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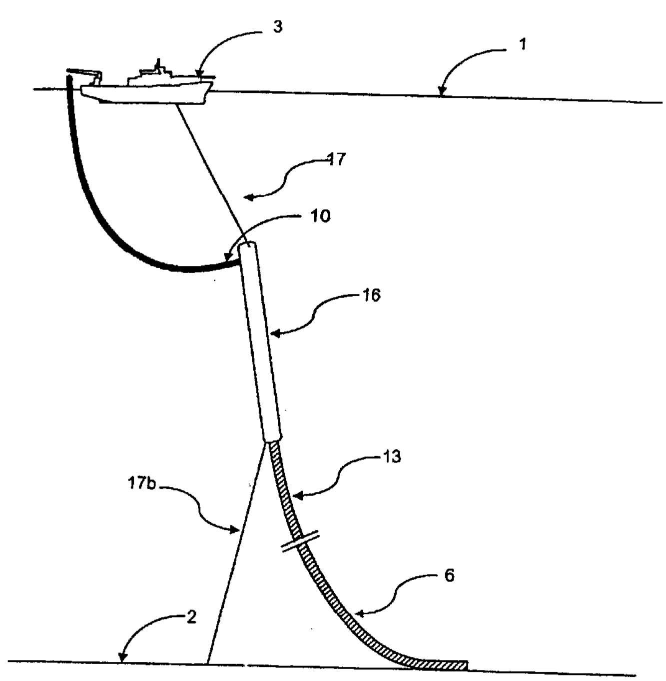
(54) Abstract Title
A riser and method of installing same

(57) A hybrid riser having a lower section (6) and an upper section (10), said upper section comprising a flexible pipe, and said lower section comprising a substantially rigid pipe in communication with the flexible pipe, said riser further comprising a buoyancy section (16) at or in the region of an upper end of said rigid pipe (13). Said buoyancy section (16) also comprises an elongate cylindrical buoyancy element fitted around the riser, which may be of a coaxial compartmentalised tubular construction having valves such that it may be controllably flooded or evacuated. The hybrid riser may be tethered to a surface vessel or to the seabed. The hybrid riser may be constructed on land, and towed to the vicinity of the installation to which it is to be connected.

Fig. 7a



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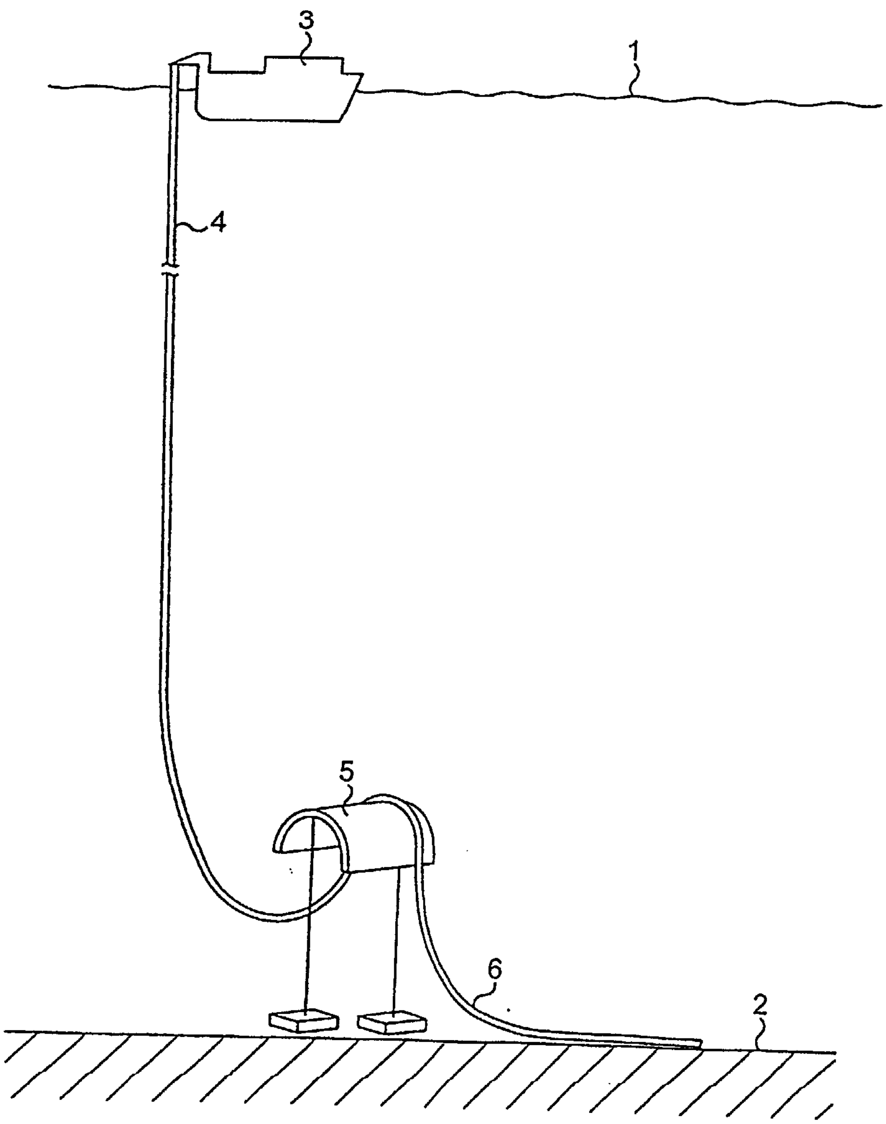


