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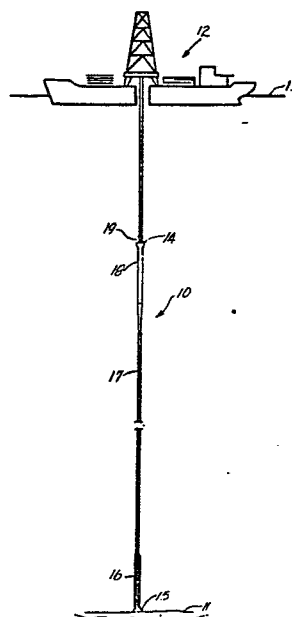
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Submerged buoyant offshore drilling and production tower and apparatus and method for defining and installing same.

A submerged tubular tower (10) (see Fig. 1) is connected at its lower end (15) to an ocean floor (11) at a site where at least one subsea hydrocarbon well is to be drilled. A riser duct (22) (see Fig. 5) for each well to be drilled extends from an upwardly accessible connection point (20) at the upper end (14) of the tower to the lower end of the tower. The tower is positively buoyant to stand erect in an unguyed manner. The upper end (18) of the tower is located a substantial distance above the ocean floor at a depth sufficiently small to enable wells to be drilled through the riser ducts, through equipment (19) landed on the top of the tower, using floating drilling equipment (12) designed for use in substantially shallower water depths.



"SUBMERGED BUOYANT OFFSHORE DRILLING AND PRODUCTION
TOWER AND APPARATUS AND METHOD FOR DEFINING AND
INSTALLING SAME"

FIELD OF THE INVENTION

5 This invention pertains to the drilling of offshore
hydrocarbons wells and to the production of hydrocarbons
from such wells. More particularly, it pertains to
apparatus and procedures enabling such wells to be drilled
and produced in water of great depth using equipment
10 designed for use in significantly shallower waters.

BACKGROUND OF THE INVENTION

Review of the Prior Art

15 Substantial reserves of hydrocarbons, i.e., oil and
gas, are known to lie beneath the floors of the oceans of
the world. Many of these reserves lie under shallow waters,
as under continental shelves relatively close to shore.
Much equipment and various procedures have been developed
over the years at great cost to tap these shallow-water
reserves. There is presently a significant worldwide
20 inventory of equipment useful to drill wells in shallow
waters and to produce oil and gas from such wells.
Production equipment for use with offshore wells most
commonly involves a tower or platform erected on the ocean
floor and extending to above the ocean surface.

1 Shallow water oil and gas reserves are being depleted
steadily. The search for offshore oil and gas is moving
into deeper and deeper water farther and farther from shore.
Substantial reserves have been located under waters 1000
5 feet (303 meters) or more in depth. Such depths are beyond
the economic threshold of development, assuming the use of
existing equipment and procedures designed and created for
use in shallower waters; in some instances, newly discovered
subsea hydrocarbons reserves are under waters of such great
10 depth as to be beyond the limits of present technology,
irrespective of cost.

Rigid bottom-supported structures, such as have been
developed for use in the North Sea, are extremely expensive;
their costs increase exponentially with increased water
15 depth. The use of existing technology and equipment is
presently limited to waters somewhat over 1000 feet (303
meters) deep or less.

Current known efforts to design hydrocarbons production
systems for use in deep water (i.e., waters deeper than
20 about 1000 feet or about 300 meters) focus predominantly
upon the use of subsea completion systems which involve
expensive and untested (in terms of reliability) control
equipment on the sea floor. In deep water, such equipment
is costly and often hazardous to maintain.

25 It is thus apparent that a need exists for new techno-
logy, equipment and procedures effective at reasonable cost
to develop and produce subsea hydrocarbons reserves lying
under waters 1000 feet (303 meters) or more in depth.

30 SUMMARY OF THE INVENTION

This invention addresses the need identified above.
It provides equipment and procedures which enable offshore
reserves of hydrocarbons lying under waters of great depth
to be developed and produced by substantial use of available

equipment and techniques originally developed for use in much shallower waters. The invention thus takes maximum technical and economic advantage of the present inventory of offshore drilling and production technology and relies
5 minimally upon wholly new, costly and unproven technology.

In a sense, an installation of this invention raises the sea floor from great depths to a depth sufficiently close to the water surface to enable existing floating equipment, originally designed and perfected for shallow
10 waters, to be used effectively, safely and economically in water depths now beyond their capability.

