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Titre: Direct tendon to pile connection.

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Abrégé: A foundation system is disclosed for securing the tendons of a TLP to the ocean floor in which a plurality of piles are secured to the ocean floor and a plurality of tendon receptacles are secured to the piles such that the load from tendons secured therein is transferred to the ocean floor through coaxially aligned load paths of tendon to tendon receptacle to pile to ocean floor. Other aspects of the present invention include an improved pile and a method of installing a TLP involving such a foundation system.

DIRECT TENDON TO PILE CONNECTION

The present invention relates to deepwater platform foundations. More particularly, it relates to a tension leg platform foundation anchored to the ocean floor through a plurality of piles.

5 As used herein, a "tension leg platform" or TLP refers to any buoyant structure tethered to the ocean floor through substantially vertical tendons tensioned to draw the buoyant structure below its normal floating draft. Various embodiments include a full scale TLP having full drilling facilities, a tension leg well platform
10 ("TLWP") having only a scaled down "completion" rig, a tension leg well jacket ("TLWJ") designed to accept well operations from an auxiliary vessel, or any other tendon deploying variation.

Tendons connect the buoyant hull to a foundation system at the ocean floor and are tensioned to draw the buoyant hull below its
15 normal floating draft. The tendons transmit this static load to the foundation system. Further, the tendons must transmit this static load while subject to additional loads which have significant cyclical components driven by environmental forces of wind, wave and current on the hull and tendons. The combined load is transmitted
20 to the ocean floor through the foundation system.

Some early designs for vertically moored platform concepts contemplated using the same tubular members simultaneously for the tendons and for the risers through which drilling and production operations were to be conducted. However, this was found to be
25 impractical due to both operational constraints and the risks, difficulties, and expense of designing the tubular goods for the internal pressure in these members as flowlines and the axial load as mooring members.

The bottoms of the tendons are secured to a foundation system
30 at tendon receiving load connections or tendon receptacles. In traditional practice, the foundation system is built around a

foundation template. The template is a framework which permanently interconnects the tendon receptacles and the pile sleeves. Vertical (surface) access of tendons and piles to tendon receptacles and pile sleeves, respectively, is provided by a horizontal offset therebetween in their position on the template.

In the conventional practice, the foundation template is placed and the piles are installed through the pile sleeves and set deeply into the sediment at the ocean floor. The piles are then secured to the pile sleeves and the foundation template is ready to accept tendons.

The foundation template serves two purposes in such a foundation system. First, it provides spacing and modular placement of the pile sleeves, the tendon receptacles, and often a plurality of well guides. Second, the template is a permanent fixture providing load bearing interconnection between piles anchored to the ocean floor and tendon receptacles.

However, the tendon-to-receptacle, to-template (and over)-to pile sleeve, to-pile, to-ocean floor load path of the conventional template based foundation system is an inefficient load transfer scheme. This also commits a large quantity of steel to the template and creates handling difficulties for transporting and deploying the massive template. Further, the lateral spacing between the tendon receptacles and the pile sleeves which introduces these inefficiencies also exacerbates the fatigue response of the template based foundation system.

A plurality of smaller corner templates have been used in designs which provide well guides outside of the template as an alternative to a unitary template which includes well guides. This does reduce the material requirements, but does not alleviate the inefficiencies in load transfer discussed above.

GB-A-2178101 and US-A-4907914 relate to TLP systems. US-A-4540314 discloses a TLP foundation system according to the preamble of claim 1.

5 It is an object of the invention to provide an improved foundation system for securing a TLP hull to the ocean floor.

It is another object of the invention to provide an improved method of installing a TLP.

10 In accordance with the invention there is provided a foundation system for securing a TLP hull to the ocean floor, comprising a plurality of primary load bearing elements, each load bearing element comprising a tendon connected at its upper end to the TLP hull, a pile comprising a tendon receptacle receiving and securing the
15 lower end of the tendon, and a pile member secured into the ocean floor and on its upper end being connected to the tendon receptacle, said tendon, tendon receptacle, and pile member defining a coaxially aligned load path from the TLP hull to the ocean floor, the foundation
20 system further comprising a guide template provided with a plurality of guide sleeves, each guide sleeve surrounding one of said piles, characterized in that the guide template includes spread members which provide spacing between clusters of said sleeves.

25 In accordance with another aspect of the invention there is provided a method of installing a TLP, the method comprising installing a plurality of piles into the ocean floor, providing tendon receptacles on the piles, and anchoring a plurality of tendons from the TLP
30 to the ocean floor through the tendon receptacles such that the anchoring load paths from the TLP to the ocean floor are established in a plurality of vertical paths extending in coaxial alignment from tendon-to-tendon receptacle-to-pile, wherein installing a plurality of
35 piles comprises placing a template on the ocean floor and

placing piles in relative position to one another by installing the piles through sleeves provided on the template, characterized in that the template is a temporary template including spread members which provide spacing between clusters of said sleeves.

