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(54) **OPEN-BOTTOM EXTENSIBLE SHELLS AND RELATED METHODS FOR CONSTRUCTING A
SUPPORT PIER IN THE SOIL**

DEHNBARE HÜLLEN MIT OFFENEM BODEN UND ZUGEHÖRIGE VERFAHREN ZUR
KONSTRUKTION EINES STÜTZPFEILERS IM BODEN

COQUES EXTENSIBLES À FOND OUVERT ET PROCÉDÉS ASSOCIÉS POUR LA
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Description

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application is an international patent application claiming priority to U.S. Patent Application Serial No. 14/809,579 filed July 27, 2015.

TECHNICAL FIELD

[0002] The present invention relates to open-end extensible shells and related methods for constructing a support pier.

BACKGROUND ART

[0003] Buildings, walls, industrial facilities, and transportation-related structures typically consist of shallow foundations, such as spread footings, or deep foundations, such as driven pilings or drilled shafts. Shallow foundations are much less costly to construct than deep foundations. Thus, deep foundations are generally used only if shallow foundations cannot provide adequate bearing capacity to support building weight with tolerable settlements.

[0004] Recently, ground improvement techniques such as jet grouting, soil mixing, stone columns, and aggregate columns have been used to improve soil sufficiently to allow for the use of shallow foundations. Cement-based systems such as grouting or mixing methods can carry heavy loads but remain relatively costly. Stone columns and aggregate columns are generally more cost effective but can be limited by the load bearing capacity of the columns in soft clay soil.

[0005] Additionally, it is known in the art to use metal shells for the driving and forming of concrete piles. One set of examples includes U.S. Patent Nos. 3,316,722 and 3,327,483 to Gibbons, which disclose the driving of a tapered, tubular metal shell into the ground and subsequent filling of the shell with concrete in order to form a pile. Another example is U.S. Patent No. 3,027,724 to Smith which discloses the installation of shells in the earth for subsequent filling with concrete for the forming of a concrete pile. A disadvantage of these prior art shells is that their sole purpose is for providing a temporary form for the insertion of cementitious material for the forming of a hardened pile for structural load support. The prior art shells are not extensible and thus do not exhibit properties that allow them to engage the surrounding soil through lateral deformations. Further, because they relate to the use of ferrous materials, which are subject to corrosion, their function is complete once the concrete infill hardens. Thus, the prior art shells are not suitable for containing less expensive granular infill materials such as sand or aggregate, because the prior art shells cannot laterally contain the inserted materials during the life of the pier. The prior art shells are also not permeable and are thus ill-suited to drain cohesive soils.

[0006] Accordingly, it is desirable to provide improved techniques for constructing a shallow support pier in soil or the ground using extensible shells formed of relatively permanent material of a substantially non-corrosive or non-degradable nature for the containment of compacted aggregate therein.

US2011/064526 A1 describes an extensible shell and method for constructing a support pier. The shell can be flexible such that the shell expands when granular construction material is compacted in the interior of the shell. US 3,798,867, DE10 2014 101914 and JPH10-37170 describe also other shells of the prior art.

BRIEF DESCRIPTION OF THE INVENTION

[0007] According to a first aspect of the present invention, there is provided an extensible shell as described in the claims. According to a second aspect of the present invention, there is provided a method for constructing a support pier in ground as described in the claims.

[0008] Extensible shells and related methods for constructing a support pier in ground are disclosed. An extensible shell defines an interior for holding granular construction material and defines an opening for receiving the granular construction material into the interior. The shell is flexible such that the shell expands laterally outward when granular construction material is compacted in the interior of the shell.

[0009] According to the invention the shell includes a first end that defines the opening. The shell may be shaped to taper downward from the first end to an opposing second end of the shell.

[0010] According to another aspect, the second end of the shell may define a substantially flat, blunt surface.

[0011] According to yet another aspect, a cross-section of the shell may form one of a substantially hexagonal shape and a substantially octagonal shape along a length of the shell extending between the first and second ends.

[0012] According to a further aspect, a cross-section of the first end of the shell is sized larger than a cross-section of the second end.

[0013] According to a still further aspect, the shell is comprised of plastic.

[0014] According to another aspect, the shell may define a plurality of apertures extending between an interior of the shell to an exterior of the shell.

[0015] According to yet another aspect not part of the invention, the shell may be substantially cylindrical in shape. According to an aspect of the invention, the shell may be substantially conical in shape.

[0016] According to the invention, the method includes positioning the shell in the ground and filling at least a portion of the interior of the shell with the granular construction material. The granular construction material is compacted in the interior of the shell to form a pier.

[0017] According to another aspect, a method may include forming a cavity in the ground. The cavity may be partially backfilled with aggregate construction mate-

rial. Next, the shell may be positioned with the cavity and at least a portion of the interior of the shell filled with granular construction material. The granular construction material may then be compacted in the interior of the shell to form a pier. The compaction may be performed with a primary mandrel. Additional compacting may be performed with a second mandrel that has a larger cross-sectional area than the primary mandrel.

[0018] According to a further aspect, the extensible shell may comprise a plurality of slots extending between an interior of the shell to an exterior of the shell, the slots being generally transverse to a centerline along the length of the shell. The slots may be discontinuous around a circumference of the shell thereby maintaining portions of continuous material connectivity along the length of the shell. The slots may have a width in the range of 1/4 inch (6.35 mm) to 3/8 inch (9.53 mm) and may be spaced at a distance of 6 inches (152 mm) from one another.

[0019] According to the invention, the disclosure is directed to an extensible shell for constructing a support pier in ground, the extensible shell defining an interior for holding granular construction material and said extensible shell defining a first end having a first opening for receiving granular construction material into the interior and a second end having a second opening, wherein the shell is flexible such that the shell expands laterally outward when granular construction material is compacted in the interior of the shell.

[0020] In another aspect, the first end defines the first opening with the shell shaped to taper from the first end to opposing second end of the shell, with the second end comprising a second opening.

[0021] According to the invention, a method for constructing a support pier in ground is provided according to independent claim 8.

[0022] In a further aspect, the disclosure is directed to a method for constructing a support pier in ground, with the method comprising: forming a cavity in the ground; partially backfilling the cavity with an aggregate construction material; positioning an extensible shell into the cavity, with the shell having a first end with a first opening and a second end having a second opening, with the shell defining an interior for holding granular construction material and defining an opening for receiving the granular construction material into the interior, wherein the shell is flexible such that the shell expands when granular construction material is compacted in the interior of the shell; filling at least a portion of the interior of the shell with the granular construction material; and compacting the granular construction material in the interior of the shell to form a support pier.

[0023] This brief description is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description of the invention. This brief description of the invention is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to

limit the scope of the claimed subject matter. Further, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024]

Figure 1A, Figure 1B, Figure 1C, Figure 1D, and Figure 1E illustrate different views of an extensible shell, not part of the present invention;

Figure 2A, Figure 2B, and Figure 2C illustrate steps in an exemplary method of constructing a pier in ground using an extensible shell, not part of the present invention;

Figure 3A, Figure 3B, Figure 3C, and Figure 3D illustrate steps in another exemplary method of constructing a support pier in ground using an extensible shell, not part of the present invention;

Figure 4, Figure 5, Figure 6, and Figure 7 are graphs showing results of load tests of support piers constructed using an extensible shell, not part of the present invention;

Figure 8 illustrates a perspective view of a slotted shell, not part of the present invention;

Figure 9 is a graph showing results of load tests of a support pier constructed using the shell as shown in Figure 8;

Figure 10A and Figure 10B illustrate a perspective view and a cross-sectional view of an example of an open-end extensible shell, not part of the invention; Figure 11A, Figure 11B, and Figure 11C illustrate perspective views and a cross-sectional view of another example of an open-end extensible shell in accordance with embodiments of the present invention;

Figure 12A and Figure 12B show an example of a process of installing the open-end extensible shell into the ground;

Figure 13 shows another example of installing the open-end extensible shell into the ground;

Figure 14 shows a flow diagram of an example of a method of using the open-end extensible shell to form a support pier;

Figure 15A and Figure 15B show certain process steps of using the open-end extensible shell to form a pier; and

Figure 16 is a graph showing results of load tests of a support pier constructed using an embodiment as shown in Figure 10A, Figure 10B and/or Figure 11A, Figure 11B, Figure 11C.

DETAILED DESCRIPTION

[0025] The present invention is directed to an extensible shell and related methods for constructing a support "shell pier" in ground. According to the invention the shell

has an interior into which granular construction material can be loaded and compacted. The shell can be positioned in a cavity formed in the ground (the cavity being formed through a variety of methods as described in more detail below, including driving the shell from grade to form the cavity). After positioning in the ground, granular construction material can be loaded into the interior through an opening of the shell. The granular construction material may be subsequently compacted. The shell is extensible (or flexible) such that walls of the shell expand when the granular construction material is compacted in the interior of the shell. Therefore, since the shell maintains the compacted granular construction material in a contained manner (i.e., the material cannot expand laterally beyond the shell walls into the in-situ soil) the ground surrounding the shell is reinforced and improved for supporting shallow foundations and other structures. The present invention can be advantageous, for example, because it allows for much higher load carrying capacity due to its ability to limit the granular construction material from bulging laterally outward during loading. The shell is typically made of relatively permanent, substantially non-corrosive and/or non-degradable material such that the lateral bulging of the material is limited for the life of the pier.

[0026] Figures 1A - 1E illustrate different views of an extensible shell 100. Figure 1A depicts a perspective view of the extensible shell 100, which includes an enclosed end 102. The surface of the enclosed end 102 can define a substantially flat, blunt bottom surface 104, which can be hexagonal in shape. In the alternative, the enclosed end 102 may have any other suitable shape or size. Further, the bottom of the shell may be open, or may be blunt as in the case of a cylindrical shell, may be pointed as the bottom of a conical shell, or may be truncated to form a blunt shape at the bottom of conical or articulated section such as, for example, a frustum, or frustoconical configuration. It is therefore understood, for the purposes of this disclosure, that the term conical includes frustoconical configurations. The length of the shell may range from about 0.5 m to about 20 m long; such as from about 1 m to about 10 m long. The surfaces of the shell (inside and/or outside) may be smooth or contain a varying degree of roughness for interaction with surrounding surfaces.

[0027] Opposing the enclosed end 102 is another end, open end 106, which defines an opening 108 for receiving granular construction material into an interior (not shown in Figure 1A) defined by the shell 100. As will be described in further detail herein below, the open end 106 is positioned substantial vertical to and above from the enclosed end 102 during construction of the pier.

[0028] Figures 1B, 1C, 1D, and 1E depict a top view, bottom view, a side view, and a cross-sectional side view of the extensible shell 100, respectively. As shown in Figure 1B, the extensible shell 100 defines a substantially hollow interior 110 extending between the open end 106 (with opening 108) and the enclosed end 102.

[0029] Figure 1C shows that a cross-section of the open end 106 may be sized larger than the bottom surface 104 of the enclosed end 102. Figure 1D shows section line A-A arrows indicating the direction of the cross-sectional side view of the extensible shell 100 depicted in Figure 1E.

[0030] The shape of the exterior of the shell 100 may be articulated to form a plurality of panels that form a hexagonal shape in cross-section as viewed from the top or bottom of the shell. Alternatively, the shape may be octagonal, cylindrical, conical, or any other suitable shape.

[0031] The extensible shell 100 is often shaped to taper downward from the open end 106 to the enclosed end 102. In one example not part of the invention, the shell 100 tapers at a 2 degree angle, although the shell may taper at any other suitable angle.

[0032] The extensible shell 100 may be made of plastic, aluminum, or any metallic or non-metallic material of suitable extensibility, and preferably substantially non-corrosive and/or non-degradable material. The shell 100 may be relatively thin-walled. The thickness of the wall of the shell 100 may range, for example, from about 0.5 mm to about 100 mm. The example shell 100 of Figure 1B has a thickness of about 0.25 inches (approximately 6.35 mm), although the shell may have any other suitable thickness. This thickness distance is the distance that uniformly separates the interior 110 and the exterior of the shell. The material of the shell and its thickness may be configured such that the shell has suitable integrity to hold construction material in its interior 110 and to expand laterally at least some distance when the construction material is compacted in the interior 110.

[0033] Figures 2A - 2C illustrate steps in an exemplary method of constructing a pier in ground using an extensible shell 100. In this example, side partial cross-section views illustrate the use of the extensible shell 100 for constructing a pier 200 in the ground (see Figure 2C). Other methods are described with reference to Figures 3A - 3D and the Examples below. The method of Figures 2A - 2C includes forming a pre-formed elongate vertical cavity 202 or hole in a ground surface 204, as shown in Figure 2A. The ground may be comprised of primarily soft cohesive soil such as soft clay and silt, or also loose sand, fill materials, or the like. The cavity 202 may be formed with a suitable drilling device having, for example, a drill head or auger for forming a cavity or hole, or may be formed by other methods for forming a cavity such as by inserting and removing a driving mandrel to the desired pre-formed cavity depth. In some examples not part of the invention, the cavity may not be formed at all prior to shell insertion, such as described below with reference to Figures 3A - 3D.

[0034] After the partial cavity 202 has been formed, the extensible shell 100 may be positioned within the cavity 202, as shown in Figure 2B, for ultimate driving to the desired depth. Particularly, an extractable mandrel 206 may be used for driving the extensible shell 100 into the

cavity 202 and ground 204. A tamper head 208 of the mandrel 206 may be positioned against a bottom surface 210 of the interior 110 and used to drive the shell 100 to the desired penetration depth, as shown in Figure 2C. The cavity 202 is at that point formed of a size and dimension such that the exterior surface of the extensible shell 100 fits tightly against the walls of the cavity 202.

[0035] After the extensible shell 100 has been driven into (while forming) the fully enlarged cavity 202, the mandrel 206 is removed, leaving behind the shell 100 in the cavity 202 and with the interior 110 being empty. The shell 100 may then be filled with a granular construction material 212, such as sand, aggregate, admixture-stabilized sand or aggregate, recycled materials, crushed glass, or other suitable materials as shown in Figure 2C. The granular construction material 212 may be compacted within the shell using the mandrel 206. The compaction increases the strength and stiffness of the internal granular construction material 212 and pushes the granular construction material 212 outward against the walls of the shell 100, which pre-strains the shell 100 and increases the coupling of the shell 100 with the in-situ soil. Significant increases in the load carrying capacity of the pier 200 can be achieved as a result of the restraint offered by the shell 100.

[0036] Figures 3A - 3D illustrate steps in another exemplary method of constructing a pier in ground using an extensible shell. Referring to Figure 3A, an aggregate construction material 300 (e.g., sand) is placed in the interior 110 of the shell 100 to a predetermined level above the bottom surface 210 of the shell 100. Next, the tamper head 208 of the extractable mandrel 206 is fitted to the interior 110 of the extensible shell 100, and against the top of the aggregate construction material 300. The mandrel 206 may then be moved towards the ground 204 in a direction indicated by arrow 302 for driving the shell 100 into the ground 204. Driving may be facilitated using a small pre-formed cavity (e.g., the cavity 202 shown in Figure 2A), or not, depending on site conditions.

