US 20030190195A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2003/0190195 A1**

(43) **Pub. Date: Oct. 9, 2003**

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(54) DRILLED PILE

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(21) Appl. No.: **10/117,451**

(22) Filed: **Apr. 3, 2002**

Publication Classification

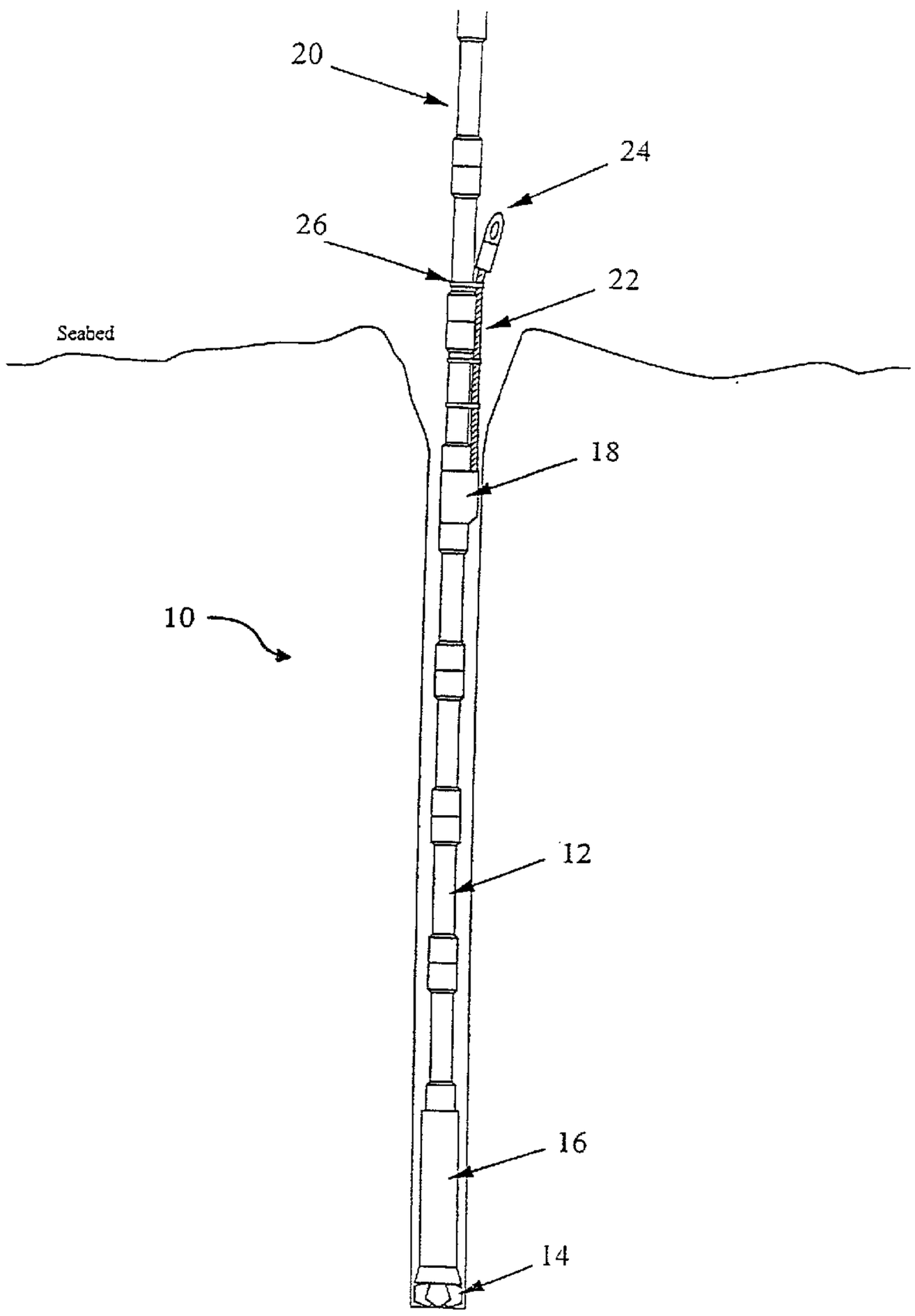
(51) **Int. Cl.**[7] **E21B 7/12**; E02D 7/14

(52) **U.S. Cl.** **405/253**; 175/5; 166/358

(57) **ABSTRACT**

A method of installing a pile **10** in a subsea substrate is provided, which method comprises the steps of providing a pile **10** with a drill bit **14** at one end, and rotating both the pile **10** and the drill bit **14** relative to a substrate to form a bore. Also provided is a subsea pile **10** in the form of an elongate member **12** with a drill bit **14** fixed at one end thereof. In certain embodiments, the elongate member **12** may be tubular, allowing fluids to be supplied to the drilling face via the pile. Such fluids may be drilling mud, sea water, or a settable material for fixing the pile in the bore.

In preferred embodiments of the invention an upper portion of the pile may be adapted to be laterally flexible.



