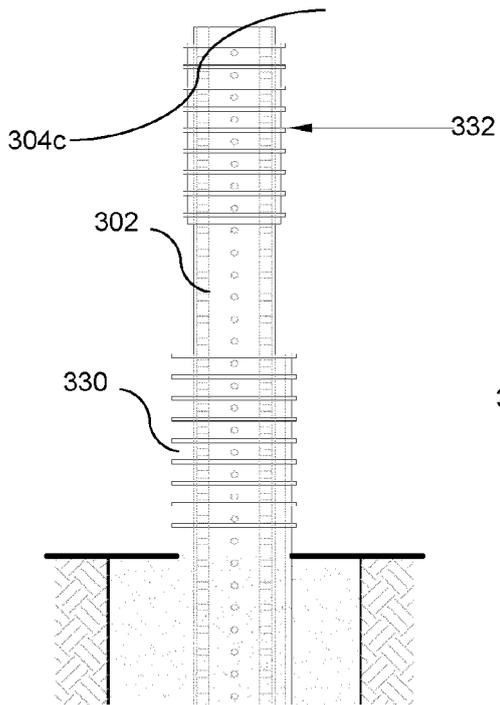
**Figure 15B**



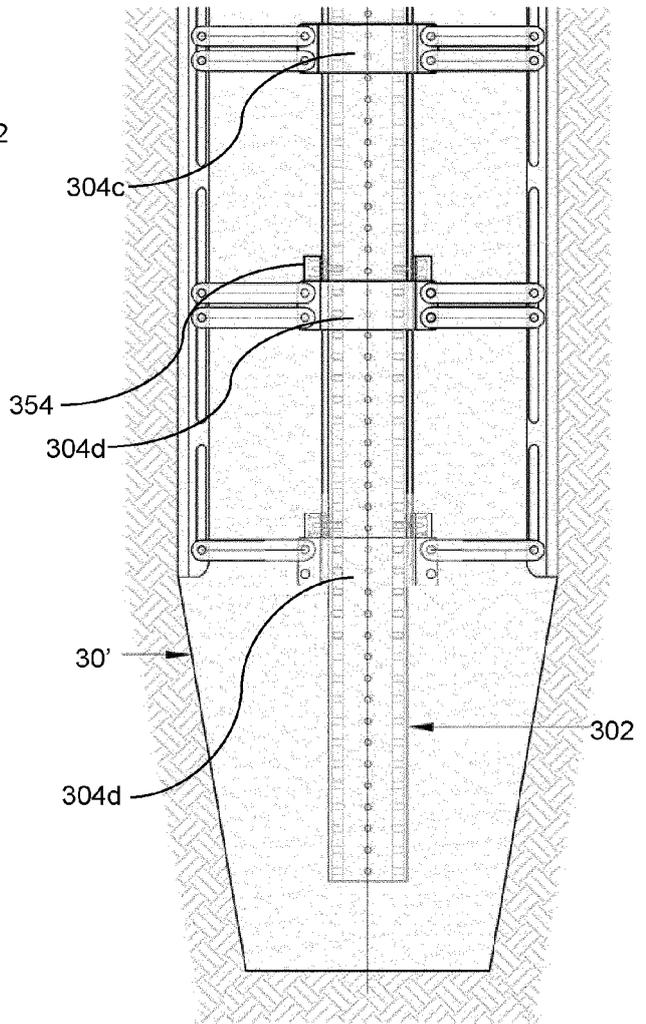
**Figure 15D**



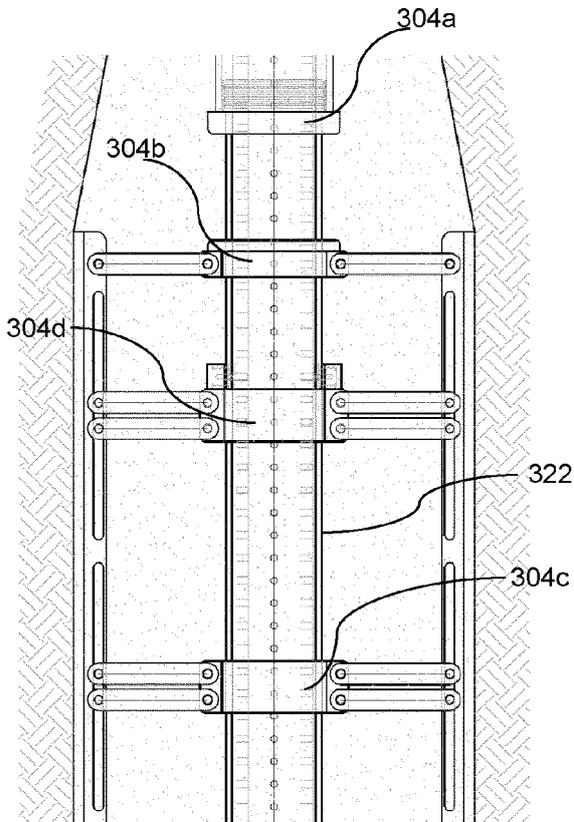
**Figure 16A**



**Figure 16C**



**Figure 