This invention also provides apparatus useful for defining, at an offshore location in an ocean and the like, in water of substantial depth, a submerged installation of
15 the invention which provides a connection point for the drilling of a subsea hydrocarbons well by use of drilling equipment normally useful only in waters of substantially shallower depth.

An installation of the invention comprises an elongate,
20 slender, unguyed, positively buoyant, erect tower structure which extends from a lower end at the ocean floor to an upper end disposed at a selected depth below the water surface.

Apparatus according to this invention comprises a
25 tubular tower lower section defining, at a lower end thereof, means adapted for the connection of the section to the ocean floor and for holding the section from upward movement when subjected to substantial upwardly directed force. The lower section has an upper end adapted to mate
30 coaxially with and to be secured to a lower end of one of a plurality of tower structure central sections. The apparatus also includes a tubular tower upper section having a lower end adapted to mate coaxially with and be secured to an upper end of one of the tower central sections. The
35 upper section has an upper end which defines at least one connection point for the drilling of a subsea hydrocarbons well. The connection point is arranged for access thereto

1 and for selection of selected equipment thereto from above.
A plurality of tower structure tubular central sections are
also provided. Each central section is adapted, at upper
and lower ends thereof, to mate coaxially with and to be
5 secured to the lower and upper ends of others of the central
sections, or to the upper end of the lower section or to the
lower end of the upper section, as appropriate. The central
sections are sufficient in number and aggregate length that
when the central sections are connected in series between
10 the lower and upper sections of the tower, there results a
tower structure having a length equal to the distance be-
tween the selected water depth and the ocean floor at the
desired offshore location. At least one tubular riser duct
section defined in the completed tower structure in a
15 selected position relative to the tower structure. At least
some, if not all, of the tower sections are arranged to
cooperate with the riser ducts to hold them in desired posi-
tion laterally, and in some cases vertically, relative to
the tower section. There are the same number of riser ducts
20 as there are connection points defined at the upper end of
the tower upper section. Each riser duct has its upper end
connected to the respective connection point. Buoyancy
means are provided within the upper section and within at
least some of the other tower sections. The buoyancy means
25 are operable for rendering the corresponding tower sections
positively buoyant. Upon connection of the serially inter-
connected tower sections and upon to the ocean floor, and
upon installation of the riser ducts in the tower, there
results a submerged tower as aforesaid which includes a
30 riser duct extending along the tower from each connection
point to the lower end of the tower.

Some ways of carrying out the invention will now be
described in detail by way of example and not by way of
limitation with reference to drawings which illustrate
35 specific embodiments of the invention in its apparatus
aspects.

1 DESCRIPTION OF THE ACCOMPANYING DRAWINGS

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10 FIG. 1 is an elevation view showing the drilling of a subsea oil or gas well from a floating drilling vessel by use of a submerged tower structure according to this invention;

FIG. 2 is an elevation view of the lower section of the tower shown in FIG. 1;

FIG. 3 is a cross-section view taken along line 3-3 in FIG. 2;

15 FIG. 4 is an elevation view of a tower central section shown connected between two adjacent central sections in the tower as illustrated in FIG. 1;

FIG. 5 is an elevation view of the upper section of the tower shown in FIG. 1;

20 FIG. 6 is a simplified elevation view showing various stages of the construction and use of the tower structure;

25 FIG. 7 is a simplified fragmentary elevation view of the lower portion of the tower showing a different arrangement of the connection of the riser ducts to the tower body;

FIG. 8 is an enlarged fragmentary elevation view in cross-section of one form of riser guide structure useful in the arrangement shown in FIG. 7;

30 FIG. 9 is an enlarged fragmentary elevation view in cross-section of another form of riser guide structure useful in the arrangement shown in FIG. 7;

FIG. 10 is an elevation view of a lower portion of a tower structure modified to define a resilient hinge feature adjacent its lower end;

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1 FIG. 11 is an elevation view illustrating the use
of an auxiliary floatation structure in the course of
assembling the tower;

5 FIG. 12 is a fragmentary elevation view in cross-
section showing the general features of the auxiliary
floatation structure and the manner of its cooperation
with the tower during the tower assembly process;

10 FIG. 13 is a fragmentary enlarged cross-section
view of the coupling mechanism provided between the
tower and the auxiliary floatation structure;

FIG. 14 is a top plan view of certain of the
structure shown in FIG. 13;

FIG. 15 is an elevation view showing a further step
in the process of assembling and installing the tower;