FIG. 1

PRIOR ART

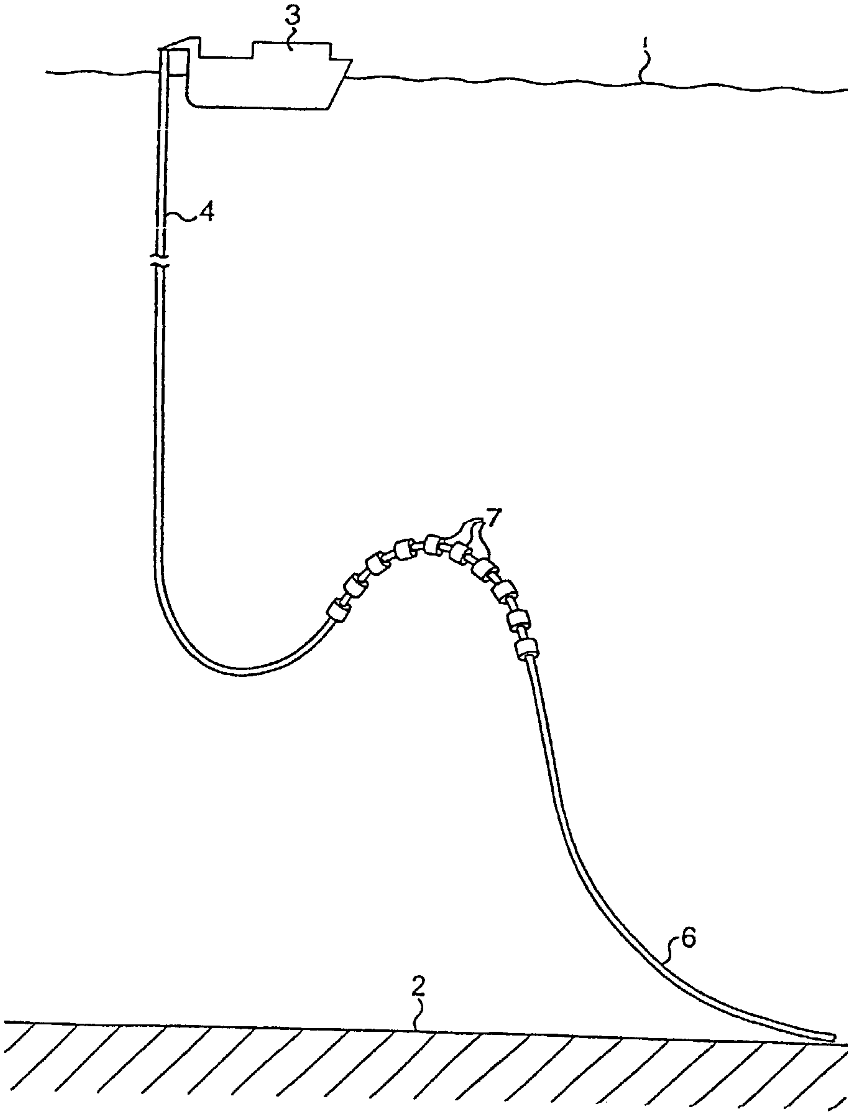


FIG. 2

PRIOR ART

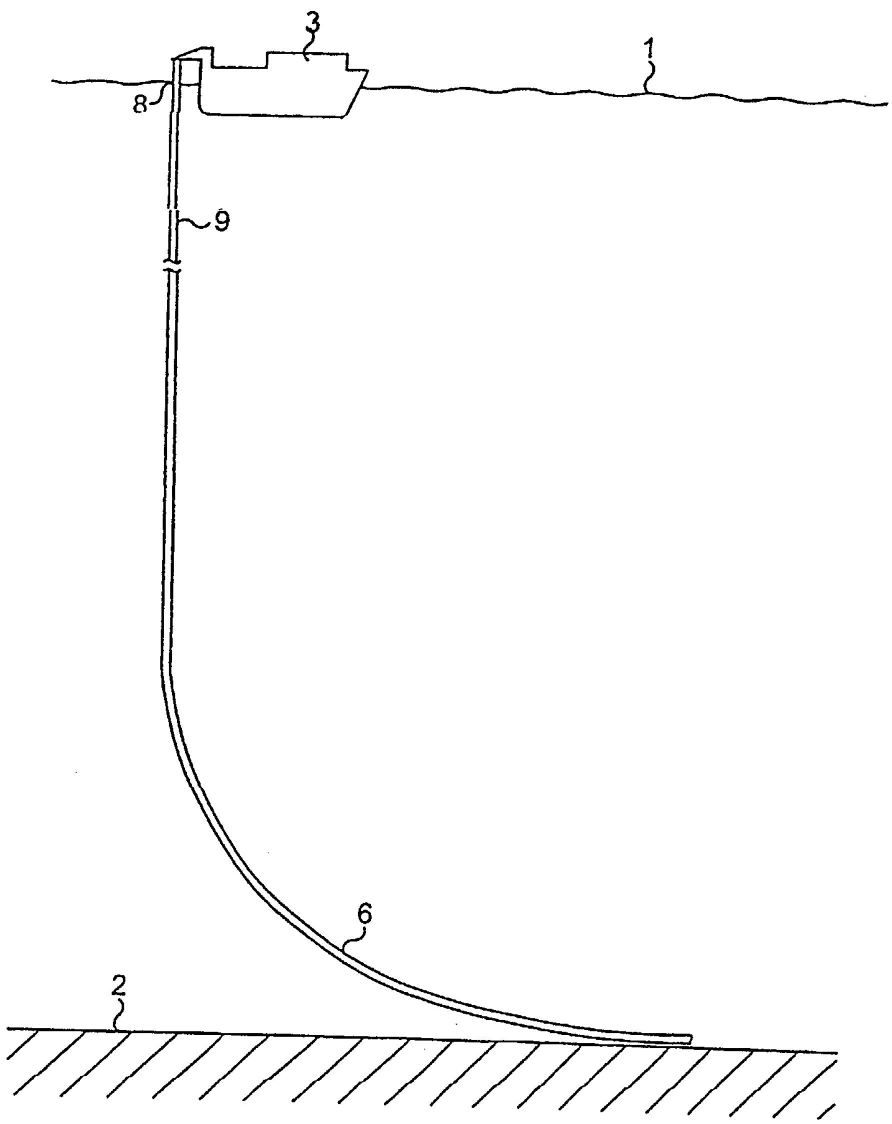


FIG. 3
PRIOR ART

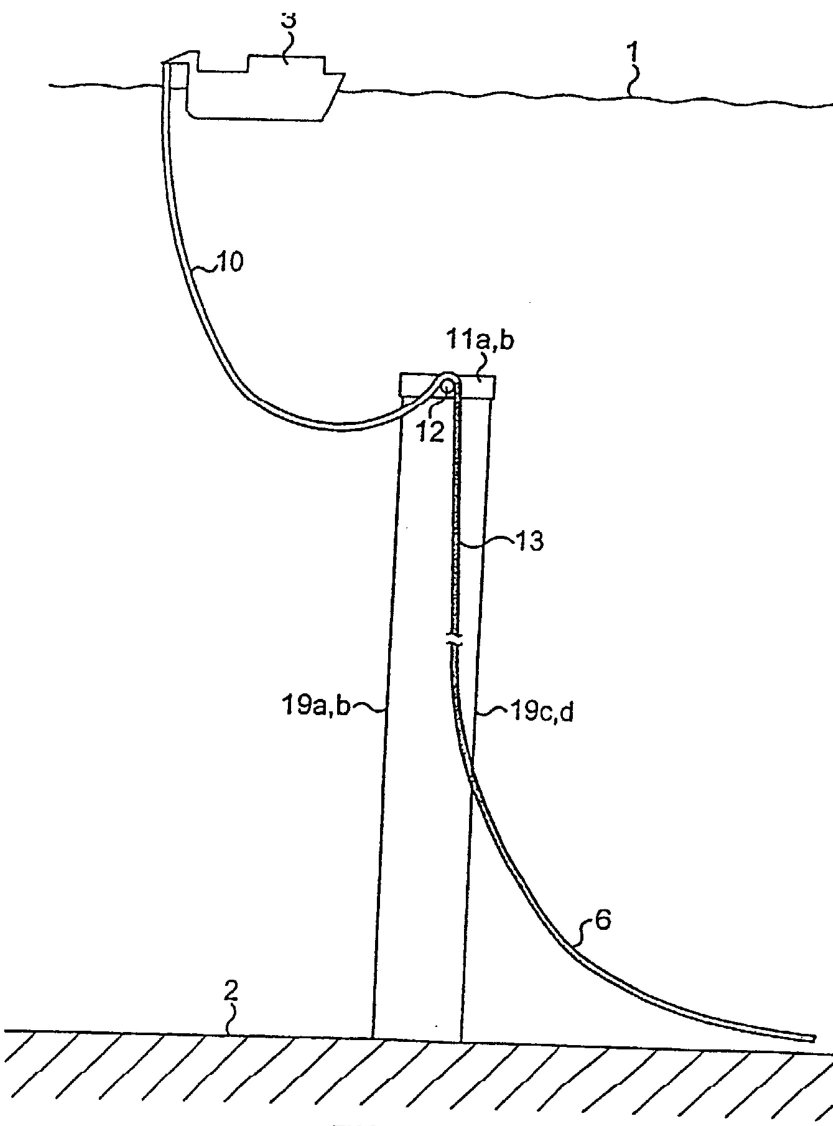


FIG. 4
PRIOR ART

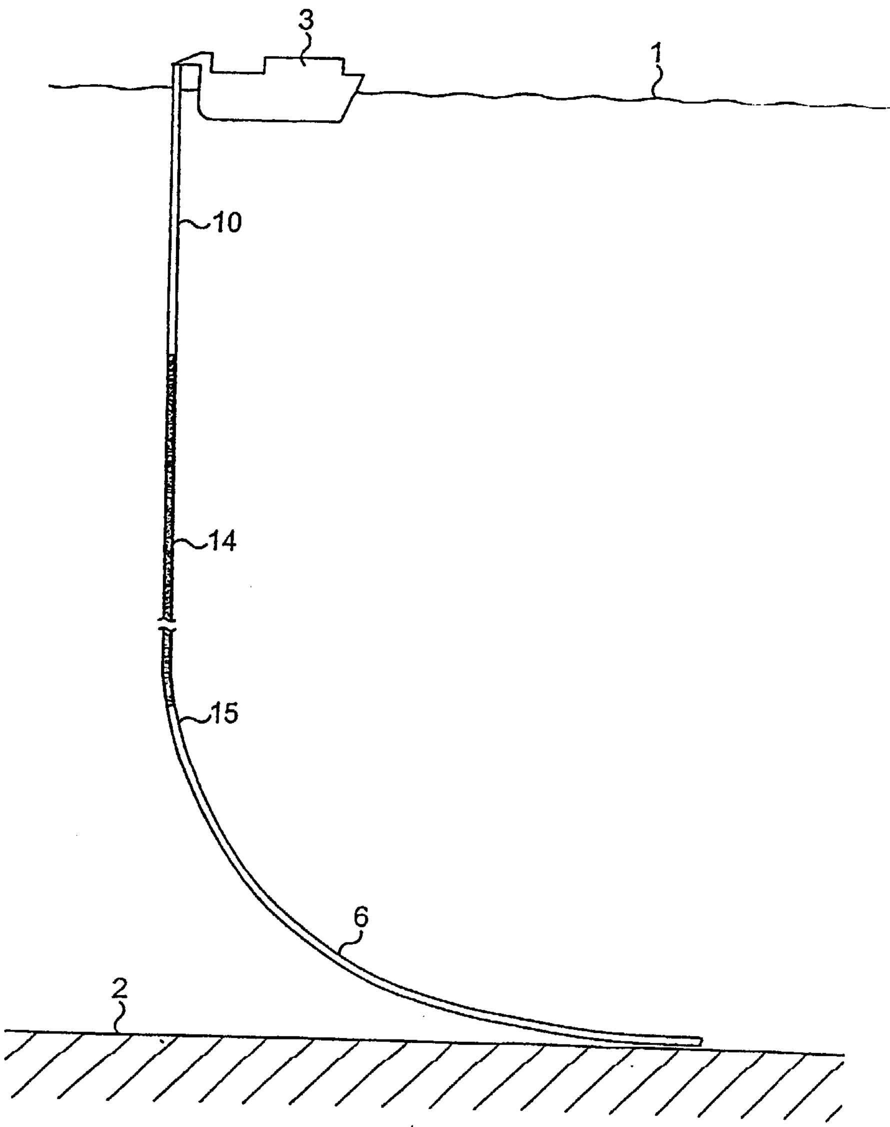


FIG. 5

PRIOR ART

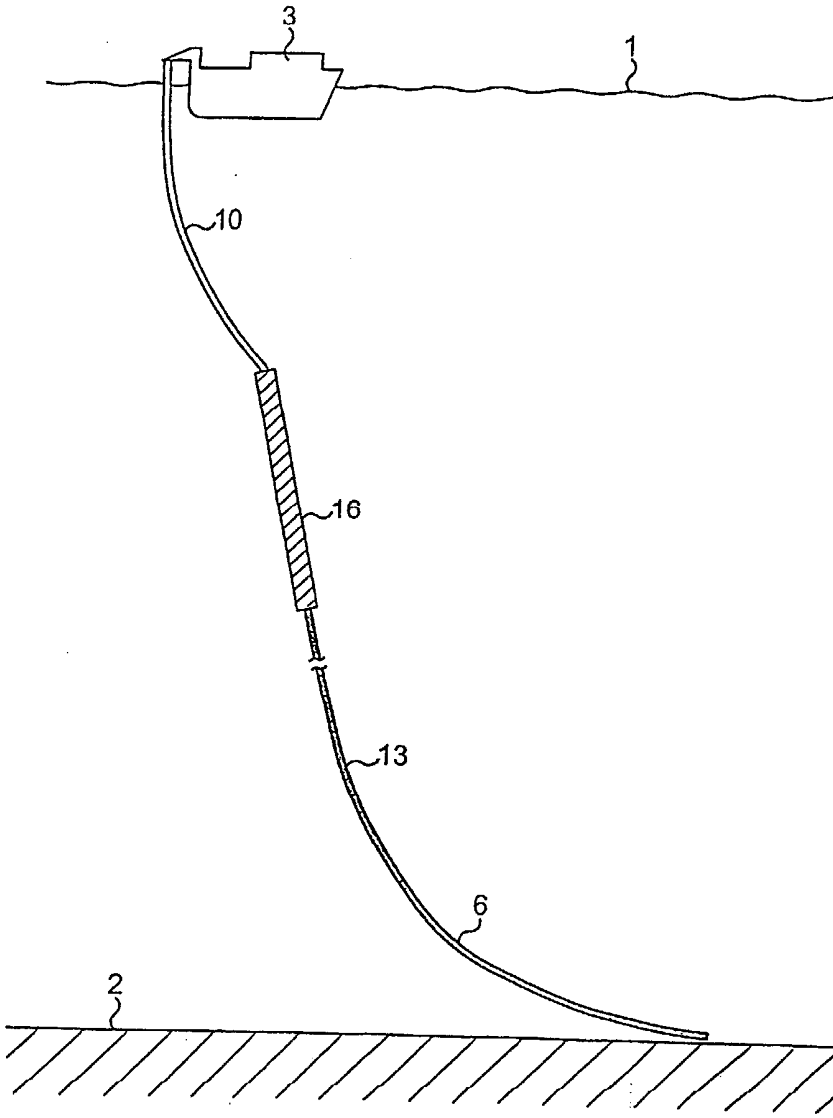
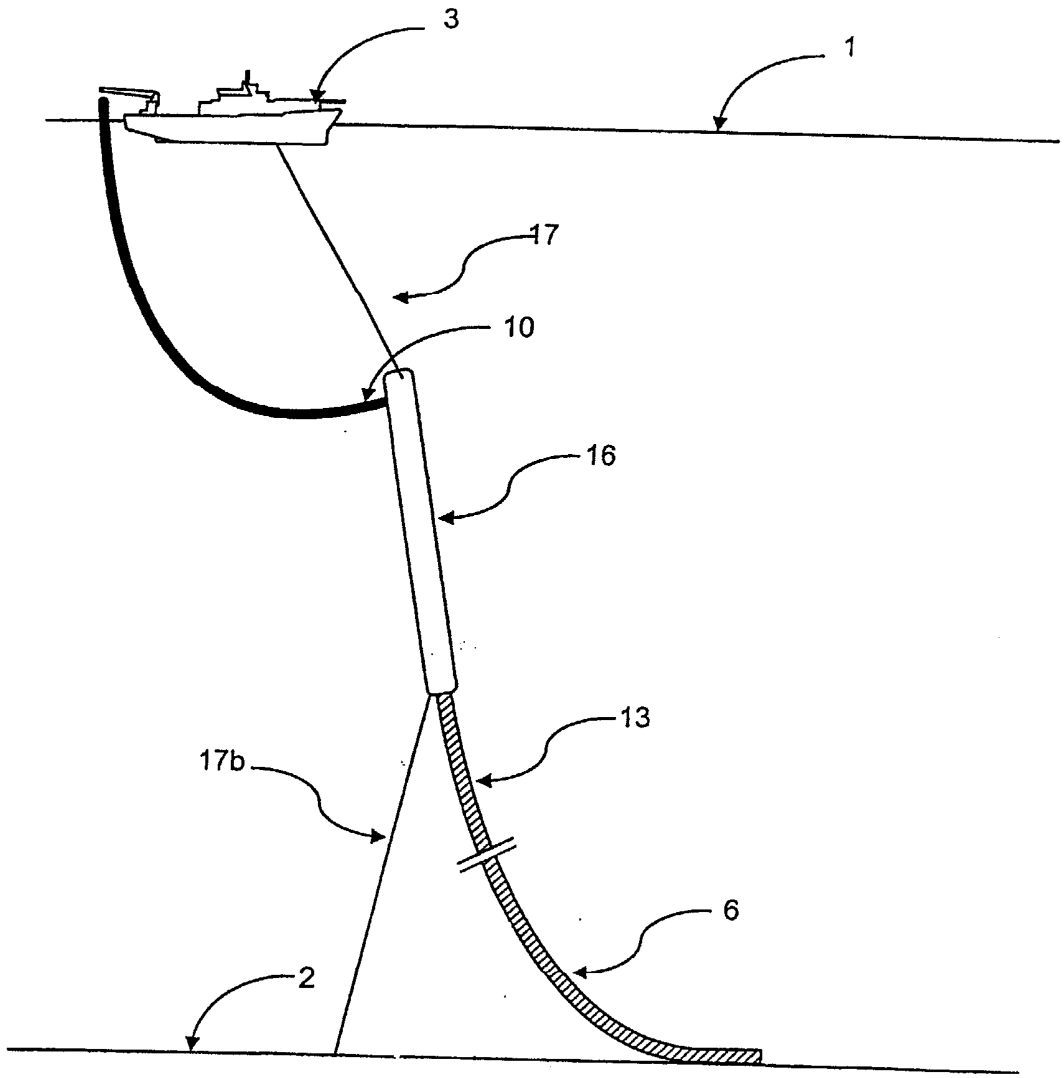