16B**



**Figure 16D**

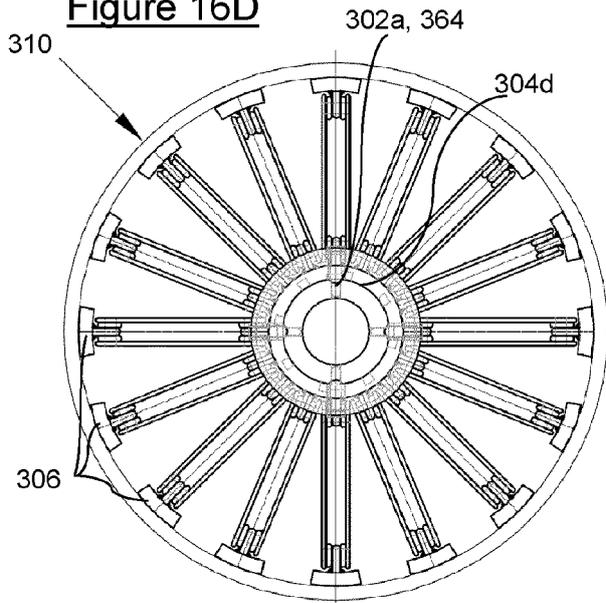


Figure 17

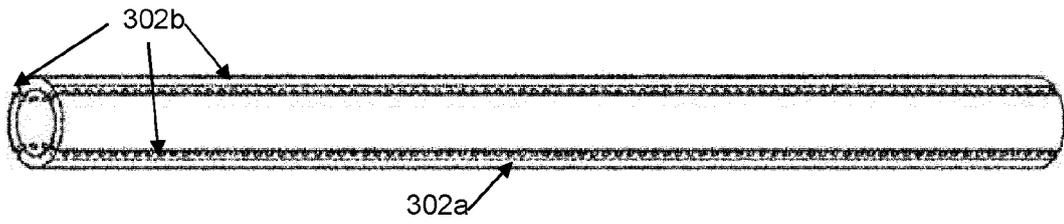


Figure 18

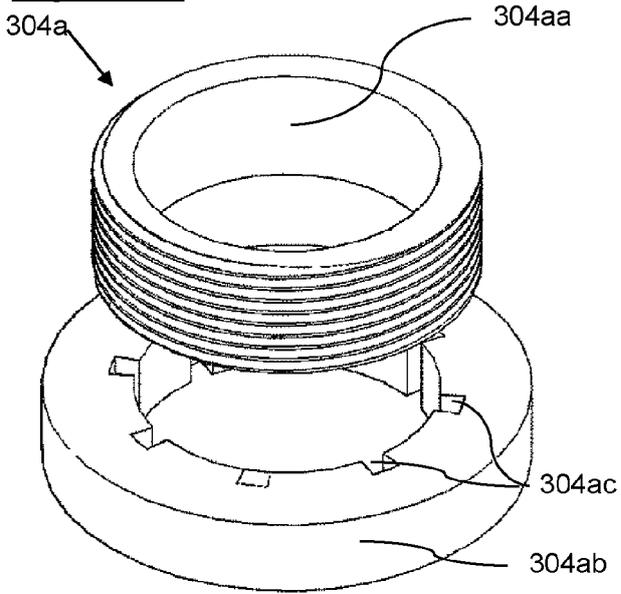


Figure 19