15 FIG. 16 is a simplified representation of a
manipulator apparatus useful in adjusting the buoyancy
of the assembled tower sections during the process of
assembling and installing the tower;

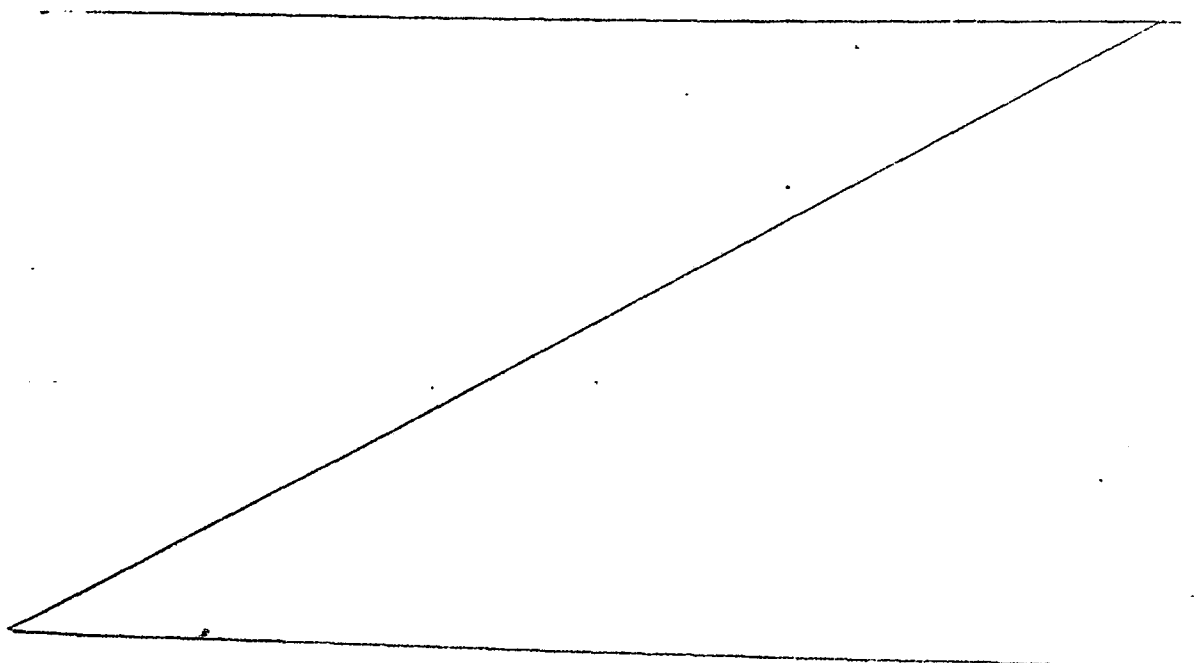
20 FIG. 17 is a schematic representation of a ballast-
deballast system which is useful with the manipulator
apparatus shown in FIG. 16; and

FIG. 18 is a fragmentary elevation view of a portion
of a tower equipped with the manipulator and ballast-
deballast arrangements shown in FIGS. 16 and 17.

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1 DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

A slender, elongate, tubular, submerged tower 10 according to this invention is shown in FIG. 1 in use in the course of drilling a subsea oil or gas well in a geological formation lying below an ocean floor 11. The well is drilled by use of a drilling platform such as a drillship 12, floating on the ocean surface 13. The water depth below drillship 12 may be on the order of 1000 feet (303 meters) or more, say, 12,000 feet (3636 meters). The tower has an upper end 14 disposed a selected distance, say 300 feet (90 meters), below ocean surface 13, and has a lower end 15 secured to the ocean floor. The distance between the water surface and the upper end 14 of tower 10 is sufficiently great to cause the upper end of the tower to be substantially below the range at which the dynamic effects of surface waves will have significant effect upon the tower, yet such distance is sufficiently low that equipment and procedures developed and useful in drilling subsea wells in substantially shallower depths, such as 300 foot (90 meter) water depths, can be used to advantage. In effect, the function of tower 10 is to artificially raise the ocean floor from an actual depth at the location of the lower end of the tower to an apparent depth corresponding to the upper end of the tower.

25 Tower 10 is composed of a series of components of modular nature which are prefabricated at a suitable onshore location, and then are brought to the offshore location at which the tower is to be installed. At the offshore location the tower components are assembled in serial order and are lowered into secure connection with ocean floor 11.