FIG. 6

Fig. 7a



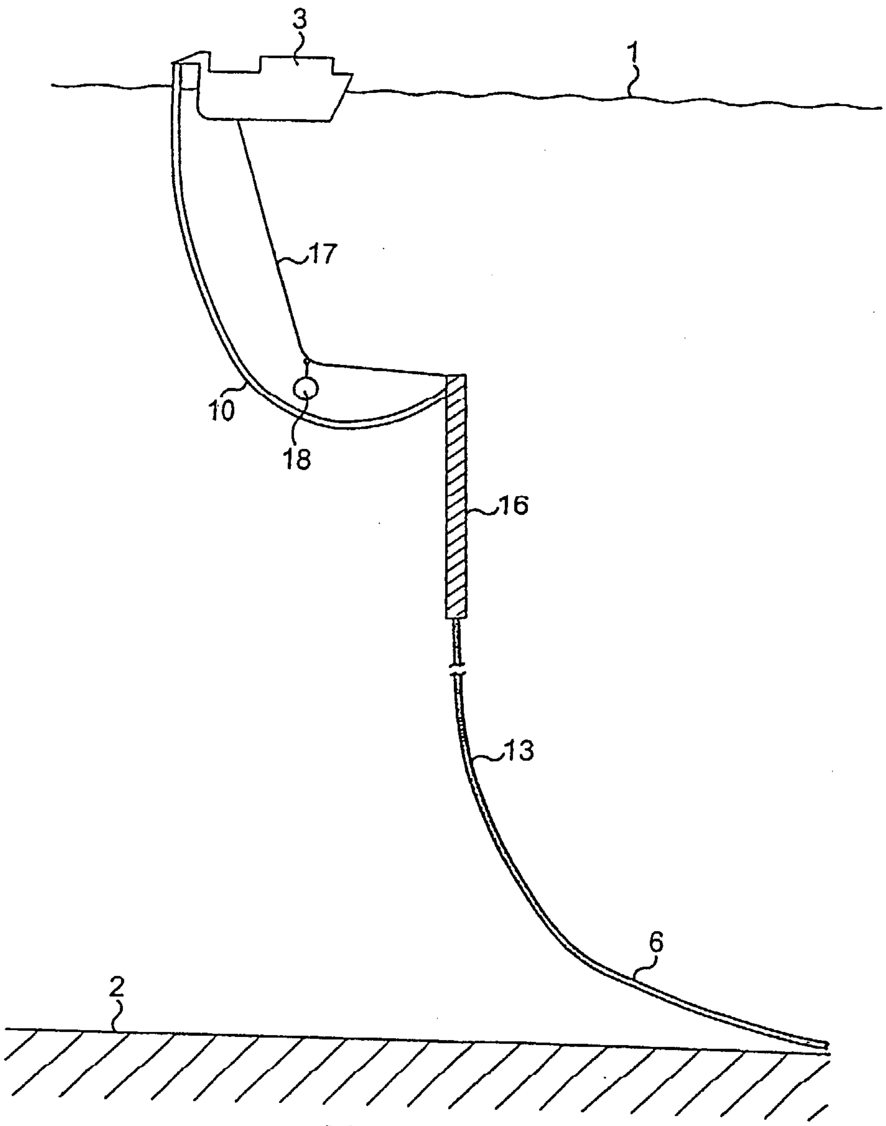


FIG. 7b

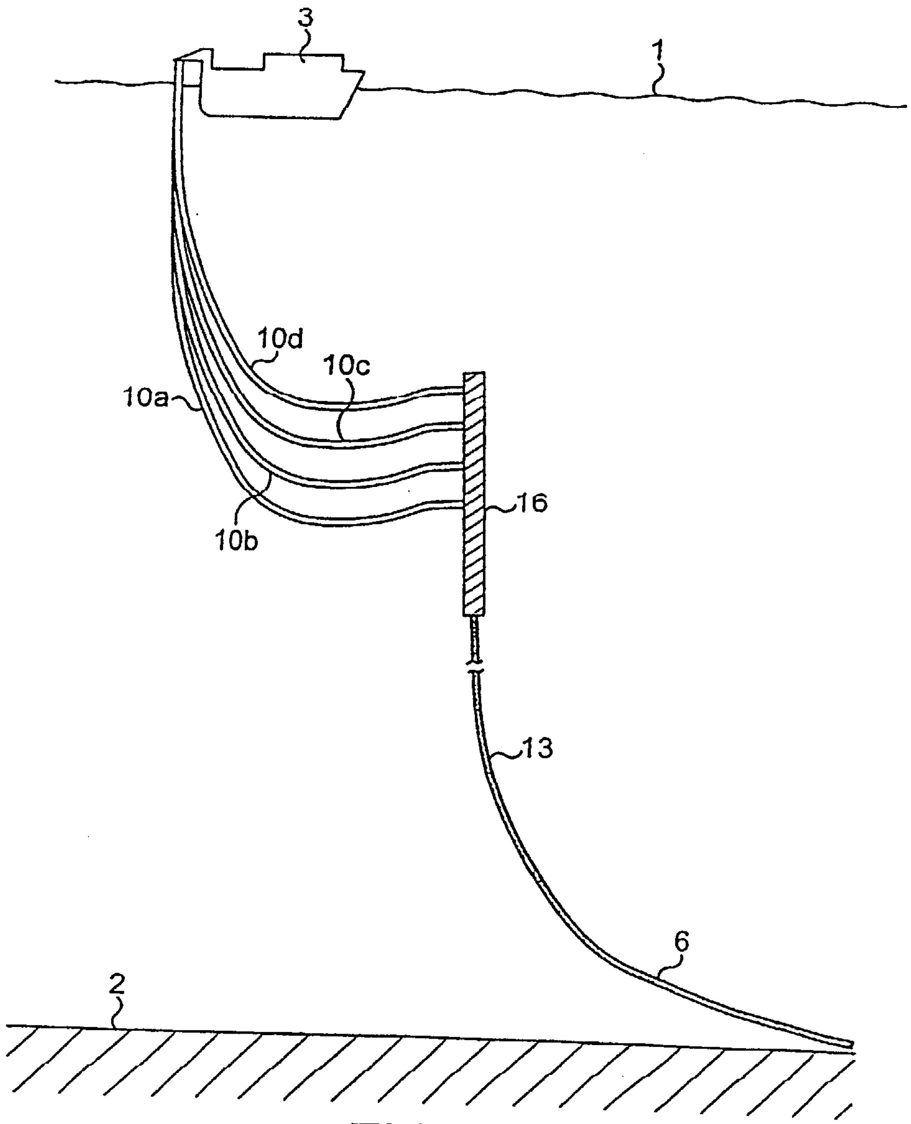


FIG. 8

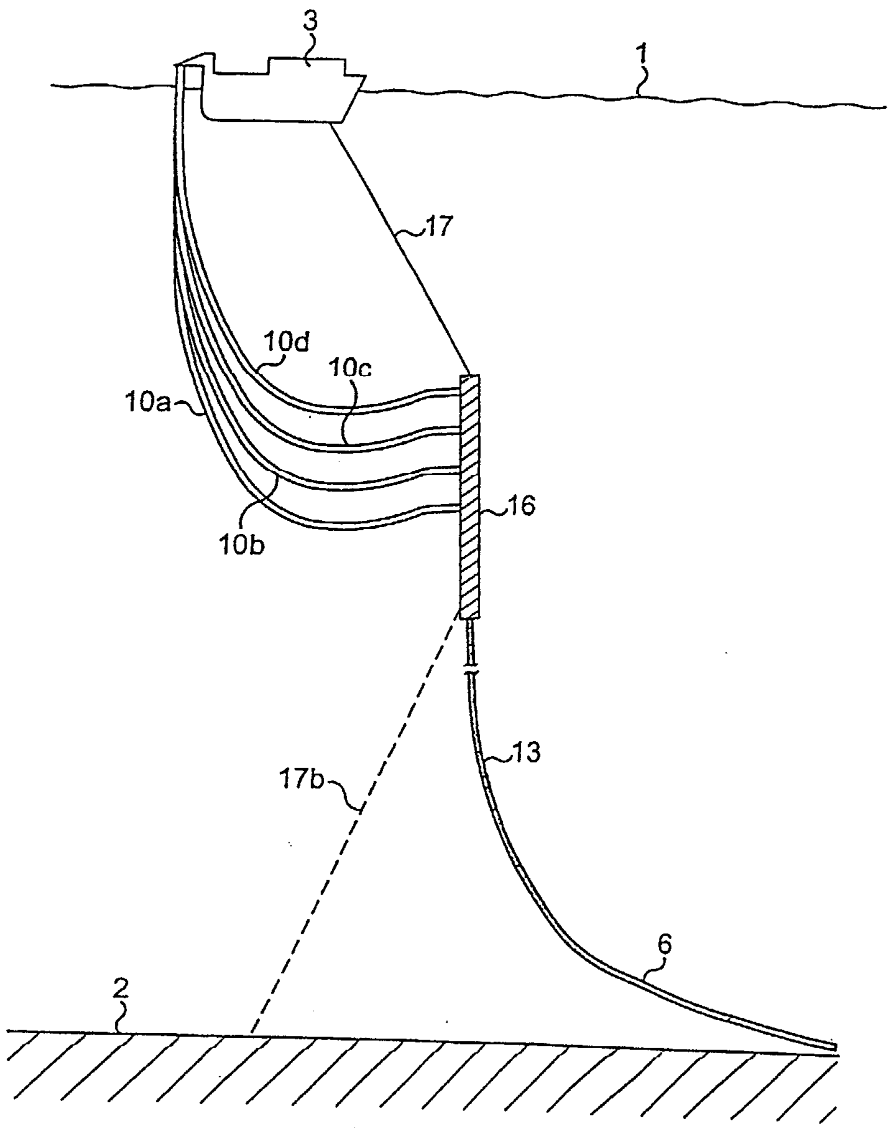


FIG. 9

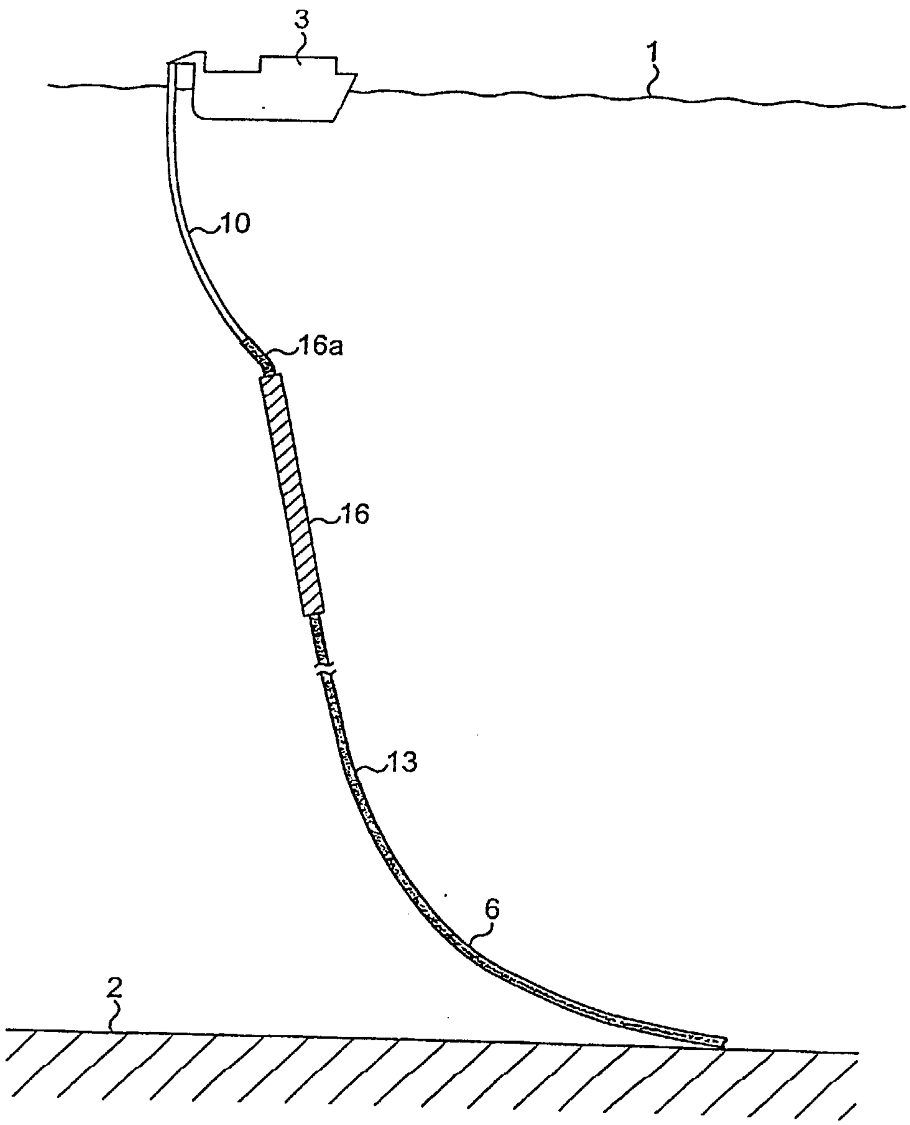


FIG. 10

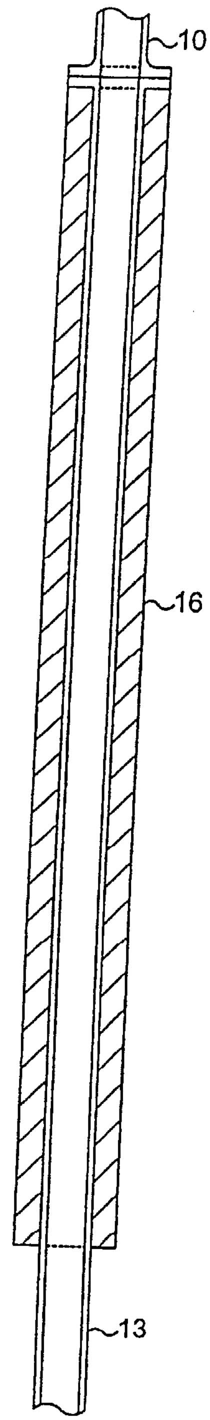


FIG. 11

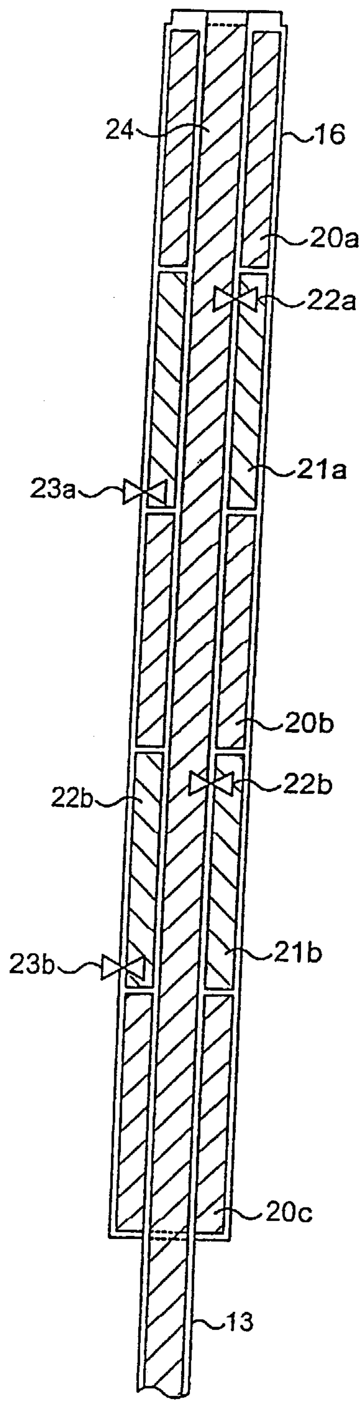


FIG. 12a

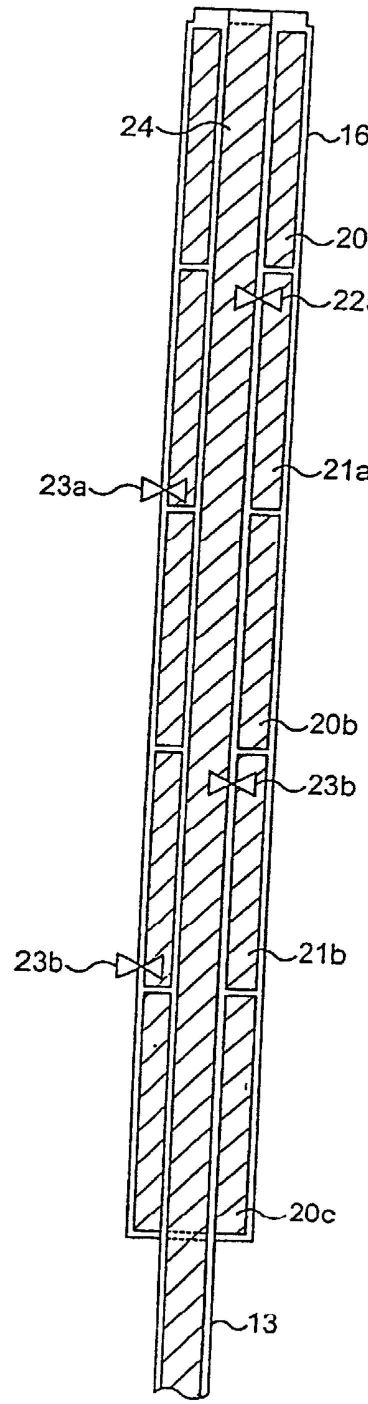


FIG. 12b

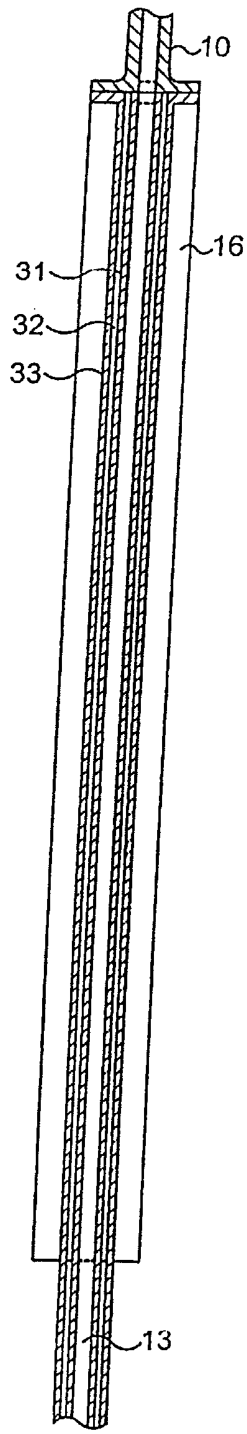


FIG. 13

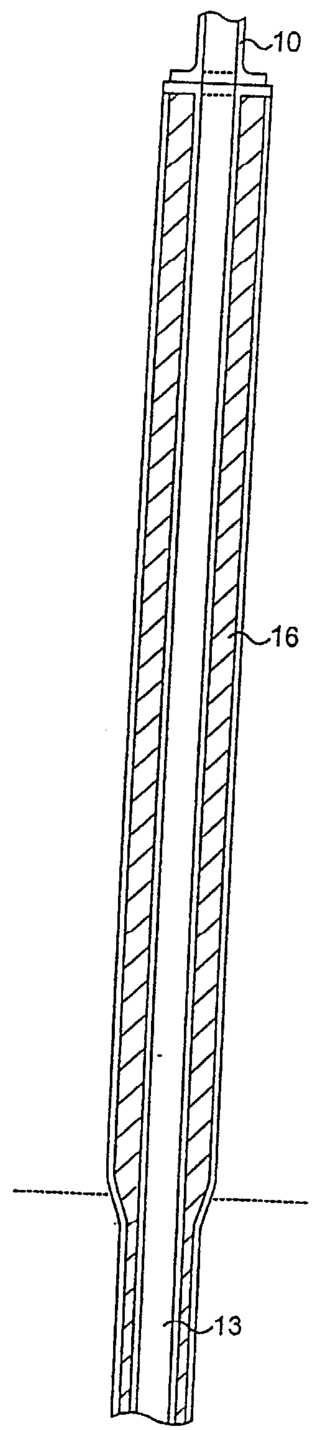


FIG. 14

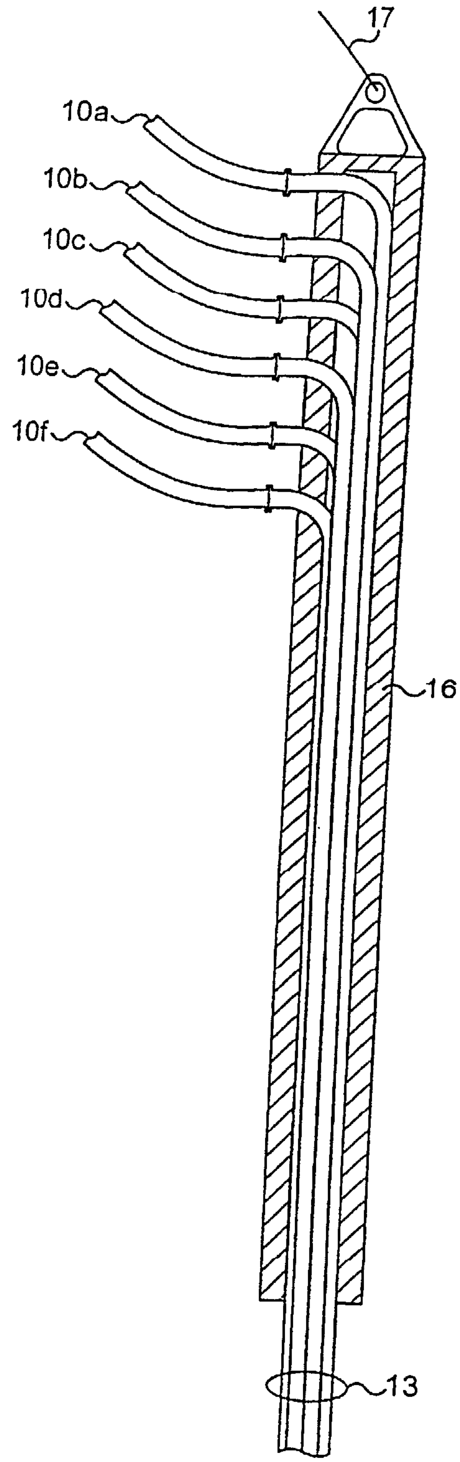


FIG. 15

Fig. 16a

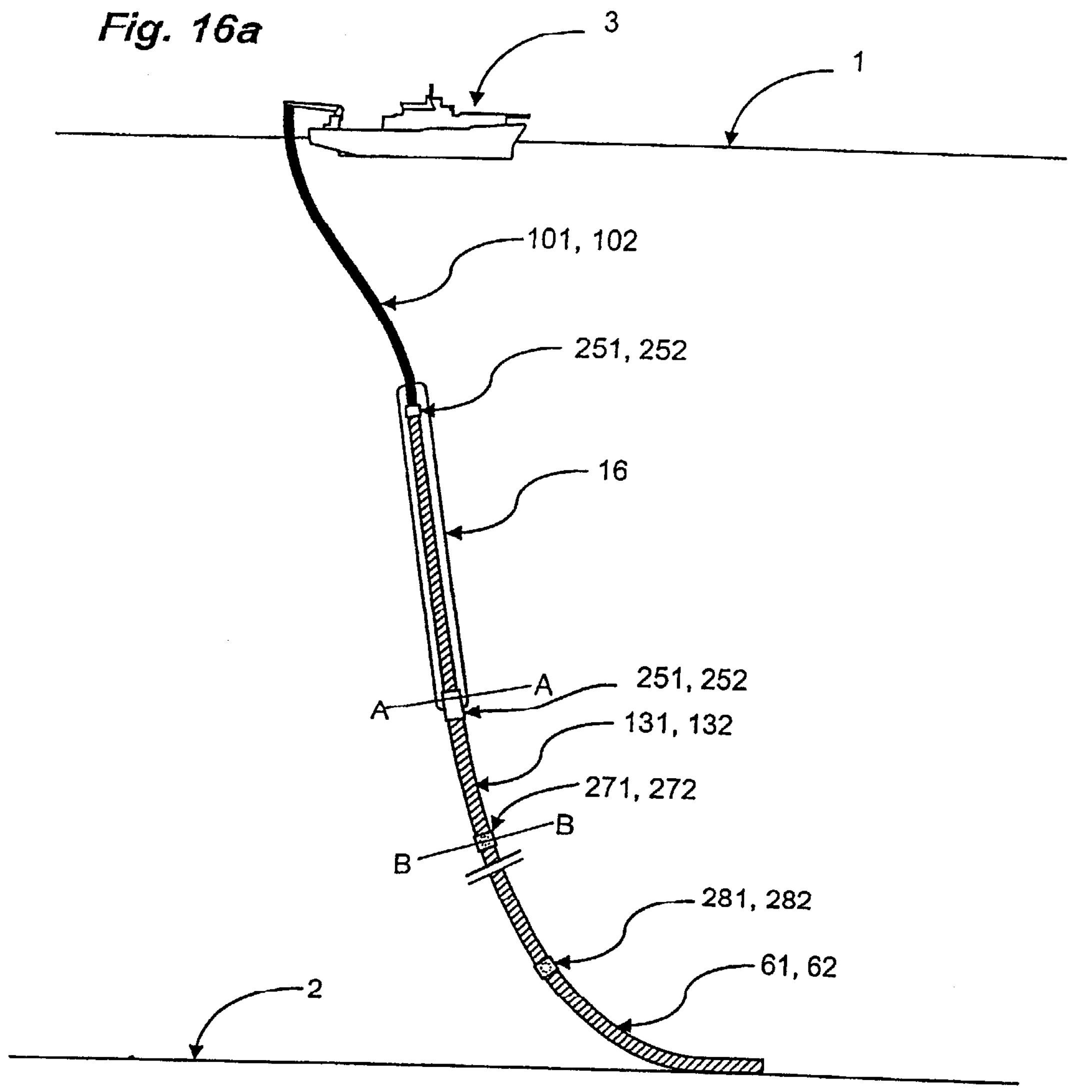


Fig. 16b

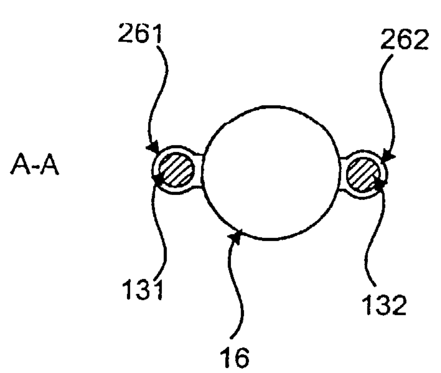


Fig. 16c

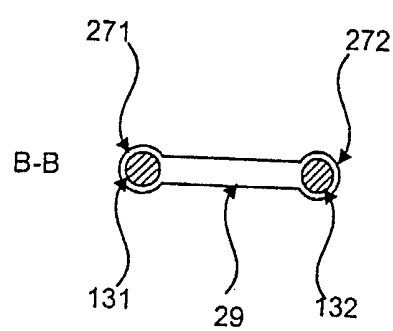


Fig. 17a

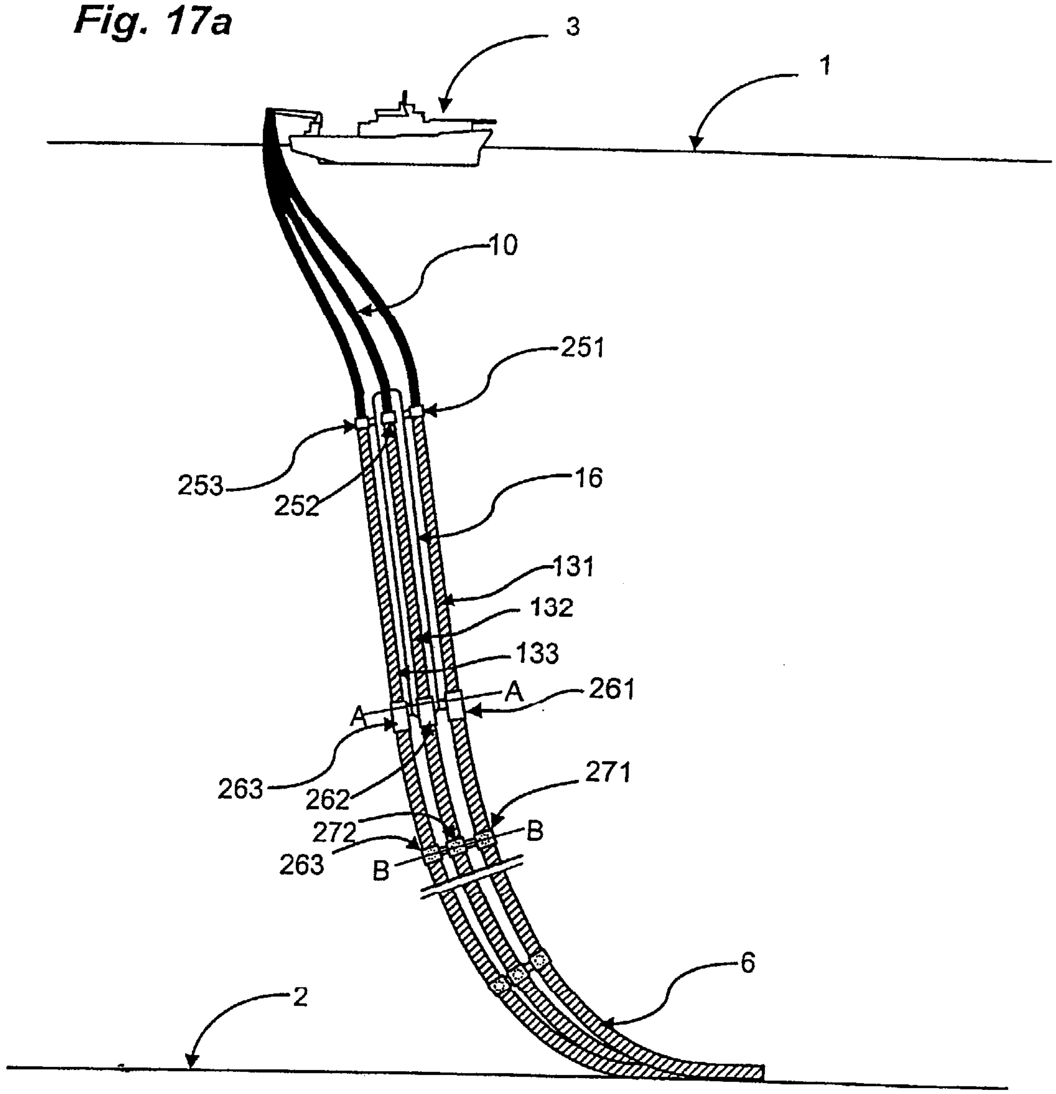


Fig. 17b

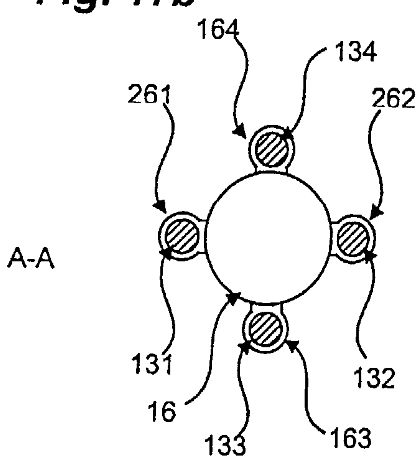


Fig. 17c

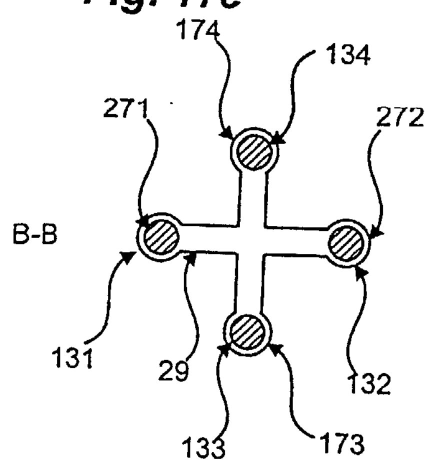


Fig. 18a

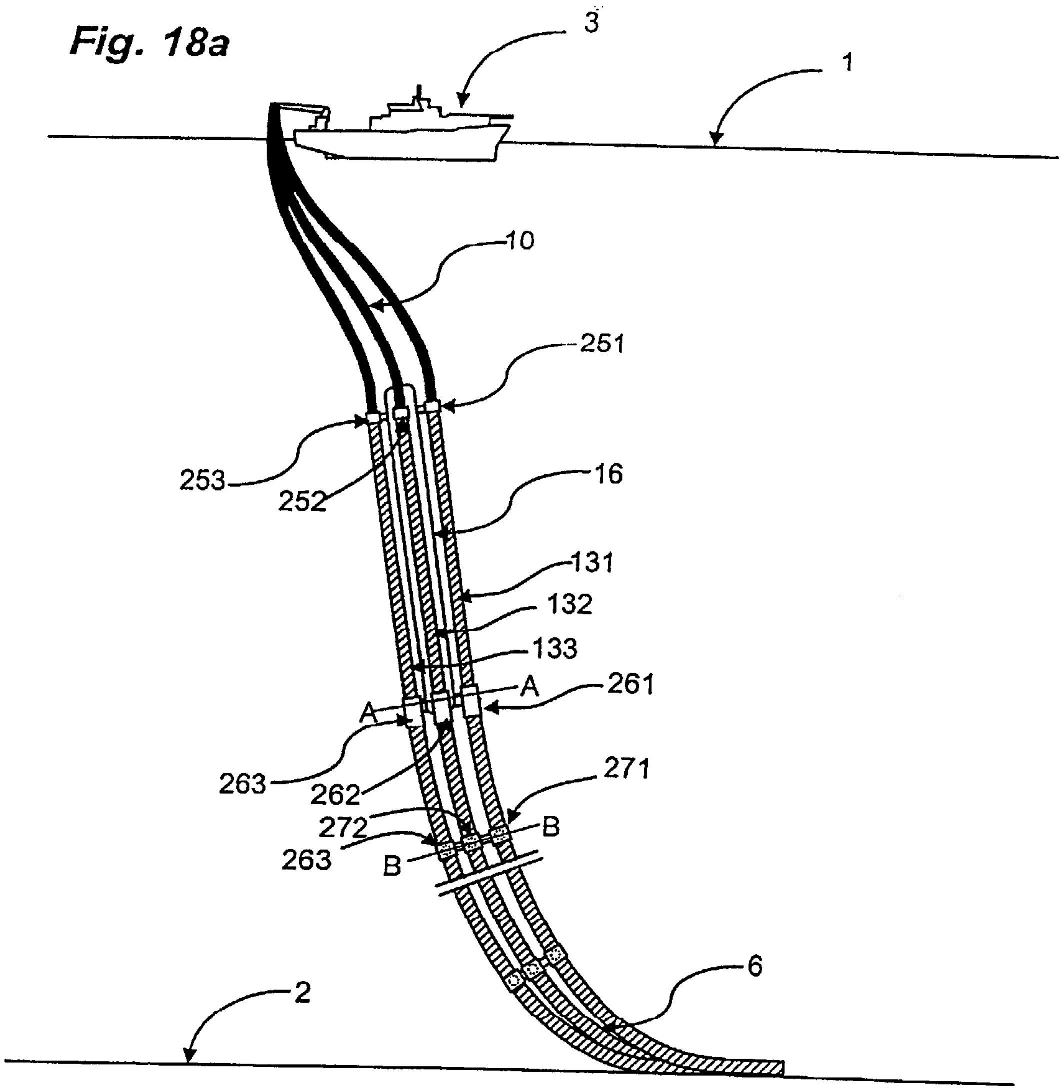


Fig. 18b

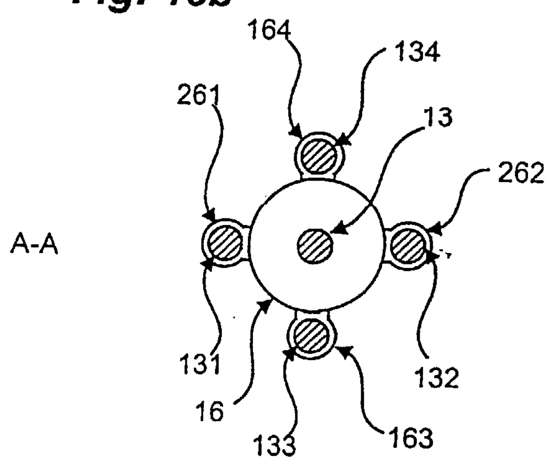


Fig. 18c

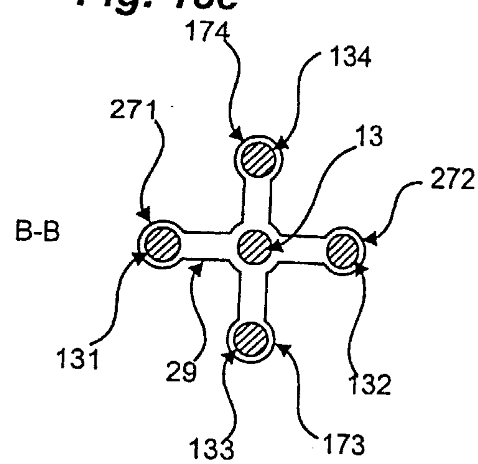


Fig. 19a

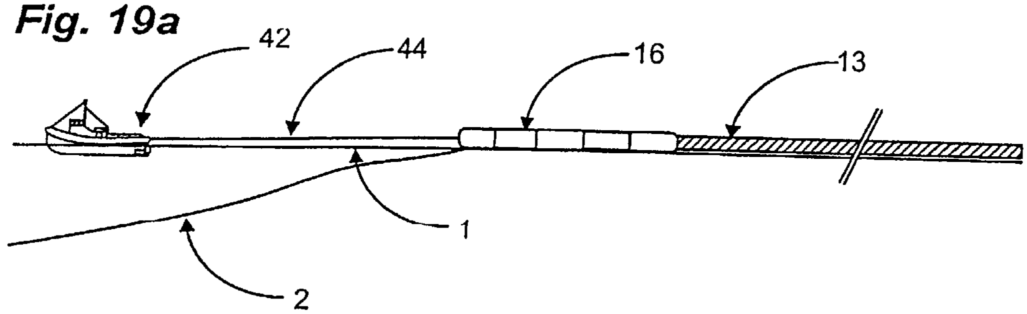


Fig. 19b

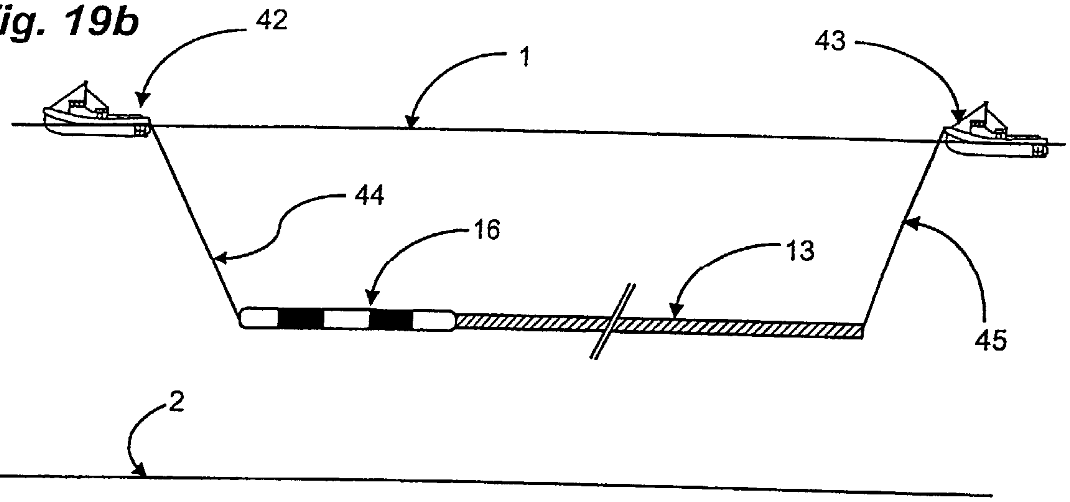


Fig. 19c

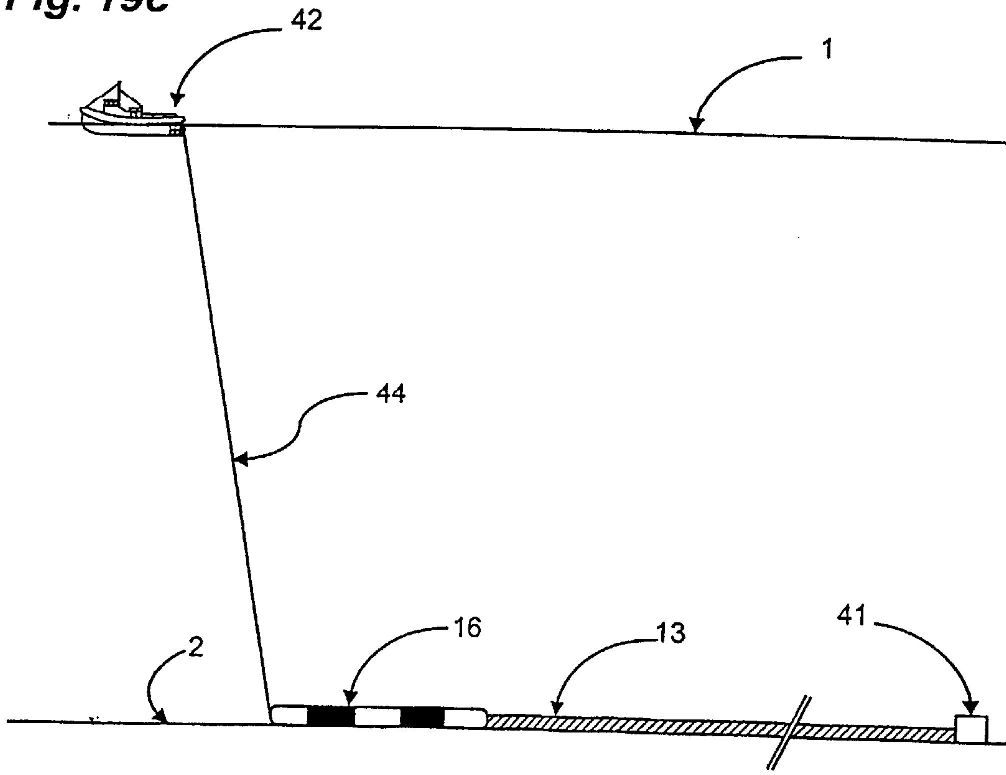


Fig. 19d

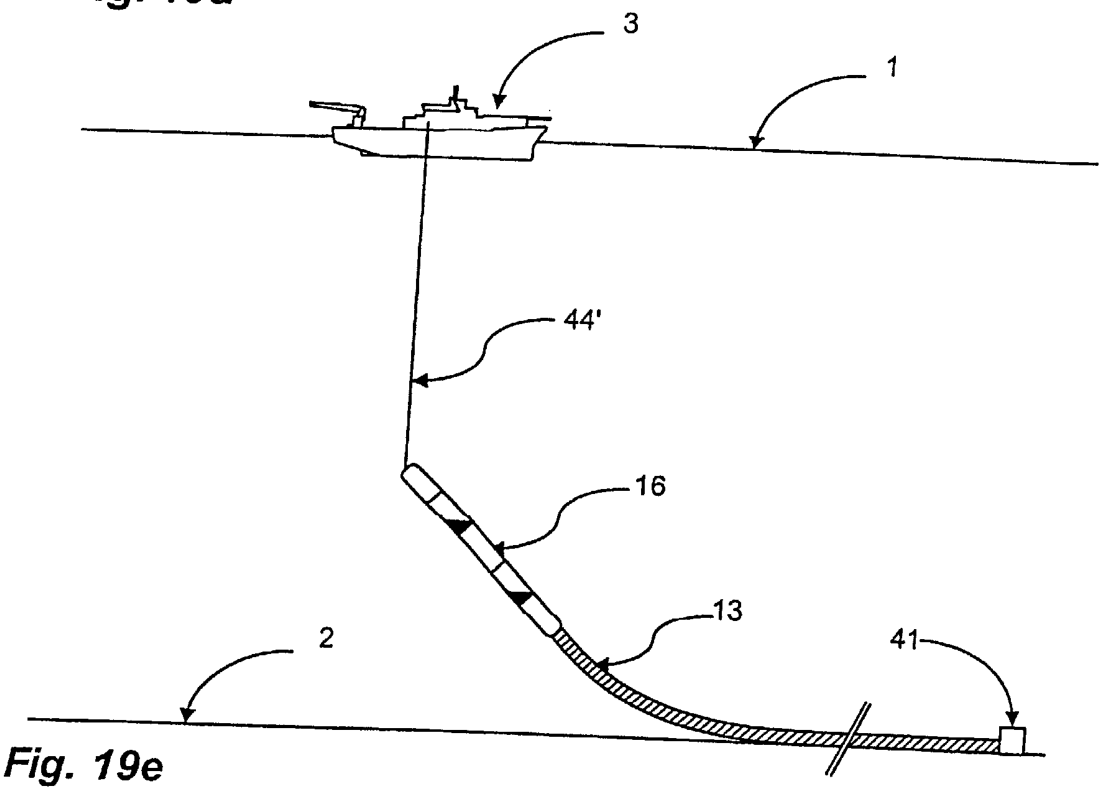
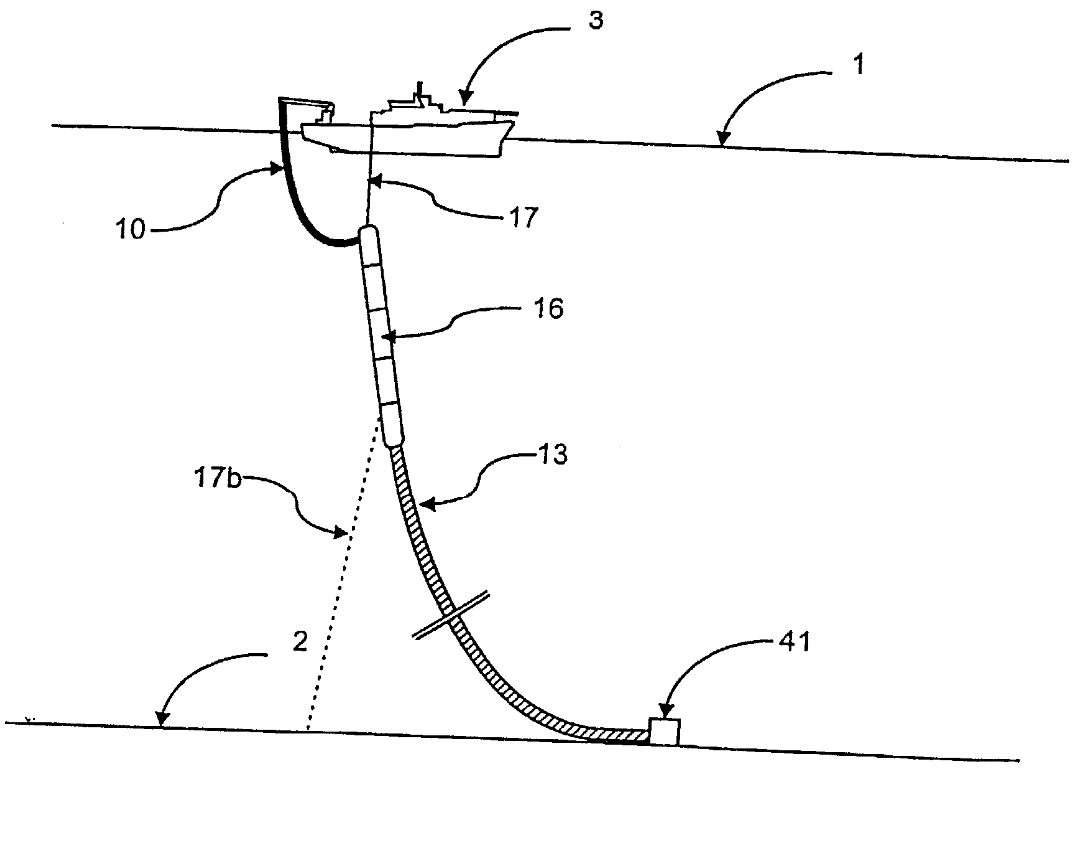


Fig. 19e



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A RISER AND METHOD OF INSTALLING SAME

The present invention concerns a riser, for the transport of fluid hydrocarbons from an underwater wellhead.