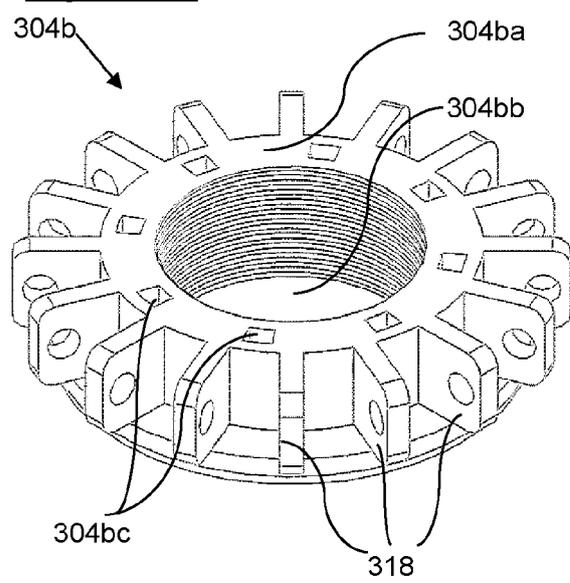


Figure 20

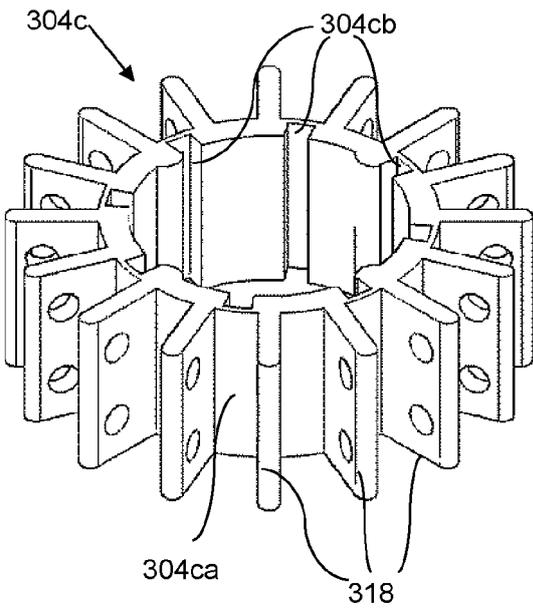


Figure 21

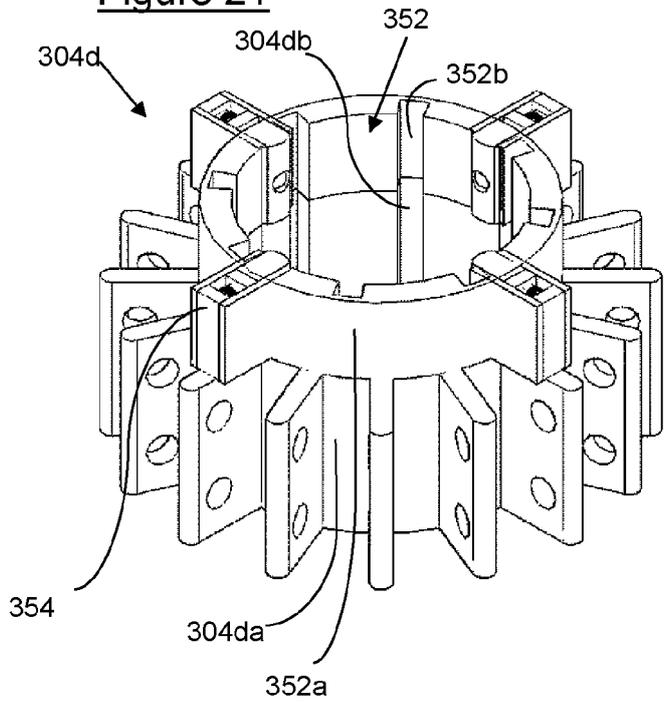


Figure 21A

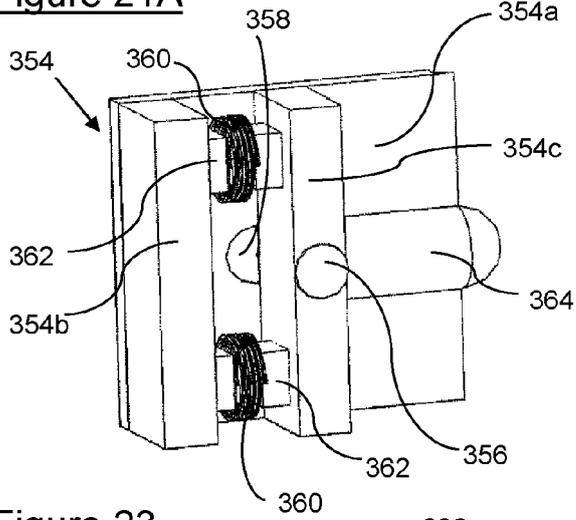