[0037] Referring to Figure 3B, the mandrel 206 is shown driving the shell 100 into the ground 204 in the direction 302 such that the shell 100 is at a predetermined depth below grade. Next, the mandrel 206 may be removed. At Figure 3C, the shell 100 is substantially filled with additional aggregate construction material 304 (e.g., sand) through opening 108, and the mandrel 206 is positioned as shown. Next, vertical compaction force and/or vibratory energy is applied to the mandrel 206 for compacting the materials 300 and 304. The shell 100 may be driven by this force to a further depth below grade. The addition of construction material 304 and subsequent compaction can be repeated several times until the final pier is constructed. Alternatively, the shell may be "topped off" with additional construction material after only one compaction cycle.

[0038] A second mandrel 212 may be used to compact the upper portion of the material 304 in the direction 302,

as shown in Figure 3D. The second mandrel 212 may have a larger cross-sectional area than the primary mandrel 206 to provide increased confinement during compaction.

[0039] The shell 100 may define apertures 218 that extend between the interior 110 and an exterior of the shell 100 to the in-situ soil (see Figures 1A and 2C). The apertures 218 may provide for drainage of excess pore water pressure that may exist in the in-situ soil to drain into the interior 110 of the shell 100. Increases in pore water pressure typically decreases the strength of the soil and is one of the reasons that prior art piers are limited in their load carrying capacity in saturated cohesive soil such as clay, silt, or the like. The apertures 218 envisioned herein allow the excess pore water pressure in the soil to dissipate into the pier 200 after insertion. This allows the in-situ soil to quickly gain strength with time, a phenomena not enjoyed by concrete, steel piles, or grout elements (i.e., "hardened" elements). The drainage of excess pore water pressures allows additional settlement of the soil that may occur as a result of pore water pressure dissipation prior to the application of foundation loads.

[0040] Other examples may not define apertures, or may provide one or more apertures 218 on only one side of the shell 100. Alternatively, the apertures 218 may be defined in the shell 100 such that they are positioned along a portion of the length of the shell 100, are positioned along the full length of the shell 100, or may be positioned asymmetrically in various configurations. The sizes and placements of the apertures 218 can vary according to the size of the shell 100, the conditions of the ground (e.g., where higher water pressure is known to exist), and other relevant factors. The apertures 218 may range in size from about 0.5 mm to about 50 mm; such as from about 1 mm to about 25 mm. The top of the shell 100 may be enclosed and connected to vacuum pressure to further increase and accelerate drainage of excess water pressure in the surrounding soil through the apertures 218.

[0041] The mandrel 206 may be constructed of sufficient strength, stiffness, and geometry to adequately support the shell 100 during driving and to be able to be retracted from the shell 100 after driving. The shape of the exterior of mandrel 206 may be substantially similar to the shape of the interior 110 defined by the shell 100. The mandrel 206 may be comprised primarily of steel. Other materials are also envisioned including, but not limited to, aluminum, hard composite materials, and the like.

[0042] The mandrel 206 may be driven by a piling machine or other suitable equipment and technique that may apply static crowd pressure, hammering, or vibration sufficient to drive the mandrel 206 and extensible shell 100 into the surface of ground 204. The machine may be comprised of an articulating, diesel, pile-driving hammer that drives the mandrel 206 using high energy impact forces. The hammer may be mounted on leads suspended from a crane. The hammer may be a sheet pile

vibrator mounted on a rig capable of supplying a downward static force. The shell 100 may be placed in a pre-formed cavity 200 and constructed without the use of an extractable mandrel. Standard methods of driving mandrels into the ground are known in the art and therefore, can be used for driving.

[0043] The following Examples illustrate further aspects.

Example I

[0044] As an example, piers were constructed using extensible shells at a test site in Iowa. Load tests were conducted on the piers using a conventional process. The extensible shells used in the tests and the methods of their use consisted essentially of that described above and shown in the attached Figures. In this test, extensible shells formed from LEXAN® polycarbonate plastic were installed at a test site characterized by soft clay soil. This testing was designed to compare the load versus deflection characteristics of an extensible shell to aggregate piers constructed using a driven tapered pipe. Two comparison aggregate piers (of fine and coarse aggregate) were constructed to a depth of 12 feet (3.7 m) below the ground surface.

[0045] In this test, the extensible shell was formed by bending sheets of the plastic to form a tapered shape having a hexagonal cross-section and that tapered downward from an outside diameter of 24 inches (610 mm) at the top of the shell to a diameter of 18 inches (460 mm) at the bottom of the shell. A panel of the shells overlapped, and this portion was both glued and bolted together. The length of the extensible shell was 9.5 feet (2.9 m). In this embodiment, apertures were formed in the extensible shell by perforating the sides of the shell with 3 mm to 7 mm diameter "weep" holes spaced apart from each another. The bottom portion of the shell was capped with a steel shoe to facilitate driving. LEXAN® polycarbonate plastic has a tensile strength of approximately 16 MPa (2300 psi) at 11 percent elongation and a Young's modulus of 540 MPa (78,000 psi). The extractable mandrel used in this test was attached to a high frequency hammer, which is often associated with driving sheet piles. The hammer is capable of providing both downward force and vibratory energy for driving the shell into the ground and for compacting aggregate construction material in the shell.

[0046] In this example, the extensible shell was driven into the ground without pre-drilling of the cavity or hole. Particularly, in this test, the two shells were installed by orientating each shell in a vertical direction, placing approximately 4 feet (1.2 m) of sand at the base of the shell, and then driving the shell into the ground surface with an extractable mandrel with exterior dimensions similar to those of the interior of the shell. The shell was driven to a depth of approximately 8.5 feet (2.6 m) below grade. The mandrel was removed and the shells were filled with sand. The extractable mandrel was then re-lowered with-

in the shells and vertical compaction force in combination with vibratory energy was applied to both compact the sand to drive the shell to a depth of 9 feet (2.7 m) below grade. The mandrel was then extracted and the upper portion of the shell was then filled with crushed stone to a depth of 0.5 ft (0.2 m) below grade. A concrete cap was then poured above the crushed stone fill to facilitate load testing.

[0047] Radial cracks were observed to extend outward from the edge of the shell pier. These cracks form drainage galleries that are the result of high radial stresses and low tangential stresses created in the ground during pier installation. Drainage was afforded by the perforations in the shell and allowed soil water to drain into the sand and aggregate filled piers.

[0048] The shell piers were load tested using a hydraulic jack pushing against a test frame. Figure 4 is a graph showing results of the load test compared with aggregate piers constructed using a similarly shaped mandrel. As shown in Figure 4, at a top of pier deflection of one inch, the piers constructed without shells supported a load of 15,000 pounds to 20,000 pounds (67 kN to 89 kN). The shell piers constructed in this example supported a load of 310 kN to 360 kN (70,000 to 80,000 pounds) at a top of pier deflection of one inch. The load carrying capacity of the shell piers constructed in this example provided a 3.5 to 5.3 fold improvement when compared to aggregate piers constructed without extensible shells.

Example II

[0049] In other testing, extensible shells were formed from high-density polyethylene polymer ("HDPE") and installed at the test site as described in Example I. This testing program was designed to compare the load versus deflection characteristics of this example to aggregate piers constructed using a driven tapered pipe as described in Example I. A total of six shell piers were installed as part of this example.

[0050] In this test, the extensible shell was formed by a rotomolding process. The shells defined a tapered shape having a hexagonal cross-section and that tapered downward from an outside diameter of 585 mm (23 inches) at the top of the shell to a diameter of 460 mm (18 inches) at the bottom of the shell. The bottom of the extensible shell was integrally constructed as part of the shell walls as a result of the rotomolding process. The mandrel in this embodiment was attached to the same hammer as described in Example I.

[0051] The installation process in this Example was somewhat different from that in Example I and included pre-drilling a 30 inch (0.76 m) diameter cavity to a depth of 2 feet (0.61 m) to 3 feet (0.9 m) below the ground surface (rather than driving the shell initially from top grade). The shell was then placed vertically in the pre-drilled cavity. The extractable mandrel was then inserted into the shell, and the shell was driven to a depth 11 feet (3.4 m) to 12 feet (3.7 m) below grade. The extensible shell was then

filled with aggregate construction material and compacted in four lifts; with each lift about 7.4 cubic feet (0.2 cubic meters) in volume. The aggregate consisted of sand in five of the piers and consisted of crushed stone in one of the piers. Each lift was compacted with the downward pressure and vibratory energy of the extractable mandrel.

[0052] After placement and compaction of sand within the extensible shells, the top of the shells were situated at about 2 feet (0.61 m) to 3 feet (0.9 m) below the ground surface. Crushed stone was then placed and compacted above the extensible shell to a depth of 1 foot (0.3 m) below the ground surface. A concrete cap was then poured above the crushed stone fill to facilitate load testing

[0053] The shell piers were load tested using a hydraulic jack pushing against a test frame. Figure 5 is a graph showing results of the load test compared with the aggregate piers described in Example I. As shown in Figure 5, at a top of pier deflection of one inch, the piers constructed without shells supported a load of 15,000 pounds to 20,000 pounds (67 kN to 89 kN). The shell piers constructed in this example supported loads ranging from 62,000 pounds (275 kN) to 71,000 pounds (315 kN) at the top of pier deflections of one inch. The load carrying capacity of the shell piers constructed in accordance with this example provided a 3.1 to 4.7 fold improvement when compared to aggregate piers constructed without extensible shells.

Example III

[0054] In another test, an extensible shell of the same embodiment described in Example II was installed at the test site as described in Example I. This testing program was designed to compare the load versus deflection characteristics of this example to aggregate piers constructed using a driven tapered pipe as described in Example I. The mandrel, hammer, and extensible shell used for testing were the same as used in Example II.

[0055] In this example, the installation process included pre-drilling a 30 inch (0.76 m) diameter cavity to a depth of 3 feet (0.9 m) below the ground surface. The extractable mandrel was then inserted into the pre-drilled cavity, to create a cavity with a total depth of 5 feet (1.5 m) below the ground surface. This cavity was then backfilled to the ground surface with sand. The extensible shell was then driven vertically through the sand filled cavity with the extractable mandrel to a depth of 9 feet (2.7 m) below the ground surface, so that the top of the shell was situated 6 inches above the ground surface. The extensible shell was then filled with sand in four lifts, with each lift about 7.4 cubic feet (0.2 cubic meters) in volume. Each lift was compacted with the downward pressure and vibratory energy of the mandrel. A concrete cap encompassing the top of the shell was then cast over the shell to facilitate load testing.

[0056] The shell pier was load tested using a hydraulic

jack pushing against a test frame. Figure 6 is a graph showing results of the load test compared with the aggregate piers described in Example I. As shown in Figure 6, at a top of pier deflection of one inch, the piers constructed without shells supported a load of 15,000 pounds to 20,000 pounds (67 kN to 89 kN). The pier constructed in this example supported a load of 57,500 pounds (255 kN) with a top of pier deflection of one inch. The load carrying capacity of the shell pier constructed in accordance with this example provided a 2.9 to 3.8 fold improvement when compared to aggregate piers constructed without extensible shells.

Example IV

[0057] In yet another test, an example was installed at a project site characterized by 3 feet (0.9 m) of loose sand soil over 7 feet (2.1 m) of soft clay soil over dense sand soil. The example at the project site was used to support structural loads, such as those associated with building foundations and heavily loaded floor slabs. The mandrel, hammer, and extensible shell used for testing were the same as used in Examples II and III.

[0058] In this example, the installation process included pre-drilling a 30 inch (0.76 m) diameter pre-drill to a depth of 3 feet (0.9 m) below the ground surface. Approximately 7.4 cubic feet (0.2 cubic meters) of sand was then placed in the pre-drilled cavity. This resulted in the pre-drilled cavity being about half-full.

[0059] The extensible shell was then placed vertically in the partially backfilled pre-drilled cavity. The extractable mandrel was then inserted into the shell, and the shell was driven to a depth 12.5 feet (3.8 m) below grade. The extensible shell was then filled with sand in four lifts; with each lift about 7.4 cubic feet (0.2 cubic meters) in volume. Each lift was compacted with the downward pressure and vibratory energy of the mandrel.

[0060] After placement and compaction of sand within the extensible shell, a lift of crushed stone about 4.9 cubic feet (0.14 cubic meters) in volume was placed and compacted within the extensible shell. Crushed stone was then placed and compacted above the extensible shell until the crushed stone backfill was level with the ground surface.

[0061] At one shell location, a 30 inch (0.76 m) diameter concrete cap was placed over the shell to facilitate load testing. At a second shell location, a 6 foot (1.8 m) wide by 6 foot (1.8 m) wide concrete cap was placed over the shell to facilitate loading and to measure the load deflection characteristics of the composite of native matrix soil and extensible shell (to simulate a floor slab).

[0062] The shell piers were load tested using a hydraulic jack pushing against a test frame, with the results of the load testing being shown in Figure 7. The shell pier tested with the 30 inch diameter concrete cap supported a load of 35,500 pounds (158 kN) at a deflection of 0.4 inches (10 mm). The shell pier tested with a 6 foot wide by 6 foot wide concrete cap supported a load of 104,700 pounds

(467 kN) at a deflection of 0.4 inches (10 mm).

Slotted Shell Embodiment

[0063] With reference to Figure 8, an alternative example is shown and which includes an extensible shell 800 with one or more slits or slots 812 that extend between an interior of the shell to an exterior of the shell. The slots 812 may be placed over the entire length of the shell 800 or only partially located along the length and have varying spacing, such as, for example, slots being spaced every 6 inches (152 mm) starting generally 1.5 foot (0.46 m) from the top and bottom. The slots 812 may be of varying widths, such as, for example, 1/4 inch (6.35 mm) to 3/8 inch (9.53 mm) wide. The slots 812 typically run generally transverse to a centerline along the length of the shell and may form a minor or major part of the circumference of the shell 800. In one embodiment, such as shown in Figure 8, the slots 812 are discontinuous around the circumference leaving three spines 814 to maintain portions of continuous material connectivity along the length of the shell 800. The shell 800 of this embodiment may be of any suitable size or shape as described above with reference to shell 100.

[0064] As an example, a slotted extensible shell of this embodiment was installed at a test site in Iowa to compare the load versus deflection characteristics of this embodiment of the extensible shell to aggregate piers constructed using a driven tapered pipe. The test site was characterized by soft clay soil and the two comparison aggregate piers (of fine and coarse aggregate) were constructed to a depth of 12 feet below the ground surface.