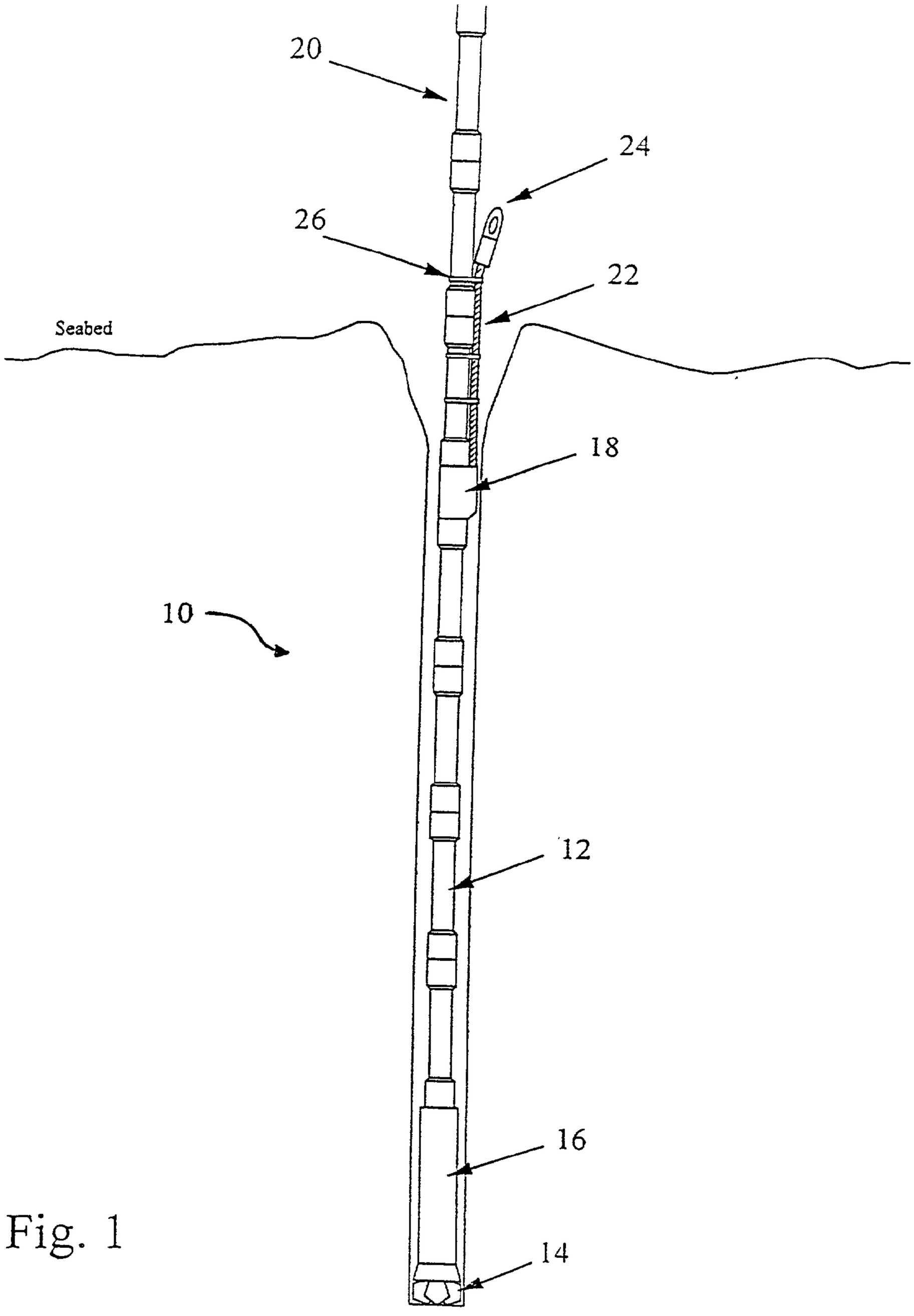


Fig. 1

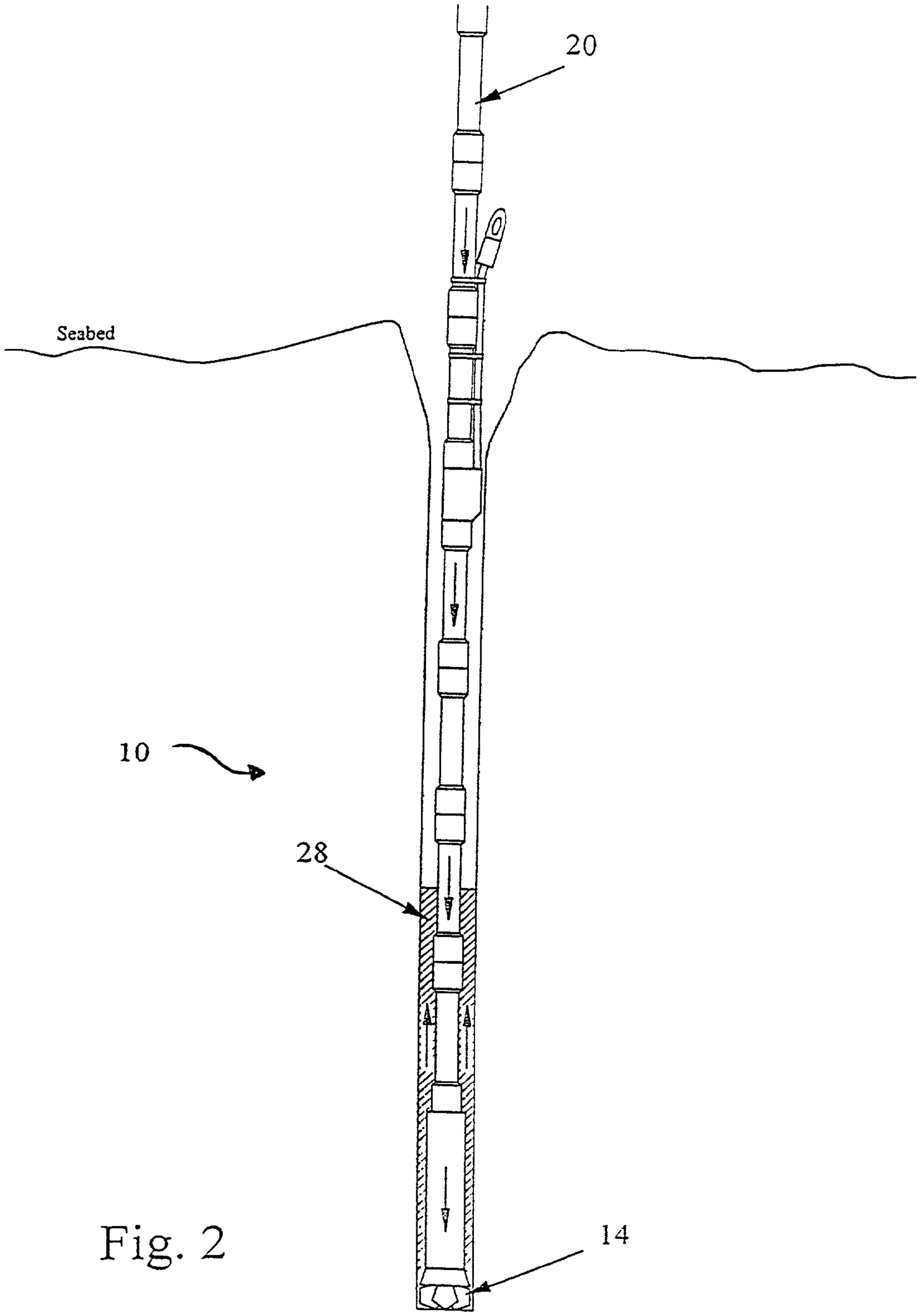


Fig. 2

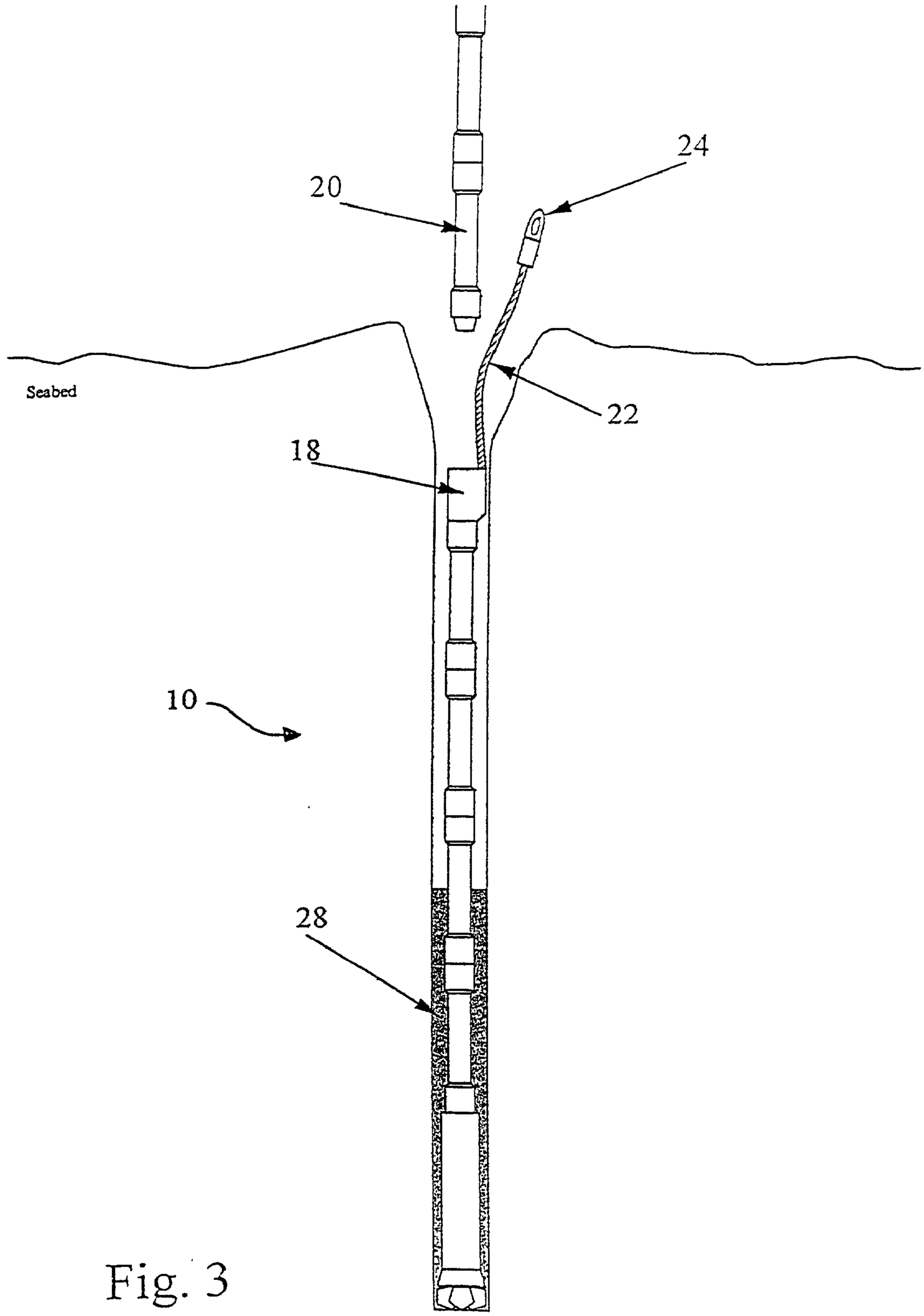


Fig. 3