The invention will be more fully described hereinafter with reference to the accompanying drawings in which:

Figure 1A is a side elevational view of a TLP deploying one embodiment of a foundation system in accordance with the present invention;

Figure 1B is a side elevational view of one of the members of the foundation system of Figure 1A;

Figure 2A is a perspective view of installation of one embodiment of the foundation system of the present invention;

Figure 2B is a side elevational view of deployment of a foundation system in accordance with an alternate embodiment of the present invention;

Figure 3A is a partially cross-sectioned view of a pile having an integral tendon receptacle in accordance with one embodiment of the present invention;

Figure 3B is a partially cross-sectioned view of an alternate embodiment of a pile having a tendon receptacle secured thereto;

Figure 3C is a partially cross-sectioned side view of a tendon receptacle formed within a pile extension in accordance with an alternate embodiment of the present invention;

Figure 3D is a cross sectional view taken along line 3D-3D of Figure 3C;

Figure 3E is a cross sectional view of an alternate connection of a pile extension to a pile in accordance with an alternate embodiment of the present invention;

Figure 4 is a partially cross sectioned view of a tendon about to engage a tendon receptacle in accordance with one embodiment of the present invention;

Figure 5 is a planar representation of the guide surfaces presented annularly within the tendon receptacle of Figure 4; and

Figure 6 is a partially cross-sectional view of another embodiment of the present invention.

Figure 1A generally illustrates a TLP 8 having buoyant hull 12 riding on ocean surface 14 and tethered in place about tendons 16 secured to the foundation system 10 of the present invention. Foundation system 10 includes tendon receptacles 18 into which the bottom of tendons 16 are secured and piles 20 which extend deep into ocean floor 22.

Figure 1B is a more detailed illustration of one of tendons 16 latched into a tendon receiving load connection 17, here in the form of tendon receptacle 18, provided on pile 20. In this embodiment, pile 20 combines an elongated cylindrical member or pile member 28

with an integrally formed tendon receptacle 18. Elongated cylindrical member 28 extends deeply into sediment 24 at ocean floor 22 to such a depth as which the skin friction between the sediment and the exterior of the pile is competent to securely retain, with an adequate margin of safety, the axial load of restraining buoyant hull 12 of TLP 8 in place and drawn below its natural buoyant draft through tendon 16. See Fig. 1A.

Returning to Figure 1B, foundation system 10 is shown to have a load path through the tendon-to-tendon receptacle-to-pile which is coaxial about axis 26 from the tendon to interaction with the sediment at the ocean floor. This alignment of tension receptacles and piles facilitates loading in tension without transmission as a bending moment laterally over to a foundation template, and from there as a bending moment across a connection to a pile sleeve.

Figure 2A illustrates another embodiment of foundation system 10 on ocean floor 22. In this embodiment, a light weight, temporary template 30 is deployed on the ocean floor. This template has spread members 32 which provide spacing between clusters of pile sleeves 34. In this embodiment, temporary light weight template 30 serves no continued structural purpose once piles 20 are spaced and it may be retrieved following pile installation.

Alternatively, the light weight template 30 may be left in place to corrode under the natural exposure without worry or need for cathodic protection. However, in yet another embodiment, sleeve bracing 36 between piles in a cluster 38 may provide benefit as structural members and pile sleeves 34 may be secured to piles 20 such as by grouting or swaging operations. In this latter embodiment, the load path would still ordinarily be from the tendon to the tendon receptacle, to the pile, coaxially. However, structurally interconnecting the piles within each cluster provides assurance that the tendons of the cluster, e.g., at the corner of a TLP, distribute the load in the event that the set of an individual pile to the ocean floor should start to fail. Even so, spread members 32 need serve only to secure spacing of the piles and that

portion of the foundation template may be removed or sacrificed to corrosion.

5 In this embodiment, fully assembled piles 20 are lowered into pile sleeves 34 one at a time, allowed to penetrate ocean floor 22 under their own weight to an initial set depth. A fluid driven pile hammer 40 then drives the pile into secure engagement with the ocean floor. In Figure 2A, pile 20A is illustrated being driven through one of pile sleeves 34 by hydraulic pile hammer 40 actuated through a hydraulic line 42. Vertical blows to a load or drive surface at
10 the top of the pile drives the lower end of the pile deeper and deeper into the sediment. Underwater hammer 40 is removed after the pile has been driven to design depth. At this point, the pile will accept a tension load, but the pile will continue to "set" over a period of time following installation during which period the load bearing capacity of the pile increases as the sediment compacts
15 about the pile.

It is common in the art to refer to driving piles "to refusal" at which point the skin friction and penetration resistance diminishes the rate of penetration. However, the "refusal" is
20 diminished penetration, advance is not totally stopped, and it remains practical in many applications to design for horizontal alignment of the tops of piles 20. For instance, the tendon receptacles 18 are formed integrally with piles 20 in Figure 2A. In this embodiment it is preferred for tendon receptacles 18 to be
25 presented in a single horizontal plane and this can be achieved through careful driving operations.

Figure 2B discloses an alternate method of freestanding pile installation in which no template is deployed, temporarily or
30 otherwise. In this templateless practice of the present invention, pile 20B is lowered on cable 40 from a crane or draw works on the surface. The bottom of pile 20B reaches ocean floor 22 to setdown and penetrates the first interval of the sediment, driven by the weight of the pile itself as alignment and position continue to be controlled through the cable. Acoustic or other reference aids are
35 used to secure position for touchdown. However, careful cable

control remains very important for the advancing pile throughout the initial interval such that the rate of feed does not exceed the rate of penetration. The setdown and orientation thus controlled by rate of feed is the only guiding mechanism absent the benefit of a
5 template secured pile sleeve.