[0065] For this test of the extensible shell, the shell was formed from High Density Polyethylene polymer and was formed by the rotomolding process. The shell formed a tapered shape that was hexagonal in cross section and tapered downward from an outside diameter of 23 inches (585 mm) at the top of the shell to a diameter of 18 inches (460 mm) at the bottom of the shell. The bottom of this embodiment of the extensible shell was integrally constructed as part of the shell walls as a result of the rotomolding process. In this example (similar to that shown in Figure 8), 1/4 inch (6.35 mm) wide slots were cut in a circumferential orientation around the extensible shell. The extensible shell was left as a single continuous piece, by not removing material from three of the six corners or spines. The extractable mandrel used in this test was attached to a high frequency hammer, which is often associated with driving sheet piles. The hammer is capable of providing both downward force and vibratory energy for driving the shell into the ground and for compacting aggregate construction material in the shell.

[0066] In this example, the installation process included a 30 inch (0.76 m) diameter pre-drill to a depth of 1.5 feet (0.46 m) below the ground surface. The shell was then placed vertically in the pre-drilled hole and then the shell was driven with an extractable mandrel with

exterior dimensions similar to those of the interior of the shell. The shell was driven to a depth of 11 feet (3.4 m) below grade. The mandrel was removed and the extensible shell was then filled with aggregate in four lifts; with each lift about 7.4 cubic feet (0.2 cubic meters) in volume. Each lift was compacted with the downward pressure and vibratory energy of the extractable mandrel.

[0067] After placement and compaction of aggregate within the extensible shell, the top of the shell was situated at about 1.5 feet (0.46 m) below the ground surface. The aggregate backfill was then leveled with the top of the shell, and a concrete cap was then poured above the shell to facilitate load testing.

[0068] The slotted shell pier was load tested using a hydraulic jack pushing against a test frame. Figure 9 is a graph showing results of the load test compared with the aggregate piers described above. As shown in Figure 9, at a top of pier deflection of one inch, the piers constructed without slotted shells supported a load of 15,000 pounds to 20,000 pounds (67 kN to 89 kN). The pier constructed in this example supported a load of 77,500 pounds (345 kN) at a top of pier deflection of one inch. The load carrying capacity of the pier constructed in accordance with this example provided a 3.9 to 5.2 fold improvement when compared to aggregate piers constructed without extensible shells.

Open-End Embodiment

[0069] With reference to Figures 10A through 15B, an embodiment not part of the present invention is shown and which includes an open-end extensible shell that can be used to form piers. Namely, Figure 10A shows a perspective view of an example of an open-end extensible shell 1000. Figure 10B shows a cross-sectional view of open-end extensible shell 1000 taken along line A-A for Figure 10A. In this example, open-end extensible shell 1000 is a hollow tubular member that has a first open end 1010 and a second open end 1012. Open-end extensible shell 1000 can be used in any orientation with respect to driving into the ground. However, for illustration purposes, first open end 1010 is hereafter referred to as advancing open end 1010, wherein advancing open end 1010 means the bottom end of open-end extensible shell 1000 that is advanced into the ground first. Further, second open end 1012 is hereafter referred to as trailing open end 1012, wherein trailing open end 1012 means the top end of open-end extensible shell 1000 that is mated to driving equipment, such as a mandrel.

[0070] Open-end extensible shell 1000 can be any length and any width or diameter. Without limitation, the length of open-end extensible shell 1000 can be from about 3.05 m (5 ft) to about 6.1 m (20 ft) in one example, or can be about 3.05 m (10 ft) in another example. Without limitation, the width or diameter of open-end extensible shell 1000 can be from about 61 cm (24 in) to about 46 cm (18 in) in one example, or can be about 51.8 cm (20.4 in) in another example. In one example, open-end extensi-

ble shell 1000 can be formed of plastic, such as high-density polyethylene polymer (HDPE) plastic. In another example, open-end extensible shell 1000 can be formed of metal, such as steel or aluminum.

[0071] Open-end extensible shell 1000 is not limited to a straight tubular shape. According to the invention, Figures 11A, 11B, and 11C illustrate various views of an example of an open-end extensible shell 100 that has a hexagon-shaped cross-section and a tapered tip; namely, advancing open end 1010 is tapered. Namely, Figures 11A and 11B show perspective views of the advancing open end 1010-portion of open-end extensible shell 100, which is hexagonal and includes a taper 1020. Figure 11C shows a cross-sectional view of open-end extensible shell 1000 taken along line B-B for Figure 11B. In one example, the width or diameter of open-end extensible shell 100 is tapered from about 51.8 cm (20.4 in) to about 46 cm (18.1 in).

[0072] Figures 12A and 12B show an example of a process of installing open-end extensible shell 1000 into the ground (e.g., ground 1205). In this example, a closed pipe mandrel 1210 that has a shoulder collar 1215 is used to drive open-end extensible shell 1000 into ground 1205. Closed pipe mandrel 1210 is inserted into open-end extensible shell 1000 until shoulder collar 1215 contacts trailing open end 1012 of open-end extensible shell 1000. In this way, driving force is transferred from closed pipe mandrel 1210 to open-end extensible shell 1000. In Figures 12A and 12B, the advancing end of closed pipe mandrel 1210 extends beyond advancing open end 1010 of open-end extensible shell 1000. In one example, the end of closed pipe mandrel 1210 extends about 1.5 m (5 ft) beyond advancing open end 1010 of open-end extensible shell 1000.

[0073] However, the position of shoulder collar 1215 can be adjustable along the length of closed pipe mandrel 1210. Namely, shoulder collar 1215 can be adjustable such that a range of depths and relative positions of open-end extensible shell 1000 and closed pipe mandrel 1210 can be achieved without the need to change mandrels. For example, Figure 13 shows the position of shoulder collar 1215 set such that the advancing end of closed pipe mandrel 1210 substantially aligns with advancing open end 1010 of open-end extensible shell 1000.

[0074] Figure 14 shows a flow diagram of an example of a method 1400 of using open-end extensible shell 1000 to form a support pier. Method 1400 may include, but is not limited to, the following steps.

[0075] At a step 1410, open-end extensible shell 1000 is driven into the ground using a mandrel. For example and referring again to Figures 12A and 12B, open-end extensible shell 1000 is driven into ground 1205 using closed pipe mandrel 1210.

[0076] At a step 1415, the mandrel (e.g., closed pipe mandrel 1210) is withdrawn from open-end extensible shell 1000, leaving open-end extensible shell 1000 in the ground. For example, Figure 15A shows open-end extensible shell 1000 in ground 1205 after closed pipe

mandrel 1210 is withdrawn, creating a shell cavity 1220. Namely, shell cavity 1220 is a portion of ground 1205 that is void of material.

[0077] At a step 1420, shell cavity 1220 is backfilled with sand, aggregate, cementitious grout, and/or any other material. For example, Figure 15B shows shell cavity 1220 of open-end extensible shell 1000 backfilled with a volume of material 1225.

[0078] At a step 1425, the mandrel (e.g., closed pipe mandrel 1210) is reinserted into open-end extensible shell 1000. Then, material 1225 is packed to below advancing open end 1010 of open-end extensible shell 1000. For example, Figure 15B shows a "bulb" of material 1225 is formed in ground 1205 below advancing open end 1010 of open-end extensible shell 1000.

[0079] At a step 1430, the mandrel (e.g., closed pipe mandrel 1210) is withdrawn from open-end extensible shell 1000, again as shown in Figure 15A.

[0080] At a step 1435, the remaining portion of shell cavity 1220 is backfilled with material 1225 (e.g., sand, aggregate, cementitious grout, and/or any other material).

[0081] At a step 1440, the mandrel (e.g., closed pipe mandrel 1210) is reinserted into open-end extensible shell 1000. Then, material 1225 is packed into shell cavity 1220 of open-end extensible shell 1000.

[0082] At a step 1445, the mandrel (e.g., closed pipe mandrel 1210) is withdrawn from open-end extensible shell 1000, again as shown in Figure 15A.

[0083] At a decision step 1450, it is determined whether the construction of the support pier is complete. If the construction of the support pier is complete, then method 1400 ends. However, if the construction of the support pier is not complete, then method 1400 returns to 1435.

[0084] A benefit of using open-end extensible shell 1000 and method 1400 is that it provides increased stiffness for the shell support layer and increased overall length of the extensible shell system in the upper zone (open-end extensible shell 1000 plus "bulb" depth).

Example V

[0085] As an example, support piers were constructed using extensible shells in accordance with embodiments of the present invention at a test site in Iowa. Load tests were conducted on the piers using a conventional process. The extensible shells used in the tests and the methods of their use consisted essentially of that described above and shown in Figures 10A through 15B. In this test, extensible shells formed of high-density polyethylene polymer (HDPE) plastic were installed at a test site characterized by soft clay soil. This testing was designed to compare the load versus deflection characteristics of an extensible shell in accordance with the present invention to aggregate piers constructed with a driven tapered pipe. Two comparison aggregate piers were constructed to a depth of 12 feet below the ground

surface.

[0086] In this test, the extensible shell was formed by a rotomolding process. The shells defined a tapered shape having a hexagonal cross-section (e.g., as shown in Figures 11A, 11B, 11C) and that tapered downward from an outside diameter of 518 mm (20.4 inches) at the top of the shell to a diameter of 460 mm (18.1 inches) at the bottom of the shell. In this embodiment of the invention the extensible shell has a total length of 3.05 m (10 feet), and both the top and the bottom ends of the shell are open such that an extractable tapered mandrel commonly used for constructing aggregate piers could fully pass through the extensible shell.

[0087] The extractable mandrel used in this test was attached to a high frequency hammer, which is often associated with driving sheet piles. The hammer is capable of providing both downward force and vibratory energy for driving the shell into the ground and for compacting aggregate construction material in the shell. The "open bottom" extensible shell pier and the aggregate pier were constructed with a similar mandrel and high frequency hammer.

[0088] In this example, a 61 cm (24 in) diameter and 61 cm (24 in) deep pre-drill hole was formed at the ground surface prior to driving the extensible shell. The purpose of the pre-drill is to facilitate the placement of a concrete cap for the load test. The extensible shell, and Tapered Mandrel were then driven into the ground such that the tip of the tapered mandrel was at a depth of about 5.2 m (17 ft) below the ground surface, the bottom of the extensible shell was at a depth of about 3.65 m (12 ft) below the ground surface, and the top of the shell was at a depth of about 61 cm (24 in) below the ground surface.

[0089] The tapered mandrel used in this example is hollow such that the mandrel can be filled with aggregate, and allowed to flow out the bottom of the mandrel. An aggregate pier is constructed with this mandrel by raising and lowering the mandrel pre-determined distances to construct the aggregate pier. In this example, an aggregate pier was constructed below and within the extensible shell using a similar process.

[0090] The open bottom extensible shell piers were load tested using a hydraulic jack pushing against a test frame. Figure 16 is a graph showing results of the load test compared with aggregate piers constructed using an embodiment as shown in Figures 10A, 10B and/or Figures 11A, 11B, 11C. As shown in Figure 16, at a top of pier deflection of one inch, the piers constructed without shells supported a load of 67 kN to 89 kN (15,000 pounds to 20,000 pounds). The piers constructed in this embodiment of the invention supported a load of 188 kN (42,300 pounds) at a top of pier deflection of one inch. The load carrying capacity of the piers constructed in accordance with the present invention provided a 2.1 to 2.8 fold improvement when compared to aggregate piers constructed without extensible shells.

Claims

1. An extensible shell (1000) for constructing a support pier in ground, the extensible shell being continuous and defining an interior for holding granular construction material (1225) and defining a first end (1010) having a first opening and a second end (1012) having a second opening for receiving the granular construction material (212) into the interior, wherein the shell is flexible such that the shell expands laterally outward in ground when granular construction material is compacted in the interior of the shell, **characterized by** the shell (1000) has a hexagonal-shaped cross-section and a tapered tip (1020) at the first end.
2. The extensible shell of claim 1, wherein a cross-section of the second end is sized larger than a cross-section of the first end.
3. The extensible shell of claim 1, wherein the shell (1000) is comprised of plastic.
4. The extensible shell (1000) of claim 1, further comprising a plurality of slots (812) extending between an interior of the shell to an exterior of the shell, the slots being generally transverse to a centerline along the length of the shell.
5. The extensible shell (1000) of claim 4, wherein the slots are discontinuous around a circumference of the shell thereby maintaining portions of continuous material connectivity along the length of the shell.
6. The extensible shell (1000) of claim 4, wherein the slots have a width in the range of 1/4 inch (6.35 mm) to 3/8 inch (9.53 mm).
7. The extensible shell (1000) of claim 4, wherein the slots are spaced at a distance of 6 inches (152 mm) from one another.
8. A method for constructing a support pier in ground, the method comprising:
 - (a) positioning a continuous extensible shell (1000) of claim 1 into the ground;
 - (b) filling at least a portion of the interior of the shell with the granular construction material; and
 - (c) compacting the granular construction material in the interior of the shell, thereby expanding the shell laterally outward, to form a support pier.
9. The method of claim 8, wherein a cross-section of the second end is sized larger than a cross-section of the first end.
10. The method of claim 8, wherein the shell (1000) is

comprised of plastic.

11. The method of claim 8 wherein the shell (1000) defines a plurality of apertures (218) extending between the interior of the shell to an exterior of the shell.
12. The method of claim 11, further comprising applying vacuum pressure through the shell.
13. The method of claim 8, wherein the positioning in step (a) further comprises partially filling the shell (1000) with the granular construction material (1225) and driving the shell into the ground subsequent to partially filling the shell.
14. The method of claim 13, wherein driving the extensible shell comprises applying a force to a mandrel (1210) for driving the shell into the ground.
15. The method of claim 8, wherein the positioning in step (a) further comprises first forming a cavity in the ground and subsequently driving the extensible shell (1000) into the cavity.
16. The method of claim 15, wherein the cavity is at least partially filled with granular construction material (1225) after forming and prior to the driving of the extensible shell into the cavity.
17. The method of claim 8, wherein the compacting in step (c) is performed with a primary mandrel (206).
18. The method of claim 17, further comprising an additional compacting step performed with a second mandrel (212) that has a larger cross-sectional area than the primary mandrel.
19. The method of claim 8, wherein the shell further comprises a plurality of slots (812) extending between an interior of the shell to an exterior of the shell, the slots being generally transverse to a centerline along the length of the shell.
20. The method of claim 19, wherein the slots are discontinuous around a circumference of the shell thereby maintaining portions of continuous material connectivity along the length of the shell.
21. The method of claim 19, wherein the slots have a width in the range of 1/4 inch (6.35 mm) to 3/8 inch (9.53 mm).
22. The method of claim 19, wherein the slots are spaced at a distance of 6 inches (152 mm) from one another.
23. The method for constructing a support pier in ground according to claim 8, the method further comprising

- (d) forming a cavity in the ground; and,
- (e) partially backfilling the cavity with an aggregate construction material (1225);

prior to: (a) positioning the extensible shell (1000) into the ground.