Over recent years, as liquid and gaseous hydrocarbon fuel resources have become more scarce, there has been a tendency to search for and extract these resources in increasingly remote and inaccessible areas, and in particular in increasingly deep parts of the sea. As the depth of these sub-sea wells below sea level has increased, the demands on the technologies used to bring the oil or gas from the well to the sea surface have increased dramatically. As more and more sophisticated techniques for overcoming these difficulties are devised however, the costs and risks associated with the construction, installation and use of these structures has grown.

Risers of two different types are commonly used in bringing oil or gas from a sub-sea well to the surface. Flexible pipes have the advantages of being relatively easy to install, reducing the cost and risks involved in the installation process itself, and being resistant to work fatigue brought on by cyclic forces exerted on the pipe by the movement of the sea and other factors. On the other hand, solid steel pipes are considerably less costly to manufacture.

On the basis of these strengths and limitations, flexible pipes have tended to be chosen for use in shallow installations. This is the case firstly since the total length of the pipeline needed for a well positioned in shallow water is sufficiently short that the cost of the more expensive flexible pipe is not prohibitive.

As well as the two types of piping commonly used to serve as risers, there are furthermore two basic geometrical configurations which are frequently used. The first of these is the vertical riser, where the riser rises directly from the sub-sea well to a vessel on the surface of the sea. The second is a catenary configuration in which the riser starts from the well head running along the seabed, before rising up from the seabed towards a vessel floating or otherwise situated on the sea's surface, such that the riser forms a gentle curve in the shape of a catenary, or the riser catenary extends directly from the well head itself to the support vessel.

Figure 1 shows the use of flexible piping in a modification of the catenary configuration, as is known in the prior art. In this embodiment, a vessel 3 is disposed on the surface of the sea 1, with a flexible riser 4, extending from the seabed up to the vessel in a configuration known as a "lazy S". An anchored mid water arch 5 is provided over which the riser 4 passes so as to provide an upper catenary section and a lower catenary section. By means of the "lazy S" configuration movement of the vessel 3 induced by the wind, waves, currents etc., does not result in the flexible riser overbending and rubbing against the ground in such a way as to induce wearing of the riser. This arrangement thus affords protection to the touch-down zone 6, where the riser meets the seabed 2.