Figure 22

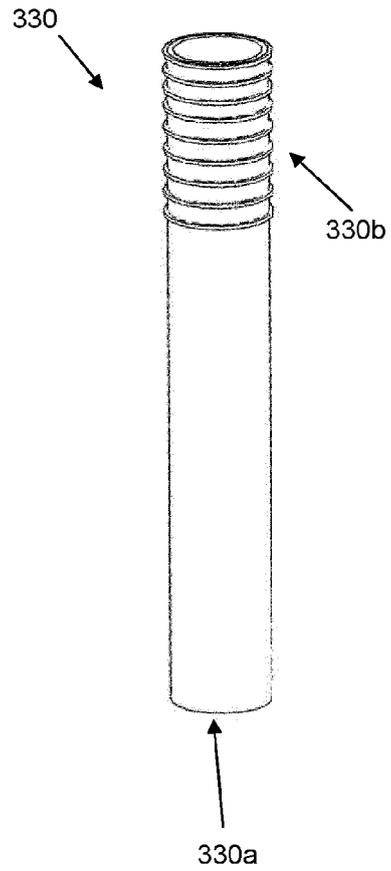


Figure 23

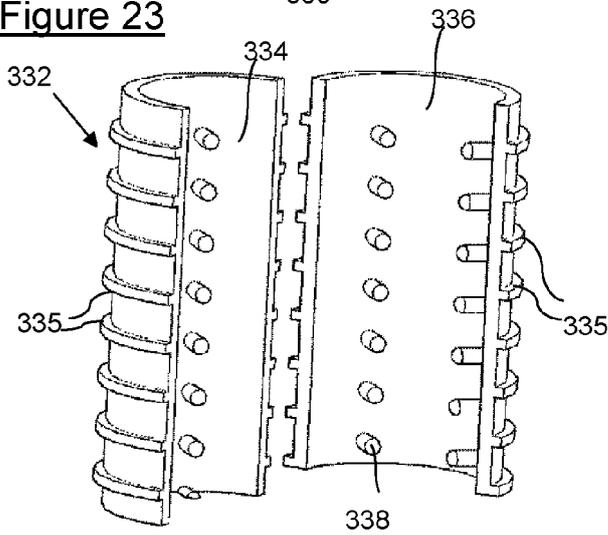


Figure 24A

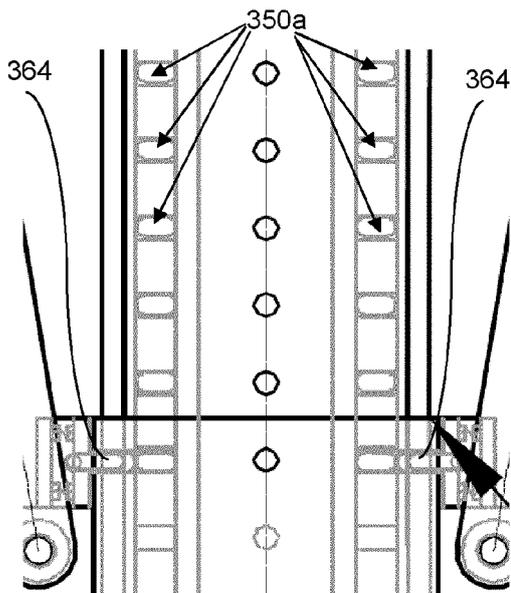
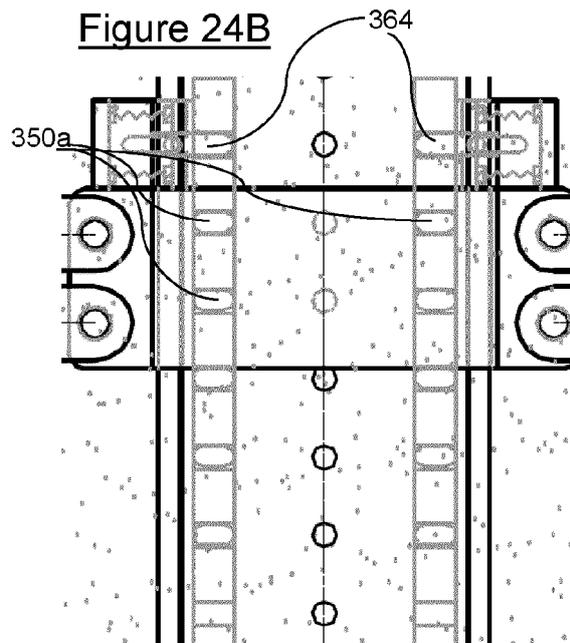