Patentansprüche

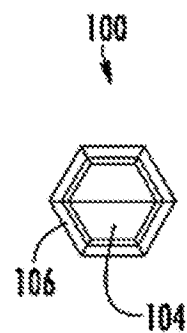
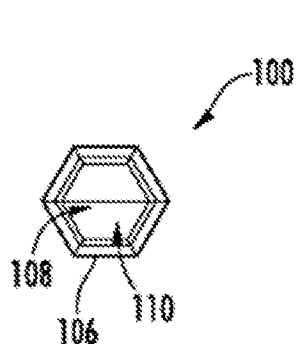
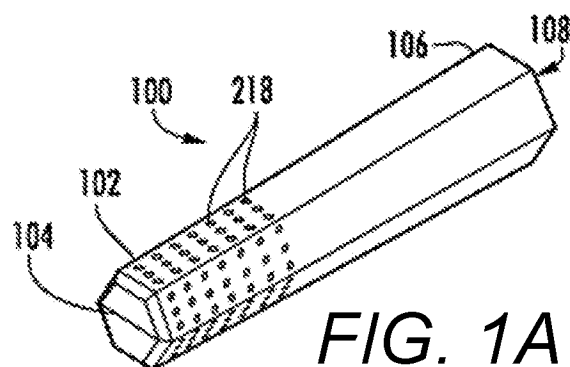
1. Dehnbare Hülle (1000) zur Konstruktion eines Stützpfeilers im Boden, wobei die dehnbare Hülle kontinuierlich ist und ein Inneres zum Halten von körnigem Konstruktionsmaterial (1225) definiert und ein erstes Ende (1010) mit einer ersten Öffnung und ein zweites Ende (1012) mit einer zweiten Öffnung zum Aufnehmen des körnigen Konstruktionsmaterials (212) in das Innere definiert, wobei die Hülle flexibel ist, sodass die Hülle seitlich nach außen im Boden expandiert, wenn körniges Konstruktionsmaterial in dem Inneren der Hülle verdichtet wird, **dadurch gekennzeichnet, dass** die Hülle (1000) einen sechseckförmigen Querschnitt und eine verjüngte Spitze (1020) an dem ersten Ende aufweist.
2. Dehnbare Hülle nach Anspruch 1, wobei ein Querschnitt des zweiten Endes größer als ein Querschnitt des ersten Endes bemessen ist.
3. Dehnbare Hülle nach Anspruch 1, wobei die Hülle (1000) aus Kunststoff besteht.
4. Dehnbare Hülle (1000) nach Anspruch 1, ferner umfassend eine Vielzahl von Schlitzen (812), die zwischen einem Inneren der Hülle zu einem Äußeren der Hülle gedehnt ist, wobei die Schlitze im Allgemeinen quer zu einer Mittellinie entlang der Länge der Hülle sind.
5. Dehnbare Hülle (1000) nach Anspruch 4, wobei die Schlitze diskontinuierlich um einen Umfang der Hülle sind, wodurch Abschnitte von kontinuierlicher Materialkonnektivität entlang der Länge der Hülle gehalten werden.
6. Dehnbare Hülle (1000) nach Anspruch 4, wobei die Schlitze eine Breite in dem Bereich von 1/4 Zoll (6,35 mm) bis 3/8 Zoll (9,53 mm) aufweisen.
7. Dehnbare Hülle (1000) nach Anspruch 4, wobei die Schlitze in einem Abstand von 6 Zoll (152 mm) voneinander beanstandet sind.
8. Verfahren zur Konstruktion eines Stützpfeilers im Boden, wobei das Verfahren Folgendes umfasst:
 - (a) Positionieren einer kontinuierlichen dehnbaren Hülle (1000) nach Anspruch 1 in den Boden;

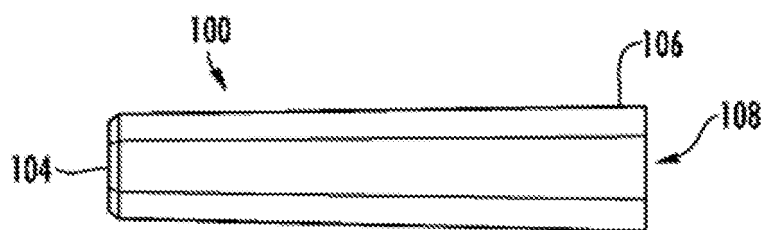
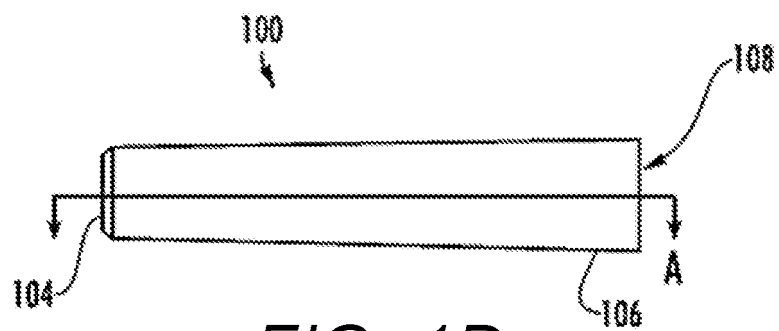
- (b) Füllen von zumindest einem Abschnitt des Inneren der Hülle mit dem körnigen Konstruktionsmaterial; und
- (c) Verdichten des körnigen Konstruktionsmaterials in dem Inneren der Hülle, wodurch die Hülle seitlich nach außen expandiert wird, um einen Stützpfeiler zu bilden.
9. Verfahren nach Anspruch 8, wobei ein Querschnitt des zweiten Endes größer als ein Querschnitt des ersten Endes bemessen ist.
10. Verfahren nach Anspruch 8, wobei die Hülle (1000) aus Kunststoff besteht.
11. Verfahren nach Anspruch 8, wobei die Hülle (1000) eine Vielzahl von Öffnungen (218) definiert, die zwischen dem Inneren der Hülle zu einem Äußeren der Hülle gedehnt ist.
12. Verfahren nach Anspruch 11, ferner umfassend Anwenden von Vakuumdruck durch die Hülle.
13. Verfahren nach Anspruch 8, wobei das Positionieren in Schritt (a) ferner teilweise Füllen der Hülle (1000) mit dem körnigen Konstruktionsmaterial (1225) und Treiben der Hülle in den Boden anschließend an das teilweise Füllen der Hülle umfasst.
14. Verfahren nach Anspruch 13, wobei das Treiben der dehnbaren Hülle Anwenden einer Kraft auf einen Dorn (1210) zum Treiben der Hülle in den Boden umfasst.
15. Verfahren nach Anspruch 8, wobei das Positionieren in Schritt (a) ferner zuerst Bilden eines Hohlraums in dem Boden und anschließend Treiben der dehnbaren Hülle (1000) in den Hohlraum umfasst.
16. Verfahren nach Anspruch 15, wobei der Hohlraum nach dem Formen und vor dem Treiben der dehnbaren Hülle in den Hohlraum zumindest teilweise mit körnigem Konstruktionsmaterial (1225) gefüllt wird.
17. Verfahren nach Anspruch 8, wobei das Verdichten in Schritt (c) mit einem primären Dorn (206) durchgeführt wird.
18. Verfahren nach Anspruch 17, ferner umfassend einen zusätzlichen Verdichtungsschritt, der mit einem zweiten Dorn (212) durchgeführt wird, der einen größeren Querschnittsbereich als der primäre Dorn aufweist.
19. Verfahren nach Anspruch 8, wobei die Hülle ferner eine Vielzahl von Schlitzen (812) umfasst, die zwischen einem Inneren der Hülle zu einem Äußeren der Hülle gedehnt ist, wobei die Schlitze im Allgemeinen quer zu einer Mittellinie entlang der Länge der Hülle sind.
20. Verfahren nach Anspruch 19, wobei die Schlitze diskontinuierlich um einen Umfang der Hülle sind, wodurch Abschnitte von kontinuierlicher Materialkonnektivität entlang der Länge der Hülle gehalten werden.
21. Verfahren nach Anspruch 19, wobei die Schlitze eine Breite in dem Bereich von 1/4 Zoll (6,35 mm) bis 3/8 Zoll (9,53 mm) aufweisen.
22. Verfahren nach Anspruch 19, wobei die Schlitze in einem Abstand von 6 Zoll (152 mm) voneinander beabstandet sind.
23. Verfahren zur Konstruktion eines Stützpfeilers im Boden nach Anspruch 8, wobei das Verfahren ferner Folgendes umfasst:
- (d) Bilden eines Hohlraums in dem Boden; und
- (e) teilweise Rückfüllen des Hohlraums mit einem aggregierten Konstruktionsmaterial (1225);
- vor: (a) Positionieren der dehnbaren Hülle (1000) in den Boden.

Revendications

1. Coque extensible (1000) pour la construction de pilier de support dans le sol, la coque extensible étant continue et définissant un intérieur pour contenir un matériau de construction granulaire (1225) et définissant une première extrémité (1010) comportant une première ouverture et une seconde extrémité (1012) comportant une seconde ouverture pour la réception du matériau de construction granulaire (212) à l'intérieur, dans laquelle la coque est souple de sorte que la coque s'expande latéralement vers l'extérieur dans le sol lorsque le matériau de construction granulaire est compacté à l'intérieur de la coque, **caractérisée en ce que** la coque (1000) comporte une section transversale de forme hexagonale et une pointe conique (1020) au niveau de la première extrémité.
2. Coque extensible selon la revendication 1, dans laquelle une section transversale de la seconde extrémité est plus grande en taille qu'une section transversale de la première extrémité.
3. Coque extensible selon la revendication 1, dans laquelle la coque (1000) est constituée de plastique.
4. Coque extensible (1000) selon la revendication 1,

- comprenant en outre une pluralité de fentes (812) s'étendant entre un intérieur de la coque et un extérieur de la coque, les fentes étant globalement transversales à une ligne centrale le long de la longueur de la coque. 5
5. Coque extensible (1000) selon la revendication 4, dans laquelle les fentes sont discontinues autour d'une circonférence de la coque, maintenant ainsi des parties de connectivité matérielle continue le long de la longueur de la coque. 10
6. Coque extensible (1000) selon la revendication 4, dans laquelle les fentes comportent une largeur comprise entre 1/4 pouce (6,35 mm) et 3/8 pouce (9,53 mm). 15
7. Coque extensible (1000) selon la revendication 4, dans laquelle les fentes sont espacées à une distance de 6 pouces (152 mm) les unes des autres. 20
8. Procédé de construction de pilier de support dans le sol, le procédé comprenant :
- (a) le positionnement d'une coque extensible continue (1000) selon la revendication 1 dans le sol ; 25
- (b) le remplissage d'au moins une partie de l'intérieur de la coque avec le matériau de construction granulaire ; et 30
- (c) le compactage du matériau de construction granulaire à l'intérieur de la coque, expansant ainsi la coque latéralement vers l'extérieur, pour former un pilier de support. 35
9. Procédé selon la revendication 8, dans lequel une section transversale de la seconde extrémité est plus grande en taille qu'une section transversale de la première extrémité. 40
10. Procédé selon la revendication 8, dans lequel la coque (1000) est constituée de plastique.
11. Procédé selon la revendication 8, dans lequel la coque (1000) définit une pluralité d'ouvertures (218) s'étendant entre l'intérieur de la coque et un extérieur de la coque. 45
12. Procédé selon la revendication 11, comprenant en outre l'application d'une pression de vide à travers la coque. 50
13. Procédé selon la revendication 8, dans lequel le positionnement à l'étape (a) comprenant en outre le remplissage partiel de la coque (1000) avec le matériau de construction granulaire (1225) et l'enfoncement de la coque dans le sol après le remplissage partiel de la coque. 55
14. Procédé selon la revendication 13, dans lequel l'enfoncement de la coque extensible comprend l'application d'une force à un mandrin (1210) pour enfoncer la coque dans le sol.
15. Procédé selon la revendication 8, dans lequel le positionnement à l'étape (a) comprend en outre d'abord la formation d'une cavité dans le sol et ensuite l'enfoncement de la coque extensible (1000) dans la cavité.
16. Procédé selon la revendication 15, dans lequel la cavité est au moins partiellement remplie de matériau de construction granulaire (1225) après la formation et avant l'enfoncement de la coque extensible dans la cavité.
17. Procédé selon la revendication 8, dans lequel le compactage à l'étape (c) est effectué avec un mandrin principal (206).
18. Procédé selon la revendication 17, comprenant en outre une étape de compactage supplémentaire effectuée avec un second mandrin (212) qui comporte une section transversale plus grande que le mandrin principal.
19. Procédé selon la revendication 8, dans lequel la coque comprend en outre une pluralité de fentes (812) s'étendant entre un intérieur de la coque et un extérieur de la coque, les fentes étant globalement transversales à une ligne centrale le long de la longueur de la coque.
20. Procédé selon la revendication 19, dans lequel les fentes sont discontinues autour d'une circonférence de la coque, maintenant ainsi des parties de connectivité matérielle continue le long de la longueur de la coque. 35
21. Procédé selon la revendication 19, dans lequel les fentes comportent une largeur comprise dans la plage de 1/4 pouce (6,35 mm) à 3/8 de pouce (9,53 mm). 40
22. Procédé selon la revendication 19, dans lequel les fentes sont espacées à une distance de 6 pouces (152 mm) les unes des autres.
23. Procédé de construction de pilier de support dans le sol selon la revendication 8, le procédé comprenant en outre
- (d) la formation d'une cavité dans le sol ; et,
- (e) le remblayage partiel de la cavité avec un matériau de construction agrégé (1225) ; avant :
- (a) le positionnement de la coque extensible (1000) dans le sol.