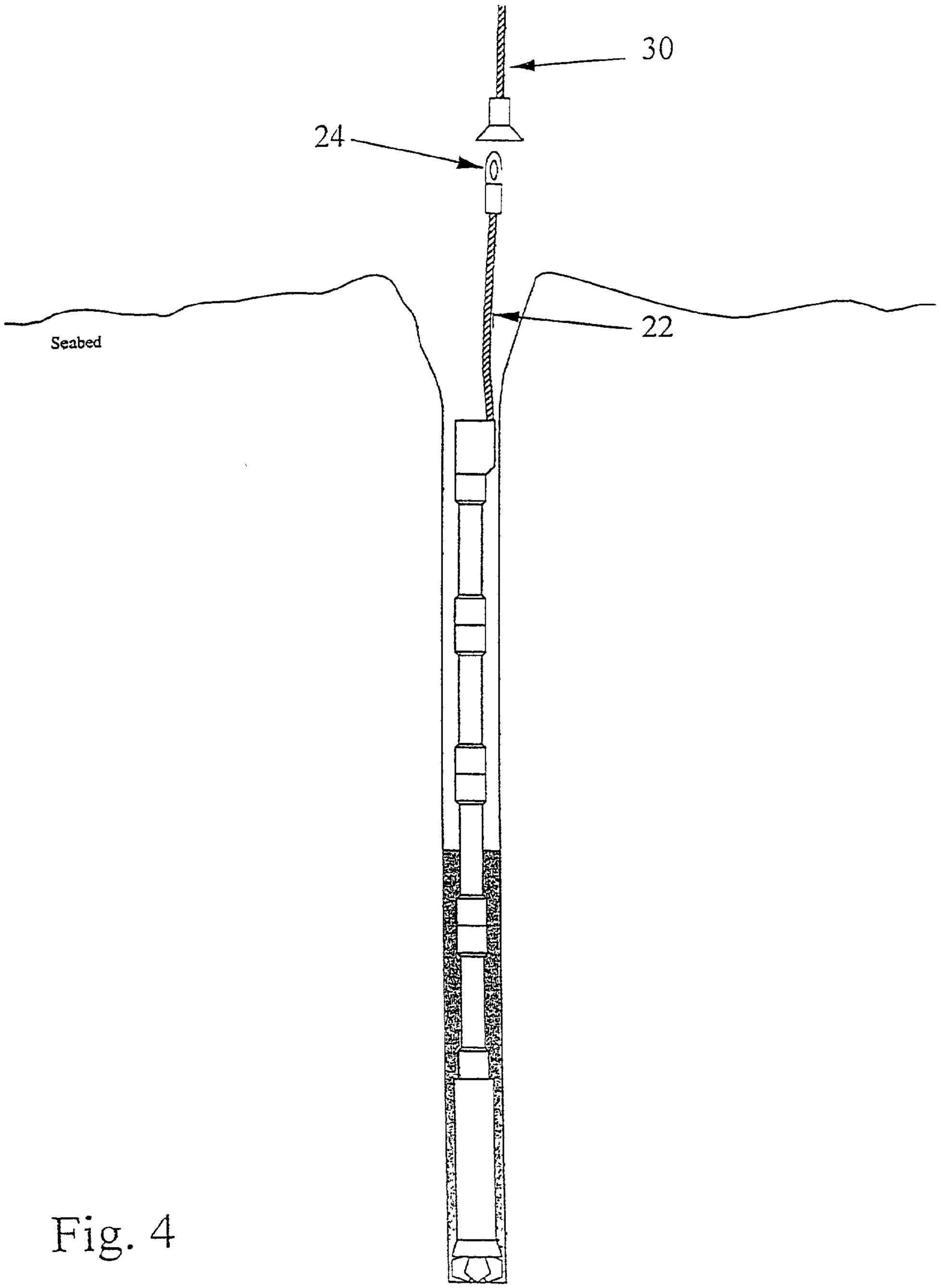


Fig. 4

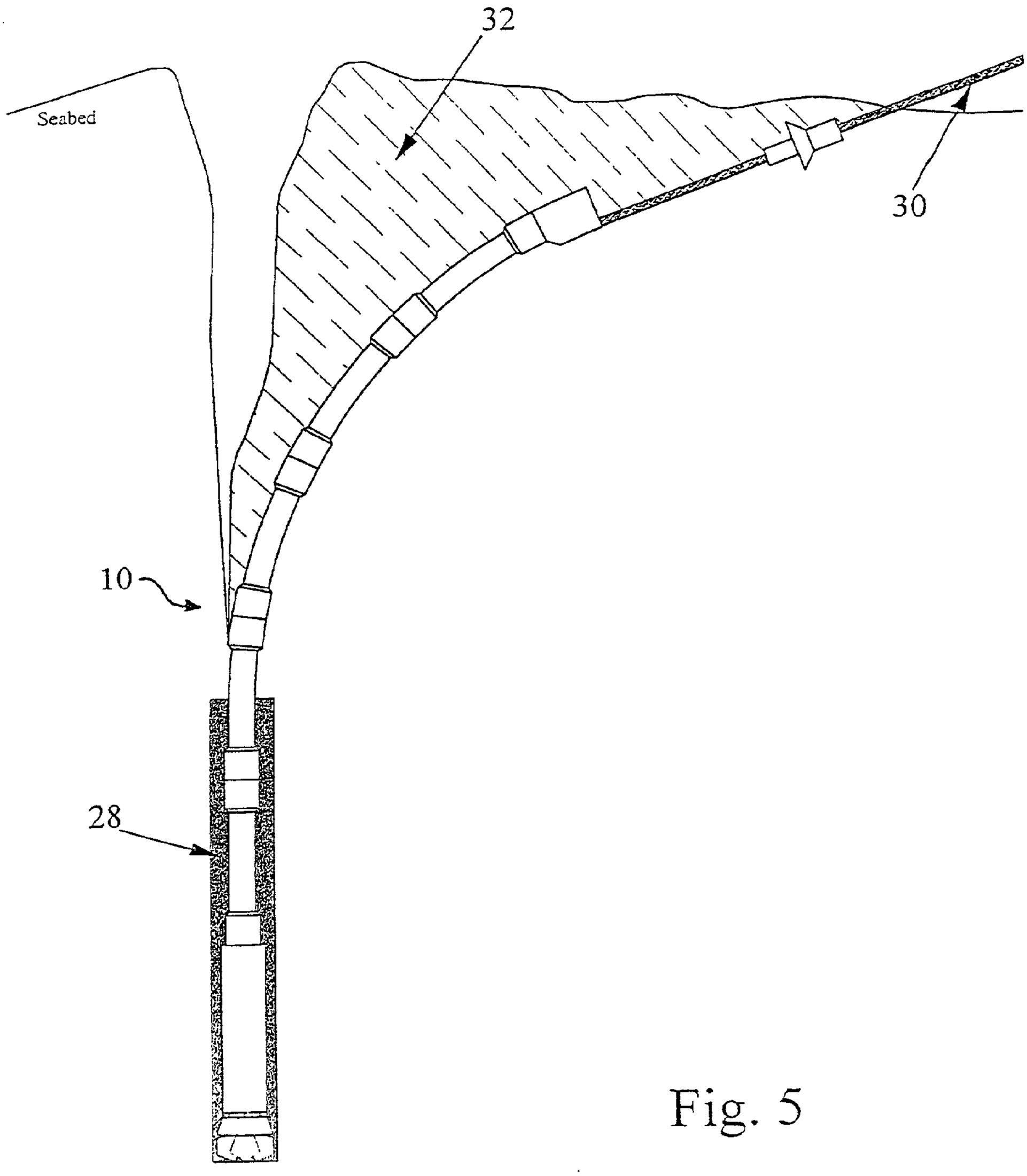


Fig. 5

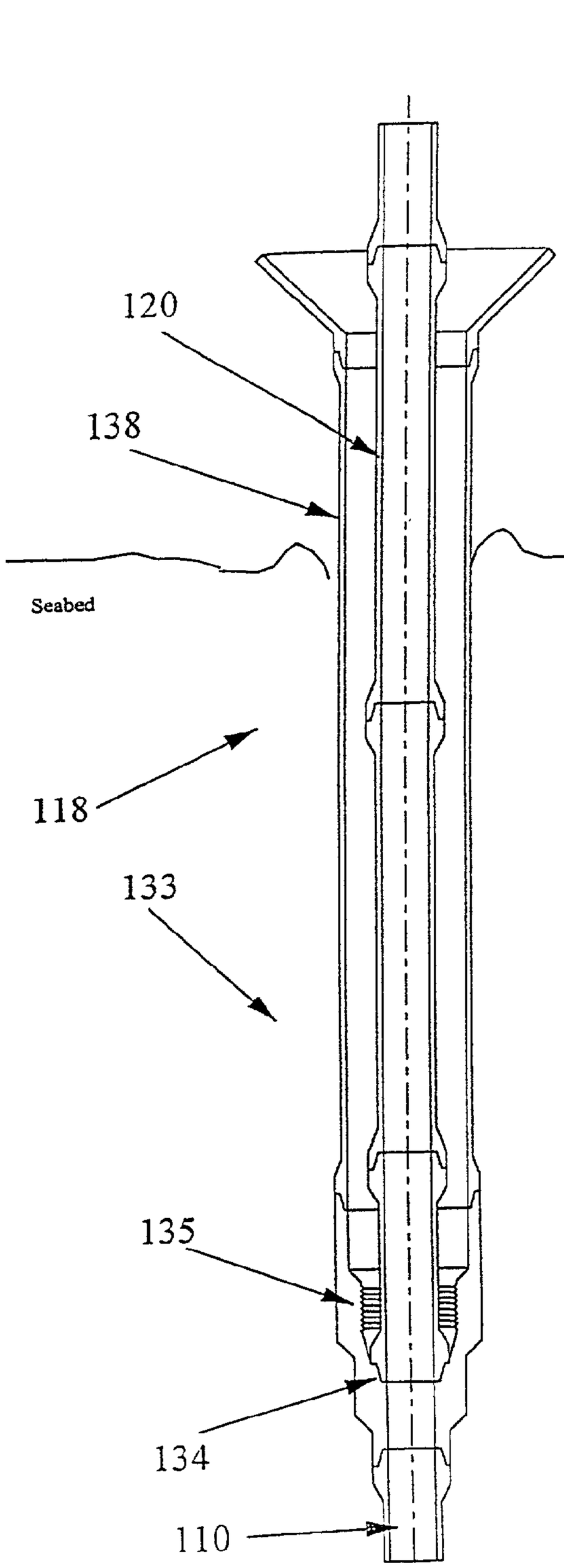


Fig. 6A