Figure 2 shows an alternative configuration of a flexible riser known from the prior art, which is commonly referred to as a "lazy wave". In this configuration, the flexible riser rises to the vessel 3 from the seabed 2 and is provided with a plurality of buoyancy elements 7 at a point along the flexible riser's length, such that a portion of the flexible riser is lifted up from the curve which the riser would otherwise adopt under its own weight as it rises from the seabed. A portion of the riser is thus retained substantially stationary in the water by the buoys, and is relatively unaffected by the movement in the vessel 3. The buoyancy elements 7 generally consist of pre-formed foam discs, which are clamped around the flexible riser.

In situations where it is necessary to provide a riser between the sea surface and a wellhead in deep water, the price for the required length of flexible riser becomes less attractive. The use of a rigid riser thus becomes more desirable. Figure 3 shows a rigid riser configuration. Rigid risers are generally constructed from steel piping, in the form of tubular sections welded together. In the configuration shown in Fig 3, this is known as a steel catenary riser (SCR). This configuration comprises a continuous steel pipe, which may be several kilometres long rising to a vessel 3 on the sea surface from the seabed 2, bending in a smooth curve, such that the rigid riser leaves the wellhead in a substantially horizontal manner and arrives at the support vessel in a vertical or nearly vertical orientation.

Although relatively cost effective, this configuration has the drawback that variations in the position of the vessel 3 result in cyclic stresses at the touch down point 6 of the catenary riser 9, such that the rigid riser is fatigued over time, and is prone to failure.

A first solution to this problem is known from US Patent 5,639,187, which discloses a configuration such as shown in Figure 4. According to this configuration, there is disclosed a hybrid configuration, in which one or more risers are draped over a bar 12 which is supported in the water by two buoyant elements 11a and 11b, disposed at either end of the bar 12 such that the three elements together form an H shape. This H shaped structure is anchored to the seabed by lines 19a, 19b, 19c and 19d. The riser between the bar 12 and the seabed 2 comprises a steel catenary riser 13, and the riser between the surface vessel 3 and the bar 12 comprises a flexible riser 10.

Thus, in operation, the riser bar 12 remains substantially stationary in the water, regardless of movements in the surface vessel 3, such that the steel catenary riser 13 is isolated from cyclic effects, and the touch down zone 6 is not fatigued. Further, the load on the surface vessel from the risers is reduced, since the buoy carries the weight of the lower part of the risers.

The cost and effort involved in installing and maintaining the system, in particular the anchoring of the float arrangements, is substantial however.

An alternative solution to certain of the problems arising from deep sea wellheads is suggested by the Patent WO 00/53884, which describes a further hybrid arrangement as shown in Figure 5. According to the teaching of this document, there is provided a riser having three sections. These three sections comprise an upper flexible riser section 10 ascending to the surface vessel 3, a second lower flexible riser section 15 ascending from the seabed, and a rigid riser section 14 disposed between and interconnecting the two flexible riser sections 10 and 15. This configuration has the advantage that substantially all forces resulting from movement of the surface vessel 3 are absorbed by the two flexible portions of the riser s 10 and 15.

This arrangement naturally comes with certain of the drawbacks of the fully flexible catenary configuration discussed above however. Further, the load of the risers at the surface vessel is relatively high.

A further alternative arrangement is the tower riser, which comprises a rigid, vertical riser tower provided with air tanks at the upper extremity, and connected to a surface vessel by a flexible riser pipe.

The present invention seeks to overcome drawbacks of various riser configurations discussed above. Objects of the present invention thus include the provision a riser configuration which is suitable for use in deep water, is less prone to fatigue effects or abrasion, and is of comparatively low cost and simple to construct and install.

According to the invention from a first aspect there is provided a riser having a lower section and an upper section, said upper section comprising a flexible pipe which may be made for example of standard flexible pipe, composite material or titanium and said lower section comprising a substantially rigid pipe in communication with the flexible pipe and forming a catenary, said riser further comprising a buoyancy section at or in the region of an upper end of said rigid riser, said buoyancy section being tethered to a vessel on the sea's surface. This has the advantage that it is less costly to tether a riser to a surface vessel than to the seabed. It had not previously been thought possible to achieve satisfactory stability in the riser by this technique. The inventor has found that recent changes in anchoring techniques have made the required stability achievable.

According to the invention from a second aspect there is provided a riser having a lower section and an upper section, said upper section comprising at least one flexible pipe and said lower section comprising at least one substantially rigid pipe and forming a catenary, said riser further comprising a buoyancy section at or in the region of an upper end of said rigid riser, said buoyancy section comprising an elongate buoyancy unit extending lengthwise of the rigid pipe. This configuration has the advantage of being relatively simple and cost effective to construct and install by a variety of methods as outlined further on.

According to a development of this second aspect of the invention said buoyancy section is tethered to a vessel on the sea's surface.

According to a further development of this second aspect of the invention said buoyancy section is tethered to the seabed.

According to a development of either of the aspects discussed above said lower section comprises a plurality of rigid pipes and said upper section each comprise a corresponding plurality of flexible pipes. This construction is advantageous in that it provides for the transportation of different fluids in different directions through the same pipeline requiring a single installation process.

According to a further development of this aspect, said plurality of rigid pipes are arranged around the outside of said buoyancy section.

According to a further development of this aspect, said plurality of rigid pipes are spaced apart evenly about the circumference of said buoyancy section.

According to a further development of any of the above aspects, each of the plurality of rigid pipes is fixed at or near an upper extremity thereof to said buoyancy section.

According to a further development of any of the above aspects, said buoyancy section is further provided with a plurality of sleeves intended to slidingly receive said plurality of rigid pipes respectively.

According to a further development of any of the above aspects, the riser, further comprises a spacer connected to each of said plurality of rigid pipes, or to each of said plurality of flexible pipes so as to maintain said plurality of rigid pipes or each of said plurality of flexible pipes in a fixed position relative the other rigid pipes or flexible pipes.

According to a further development of any of the above aspects, said spacer is provided at a point on said rigid riser below a lower extremity of said buoyancy section.

According to a development of any of the above aspects each of said at least one flexible pipes is joined to a respective one of at least one rigid pipes at a substantially right angle. This configuration is advantageous in that the connection of a tether to the upper part of the buoyancy section is facilitated.

According to a development of any of the above aspects the substantially right-angled joins between respective rigid and flexible pipes are spaced apart from one another along the length of said buoyancy section. This configuration is advantageous in that the joints between the flexible and rigid sections can easily be separated from one another so as to facilitate connection of these joints during an installation process.

According to a development of any of the above aspects said buoyancy section is made of a foam. This has the advantage of not being affected by leaks in the structure of the riser.

According to a development of any of the above aspects said buoyancy section is a tube arranged such that the rigid riser runs therethrough. This construction is highly cost effective.

As a further development of this construction there is provided a riser wherein said tube is made of steel or aluminium or a composite material. A buoyancy unit according to this construction can be produced using the techniques conventionally used in the construction of rigid riser pipes, therefore further improving economy and autonomy.

As a further development of this construction there is provided a riser wherein said solid tube arranged is arranged coaxially to said rigid riser. This configuration makes it easier to ensure a predictable spacing between the inner and outer tubes, with associated effects on the mechanical and thermodynamic properties of the riser as a whole. This is commonly called a Pipe-In-Pipe system

As a further development of the above constructions there is provided a riser wherein said buoyancy section further comprises a plurality of bulkheads dividing said buoyancy section into a plurality of closed chambers. This makes is possible to finely control the buoyancy of the buoyancy unit, and therefor the riser as a whole. It also introduces a degree of leak and damage resistance.

As a further development of this construction there is provided a riser wherein at least one valve is provided allowing flow of a fluid from inside said rigid riser to the interior of a respective at least one of said closed chambers. A further development involves the provision of at least one valve allowing flow of a fluid from inside a respective at least one of said closed chambers to the exterior of said buoyancy unit. By means of these valves it is possible to control the buoyancy of the buoyancy unit.

According to a development of any of the above aspects wherein an upper extremity of said rigid pipe is aligned away from the axis of the part of said riser immediately below said upper extremity. By this means it is possible to optimise the transmission of forces along the riser.

According to the invention from a third aspect there is provided a method of installing a riser having a lower section and an upper section, where said upper section comprises a flexible pipe, and said lower section comprises a rigid pipe in communication with the flexible pipe, and wherein said riser further comprises a buoyancy section at an upper end of said rigid pipe, said method involving the steps of;

i. constructing a rigid pipe and the buoyancy section on land,
ii. at least partially flooding said buoyancy unit, such that the buoyancy of the riser is negative,
iii. towing said rigid riser section and the buoyancy section out to sea to the location where the riser is to be installed by at least a first tug using a first tether,
iv. allowing said rigid pipe and the buoyancy section to sink to the floor of the sea,
v. connecting the end of the rigid pipe furthest from the buoyancy unit at a wellhead or flowline tie in,
vi. expelling fluid from the buoyancy unit, such that a buoyancy force is exerted on the buoyancy section,

vii. allowing the buoyancy section to rise towards the surface of the sea under the guidance of said at least one installation/surface vessel such that the rigid pipe bends upwards to form a catenary configuration, and

viii. attaching a flexible pipe between said installation/surface vessel and the upper end of the rigid pipe.

This method is advantageous in that it can be carried out without specially adapted deployment vessels.

According to the invention from a fourth aspect there is provided a method of installing a riser having a lower section and an upper section, where said upper section comprises a flexible pipe, and said lower section comprises a rigid pipe in communication with the flexible pipe, and wherein said riser further comprises a buoyancy section at an upper end of said rigid pipe, said method involving the steps of;

i. constructing a rigid pipe and the buoyancy section on land,

ii. weighting said buoyancy unit, such that the buoyancy of the riser is negative,

iii. towing said rigid pipe section and the buoyancy section out to sea to the location where the riser is to be installed by at least a first tug using a first tether,

iv. allowing said rigid pipe and the buoyancy section to sink to the floor of the sea,

v. connecting the end of the rigid pipe furthest from the buoyancy unit at a wellhead or flowline tie-in,

vi. removing said weighting from the buoyancy unit, such that a buoyancy force is exerted on the buoyancy section ,

vii. allowing the buoyancy section to rise towards the surface of the sea under the guidance of said at least one installation/surface vessel, such that the rigid pipe bends upwards to form a catenary configuration, and

viii. attaching a flexible pipe between said installation/surface vessel and the upper end of the rigid pipe.

According to a development of this method one or more temporary buoyancy elements are connected to said rigid riser such that buoyancy is distributed along the length of the riser substantially evenly.

According to a development of this method, the lower end of said rigid riser may be connected to said well head by means of jumpers or rigid spools.

According to a development of the above method, said rigid pipe and the buoyancy section are towed out to sea to the location where the riser is to be installed further using a second tug and a second tether said second tether being connected to a point along the rigid riser behind the point to which said first tether is connected.
By this means the riser can be steered and manoeuvred by the second tug while the first tug provides motive force.

According to a development of the above method, said rigid riser is pressurised with a gas prior to said step of expelling fluid from the buoyancy unit. This makes the provision of external pumping or pressurising means during the installation process unnecessary.

According to the invention from a fourth aspect there is provided a method of installing a riser configuration having a lower section and an upper section, where said upper section comprises a flexible pipe, and said lower section comprises a rigid pipe in communication with the flexible pipe, and wherein said riser further comprises a buoyancy section at an upper end of said rigid pipe, said method involving the steps of:

i. constructing the entire riser structure on land,
ii. at least partially flooding said buoyancy unit, such that the buoyancy of the riser is negative,
iii. towing the riser out to be installed at sea to the location where the riser is to be installed by at least a first tug (42) using a first tether (44),
iv. allowing riser to land on the seabed,

v. connecting the end of the rigid pipe furthest from the buoyancy unit (16) at a wellhead or flowline tie-in ,
vi. expelling fluid from the buoyancy unit, such that a buoyancy force is exerted on the buoyancy section,
vii. allowing the buoyancy section to rise towards the surface of the sea under the guidance of said at least one installation/surface vessel, such that the rigid pipe bends upwards to form a catenary configuration, and
viii. attaching a flexible pipe to a surface vessel.

This simplifies the installation process since it is no longer necessary to connect the flexible and rigid riser pipes underwater.

The above methods may also comprise the step attaching a tether between the buoyancy unit and said surface/installation vessel (3) or the seabed, so as to reduce the strains exerted on the riser.

According to the invention from a fifth aspect there is provided a method of installing a riser having a lower section and an upper section, said upper section comprising a flexible pipe and said lower section comprising a rigid pipe in communication with the upper section, said riser further comprising a buoyancy section at an upper end of said rigid pipe, said method the steps of

i. lowering successive lengths of rigid pipe section in the sea, each length being connected endwise to the length of pipe section below it;
ii. connecting a lower end of a further length of rigid pipe section having a buoyancy section comprising an elongate buoyancy unit extending lengthwise of said further length of rigid pipe section to an upper end of the length of rigid pipe section immediately below it, to form said rigid pipe;
iii. connecting a flexible pipe to an upper end of said rigid pipe;
iv. lowering the flexible pipe;
v. allowing the buoyancy unit to sink;
vi. adjusting the position of the floating vessel such that the rigid pipe assumes the configuration of a catenary in the sea water and,

vii. connecting a lower end of the rigid pipe to a wellhead or flowline.

The buoyancy unit is many times its diameter in length, and is disposed along the length of the upper part of the rigid catenary section.

The buoyancy unit may float freely in the water, or may be tethered to an object on the surface of the sea or at the seabed.

For a better understanding of the present invention as well as preferred and other embodiments thereof, reference is made by way of example to Figures 1 to 16, in which;

Figure 1 is a side view showing a riser configuration according to a first arrangement known in the prior art;

Figure 2 is a corresponding view of a second riser configuration known in the prior art;

Figure 3 is a side elevation of a third riser configuration known in the prior art;

Figure 4 is a side view of a riser configuration known in the prior art;

Figure 5 is a side view of a fifth riser configuration known in the prior art;

Figure 6 is a side view of a first embodiment according to the present invention;

Figure 7a is a side view of a second embodiment according to the present invention;

Figure 7b is a side view of a second variant of the second embodiment of the present invention as shown in Figure 7a;

Figure 8 is a side view of a third embodiment of the present invention;

Figure 9 shows a fourth embodiment of the present invention;

Figure 10 shows a fifth embodiment of the present invention;

Figure 11 shows details of the buoyancy unit incorporated in an embodiment of the present invention;

Figure 12a shows details of the buoyancy unit 16 incorporated in an embodiment of the present invention in a first state;

Figure 12b shows details of the buoyancy unit 16 incorporated in an embodiment of the present invention in a second state;

Figure 13 shows details of the buoyancy unit 16 incorporated in an embodiment of the present invention;

Figure 14 shows details of the buoyancy unit 16 and the lower rigid catenary pipe section 13 incorporated in an embodiment of the present invention;

Figure 15 shows details of the buoyancy unit, the upper portion of the rigid catenary pipe section and the flexible riser of Figure 9;

Figure 16 shows a sixth embodiment of the present invention.

Figure 16b shows a cross-section through the diameter of the buoyancy unit (16) of figure 16 a through the line AA.

Figure 16c shows a cross-section through the diameter of the riser pipes of figure 16a through the line BB

Figure 17a shows a further development of the sixth embodiment of the invention.

Figure 17b shows in further detail the configuration of the elements shown in Figure 17a at a cross-section through the line AA.