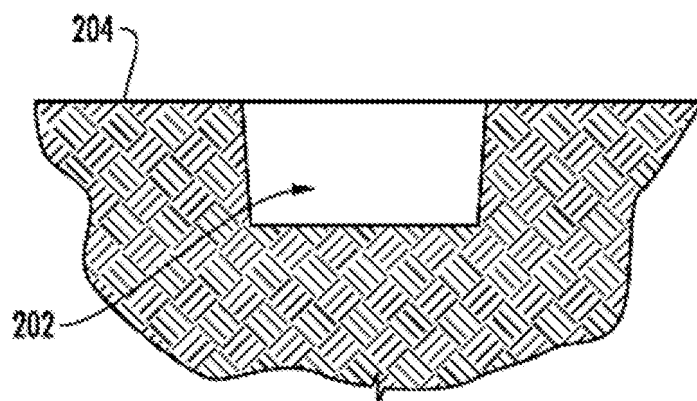


FIG. 2A

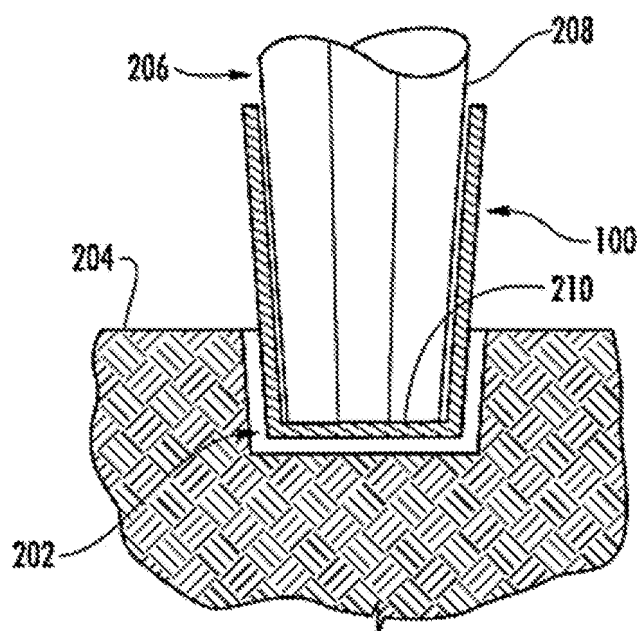


FIG. 2B

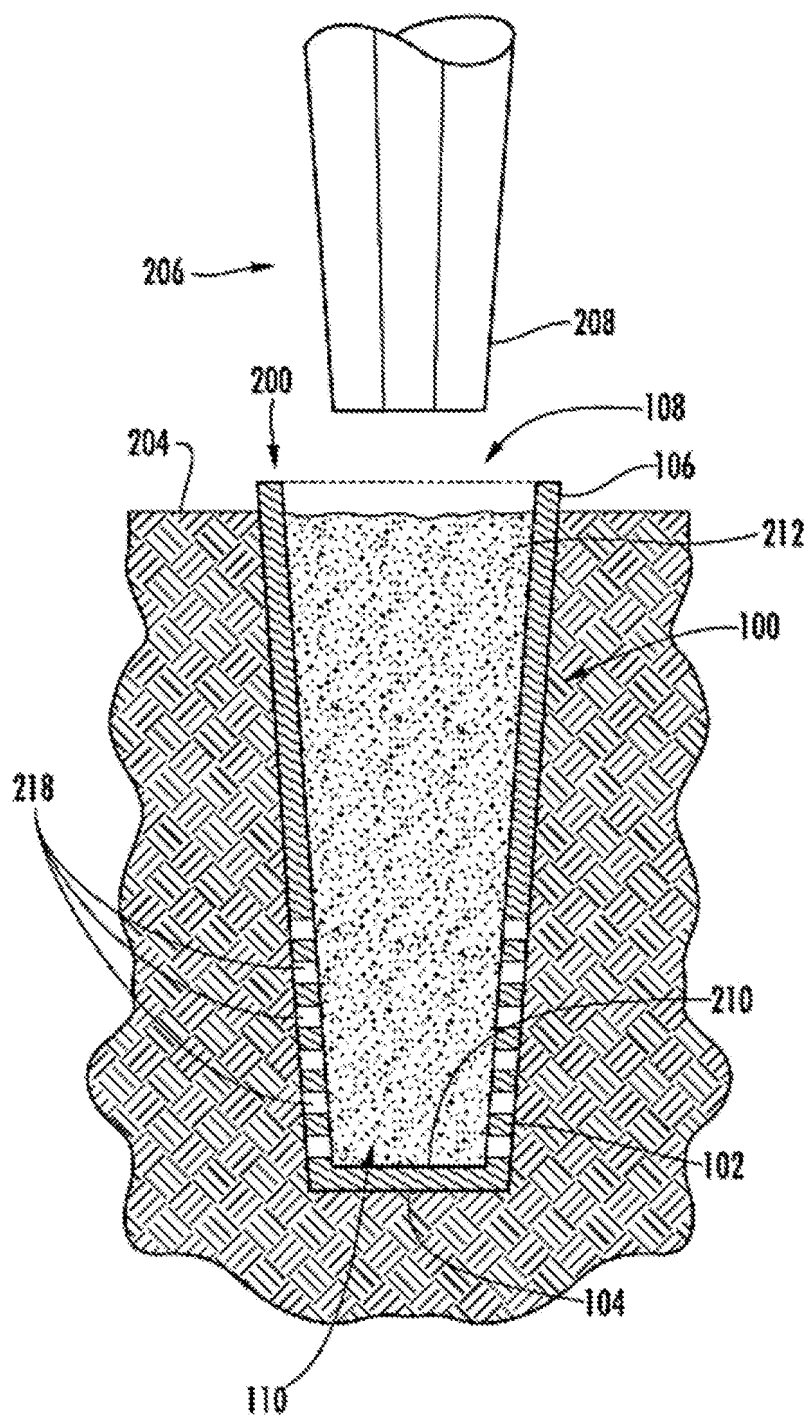


FIG. 2C

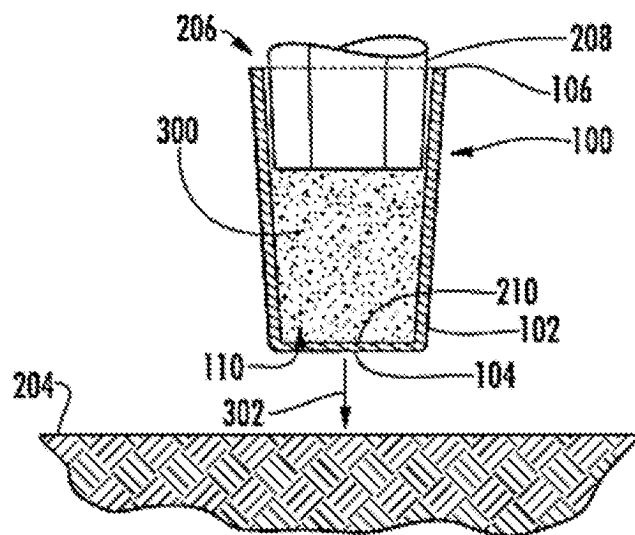


FIG. 3A

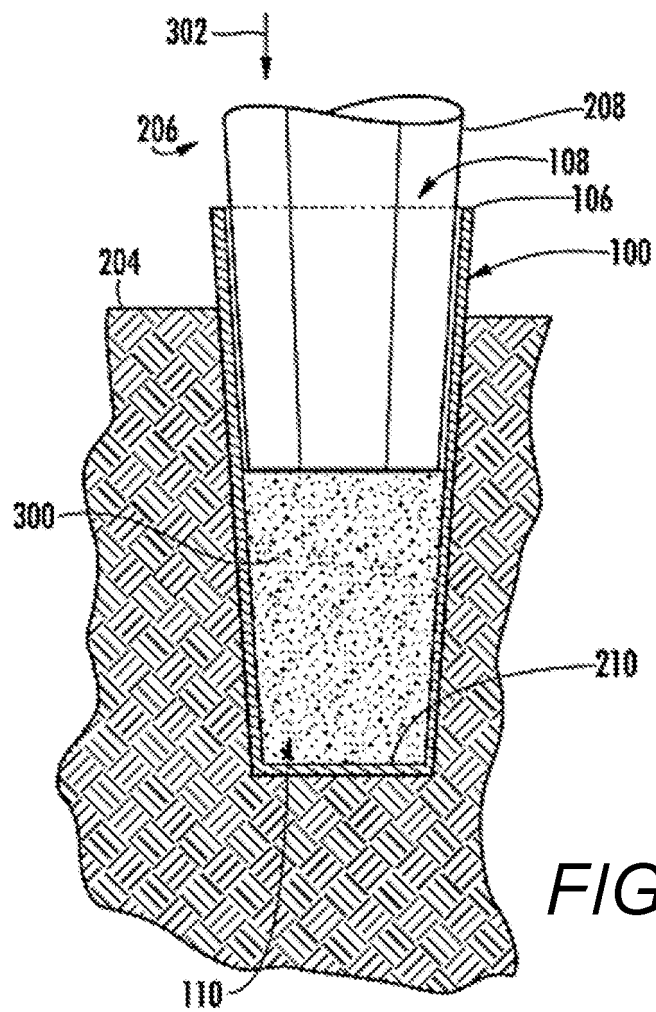


FIG. 3B

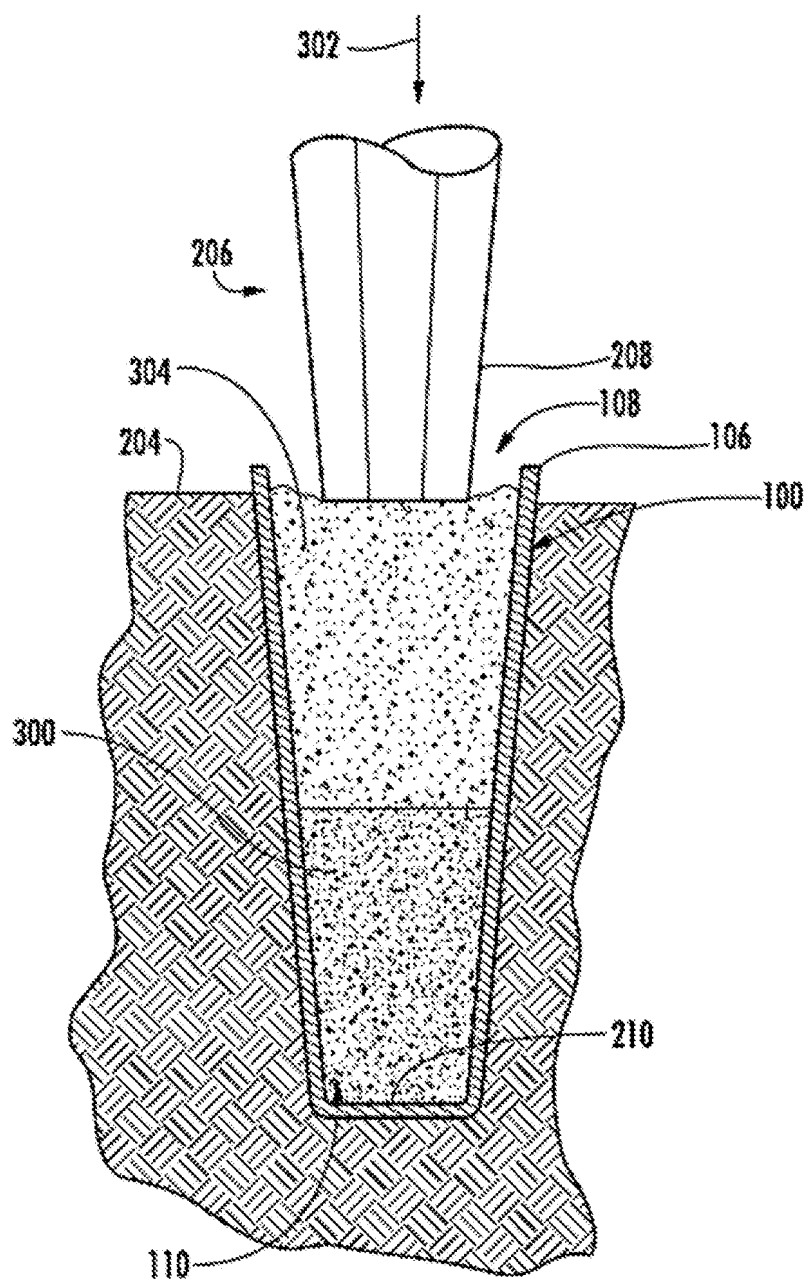