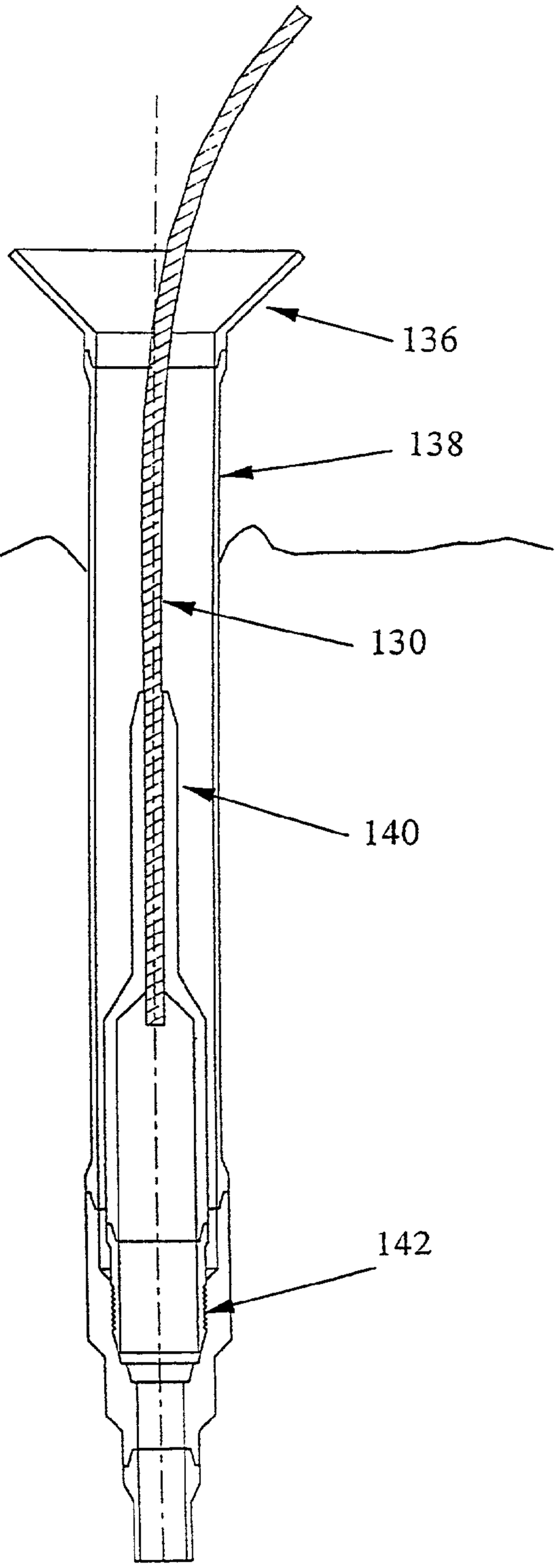


Fig. 6B

DRILLED PILE

DESCRIPTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a drilled pile, particularly for use in subsea applications. The pile is suitable for use as a mooring termination point or anchor on the seabed. The invention further relates to a method of installing such a pile.