The components of the tower include a lower section 16 (see FIG. 2), an appropriate plurality of essentially identical central sections 17 (see FIG. 4), and an upper section 18 (see FIG. 5).

1 As shown in FIG. 1, when the several sections of the
tower are interconnected in serial order and the assembled
structure is secured to the ocean floor, there results an
elongate, positively buoyant, unguyed, tubular tower which
5 has a high slenderness ratio so that the tower is compliant
to, rather than resistant to, environmental loads such as
ocean currents and lateral drag forces applied to the tower
by such currents. By reason of its positively buoyant
characteristics, the principal design considerations which
10 apply to the tower are those of axial tensile loading and
transverse bending moment. Considerations involving com-
pressive loads on columns are not relevant to the effective
design of tower 10.

As installed on ocean floor 11, tower 10 provides at
15 least one, and preferably a plurality of riser ducts 22 (see
Fig. 4, e.g.) which extend along the entire length of the
tower, preferably principally externally of the tower struc-
ture per se. The riser ducts extend from connection points
20 (see Fig. 5) accessible from above at the upper end of
the tower to lower ends at the lower end of the tower. The
connection points are capable of receiving and mating with
conventional subsea drilling equipment, such as a blowout
preventer shown generally at 19 in FIG. 1 and in more detail
in FIG. 5. Each connection point 20 preferably has the
25 structure and configuration of a landing stump such as is
typically included in a landing base used in drilling off-
shore oil and gas wells in water depths of 300 feet or so.

Tower lower section 16 (see FIG. 2) is prefabricated
as a unit having a length substantially greater than the
30 fabricated length of any of the modular central sections 17
shown in FIG. 4; as shown in FIG. 2, the tower lower section
may have a fabricated length on the order of 100 feet (30
meters) or so. The lower section has a lower end corre-
sponding to tower lower end 15 which is defined by a base
35 structure 21 which defines a hollow housing at the lower end

1 of the tower. Within the interior of base structure 21, in
association with the lower ends of corresponding riser duct
sections 22, are located suitable structures from which
appropriate lengths of different diameter surface casing may
5 be hung off from the base structure in the course of drilling
oil or gas wells in ocean floor 11 through the riser ducts.
The riser ducts have upper ends connected to connection
points 20 at the upper end of the tower; see Fig. 5. The
tower lower section above base structure 21 is of decreasing
10 diameter proceeding upwardly along the lower section to its
upper end 23 where the lower section defines a component 27
of a connector adapted to mate coaxially with and to be
secured to a lower end of one of tower central sections 17.

Also, at its lower end, the tower lower section carries
15 means which adapt the tower, and the lower section thereof,
for connection to ocean floor 11 sufficiently securely to
enable the tower, when completed and rendered maximally
positively buoyant, to be held from upward movement away
from the ocean floor. For purposes which will become
20 apparent from the following description, in the case of
tower 10 as illustrated in the accompanying drawings, the
mechanism used to secure the tower to the ocean floor is an
elongate hollow tubular grouting stub assembly 24 which is
open at its lower end. The grouting stub assembly may have
25 a length on the order of 30-40 feet and may have a diameter
of 5-6 feet, as desired.

The tubular body 25 of the tower lower section may
have a diameter on the order of 15-18 feet (3.64-5.45 meters)
at its lower end and a diameter on the order of 14 feet (4.24
30 meters) or so at its upper end equal to the uniform diameter
of the body 26 of any of the essentially identical tower
central sections 17.

As shown in FIG. 3, in tower 10 there are six riser
ducts 22 disposed externally of the tower body to extend
35 parallel to the length of the tower at equally spaced

1 intervals about the circumference of the tower.

One of the several tower central sections 17 is shown in FIG. 4 as installed in the finished tower in end-to-end relation with coaxially aligned adjacent central sections.

5 The several tower central sections are essentially identical and are comprised principally of an elongate tubular body 26 and a number of sections of riser ducts 22; there are the same number of riser duct sections associated with each tower section as there are well connection points 20 defined
10 at the upper end of the tower. If the tower is to be used to drill a single well in ocean floor 11, the riser duct may be defined coaxially within the tower. However, if as preferred, and as shown in the accompanying drawings, the tower is to be used to drill a plurality of wells in ocean
15 floor 11, the riser ducts are defined externally of the tower body over substantially the entirety of the length of the tower except in association with tower upper section 18 as shown in FIG. 5. As shown in FIG. 4 with reference to the tower central sections, it is preferred that each
20 individual riser duct section 28 be carried at its upper end in a hanger structure 29 which extends radially outwardly from the upper exterior of the central section body 26. The upper end of each riser duct section is pendulously connected to a corresponding hanger structure to be secure from axial
25 motion relative to the adjacent central section body. Each hanger structure defines an upwardly open guide funnel 30 for guiding the lower end of the riser duct section carried by the tower section next-above the hanger structure into registry, in a stab action manner, with the upper end of the
30 riser duct section carried by the hanger structure. The lower end of each riser duct section 28 is configured to make a stab-type mating connection with the upper end of the riser duct section on another section of the tower.