FIG. 3C

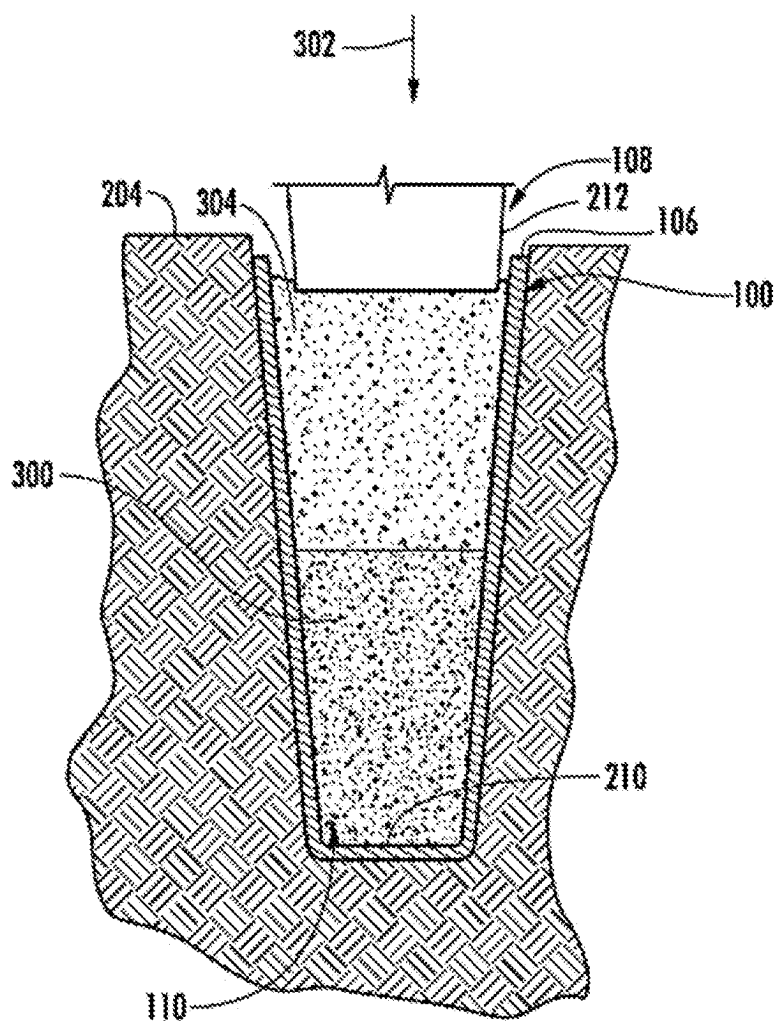


FIG. 3D

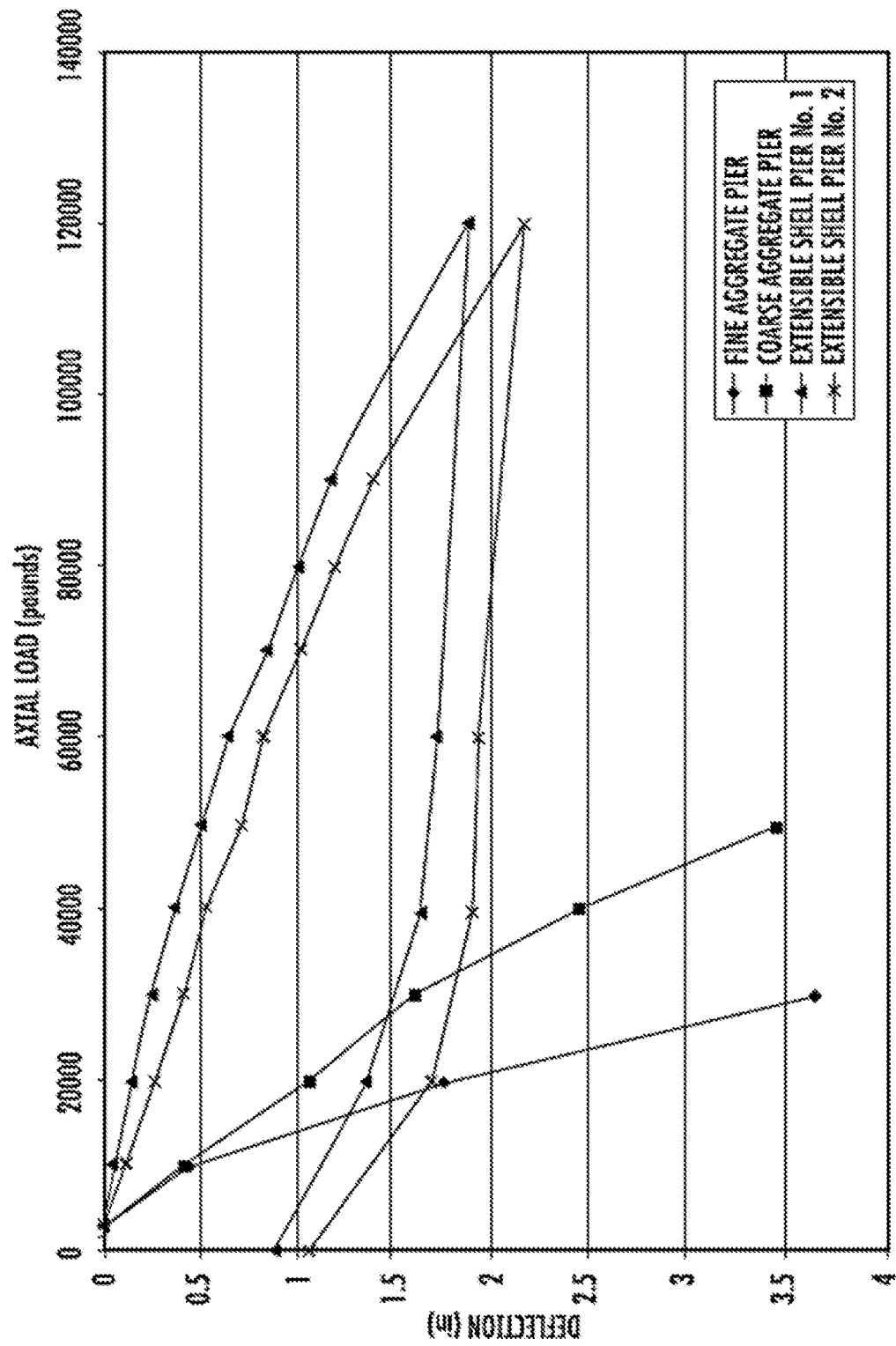


FIG. 4

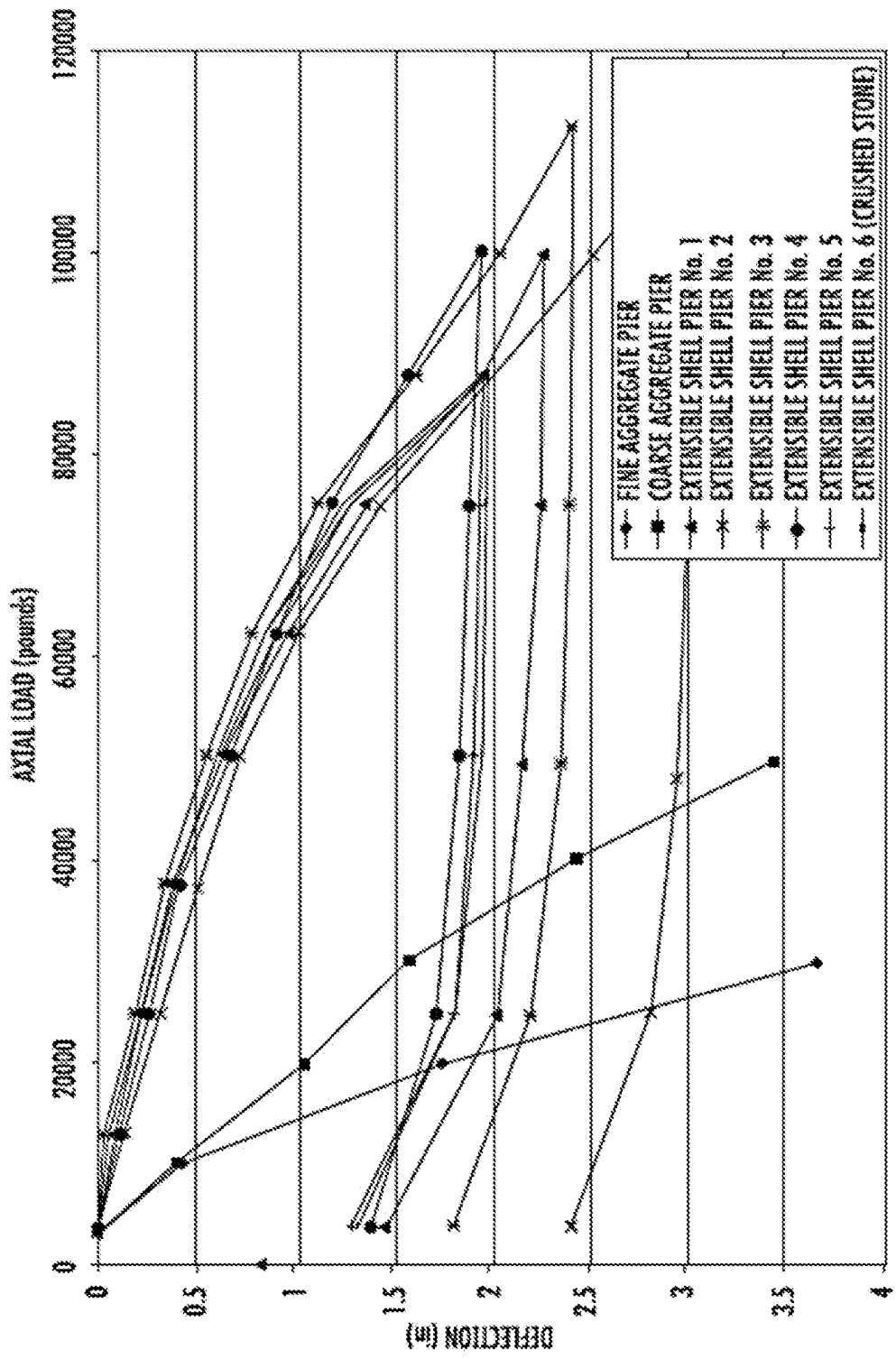


FIG. 5

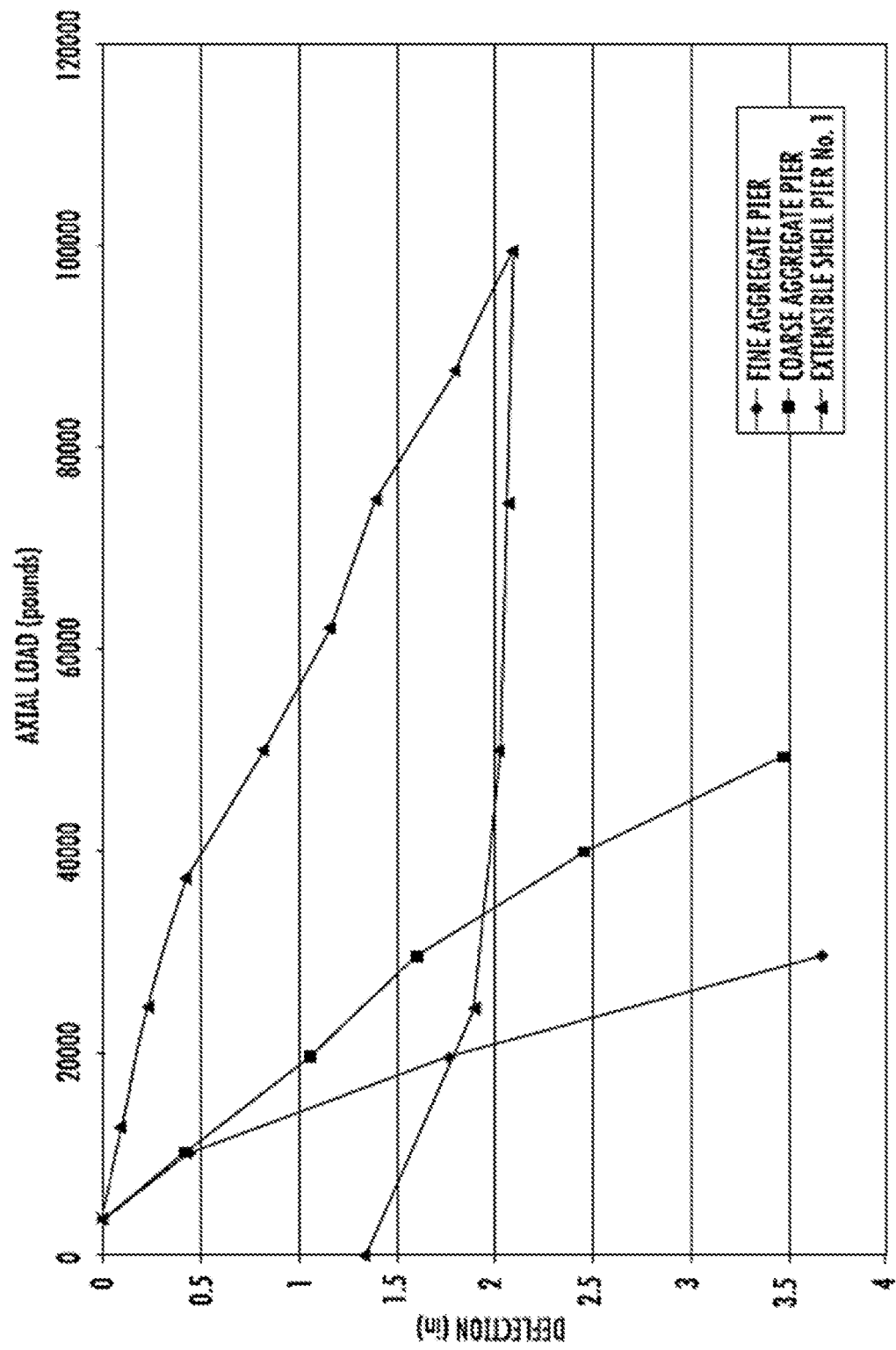


FIG. 6

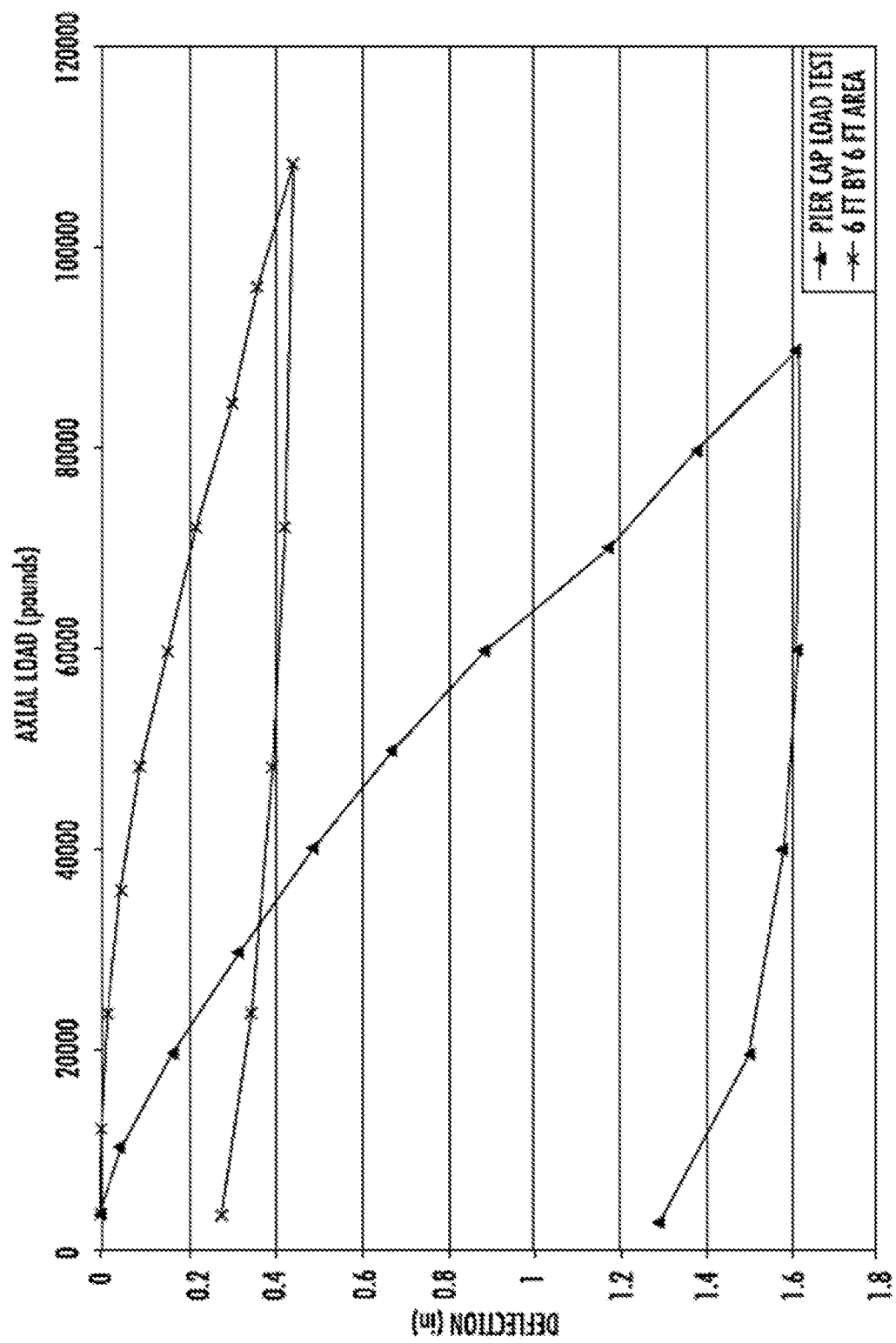
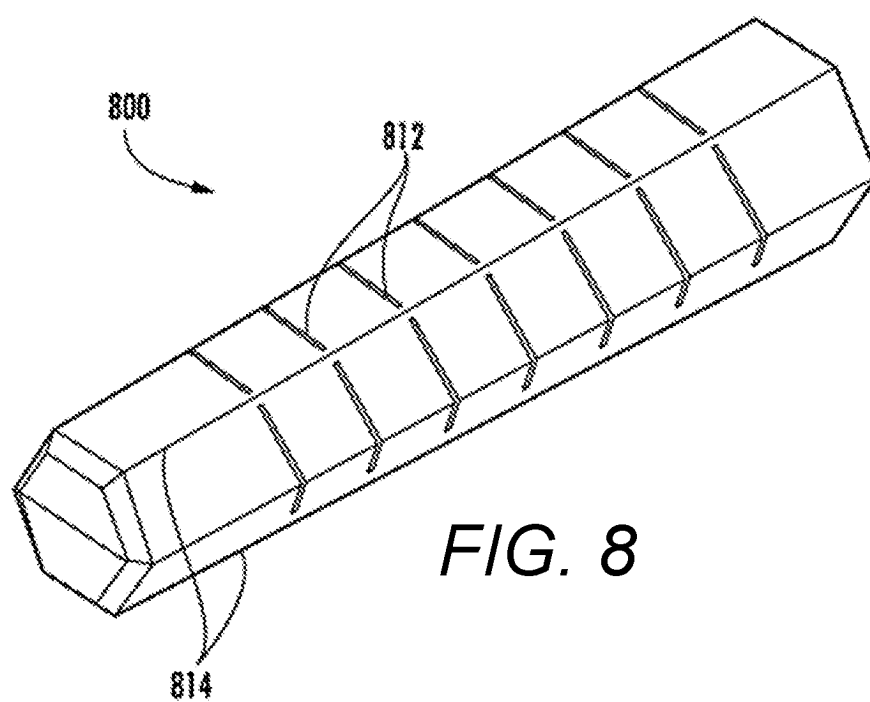