[0003] 2. Background to the Invention

[0004] A variety of pile systems and anchoring systems are known in the art; however, such systems suffer from a number of disadvantages. Conventional drilled piles either require the pre-drilling of a hole, removal of the drilling apparatus, and insertion of the pile; or are provided as an integral pile\drilling member, with the drilling member being removed from the pile after drilling. Either of these systems is relatively costly and time-consuming to install.

[0005] Further, such conventional piles are constructed so as to be resistant to bending forces, as will be experienced by the pile on application of any non-axial loading. Accordingly, piles are conventionally formed of heavy rigid tubing of relatively large diameter; the relatively large diameter of the tubing is also useful in transferring lateral forces into the surrounding soil. At least in an integral pile/drilling member, the large diameter of the pile also facilitates accommodation of the drilling member and associated drilling apparatus within the relatively large diameter pile bore. However, handling of such large diameter heavy piles is difficult and, more significantly, the drilling of a large diameter bore to accommodate the pile is time-consuming, and thus expensive.

[0006] It is among the objectives of embodiments of the present invention to obviate or alleviate these and other disadvantages of known piling systems.

SUMMARY OF THE INVENTION

[0007] According to a first aspect of the present invention, there is provided a method of installing a pile in a subsea substrate, the method comprising the steps of:

[0008] providing a pile with a drill bit at an end thereof; and

[0009] rotating and advancing the pile and the drill bit relative to a substrate to form a bore.

[0010] According to a second aspect of the present invention, there is provided a subsea pile comprising an elongate member with a drill bit fixed at one end thereof.

[0011] The present invention provides an integral pile\drilling means which may be used to drill a bore into which the pile advances as the bore is formed. Typically, the drill bit is not recovered, thereby making the method fast and relatively inexpensive.

[0012] The pile and the drill bit are rotated together, thereby removing the need for bearing arrangements to enable the drill bit to rotate separately of the pile. In certain embodiments, the pile may comprise a section of conventional drill pipe, with a drill bit at an end thereof. As the pile is rotated as it is advanced through the drilled bore, the friction between the bore wall and the pile is relatively low, in contrast to arrangements in which a pile is advanced into a drilled bore without rotation.

[0013] Preferably, the pile is an elongate tubular member. This permits fluids, such as drilling fluid or "mud", to be supplied to the drill bit and drilling face via the pile. Other drilling fluids, including sea water, may be utilised; sea water offers the advantage that the fluid need not be recovered, providing a considerable simplification in the pile drilling apparatus.

[0014] Preferably, the method further comprises the step of securing the pile in the bore. This may be achieved by passing a settable material into the bore, between the pile member and the bore wall, and allowing the material to set in the bore. Conveniently, the settable material is cement, grout or the like, and will be delivered to the section of the bore which passes through the firmer soil formations which are generally found at depth below the surface soil layers. Use of the preferred tubular member to deliver a settable material downhole provides a simple and efficient means to fix the pile in the bore. The absence of any separate drilling member within the pile of the present invention also avoids the risk of the drilling member being cemented within the pile. Alternatively, the pile may be cemented or grouted in the bore by delivering cement via a separate arrangement of conduits and hoses, and a cement fill-up device may be used to divert slurry into cement hoses, which are directed into the bore externally of the pile.

[0015] In other embodiments of the invention it may be possible to secure the pile in the bore by other means, for example by providing radially extending members on the pile. Of course, in some embodiments the soil formations may swell or collapse to grip the pile, or the intended function of the pile may not require the pile to withstand elevated axial loads, such that cementing or the provision of securing members is not required.

[0016] Preferably, at least an upper portion of the pile is adapted to flex in response to lateral loading. The pile may be formed of standard oilfield tubulars, such as drill pipe; drill pipe is designed for straightforward and secure connection and has a low bending stiffness but high tensile strength and resistance to fatigue failure. Further, the resistance of the pile to lateral forces may be varied along its length, such that the bending characteristics and bending radii of the pile may be controlled. For example, a lower portion of the pile may be relatively rigid, and may be grouted or cemented in the bore. The relatively high rigidity may be achieved by using heavier section drill pipe, drill collars or even bore casing to form the pile. The pile may thus be adapted for specific applications, and particular soil and rock formations, as would be known to the pile installer from previous surveys, knowledge or experience. A pile having such a flexible upper portion will withstand axial loads in a comparable manner to a conventional pile, but when subjected to lateral forces the upper portion of the pile will bend, and effectively translate the lateral forces to axial forces which are withstood by the lower portion of the pile. This enables the pile to be more versatile and durable than laterally rigid piles. Conventional piles may be installed with force-dispersing collars, in order to transmit lateral forces and stresses away from the pile into the surrounding medium; such arrangements are generally unnecessary with

a laterally flexing pile. Conventional piles are also typically of large diameter, for similar reasons; the present invention enables piles to be made more slender. As well as reducing the bulk and expense of the pile, the provision of a smaller diameter pile facilitates drilling of the bore to accommodate the pile; if the diameter of a pile in accordance with an embodiment of the invention is even only half the diameter of a corresponding conventional pile, the bore drilled to accommodate the pile is only one quarter of the area of the bore necessary to accommodate the conventional pile.

[0017] Preferably, the pile is provided with a mooring line connection. Most preferably, the mooring line connection includes a flexible member which may be in the form of a wire rope, chain or the like. If a mooring line is not to be connected prior to installation of the pile, the flexible member may be secured to the body of the pile by cable ties or other restraining means; this avoids the risk of the connection obstructing the installation of the pile. A portion of the connection may be buoyant, to facilitate location of the connection following installation of the pile. Alternatively, a mooring line connection may be rotatably mounted on the pile.