The pile becomes self supporting after an initial interval and it is no longer necessary to maintain alignment of pile 20B with cable 40. The pile is then self guiding through the second interval to "refusal" at the full depth of self penetration. Cable 40 is
10 released from its connection to the pile and a pile hammer is then deployed in the same manner as for Figure 2A, discussed above, to continue driving pile 20B to a secure depth competent to restrain the tendon loads. Pile deployment designs for a large scale TLP for selected seabed sediments in the Gulf of Mexico were recently
15 calculated based on a 84 inch diameter, 1.125 to 1.75 inch wall thickness pile and found to be self-supporting in 50-60 feet and self penetrating to 100-120 feet of a total 355 foot drive depth.

Figures 3A-3E illustrate a sampling of embodiments of the present invention. These are each illustrated with guide surfaces
20 50 inside tendon receptacles 18 suitable to cooperate with a rotating lug tendon anchor assembly 52 (see Figure 4). However, those having ordinary skill in the art will appreciate that any number of hydraulic or mechanical latching mechanisms or other connection systems may be used in the practice of the present
25 invention.

Figure 3A illustrates an embodiment of pile 20 in which tendon receptacle 18 is formed integrally with elongated cylindrical member
28. Here the upper end of pile 20 includes a drive head 70, a load ring 72, a receptacle body 74 and a transition section 76. The
30 drive head accepts an externally mounted underwater hammer and presents drive surface 78 through which hammer blows are delivered to drive the pile. It is preferred that the walls of drive head 70 be thickened to protect against deformation during driving operations. Receptacle body 74 is also strengthened with a thicker
35 wall in this embodiment to transmit the force of the hammer while

protecting the dimensional integrity of guide surfaces 50 and protecting against metal fatigue. Transition section 76 reduces stress concentration in narrowing this wall thickness to that of elongated cylindrical member 28.

5 The embodiment illustrated in Figure 3B is configured to accept an internally deployed underwater hammer. Funnel guide 80 will guide reception of the pile hammer for pile installation and later, the end of the tendon at a tendon anchor assembly. See Figure 5. Returning to Figure 3B, drive surface 78 is provided in the form of
10 load shoulder 78B and is positioned below receptacle body 74. This allows the direct force of the hammer blows to bypass the tendon load connection. In this illustration, transition section 76 of tendon receptacle 18 bridges a significant difference in diameters between receptacle body 74 and elongated cylindrical member or pile
15 member 28.

Figure 3C illustrates an embodiment in which piles are set by drill and grout operations and tendon receptacle 18 is provided as a pile extension 18C. Pile and grout operations use a jet assembly to start a borehole, then use drilling operations to complete the
20 interval into which the pile is placed. Grout 81 is then injected into the annular space 82 between the pile and the borehole, e.g. by circulating down the borehole and returning up the annulus. Alternatively, the borehole may be filled with grout before the pile is inserted. The pile is secure after the grout sets. Those having
25 ordinary skill in the art will appreciate that other bonding and setting agents may be used in place of conventional grout.

In this illustration, pile extension 18C telescopically engages the top of elongated cylindrical member 28, here pile member 28C. This sleeve or overlapping annular region 84 is grouted to secure a
30 connection 85 of the pile extension to the elongated cylindrical member. Further, the structural integrity of the connection is enhanced by using a plurality of interspaced rails 86 projecting into the grouted overlapping annular space 84. See Figure 3D.

Figure 3E illustrates another connection 85 of pile extension 18C to pile member 28. In this example the top of the pile member
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is swaged out into one or more annular rings 88 presented on the interior of the pile extension 18C. This swaging operation may be accomplished by packing off the inside of pile member 28 adjacent the annular rings and using hydraulic pressure denoted by arrow "p" or by mechanical swaging tools to cause the pile member to plasticly deform into ring 88.

Alternatively, the pile extension may be configured for reception within pile member 28 and connected through analogous grouting or swaging operations. Other methods for connecting a pile extension to a pile member either before or after the pile member has been installed are available to those having ordinary skill in the art who are provided with the teachings of the present disclosure. These may also vary depending upon whether the pile is driven or drilled and grouted.

The use of pile extensions also provides an opportunity for rehabilitating a pile having an integrally formed tendon receptacle that was damaged in installation. The damaged receptacle may be cut off, removed and replaced with a pile extension presenting a new tendon receptacle.

Figures 4 and 5 illustrate one system for connecting the bottom of tendon 16 to a tendon receptacle 18. Such a connection is disclosed in detail in U.S. patent 4,943,188, the disclosure of which is hereby fully incorporated and made a part hereof by reference. This type of connection uses guides 50 within tendon receptacle 18 to guide the rotation of rotating lug anchor connector 52.

In this embodiment, the lower extension of tendon 16 is provided with a rotating lug anchor connector 52. The anchor connector provides a plurality of spaced lugs 54 on a load ring 56. The load ring is allowed to rotate freely about retaining ring 58. A limited degree of freedom for pivotal rotation is provided in the connection between tendon 16 and tendon receptacle 18 in the embodiment of Figure 4 by an elastomeric member 60 that connects retaining ring 58 to a load shoulder 62 on the base of tendon 16.