Figure 17c shows in further detail the configuration of the elements shown in Figure 17a at a cross-section through the line BB.

Figure 18a shows a combination of the embodiments of Figure 6 and Figure 17a.

Figure 18b shows in further detail the configuration of the elements shown in Figure 18a at a cross-section through the line AA.

Figure 18c shows in further detail the configuration of the elements shown in Figure 18a at a cross-section through the line BB.

Figures 19a to 19e show stages of a method of installing a riser of an embodiment of the present invention.

Figure 6 shows a first embodiment of the present invention. In this embodiment a hybrid riser ascends to a surface vessel 3 from the seabed 2, and comprises a flexible pipe section 10 connected to said surface vessel 3 and the top part of a rigid riser 13 having the configuration of a catenary, which is further connected to a wellhead on the seabed 2. The surface vessel 3 may be a ship, a semi-submersible unit, a Tension Leg Platform, a Spar platform or other surface vessel as appropriate. The riser may alternatively be terminated at a riser base, and thus not extended all the way to the well head. It may also be used as an export riser. There is furthermore provided a buoyancy unit 16, which is of a substantially elongate shape, such that its length is many times its diameter and is arranged along the length of the upper portion of said rigid riser 13.

Thus, in operation, once installed, the rigid riser portion 13 is held substantially immobile in the sea by the buoyancy unit 16. The flexible riser portion 10 absorbs the motion of the surface vessel 3, and other forces exerted thereon, for example by the movement of the sea itself.

Although Figure 6 to 10 show the surface vessel 3 as being distant from the well head, it will be appreciated that the arrangement of the present invention also allows for the situation of the surface vessel above the well head. In this, and other cases, the upper riser section will depart from the buoyancy unit at a different location and angle to those shown in Figures 6 to 10.

According to a second embodiment of the present invention, as shown in Figure 7a, the flexible riser 10 is attached to the upper end of the rigid riser 13 at right angles and hangs suspended in the water in the configuration of a catenary. Furthermore, a tether 17 may be provided between the upper part of the buoyancy unit 16 and surface vessel 3, or alternatively, a tether 17b may be provided between the upper part of the buoyancy unit 16 and a point on the sea surface or seabed .

This arrangement is advantageous over the prior art as embodied for example by the tower riser as discussed above. in that the demands of anchoring the rigid riser to the seabed are reduced, there is no requirement for a flexible joint, and the degree of buoyancy required is reduced.

The positioning of the joint between the rigid and flexible riser parts substantially parallel with the side of the buoyancy unit 16 has the advantage of facilitating the attachment of a tether 17 to the upper end of the buoyancy unit 16 so that extreme movements of the surface vessel 3 will not exert undesirably large forces on the flexible 10, but will rather be absorbed by the tether 17.

A variation of this second embodiment is shown in Figure 7b, where the tether 17 is further provided with at least one tensioning weight 18, which causes the tether 17 to deviate from a substantially straight line between the surface vessel 3 and the top of the buoyancy unit 16. A variation of this is to use at least one heavy tether segment such as a chain segment for example.

This has the effect of limiting the forces exerted on the buoyancy unit 16 to a substantially horizontal plane, thereby reducing the risk of inducing fatigue in the lower portion 6 of the rigid riser 13.

According to a third embodiment of the present invention as shown in Figure 8, the rigid riser section 13 comprises a plurality of individual rigid pipes bundled together. The pipes are intended for carrying the same or different fluids, selected from production fluid, natural gas, injection air and water, for example. Flexible riser sections 10a, 10b, 10c, 10d, etc. are coupled at right angles to respective rigid pipes in the rigid section 13, at intervals along the parts of the rigid riser section along which extends the buoyancy unit 16. By arranging the perpendicular joints between the rigid and flexible sections in this manner, the connection of the respective rigid and flexible pipes of each pair may be effected without interference from an adjacent pair during installation of the riser structure.

Figure 9 shows an equivalent structure to that of Figure 8, but with the further provision of a tether 17 between the top of the buoyancy unit 16 and the sea surface 1.

In operation, the provision of this tether has the effect of reducing the forces exerted on the flexible riser sections 10a, 10b, 10c, 10d, etc.

According to a fifth embodiment of the present invention shown in Figure 10, it may be desirable to pre-form the top of the rigid section, such that a top section of the rigid riser extends beyond the upper end of the buoyancy unit and deviates from the line defined by the essentially vertically rising section of the rigid riser.

Alternatively it may be desirable to pre-form the top of the rigid section 13 and the buoyancy unit 16, such that a top section of these two elements 16a deviates from the line defined by the essentially vertically rising section of the rigid riser.

In operation this may be found to be advantageous, in that the shear forces exerted on the joint between the flexible riser 10 and the rigid riser 13 present when the buoyancy unit 16 is not vertically below the surface vessel 3 are reduced.

Figure 11 shows further detail of the buoyancy unit 16 used in Figure 6 (or in any of Figures 7 to 10 with obvious adaptation).

In this embodiment, the buoyancy unit comprises an essentially tubular structure arranged coaxially with the rigid riser 13. The buoyancy unit is made of any suitable buoyant material, for example a foam. It may alternatively comprise a rigid hollow buoyant tank made of steel, composite material, aluminium or other materials as will readily occur to the skilled person, which is either an intrinsic part of the upper section of the rigid riser , or a separate tubular structure which is secured thereto. Such a tank may be filled with gas, or a foam or other buoyant material.

Figure 12a shows the structure of the buoyancy unit 16 according to a preferred configuration. In this arrangement, the buoyancy unit 16 is formed by positioning the rigid riser 13 coaxially inside a second pipe of larger diameter, such that a tubular space is formed between the two pipes. Six annular bulkheads are provided in this tubular space, so as to divide it into five separate tanks. Furthermore, valves 22a and 22b are provided between the inside of said rigid riser 13, and the inside of a second and fourth of said tubular spaces 21a and 21b. A further two valves 23a and 23b are provided between said second and fourth tubular spaces 21a and 21b, and the outside of said buoyancy unit 16.

In operation, the ends of the rigid riser 13 are sealed, and the rigid riser is pre-pressurised, for example with nitrogen (N_2) gas. First, third and fifth tubular spaces 20a, 20b and 20c are similarly filled with gas. The second and fourth tubular spaces 21a and 21b are filled with seawater, or another fluid having a higher density than the gas with which the rigid riser pipe 13 is filled.

Naturally, the number and configuration of the tanks into which the tubular space is divided may be varied as expedient. It may also be found advantageous to provide tubing connecting the different valves, or to connect one or more chambers together by tubing such that they can be vented through a common valve, or other arrangements so as to facilitate the transfer of fluids to and from the buoyancy unit. It may further be found to be advantageous to provide means such that the transfer of fluids to and from the buoyancy unit can be effected after the installation of the riser.

Figure 12b shows the riser 16 of the same preferred embodiment of Figure 12a, in a second state. In operation, the valves 22a, 22b, 23a and 23b can be opened, such that the water in the second and fourth tubular spaces 21a and 21b is expelled through valves 23a and 23b, and displaced by the pressurised gas from said rigid riser 13, which flows into said second and fourth tubular spaces through said valves 22a and 22b.

This has the effect of reducing the overall average density of the buoyancy unit 16.

Figure 13 shows a further configuration of the structure of the buoyancy unit 16, in which a tubular gap 32 is provided between the rigid riser 13 and the buoyancy unit 16. This gap 32 is defined by the inner wall 33 of the buoyancy unit 16 and the outer wall 31 of the rigid riser 16.

This gap is provided to provide insulation between the fluids flowing through the rigid riser 13 and the surrounding seawater. The gap may be filled with a gas, a fluid or any other insulating material, and may further comprise spacers to maintain the coaxial configuration of the riser 13 and the buoyancy unit 16.

It is also possible to collect a plurality of riser pipes such as that shown in Figure 13 so as to form a bundle, where each pipe has its own buoyancy sleeve. Naturally, the number and configuration of the riser pipes may be varied as expedient. For example, the rigid pipes may be arranged such that the bundle describes a circle in cross section, or a "flat pack" arrangement, in which the separate pipes are arranged in rows, or other arrangements as may be found to be advantageous.

Figure 14 shows details of a further design for the buoyancy unit 16 and the rigid riser 13, in which the structure of the buoyancy unit 16 is extended along the entire length of the rigid riser 13. A lower portion of the buoyancy unit 16 is reduced in outer diameter, such that the external diameter of the structure is reduced, the internal diameter of the rigid riser 13 remaining constant. The cross-sectional area of insulating material which may for example comprise gas, foam, gel etc, and may be different in the boy section than in the riser within the buoyancy unit 16 in this lower section is thus reduced. Thus, in operation, while the upper portion of the buoyancy unit 16 provides substantially all the buoyancy required to support the rigid riser 13, the lower section of the buoyancy unit 16 extends along the length of the rigid riser 13 so as to perform an insulating function.

It is also possible to collect a plurality of riser pipes such as that shown in Figure 14 so as to form a bundle, where each pipe has its own buoyancy sleeve. Naturally, the number and configuration of the riser pipes may be varied as expedient. For example, the rigid pipes may be arranged such that the bundle describes a circle in cross section, or a "flat pack" arrangement, in which the separate pipes are arranged in rows, or other arrangements as may be found to be advantageous.

Figure 15 shows further details of the buoyancy unit 16 according to the embodiment of the present invention shown in Figure 9. According to this embodiment, the rigid riser 13 comprises a bundle of rigid pipes, which are at their upper ends with respective flexible pipes perpendicular thereto, at lateral positions spaced longitudinally along the upper portion of the buoyancy unit 16. In the configuration shown in Figure 15, there are provided six rigid riser pipes, which are connected respectively to flexible riser pipes 10a, 10b, 10c, 10d, 10e and 10f. There is further provided a tether 17, connected to an upper surface of said buoyancy section 16.

Naturally, the number and configuration of the riser pipes may be varied as expedient. For example, the rigid pipes may be arranged such that the bundle describes a circle in cross section, or a "flat pack" arrangement, in which the separate pipes are arranged in rows, or other arrangements as may be found to be advantageous.

Figure 16 shows a sixth embodiment of the present invention. In this embodiment, two hybrid risers ascend to a surface vessel (3) from the seabed (2), each comprising a flexible pipe section (101, 102) which may be made for example of standard flexible pipe, composite material or titanium composite or other material, connected to said surface vessel (3), and the top part of a rigid riser (131, 132) having the configuration of a catenary, and a lower extremity thereof may further be connected to a wellhead on the seabed (2). The surface vessel (3) may be a ship, a semi-submersible unit, a tension leg platform, a spar platform or other surface vessel as appropriate. The riser may alternatively be terminated at a riser base, and thus not extend all the way to the wellhead. Such a riser may also be used as an export riser or indeed in any other such application. There is further provided a buoyancy unit (16), disposed between the upper part (131) of the first rigid riser, and the upper part (132) of the second rigid riser. The buoyancy unit (16) is of a substantially elongate shape, such that its length is many times its diameter and is arranged along the length of the upper part (131) and (132) of the rigid risers respectively.

The buoyancy unit is made of any suitable buoyant material, for example a foam. It may alternatively comprise a rigid hollow buoyant tank made of steel, composite material, aluminium or other materials as will readily occur to the skilled person, which is either an intrinsic part of the upper section of the rigid riser , or a separate tubular structure which is secured thereto. Such a tank may be filled with gas, or a foam or other buoyant material.

The upper part of each rigid riser (131, 132) may be connected to the buoyancy unit (16) by means of a hang-off arrangement or other bearing or fixture (251, 252), or may simply be welded or otherwise fixed thereto. A similar arrangement may be provided at other points along the length of the buoyancy unit (16). Furthermore, one ore more sleeves (261, 262) may be attached to the buoyancy unit, with the rigid riser (131, 132) fitting slidingly through the sleeve. In this configuration, there is provided no permanent connection between the inside surface of the sleeve and the outer surface of the rigid riser, such that the mutual alignment of the buoyancy unit (16) and the rigid riser (131, 132) can be maintained, without exerting any substantial tensional force along the length of the riser pipe.

The mutual spacing of the riser pipes (131, 132) can be maintained below the lower extremity of the buoyancy unit (16) by means of a spacer (29) situated between two clamps (271, 272), each clamp connecting to the rigid riser (271, 272) respectively. THe clamps may connect the riser fixedly or slidingly, so as to allow for expansion. By this means, the two rigid risers (271, 272) can be retained in a parallel or other desired configuration as they descend in a catenary manner to the sea floor. It may be desirable to employ spacers of different lenths along the length of the risers, so that the separation thereof changes as a function of distance from the sea bed.

Although as described above with reference to Figure 16, the two risers are provided on opposite sides of the buoyancy unit (16), that is, separated by an angle of 180°, it is also possible to position the risers at other angles, so as to bring the rigid risers closer to each other on one side of the buoyancy unit (16).

Figure 16b shows a cross-section through the diameter of the buoyancy unit (16) through the line AA. In this figure can be seen more clearly the configuration of the rigid riser pipes (131, 132), the sleeves (261, 262), and the buoyancy unit (16).

Similarly, Figure 16c shows a cross-section through the diameter of the riser pipes (131, 132) through the line BB, in which can be seen more clearly the configuration of the clamps (271, 272), the risers (131, 132) and the spacer bar (29).

It is also possible to construct the riser structure using conventional methods whilst at sea such as J-lay, reeling etc. For example, by adding pipe sections to the riser one by one as the pipe is deployed from a surface vessel. In the case of reeling it may be appropriate to land the buoyancy tank 16 on the seabed and start reeling from there.

Furthermore, the invention is not limited to two riser pipes, but is further applicable to a larger plurality thereof. For example, Figure 17a shows a further development of the sixth embodiment of the invention, wherein four riser pipes (131, 132, 133, 134) are disposed around a buoyancy unit (16). As described with regard to Figure 16, the risers may be maintained in position by hang-off units (251, 252, 253 and 254), and sleeves (261, 262, 263, 264) respectively. Furthermore, the risers can be retained in a desired configuration below the lower extremity of the buoyancy unit (16) by means of clamps (271, 272, 273, 274), held in position by a spacer element (29).

Figures 17b and 17c show cross-sections through the lines AA and BB respectively and show in further detail the configuration of the elements shown in Figure 17a.

As will be clear to the skilled person, it is possible to combine the teachings of the above-described embodiments. For example, Figure 18a shows a combination of the embodiments of Figure 6 and Figure 17, in which a first riser is arranged concentrically with a buoyancy unit (16), such that the riser is surrounded by the buoyancy unit, while a further four risers (131, 132, 133 and 134) are arranged around the outside of the buoyancy unit (16). The external riser pipes (131, 132, 133 and 134) may be maintained in position by hang-off elements (251, 252, 253 and 254) and sleeves (261, 262, 263 and 264) as described in relation to Figure 17.

All five risers (13, 131, 132, 133 and 134) can be retained in a desired configuration, for example one similar to that imposed by the arrangement of the risers through and around the buoyancy unit (16) respectively, by means of clamps (271, 272, 273 and 274). The central riser 13 may be replaced by a plurality of risers.

Figures 18b and 18c show cross-sections through the lines AA and BB respectively and show in further detail the configuration of the elements shown in Figure 18a.