Figure 24B





**PARTIAL EUROPEAN SEARCH REPORT**

Application Number

under Rule 62a and/or 63 of the European Patent Convention.  
This report shall be considered, for the purposes of subsequent proceedings, as the European search report

EP 20 20 3685

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DOCUMENTS CONSIDERED TO BE RELEVANT				
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)	
X	KR 102 159 906 B1 (KOREA CONSTRUCTION TEST INST CO LTD [KR]; LEE SEONG JIN [KR]) 24 September 2020 (2020-09-24)	1-3,5, 11,12	INV. E02D5/54 E02D5/80	
Y	* abstract *	4,10		
A	* paragraphs [0018], [0019]; figures 1,3-6 *	6-9		
-----				
X	KR 2009 0074124 A (HAN CHANG HEON [KR]) 6 July 2009 (2009-07-06)	1-3,5, 11,12		
Y	* abstract; figures 1-5 *	4,10		
A		6-9		
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X	KR 100 919 277 B1 (PARK C WOO [KR]) 30 September 2009 (2009-09-30)	1-3,5, 11,12		
Y	* abstract; figures 1-5 *	4,10		
A		6-9		
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Y	KR 2011 0003998 U ((CHOI-I) CHOI W B) 22 April 2011 (2011-04-22) * abstract; figures 1-11; compounds 33,105,5 *	4,10		
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			TECHNICAL FIELDS SEARCHED (IPC)	
			E02D E21B E04H	
<b>INCOMPLETE SEARCH</b>				
The Search Division considers that the present application, or one or more of its claims, does/do not comply with the EPC so that only a partial search (R.62a, 63) has been carried out.				
Claims searched completely :				
Claims searched incompletely :				
Claims not searched :				
Reason for the limitation of the search: see sheet C				
Place of search		Date of completion of the search	Examiner	
Munich		14 May 2021	Koulo, Anicet	
CATEGORY OF CITED DOCUMENTS				
X : particularly relevant if taken alone		T : theory or principle underlying the invention		
Y : particularly relevant if combined with another document of the same category		E : earlier patent document, but published on, or after the filing date		
A : technological background		D : document cited in the application		
O : non-written disclosure		L : document cited for other reasons		
P : intermediate document		& : member of the same patent family, corresponding document		

EPO FORM 1503 03.82 (P04E07)

**INCOMPLETE SEARCH  
SHEET C**Application Number  
EP 20 20 3685

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Claim(s) completely searchable:  
1-12

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Claim(s) not searched:  
13-15

Reason for the limitation of the search:

15

The applicant was invited according to R. 62a (1) EPC to choose one of the independent product claims 1 and 13 to be searched. He replied by stating that he contests the objection under R. 62a EPC, but however requested the search be carried out at the earliest possible opportunity for claims 1-12.

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Since the Search Division is of the opinion that the two product claims 1 and 13 do not fulfil the requirements of R. 43(2) EPC and the applicant has failed to submit convincing arguments that product claims 1 and 13 fulfil the provisions of R. 43 (2) EPC when replying to the invitation according to R. 62 a(1) EPC, the search is limited to product claim 1 and to its dependent claims 2-10 as well EXCEPTIONALLY (R. 43 (2) EPC) to the two independent method claims relating to that product of claim 1.

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**ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.**

EP 20 20 3685

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.  
The members are as contained in the European Patent Office EDP file on  
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

14-05-2021

10	Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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	KR 100919277 B1	30-09-2009	NONE	
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	KR 20110003998 U	22-04-2011	NONE	
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82