The latch sequence for connecting tendon 16 to the tendon receptacle 18 begins with lowering rotating lug anchor connector 52 into the tendon receptacle. Actuating lugs 64 carried on the anchor connector engage guides 50 within tendon receptacle 18. This initial stab-in causes a rotation of the rotating lug anchor connector 52 such that lugs 54 on load ring 56 pass between lugs 66 on load ring 72 within tendon receptacle 18.

Figure 5 is an illustration of the path of one of actuation lugs 64 interacting with guides 50 in a figure that has been "flattened-out" to a planar view for simplification. The initial stab is illustrated by path 100. Pulling the tendon upward causes rotation of connector 52 as actuation lugs 64 travel a course illustrated as path 102. This brings lugs 54 into alignment with lugs 66 and securely engages anchor connector 52 of the tendon within tendon receptacle 18.

If necessary, this engagement may be released by a second down and up stroke on tendon 16. This course is illustrated by paths 104 and 106 which will rotate the lugs out of alignment and permit release of the tendon.

Figure 6 illustrates another embodiment which provides for a rigid tendon anchor to tendon receptacle engagement at tendon load connection 17. In this illustration, tendon 16 terminates in a threaded tendon anchor 17A which threadingly engages tendon receptacle 18 in threaded region 17B below drive head 70 of pile 20. The necessary degree of freedom for rotation is accommodated by elastic flexure at stress joint 92 in pile 20. Alternatively, rigid tendon load connection 17 might be provided by one or more rotating lug rings on the bottom of a tendon without an elastomeric flex-element.

Other modifications, changes and substitutions are intended in the foregoing disclosure and in some instances some features will be employed without a corresponding use of other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the spirit and scope of the invention herein.

C L A I M S

1. A foundation system for securing a TLP hull to the ocean floor, comprising a plurality of primary load bearing elements, each load bearing element comprising a tendon connected at its upper end to the TLP hull, a pile comprising a tendon receptacle receiving and securing the lower end of the tendon, and a pile member secured into the ocean floor and on its upper end being connected to the tendon receptacle, said tendon, tendon receptacle, and pile member defining a coaxially aligned load path from the TLP hull to the ocean floor, the foundation system further comprising a guide template provided with a plurality of guide sleeves, each guide sleeve surrounding one of said piles, characterized in that the guide template includes spread members which provide spacing between clusters of said sleeves.
2. The foundation system of claim 1 wherein the tendon receptacle is formed integrally with the pile member.
3. The foundation system of claim 1 wherein the tendon receptacle is attached to the pile member as a separate assembly.
4. The foundation system of any of claims 1-3 further comprising an angular rotation system adjacent the connection of the lower end of the tendon to the tendon receptacle.
5. The foundation system of claim 4, wherein the angular rotation system includes an elastomeric flex-joint within the connection of the tendon to the tendon receptacle.
6. The foundation system in accordance with claim 4, wherein the connection of the tendon to the tendon receptacle is rigid and angular rotation is provided by a stress joint on the lower end of the tendon.

7. A method of installing a TLP, the method comprising installing a plurality of piles into the ocean floor, providing tendon receptacles on the piles, and anchoring a plurality of tendons from the TLP to the ocean floor through the tendon receptacles such that the anchoring load paths from the TLP to the ocean floor are established in a plurality of vertical paths extending in coaxial alignment from tendon-to-tendon receptacle-to-pile, wherein installing a plurality of piles comprises placing a template on the ocean floor and placing piles in relative position to one another by installing the piles through sleeves provided on the template, characterized in that the template is a temporary template including spread members which provide spacing between clusters of said sleeves.

8. The method of claim 7 further comprising retrieving the temporary template after the piles are installed and before the tendons are anchored.

9. The method of claim 7 further comprising leaving the temporary template in place without structurally interconnecting the piles to the pile sleeves.