[0018] The pile and drill bit may be driven by connection to a drill string or other elongate member. The drill string may be substantially conventional and preferably the connection between the string and the pile may be broken from surface once the pile is installed to the correct depth, such that the drill string may be retrieved. Conveniently, this may be achieved by an appropriate termination assembly, for example, a low torque back-off disconnection system. Alternative termination assemblies as known in the art may also be utilised. Most preferably, the termination assembly is positioned at a level relative to the substrate surface such that the pile, or a portion of the pile, does not have to be recovered once the pile is no longer in use.

[0019] The drill string may extend to and be driven from surface, for example by a rotary motor provided on an installation vessel. Alternatively, the pile may be driven by a motor, such as a conventional "downhole" motor, suspended from a drilling vessel on a drill string or suspended from a barge or the like by a flexible member such as a crane line and coupled to a fluid supply by an appropriate hose. This latter arrangement allows the drilling operation to be carried out without requiring the provision of a relatively expensive floating drilling unit, there being no requirement to provide rotary transmission from surface. It is envisage that the drive assembly may be coupled to some means of opposing reactive torque generated by the motor, which would otherwise tend to cause the assembly to rotate in the opposite direction to the desired direction of rotation of the drill bit. This could be a guide-frame located on the seabed, with a key way that interacts with anti-rotation keys on the assembly.

[0020] The drill bit may take any suitable form, depending on the soil conditions and other requirements, such as the bore length and diameter. As the drill bit is likely to be left in the bore with the pile, that is be non-recoverable, the bit will therefore only be required to drill a single relatively short bore and may therefore be of less robust construction, and therefore less expensive, than a conventional drill bit. The drill bit may be of conventional form or may be formed integrally with the end of the pile, for example by welding, depositing or otherwise forming cutting structures on the end of the pile, such as blades provided with tungsten carbide aggregate thereon. Typically, the drill bit will be of a diameter greater than the pile. Alternatively, the drill bit will be of smaller diameter than the pile, fluid erosion or applied weight being utilised to displace softer sediments to accommodate the pile.

[0021] According to a further aspect of the present invention, there is provided a pile comprising an elongate member with a drill bit at one end thereof, wherein the pile has at least an upper portion adapted to flex in response to application of lateral loading thereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] These and other aspects of the present invention will now be described, by way of example, only with reference to the accompanying figures, in which:

[0023] **FIG. 1** shows a side elevation of a pile according to an embodiment of the present invention during the drilling phase of installation;

[0024] **FIG. 2** shows the pile of **FIG. 1** during the grouting phase;

[0025] **FIG. 3** shows the pile of **FIG. 1** during the disconnection of the drill string;

[0026] **FIG. 4** shows the pile of **FIG. 1** during the connection of the mooring line;

[0027] **FIG. 5** shows the pile of **FIG. 1** when connected to a mooring line; and

[0028] **FIG. 6** shows a mooring line connection in accordance with a further embodiment of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

[0029] FIGS. **1** to **5** of the drawings show a pile in accordance with an embodiment of the present invention. The pile **10** comprises a tubular elongate member **12**, in this example formed predominately of standard joints of drill pipe, with a rotary drill bit **14** connected to the lower end of the member **12**, in the illustrated example the diameter of the drill bit **14** being greater than the member **12**. A drill collar **16** is provided at the lower end of the member **12** above the drill bit **14**. A connection assembly **18** is provided at the upper end of the pile **10** and releasably connects the pile **10** to a rotary drill string **20**. The drill string **20** extends to the surface and an appropriate installation vessel (not shown) provided with a motor for driving the string **20**.

[0030] Also connected to the connection assembly **18** is a cable **22** at the free end of which is a mooring line coupling **24**. The other end of the cable **22** is coupled to the pile **10**, the intermediate portion of the cable **22** being releasably secured to the drill string **20** by means of a number of cable ties **26**.

[0031] The installation of the pile **10** is carried out as follows. The pile **10** and drill bit **14** are rotated together by means of the drill string **20**, and driven into the bore thereby generated in the seabed (**FIG. 1**). Cutting or drilling fluid is pumped from the surface through string **20** and the member **12** to the drill bit **14**. The cutting fluid passes from jetting nozzles in the bit **14**, cooling the bit and washing cuttings away from the end of the bore. The cutting fluid and the

entrained cuttings pass up between the member **12** and the bore wall to discharge into the sea.

[**0032**] In this example, the pile is driven to a depth where the end of the pile **10**, marked by the connection assembly **18**, is below the surface of the seabed, to ensure that the upper end of the pile does not constitute a subsea obstruction which would have to be removed after use.

[**0033**] Once the pile has been drilled to the desired depth, as shown in **FIG. 2**, cement **28** is pumped down the drill string **20** from surface, and passes through holes (not shown) in the pile **10** and drill bit **14**, and into the borehole surrounding the pile **10**. The fill level of the cement **28** may be determined as appropriate for the specific application and soil conditions, and in this example it will be seen that the bottom half of the pile is cemented in the bore.

[**0034**] This section of the pile is located in firmer soil sediments, below the softer surface sediments.

[**0035**] Once the cement **28** has set, and the pile **10** is secured in the hole, the drill string **20** is disconnected from the pile **10** at the connection assembly **18** (**FIG. 3**) by rotating the string **20** counter-clockwise. The cable ties **26** break as the drill stay **20** retracts, releasing the cable **22**. The coupling **24** at the end of the cable **22** may be kept clear of the drilled hole and the seabed by means of a buoyant attachment.

[**0036**] As shown in **FIG. 4 a** mooring line **30** is then connected to the cable **22**. The mooring line **30** may be guided and connected by a remotely operated vehicle or by other means.