FIG. 7



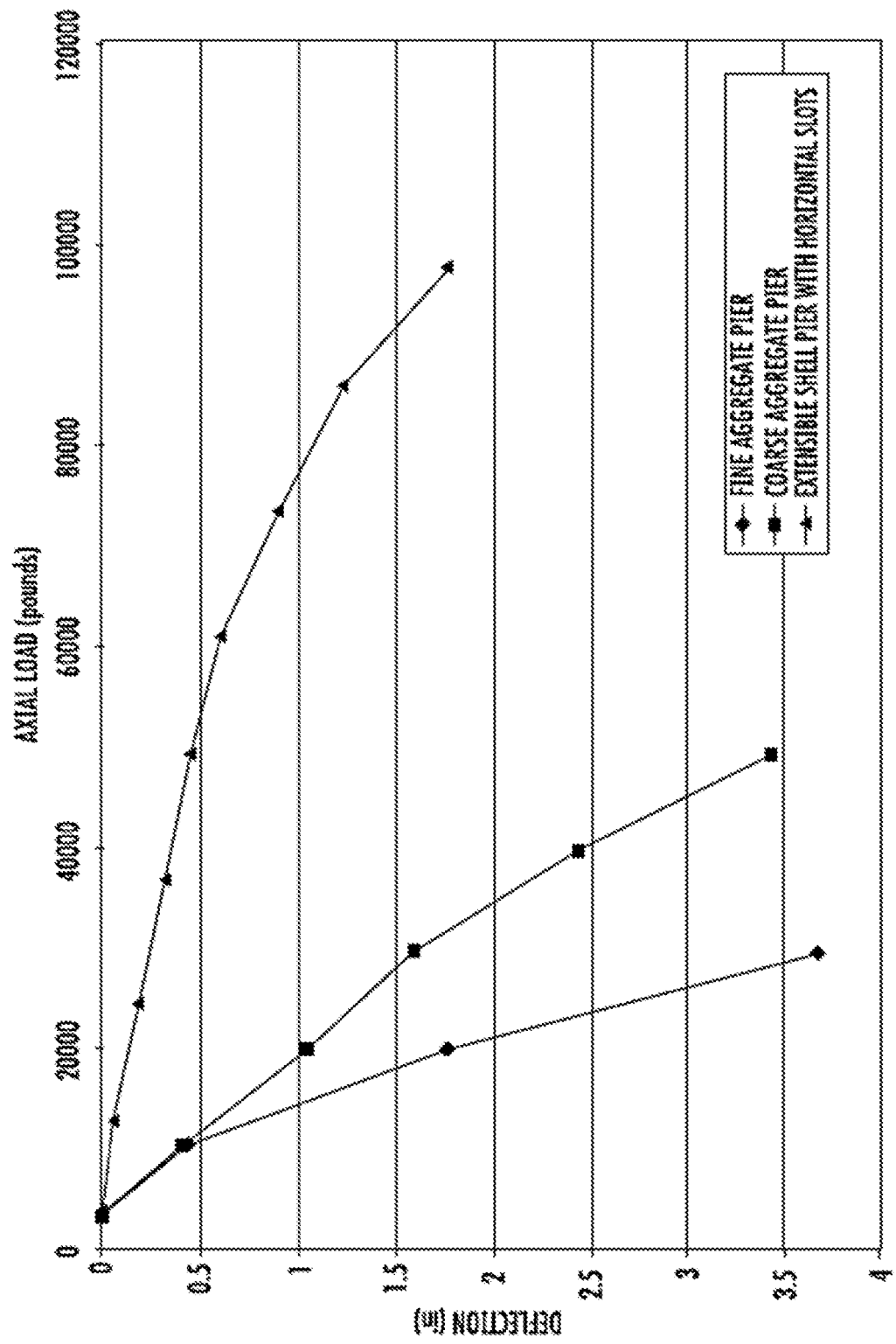


FIG. 9

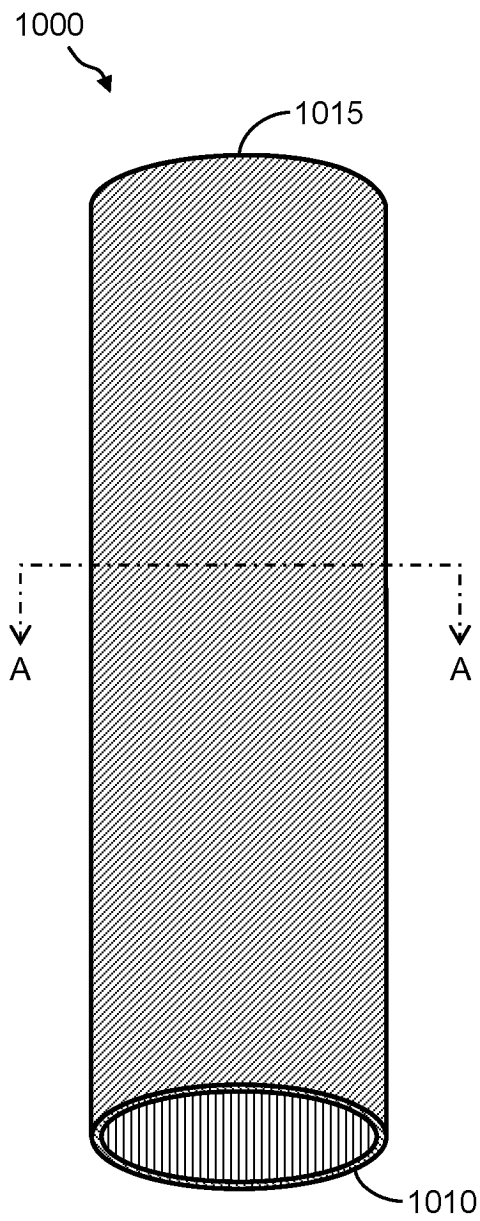


FIG. 10A

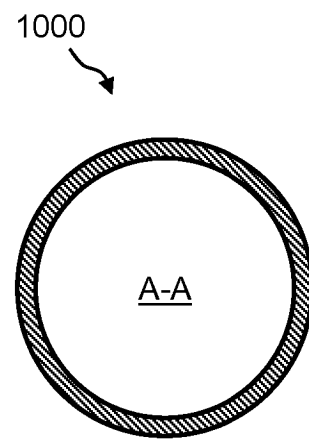


FIG. 10B

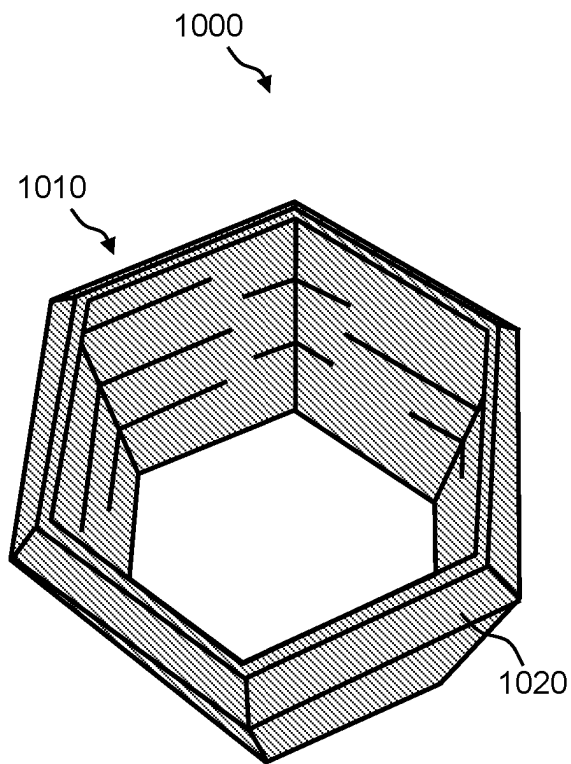


FIG. 11A

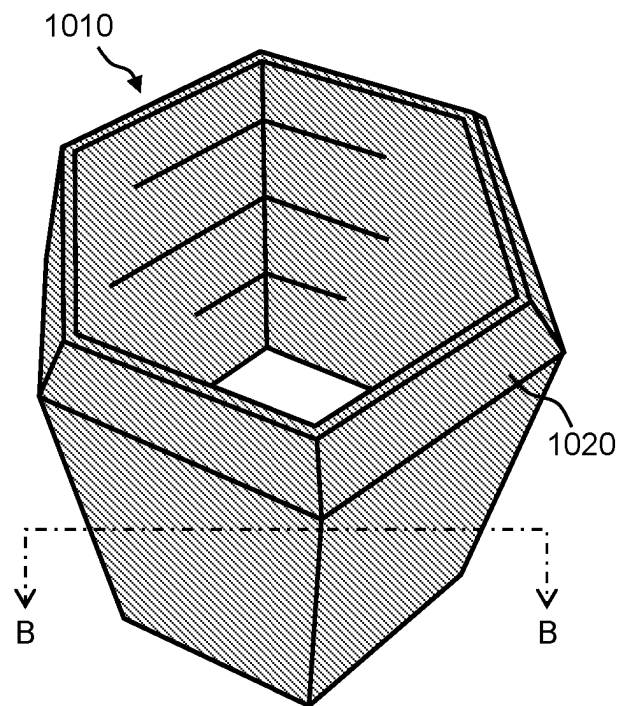


FIG. 11B

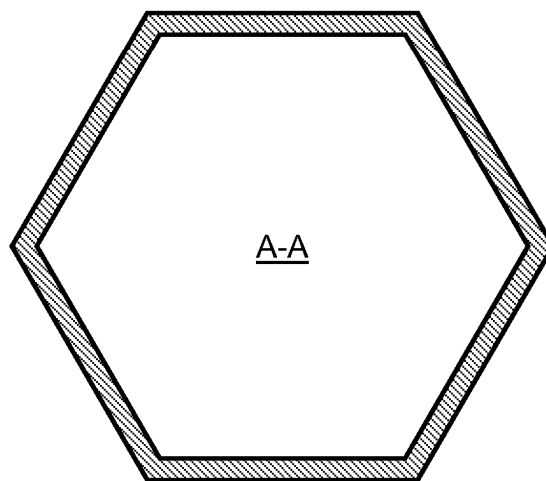


FIG. 11C

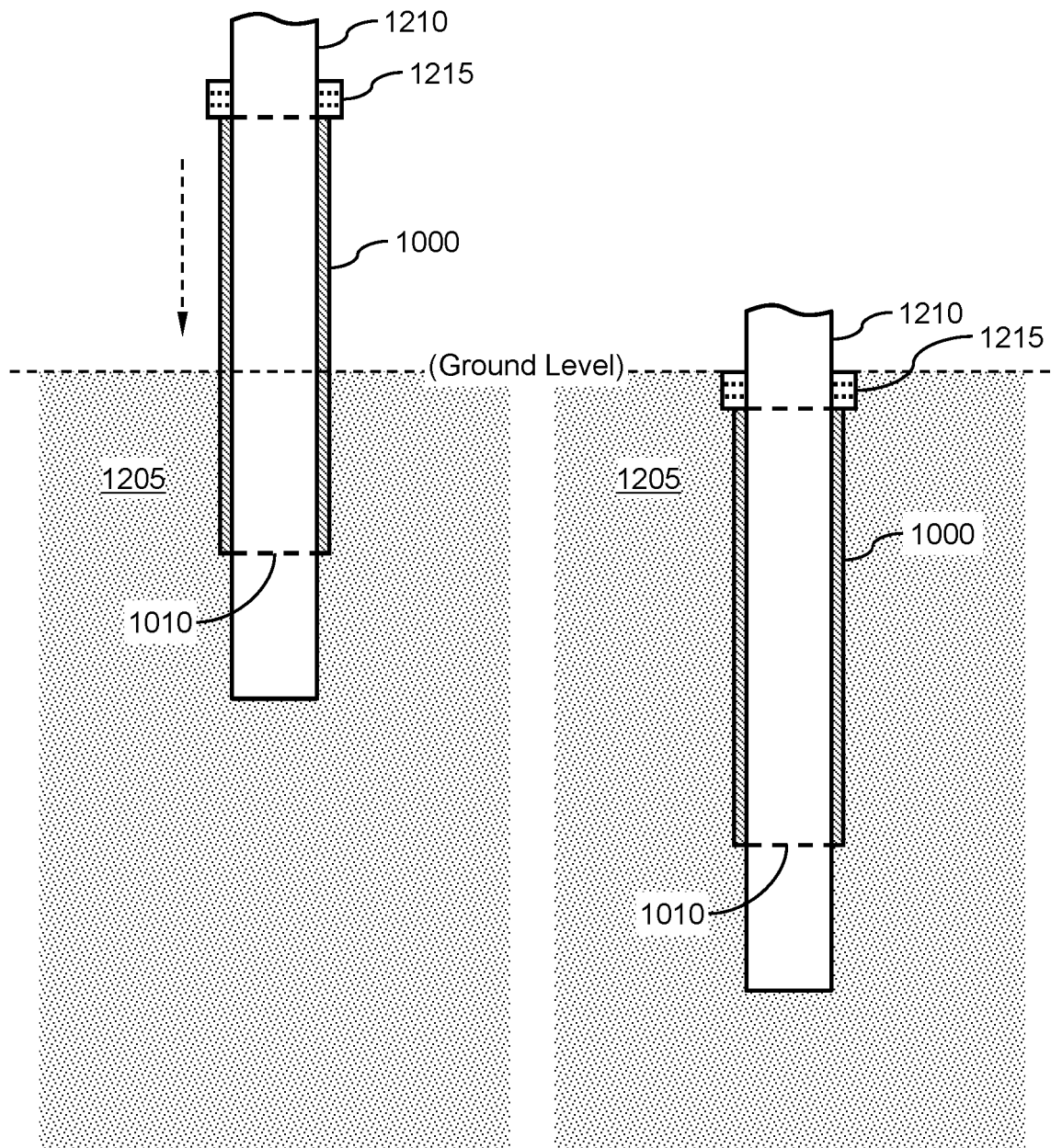