FIG.1A

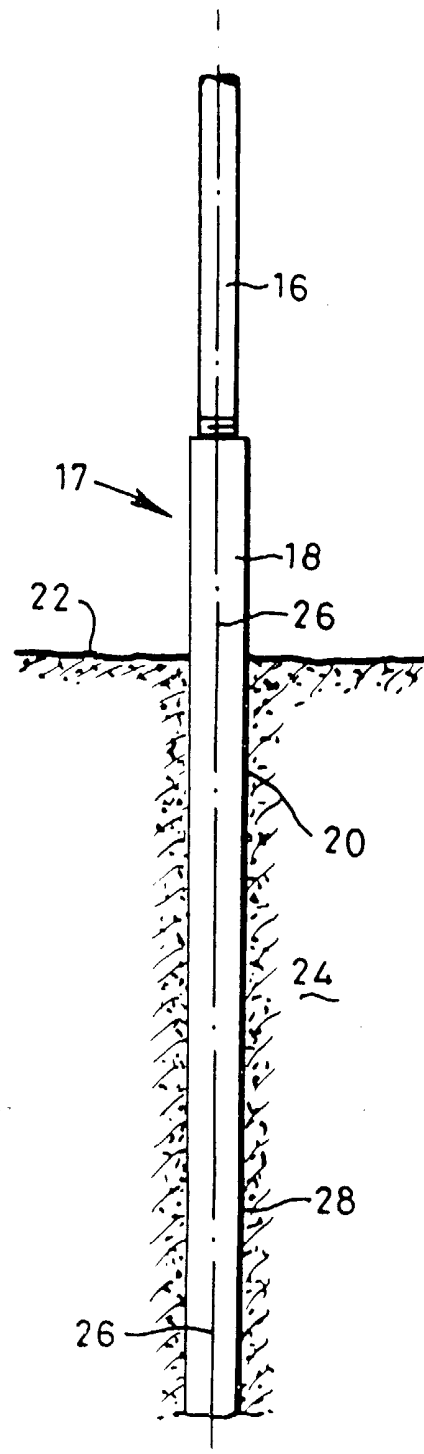
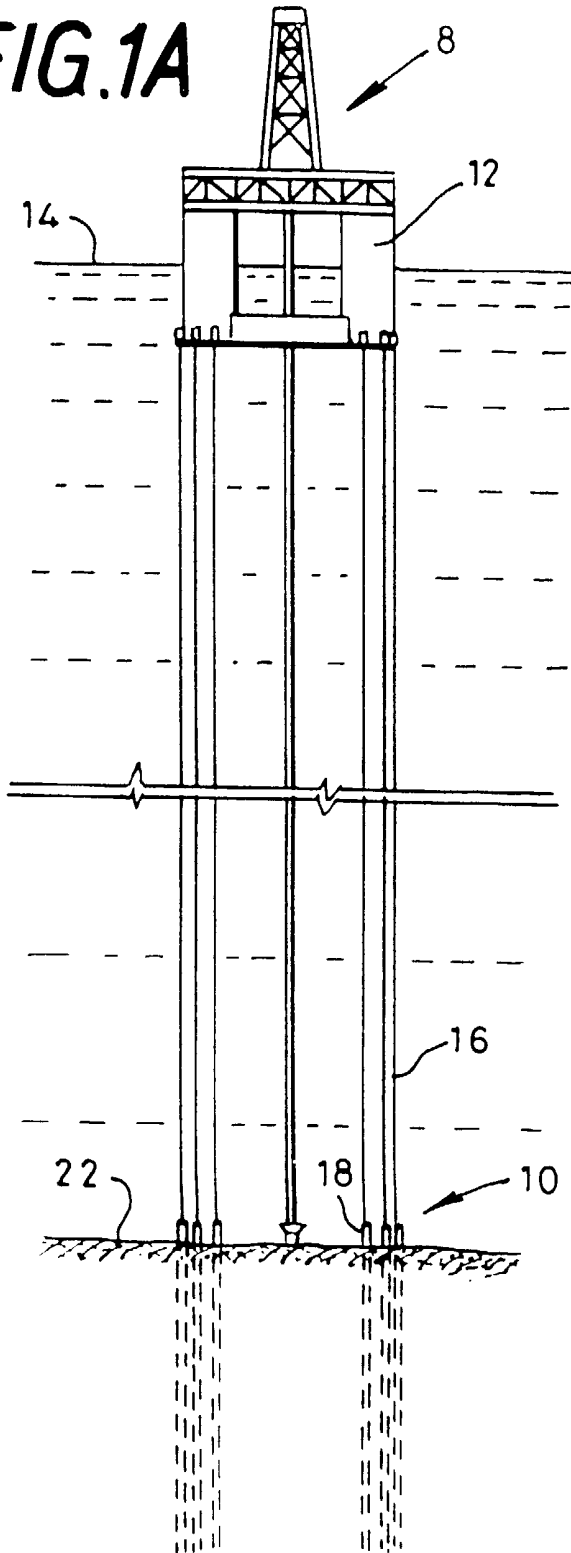