[**0037**] **FIG. 5** illustrates the response of the pile **10** when subjected to lateral mooring line loads once the installation is complete; lateral forces applied via the mooring line **30** deflect the flexible upper portion of the pile **10** above the section secured with cement **28**. Such deflection may be elastic or in some applications plastic, causing permanent deformation of the pile. The deflection of the pile **10** displaces some of the surrounding softer surface sediments **32** and causes the lateral forces to be translated to axial forces which are resisted by the cemented lower portion of the pile.

[**0038**] Finally, **FIGS. 6***a* and **6***b* show cross-sections of a combination drill string disconnection\mooring line connection subassembly **118**, in accordance with a further embodiment of the present invention. In **FIG. 6***a* the upper drill string **120**, used to support and rotate the pile **110** during installation, is provided with a termination assembly **133** for transferring torque from the drill string **120** to the pile **110**, the string termination assembly **133** including a male ratchet thread **135** for engaging a corresponding female thread. Disconnection of the drill string **120** occurs at a releasable joint **134**, which in this particular example is a low torque left-hand back-off disconnection system or safety joint.

[**0039**] The termination subassembly **118** includes a guide comprising a funnel **136** and a length of plastic pipe **138**. This serves the function, shown in **FIG. 6***b*, of aligning a mooring connection assembly **140** with the termination assembly **133**, and of course prevents the surrounding soft soil from covering the safety joint **134** after the withdrawal of the drill string **120**. The mooring connection assembly **140** comprises the mooring line **130**, a mooring line socket **140**, and a male thread ratchet assembly **142**.

[**0040**] It will be seen that the foregoing embodiments of the invention provide relatively simple and inexpensive alternatives to conventional piles and installation methods. In the preferred embodiment of the present invention, the provision of a flexible pile allows the orientation of the load applied to the pile to be controlled: under lateral loading the pile has a tendency to form an arc, substantially aligning the axis of the part of the pile subject to load with the orientation of that load. This also allows the bending stresses to be relatively evenly applied across a relatively long section of the pile, as opposed to the use of a stiff or inflexible pile which results in the bending stresses being concentrated in a small section of the pile. A pile in accordance with the preferred embodiments of the present invention might thus typically deflect under load by 5-80 degrees, as opposed to a 0.1 to 5 degree deflection of a conventional pile. Using a flexible pile, and omitting a separate drill string within the pile, allows use of piles in accordance with embodiments of the invention with an outside diameter (OD) typically 3-6 times less than a conventional pile to provide similar load-bearing capabilities. For example, a conventional pile of 15-30" OD may be replaced with a pile in accordance with an embodiment of the invention formed of 5" drillpipe.

[**0041**] Although the invention has been described primarily with reference to subsea applications, it will be understood by those of skill in the art that the invention is not limited thereto.

What is claimed is:

1. A method of installing a pile in a subsea substrate, the method comprising the steps of:

providing a pile with a drill bit at an end thereof; and

rotating and advancing the pile and the drill bit relative to a substrate to form a bore.

2. The method of claim 1, wherein the drill bit is not recovered.

3. The method of claim 1, wherein the pile is an elongate tubular member and drilling fluid is supplied to the drill bit via the pile.

4. The method of claim 1, further comprising the step of securing the pile in the bore.

5. The method of claim 4, wherein the pile is secured in the bore by passing a settable material into the bore, between the pile member and the bore wall, and allowing the material to set in the bore.

6. The method of claim 5, wherein the settable material is delivered to the bore via an internal bore in the pile.

7. The method of claim 1, wherein the pile is at least partially formed from standard oilfield tubulars.

8. The method of claim 1, wherein the pile and drill bit are rotated by a driven elongate member connected thereto.

9. The method of claim 8, wherein the connection between the elongate member and the pile is broken from surface once the pile is installed to the correct depth, such that the elongate member may be retrieved.

10. The method of claim 9, wherein the connection is positioned at a level relative to the substrate surface such that the pile does not have to be recovered once the pile is no longer in use.

11. The method of claim 8, wherein the elongate member extends to and is rotationally driven from surface.

12. The method of claim 8, wherein the elongate member is rotationally driven by a motor positioned below the surface of the water.

13. A subsea pile comprising an elongate member with a drill bit fixed at one end thereof.

14. The pile of claim 13, wherein the pile is an elongate tubular member.

15. The pile of claim 13, wherein at least an upper portion of the pile is adapted to flex one or both of elastically and plastically in response to lateral loading.

16. The pile of claim 13, wherein the pile comprises standard oilfield tubulars.

17. The pile of claim 15, wherein the resistance of the pile to lateral forces varies along its length, such that the bending characteristics and bending radii of the pile may be controlled.

18. The pile of claim 17, wherein a lower portion of the pile is relatively rigid.

19. The pile of claim 13, wherein a lower portion of the pile is adapted to be grouted or cemented in the bore.

20. The pile of claim 13, wherein a lower portion of the pile comprises relatively high rigidity members, including one or more of heavy section drill pipe, drill collars and bore casing.

21. The pile of claim 13, wherein an upper portion of the pile is adapted to bend when subjected to lateral forces and translate the lateral forces to axial forces which are substantially withstood by the lower portion of the pile.

22. The pile of claim 13, wherein the pile is provided with a mooring line connection.

23. The pile of claim 22, wherein the mooring line connection includes a flexible member.

24. The pile of claim 23, wherein a portion of the connection is buoyant, to facilitate location of the connection following installation of the pile.

25. The pile of claim 13, in combination with an elongate member for extending to surface, and a connection between the elongate member and the pile which is adapted to be broken from surface once the pile is installed to the correct depth, such that the elongate member may be retrieved.

26. The combination of claim 25, wherein the connection is a low torque back-off disconnection system.

27. The combination of claim 25, wherein the elongate member is adapted to be rotationally driven from surface.

28. The combination of claim 25, further including a motor for location below the sea surface.

29. A pile comprising an elongate member with a drill bit at one end thereof, wherein the pile has at least an upper portion adapted to flex in response to application of lateral loading thereto.

* * * * *