FIG. 12A

FIG. 12B

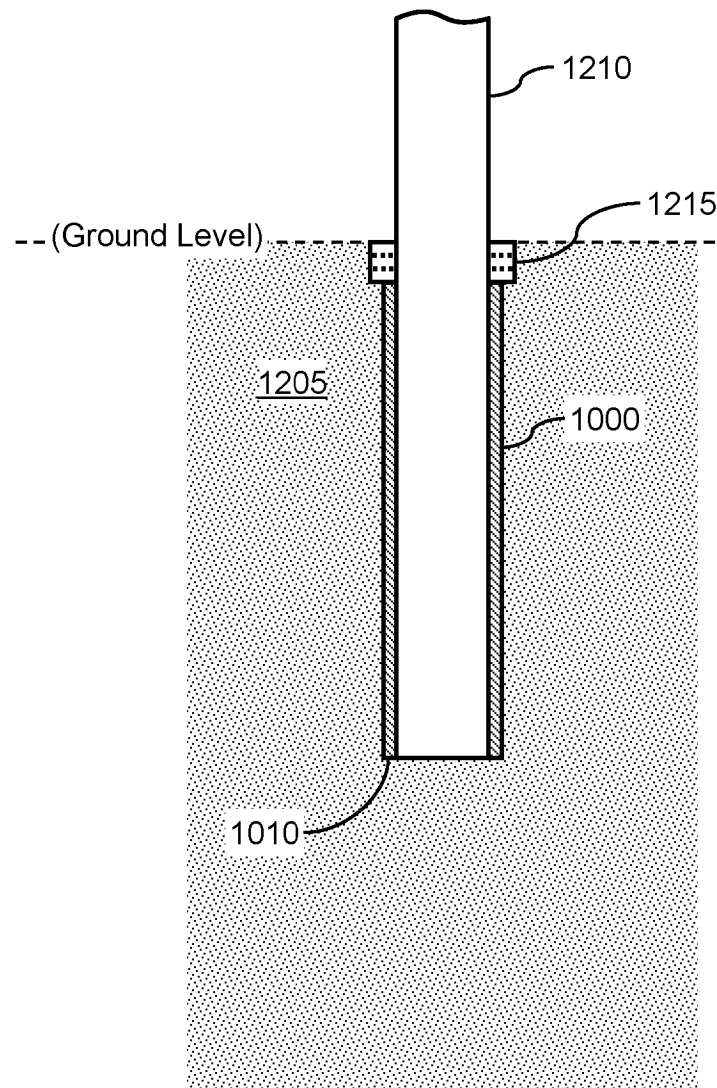


FIG. 13

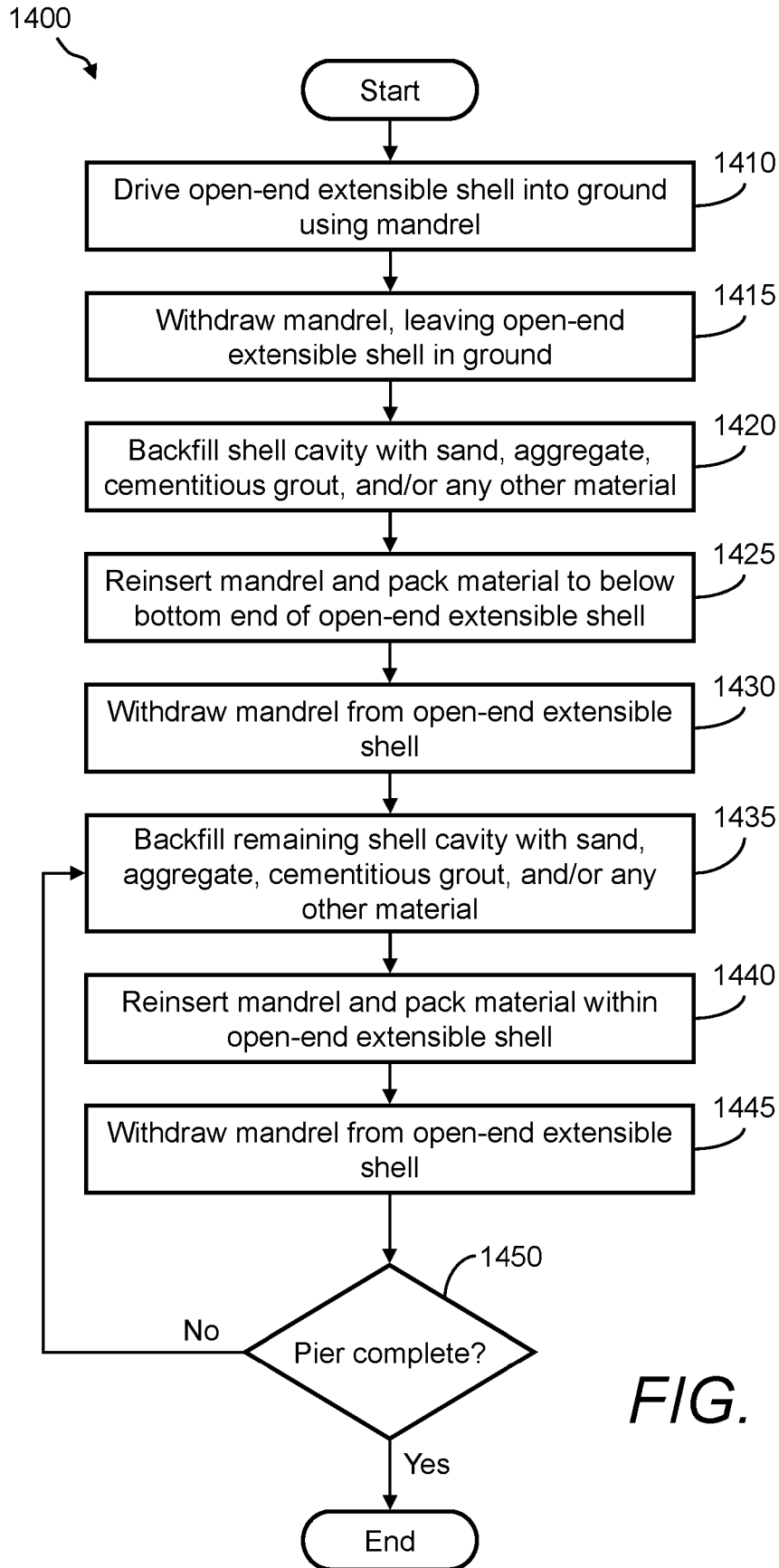


FIG. 14

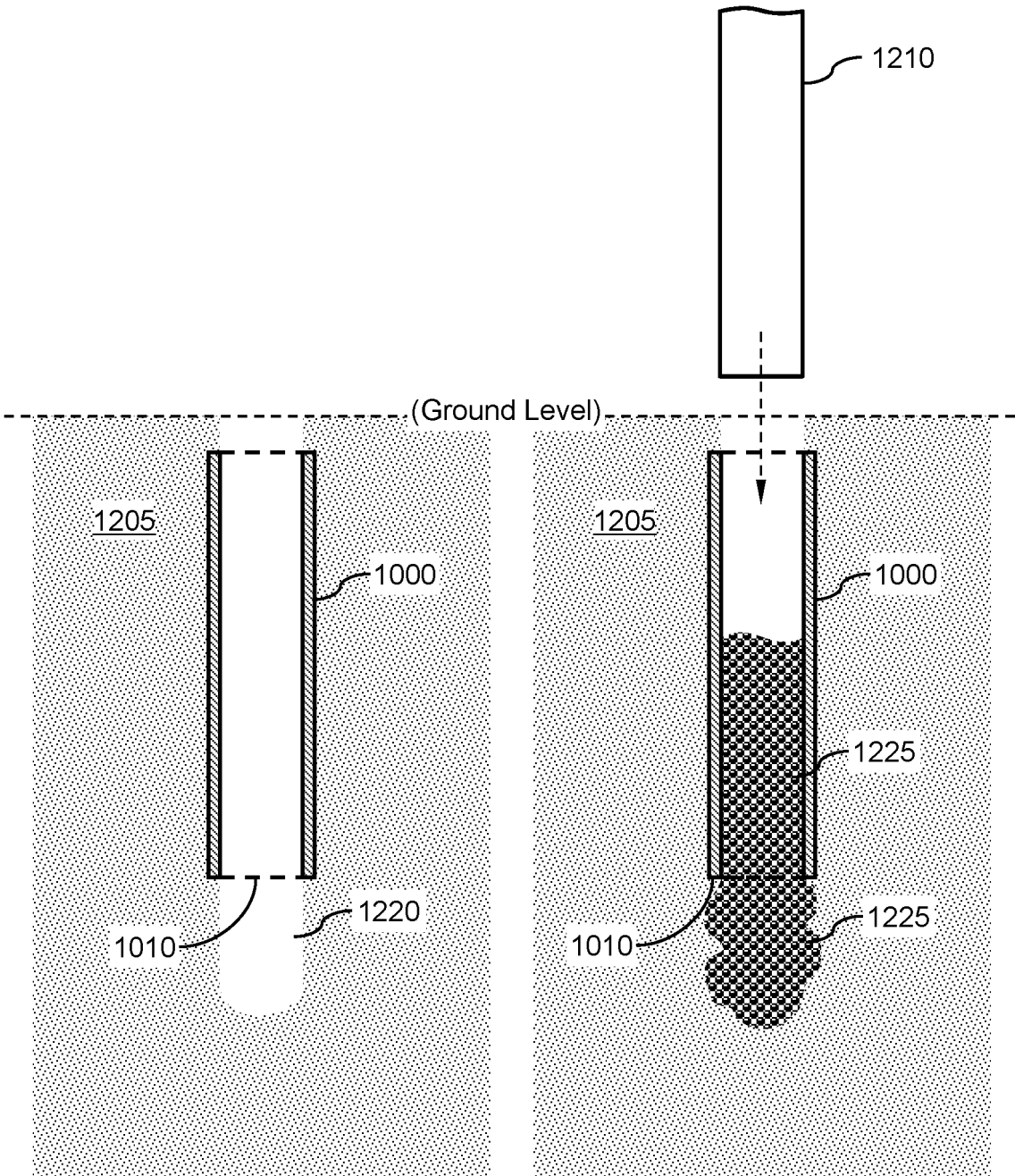


FIG. 15A

FIG. 15B

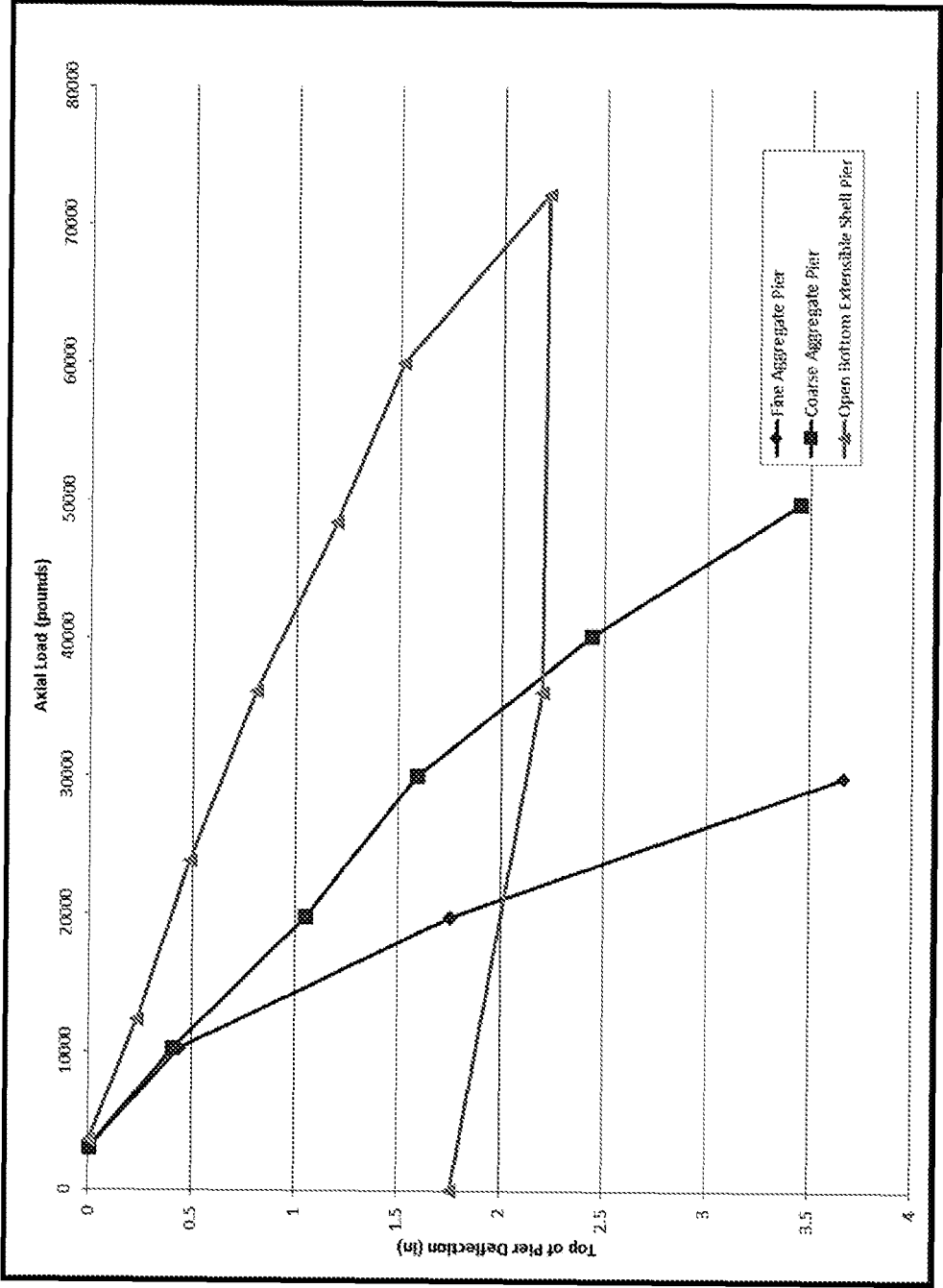


FIG. 16

REFERENCES CITED IN THE DESCRIPTION

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