FIG.1B

FIG.2B

FIG.2A

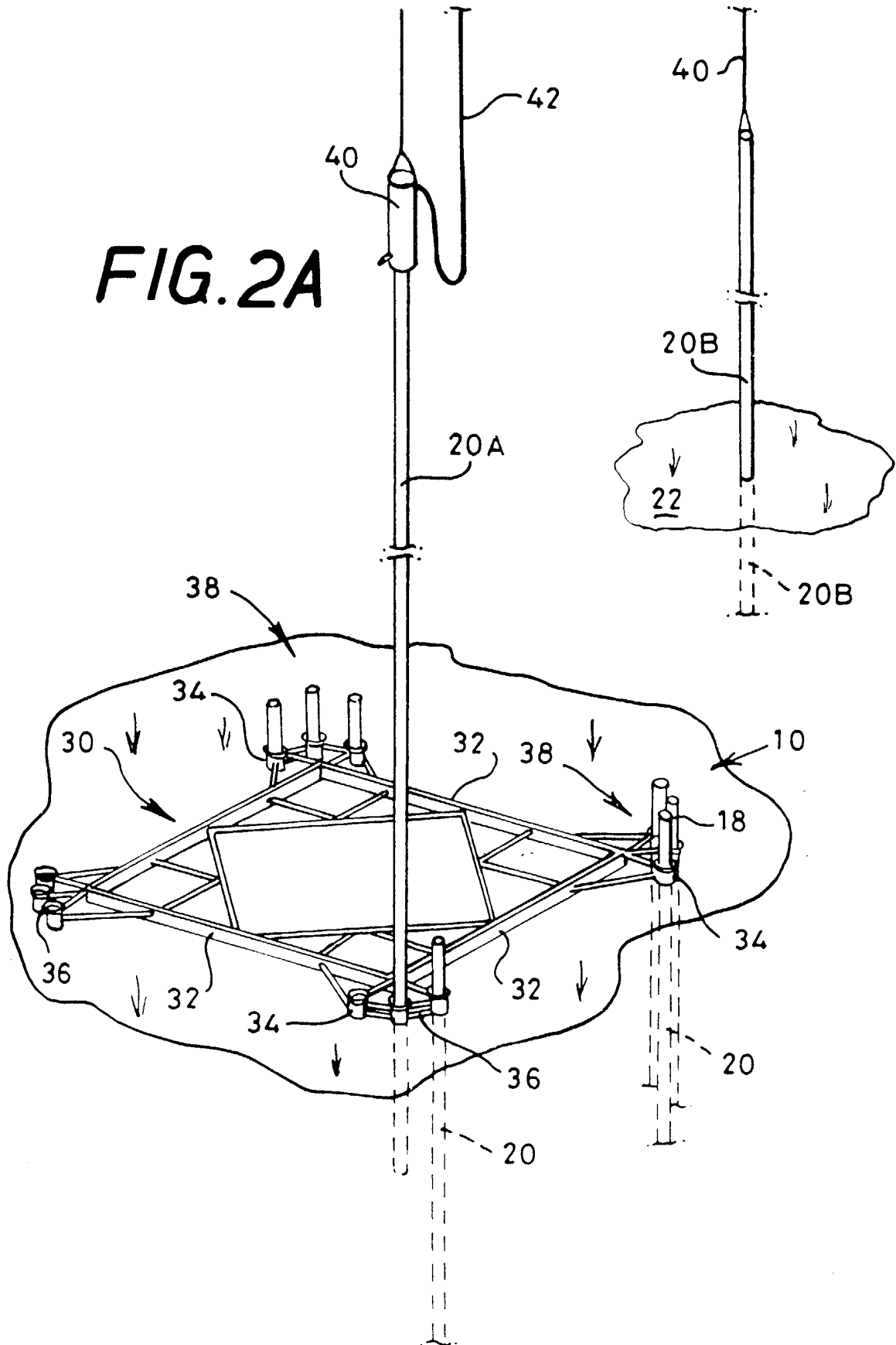


FIG.3A

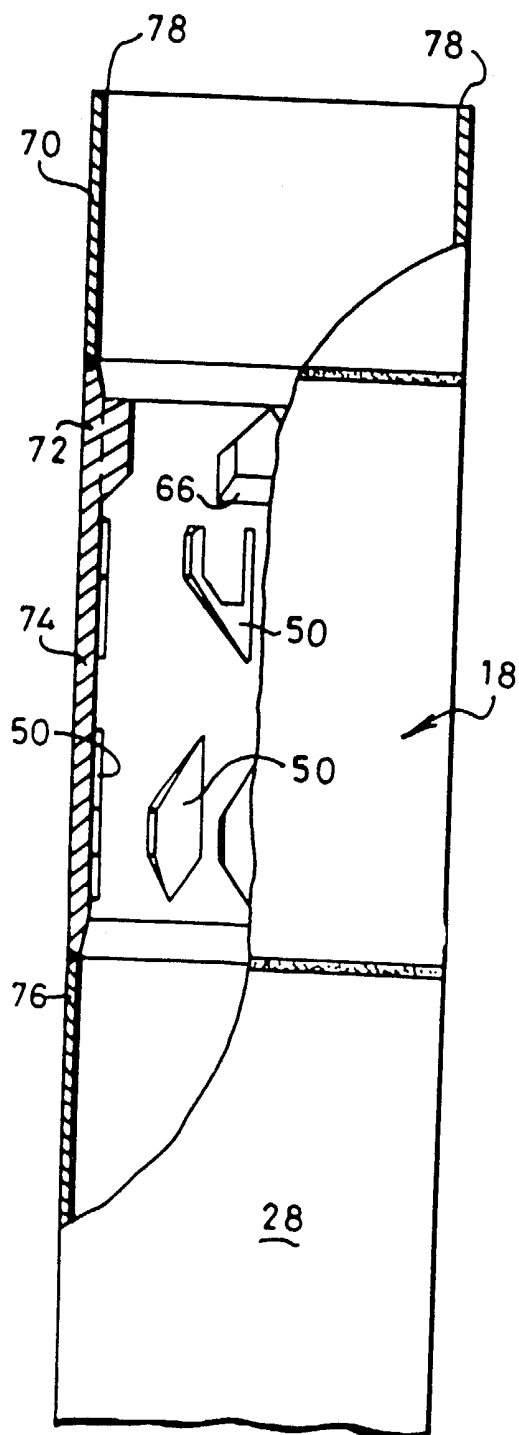
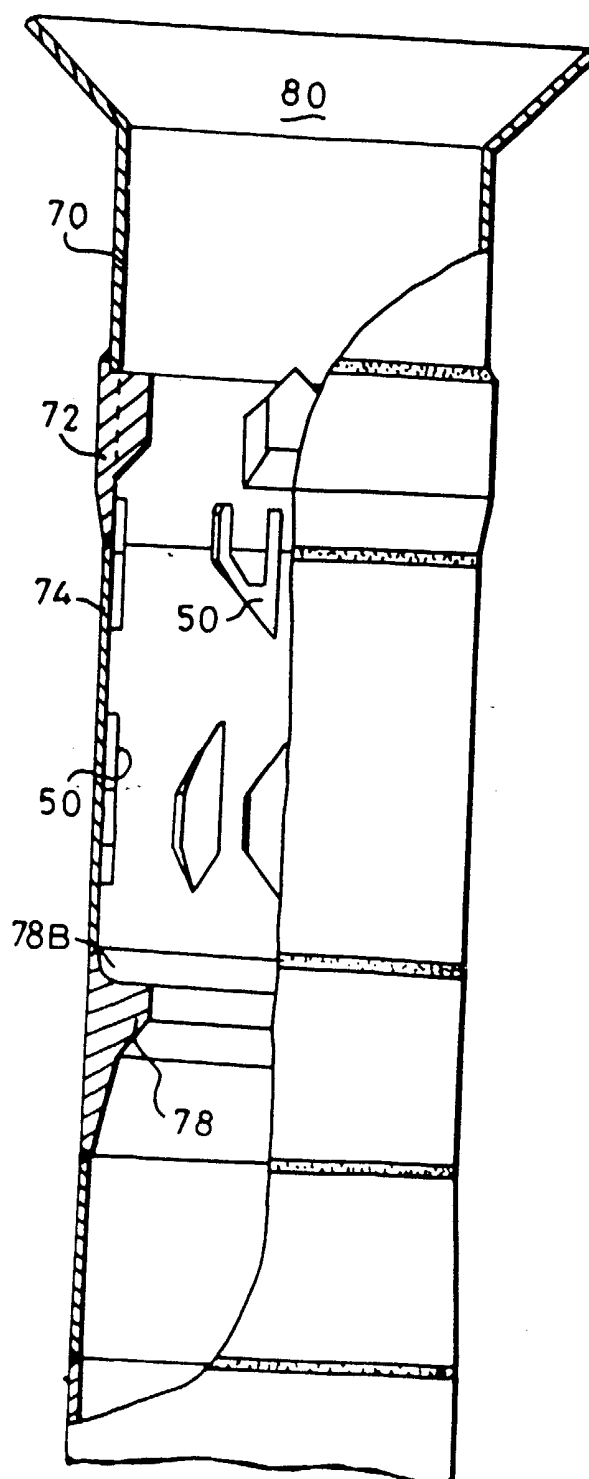