Figure 19 shows a method of installing a riser according to any one of the preceding embodiments.

Figure 19a shows a first step in this method of installing the riser, in which the rigid riser section 13 which may be typically in the order of seven kilometres long, and the buoyancy section 16 are constructed on land. The rigid riser section and the buoyancy section 16 are then towed out to sea by a tug 42 using a tether 44, according to a procedure sometimes known as a "bundle tow".

Figure 19b shows a second step in the method of installing the riser. In this step the rigid riser section 13 and buoyancy unit 16 are towed out to sea by at least one tug 42 and tether 44, and optionally a second tug 43 and tether 45. The buoyancy unit 16 is preferably partially flooded, such that the riser as a whole has substantially neutral buoyancy. Preferably, this is realised according to the buoyancy unit of Figure 12 of the present invention, whereby annular spaces 21a and 21b are flooded with water, and the rigid riser 13 is pre-pressurised with nitrogen gas.

Figure 19c shows a third step of the method of installing the riser. Once the riser has been towed to the vicinity of the well 41, the riser is allowed to sink to or land on the seabed and the end of the rigid riser 13 furthest from the buoyancy unit 16 is connected to the wellhead 41, for example by means of jumpers.

Figure 19d shows a fourth step in the method of installing the riser according to the present invention. In this step, the water flooding the ring-shaped spaces 21a and 21b is expelled by opening the valves 22a and 22b, such that the average density of the buoyancy section 16 decreases, and a buoyancy force is exerted on the buoyancy section 16 towards the surface of the sea. Under the guidance of a tug, or surface vessel 3 by means of a tether 44', which may or may not be the same tether as used to tow the riser into position, the buoyancy section is allowed to rise towards the surface of the sea, causing the rigid riser 13 to bend upwards to form a catenary configuration.

Figure 19e shows a fifth and final step in the method of installing the riser. In this step, a tether 17 is attached to a surface vessel or installation vessel 3, and flexible riser pipes 10a, 10b, 10c, 10d, etc. are attached between said surface vessel 3 and the upper end of the rigid riser 13, as discussed above with reference to Figure 9.

The installation of the riser is thus complete, and hydrocarbon transport may commence.

The skilled man will appreciate that variations may be made to the sequence in which the above steps are carried out. In particular, step d, where the buoyancy section is allowed to rise towards the surface of the sea, causing the rigid riser 13 to bend upwards to form a catenary configuration, may in fact take place before the end of the rigid riser 13 furthest from the buoyancy unit 16 is connected to the wellhead 41.

As a variation of the method described above with reference to Figure 16, it is also possible to cause the riser to sink to the sea bed at the installation site by weighting it by means other than allowing the buoyancy tanks to flood. For example chains may be attached to the pipe, such that the riser sinks until the chain drapes on the seabed.

According to an alternative method, it is also possible to construct the entire riser structure comprising at least one flexible pipe 10, at least one corresponding rigid pipe 13 connected thereto as described above and the buoyancy unit 16 disposed along and the lengthways of the rigid pipe nearest said flexible pipe on land, before towing the whole structure out to be installed at sea.

It is also possible to construct the riser structure using conventional methods whilst at sea such as J-lay, reeling etc. For example, by adding pipe sections to the riser one by one as the pipe is deployed from a surface vessel. In the case of reeling it may be appropriate to land the buoyancy tank 16 on the seabed and start reeling from there. More specifically, in accordance with such a constructional method successive lengths of rigid pipe section in the sea, each length being connected endwise to the length of pipe section below it. Then a lower end of a further length of rigid pipe section having a buoyancy section comprising an elongate buoyancy unit extending lengthwise of said further length of rigid pipe section is connected to an upper end of the length of rigid pipe section immediately below it, to form the rigid pipe. A flexible pipe is connected to an upper end of the rigid pipe, after which the flexible pipe is lowered, until the rigid pipe hangs suspended in the water from its upper end. Next the buoyancy unit is allowed to sink and a lower end of the rigid pipe is connected to a wellhead. Finally, to complete the installation, the position of the floating vessel is adjusted such that the rigid pipe assumes the configuration of a catenary in the seawater.

In all of the embodiments discussed in relation to Figures 6 to 19, and in particular those embodiments where there is provided no tethering means, as shown in, for example, Figures 6, 8 and 10, it may be found desirable to add weighting to the flexible riser pipe 10. This has the effect of reducing its movement of the buoyancy unit in the water.

In all of the embodiments discussed in relation to Figures 6 to 19, the buoyancy unit 16 preferably has a length equal to at least twice its diameter. More preferably, the buoyancy unit 16 has a length equal to at least thirty times its diameter. Yet more preferably, the buoyancy unit 16 has a length equal to at least 100 times its diameter.

Although the above embodiments of the invention have been described in terms of a production riser connecting a surface vessel to a well head, the skilled person will realise that they are equally appropriate to other applications, for example tying a surface vessel in to a sea floor flowline, so as to function for example as an export riser.

CLAIMS:

1. A riser having a lower section (6) and an upper section (10), said upper section comprising a flexible pipe and said lower section comprising a substantially rigid pipe and forming a catenary in communication with the flexible pipe, said riser further comprising a buoyancy section (16) at or in the region of an upper end of said rigid pipe (13), said buoyancy section being tethered to a vessel on the sea's surface.

2. A riser according to claim 1 wherein said buoyancy section (16) comprises an elongate buoyancy element fitted around the riser.

3. A riser having a lower section (6) and an upper section (10), said upper section comprising at least one flexible pipe and said lower section comprising at least one substantially rigid pipe and forming a catenary, said riser further comprising a buoyancy section (16) at or in the region of an upper end of said rigid pipe (13), said buoyancy section (16) comprising an elongate buoyancy unit extending lengthwise of the rigid pipe.

4. A riser according to claim 3 wherein said buoyancy section is tethered to a vessel on the sea's surface.

5. A riser according to claim 3 wherein said buoyancy section is tethered to the seabed.

6. A riser according to any of claims 1 to 5 wherein said lower section comprises a plurality of rigid pipes and said upper sections each comprise a corresponding plurality of flexible pipes.

7. A riser according to claim 6 wherein said plurality of rigid pipes are arranged around the outside of said buoyancy section.

8. A riser according to claim 7 wherein said plurality of rigid pipes are spaced apart evenly about the circumference of said buoyancy section.

9. A riser according to claim 7 or 8 wherein each of said plurality of rigid pipes is fixed at or near an upper extremity thereof to said buoyancy section.

10. A riser according to any of claims 7 to 9, wherein said buoyancy section is further provided with a plurality of sleeves intended to slidingly receive said plurality of rigid pipes respectively.

11. A riser according to any of claims 6 to 10, further comprising a spacer connected to each of said plurality of rigid pipes, or to each of said plurality of flexible pipes so as to maintain said plurality of rigid pipes or each of said plurality of flexible pipes in a fixed position relative the other rigid pipes or flexible pipes.

12. A riser according to claim 11, wherein said spacer is provided at a point on said rigid riser below a lower extremity of said buoyancy section.

13. A riser according to any of claims 1 to 12 wherein each of said at least one flexible pipes is joined to a respective one of at least one rigid pipes at a substantially right angle.

14. A riser according to claim 13 wherein the substantially right-angled joins between respective rigid and flexible pipes are spaced apart from one another along the length of said buoyancy section (16).

15. A riser according to any preceding claim wherein said buoyancy section is made of a foam.

16. A riser according to any preceding claim wherein said buoyancy section is a tube arranged such that the rigid pipe runs therethrough.

17. A riser according to claim 16 wherein said tube is made of steel or aluminium or a composite material.

18. A riser according to claim 16 or claim 17 wherein said solid tube arranged is arranged coaxially to said rigid pipe.

19. A riser according to any of claims 6 to 18 wherein said buoyancy section further comprises a plurality of bulkheads dividing said buoyancy section into a plurality of closed chambers.

20. A riser according to claim 19 wherein at least one valve is provided allowing flow of a fluid from inside said rigid pipe to the interior of a respective at least one of said closed chambers.

21. A riser according to claim 19 or claim 20 wherein at least one valve is provided allowing flow of a fluid from inside a respective at least one of said closed chambers to the exterior of said buoyancy unit.

22. A riser according to any preceding claim wherein an upper extremity of said rigid pipe is aligned away from the axis of the part of said riser immediately below said upper extremity.

23. A method of installing a riser having a lower section (6) and an upper section (10), where said upper section comprises a flexible pipe, and said lower section comprises a rigid pipe in communication with the flexible pipe, and wherein said riser further comprises a buoyancy section (16) at an upper end of said rigid pipe (13), said method involving the steps of;

i. constructing a rigid pipe (13) and the buoyancy section (16) on land,
ii. at least partially flooding said buoyancy unit, such that the buoyancy of the riser is negative,

iii. towing said rigid pipe section (13) and the buoyancy section (16) out to sea to the location where the riser is to be installed by at least a first tug (42) using a first tether (44),
iv. allowing said rigid pipe (13) and the buoyancy section (16) to sink to the floor of the sea,
v. connecting the end of the rigid pipe (13) furthest from the buoyancy unit (16) at a wellhead (41) or flowline tie-in ,
vi. expelling fluid from the buoyancy unit, such that a buoyancy force is exerted on the buoyancy section (16),
vii. allowing the buoyancy section to rise towards the surface of the sea under the guidance of said at least one installation/surface vessel (3), such that the rigid pipe (13) bends upwards to form a catenary configuration, and
viii. Attaching a flexible pipe (10a) between said installation/surface vessel (3) and the upper end of the rigid pipe (13).

24. A method of installing a riser having a lower section (6) and an upper section (10), where said upper section comprises a flexible pipe, and said lower section comprises a rigid pipe in communication with the flexible pipe, and wherein said riser further comprises a buoyancy section (16) at an upper end of said rigid pipe (13), said method involving the steps of;

i. constructing a rigid pipe (13) and the buoyancy section (16) on land,
ii. weighting said buoyancy unit, such that the buoyancy of the riser is negative,
iii. towing said rigid pipe section (13) and the buoyancy section (16) out to sea to the location where the riser is to be installed by at least a first tug (42) using a first tether (44),
iv. allowing said rigid pipe (13) and the buoyancy section (16) to land on seabed,
v. connecting the end of the rigid pipe (13) furthest from the buoyancy unit (16) at a wellhead (41) or flowline tie-in ,

vi. removing said weighting from the buoyancy unit, such that a buoyancy force is exerted on the buoyancy section (16),

vii. allowing the buoyancy section to rise towards the surface of the sea under the guidance of said at least one installation/surface vessel (3), such that the rigid pipe (13) bends upwards to form a catenary configuration, and

viii. attaching a flexible pipe (10a) between said installation/surface vessel (3) and the upper end of the rigid pipe (13).

25. The method of claim 23 or 24 wherein one or more temporary buoyancy elements are connected to said rigid riser such that buoyancy is distributed along the length of the riser substantially evenly

26. The method of claim 23 or claim 24 wherein the lower end of said rigid pipe is connected to said well head or flowline by means of jumpers or spools.

27. The method of any one of claims 23 to 26 wherein said rigid pipe (13) and the buoyancy section (16) are towed out to sea to the location where the riser is to be installed further using a second tug (43) and a second tether (45), said second tether being connected to a point along the rigid pipe behind the point to which said first tether is connected.

28. The method of any one of claims 23 to 27 wherein said rigid pipe (13) is pressurised with a gas prior to said step of expelling fluid from the buoyancy unit.

29. A method of installing a riser configuration having a lower section (6) and an upper section (10), where said upper section comprises a flexible pipe, and said lower section comprises a rigid pipe in communication with the flexible pipe, and wherein said riser further comprises a buoyancy section (16) at an upper end of said rigid pipe (13), said method involving the steps of:

i. constructing the entire riser structure on land,

ii. at least partially flooding said buoyancy unit, such that the buoyancy of the riser is negative,

iii. towing the riser out to be installed at sea to the location where the riser is to be installed by at least a first tug (42) using a first tether (44),

iv. allowing riser to sink to the floor of the sea,

v. connecting the end of the rigid pipe (13) furthest from the buoyancy unit (16) at a wellhead (41) or flowline tie-in ,

vi. expelling fluid from the buoyancy unit, such that a buoyancy force is exerted on the buoyancy section (16),

vii. allowing the buoyancy section to rise towards the surface of the sea under the guidance of said at least one installation/surface vessel (3), such that the rigid pipe (13) bends upwards to form a catenary configuration, and

viii. attaching a flexible pipe (10a) to said installation/surface vessel (3).

30. The method of claim 23, 24 or 29 further comprising the step of attaching a tether (17) between said buoyancy unit and said surface/installation vessel (3) or the seabed.

31. A method of installing a riser having a lower section (6) and an upper section (10), said upper section comprising a flexible pipe and said lower section comprising a rigid pipe in communication with the upper section, said riser further comprising a buoyancy section (16) at an upper end of said rigid pipe (13), said method comprising the steps of:

i. lowering successive lengths of rigid pipe section in the sea, each length being connected endwise to the length of pipe section below it;

ii. connecting a lower end of a further length of rigid pipe section having a buoyancy section comprising an elongate buoyancy unit extending lengthwise of said further length of rigid pipe section to an upper end of the length of rigid pipe section immediately below it, to form said rigid pipe;

iii. connecting a flexible pipe to an upper end of said rigid pipe;

iv. lowering the flexible pipe;

v. allowing the buoyancy unit to sink;

vi. adjusting the position of the floating vessel such that the rigid pipe assumes the configuration of a catenary in the sea water and;

vii. connecting a lower end of the rigid pipe to a wellhead or flowline.

32. A riser substantially as hereinbefore described with reference to Figs. 6 and the modification of Fig. 11 or Fig. 12a and Fig. 12b or Fig. 13 or Fig. 14; Fig 7a; Fig. 7b; Fig. 8; Fig. 9 and Fig. 15; or Figs 16a, 16b and 16c, or Figs 17a, 17b and 17c or Figs 18a, 18b and 18c, or Fig 10 of the accompanying drawings.

33. A method of installing a riser substantially as hereinbefore described with reference to Figs. 19a-19e of the accompanying drawings.

34. A method of installing a riser according to any one of claims 23, 24, or 29 substantially as hereinbefore described with reference to Figs. 19a-19e of the accompanying drawings.

35. A method of installing a riser according to claim 29 substantially as hereinbefore described.

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Application No: GB 0209031.4 **Examiner:** Damien J Huxley
Claims searched: 1 to 35 **Date of search:** 30 August 2002

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

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Other: ONLINE: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	GB 2309576 A	(CRP GROUP LTD) see the figures in particular.	2, 3, 15 to 21
Y	WO 00/53884 A1	(KODAISSI) see the figures and WPI Abstract Accession Number 2000-565607.	2, 3, 15 to 21
X, Y	WO 00/05129 A1	(FMC CORPORATION) see the whole document.	X: 1, 2, 3, 6, 15 to 21 & 31 Y: 2, 15 to 21.
X, Y	US 5639187	(MOBIL OIL CORPORATION) see the figures especially.	X: 1 & 3 Y: 2
A	US 5275510	(DE BAAN) see the figures.	
Y	US 3902531	(UNIROYAL LIMITED) see the figures especially.	2, 3, 15 to 21

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