FIG.3B



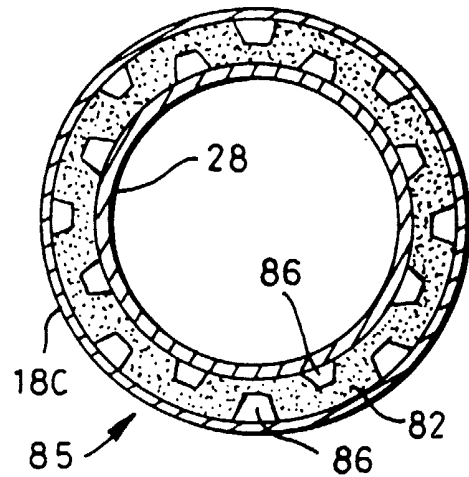
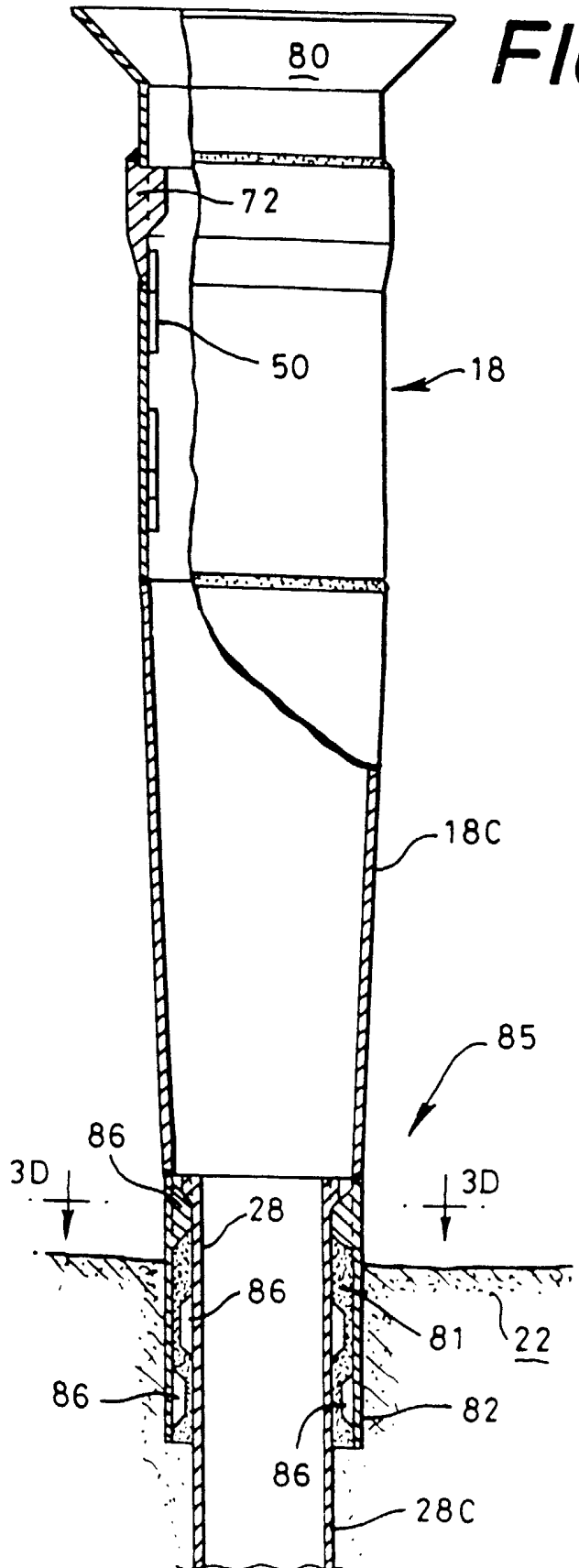
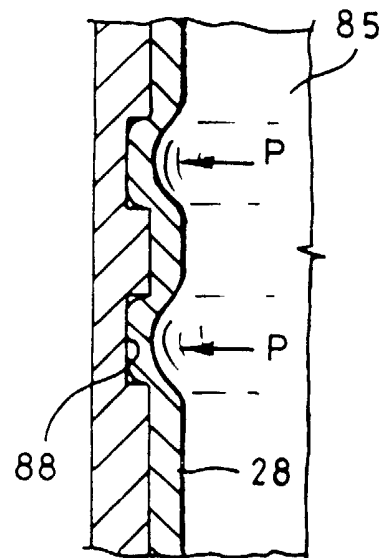


FIG. 3E



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FIG.4

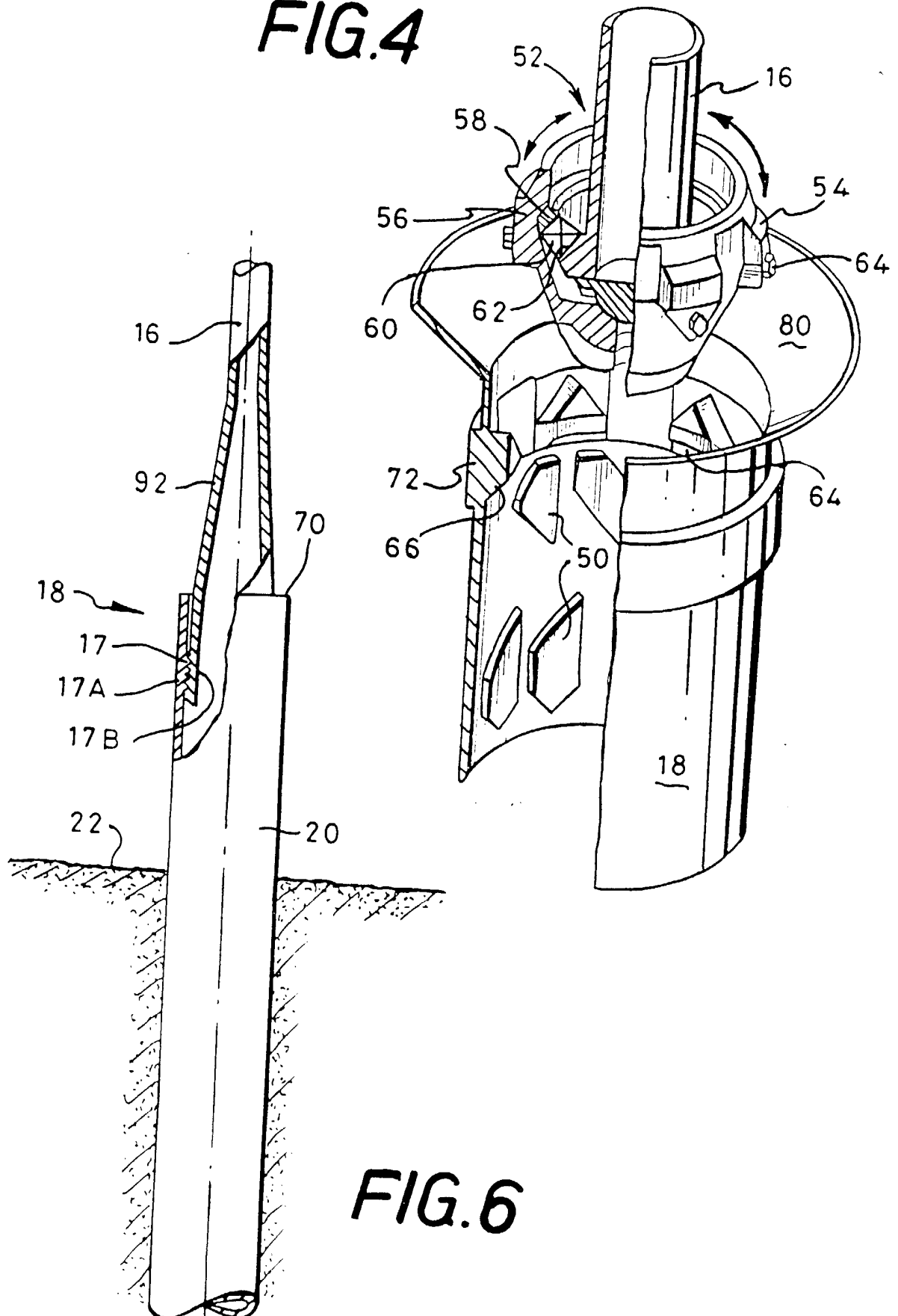


FIG.6

FIG. 5