1 Preferably the connection between mated riser duct sections affords limited axial motion between the duct sections without impairment of continuity of fluid flow through the overall riser duct.

5 Each tower central section body 26 terminates at its lower end in a connector 31 and at its upper end in a connector 32. Connectors 31 and 32 are configured to mate and cooperate with each other for securing the tower central sections in coaxial alignment with each other. These
10 connectors are also designed to hold against substantial upward loads applied to them. Each connector 32 is identical with connector 27 at the upper end of tower lower section 16.

The interior space of at least some of the bodies 26
15 of the tower central sections are arranged to define an airtight buoyancy chamber which extends substantially the entire length of the central section. Those central tower sections which define internal buoyancy chambers are equipped with buoyancy control means for controllably
20 flooding and purging the respective buoyancy chamber, such means including controllable means for supplying compressed air to and venting air from the buoyancy chamber and controllable means for enabling water to flow into and out of the chambers, as desired. The buoyancy control means in-
25 cludes a suitable air supply, such as an air injection conduit 33 as shown in FIG. 4, and appropriate valves operable from remote locations or operable in response to the existence of predetermined local pressure differentials. As will be apparent from the following description, the
30 buoyancy control means associated with the several buoyancy chambers provided in tower 10 are operable to establish three different buoyancy conditions in tower 10 at different times, in the course of its installation, namely:

1) a condition of overall substantially neutral
35 or slight positive buoyancy in the course of

- 1 interconnection of the several tower sections
in sequence,
- 2) a condition of overall negative buoyancy when the
tower has been fully assembled, has been landed on
5 ocean floor 11, and is in the course of being
secured to the ocean floor, and
- 3) a condition of overall substantial positive
buoyancy after the tower has been landed upon and
secured to the ocean floor.
- 10 In all of these three overall buoyancy conditions, the
center of buoyancy of the immersed tower structure is
located in the tower substantially above the center of
mass of the tower structure to assure that the tower itself
always seeks a vertically erect attitude in the water.
- 15 The prefabricated modular sections of tower 10 include
an upper section 18 shown in FIG. 5. Tower upper section 18
may have a prefabricated length on the order of 50 feet
(15.2 meters), whereas the central sections may have a
prefabricated length on the order of 40 feet (12.1 meters).
- 20 As shown in FIG. 5, tower upper section 18 has a body 35
which is of substantially increased diameter relative to
the body 26 of any of the tower central sections; the
diameter of the tower central section bodies may be on the
order of 14 feet (4.2 meters) whereas the diameter of the
25 tower upper section may be on the order of 25 feet (7.6
meters). The tower body 35 preferably has a cylindrical
upper portion 36 and an inverted frusto-conical central
portion 37 connected to the lower end of body section 36
at its upper end and connected at its lower end to a body
30 central portion 38 which has a diameter corresponding to
the diameter of a tower central section body 26.

As noted above, there is defined externally of tower
upper section 18 at its upper end at least one, and
preferably a plurality of, connection points 20 for the

1 drilling and production of a corresponding number of subsea wells which are to be drilled through tower 10 after installation of the assembled tower on ocean floor 11. Where a plurality of connection points are defined at the
5 upper end of the tower, these connection points are defined at regularly spaced intervals around the circumference of a circle disposed concentrically of a tower axis 39; this circle may have a diameter of 16 feet (4.8 meters) as shown in FIG. 5. As noted above, each connection point is defined
10 to have an external configuration similar to the configuration of a landing stump of the type regularly encountered in landing bases for shallow water subsea wells. Also, there are preferably provided, in association with each connection point, a pair of upwardly extending guide posts
15 40 in predetermined spaced relation to the corresponding connection point. The guide posts enable subsea drilling and production equipment to be guided into registry with each connection point 20 according to procedures well known in the art pertinent to the drilling of shallow water subsea
20 wells.

Tower upper section 18 also includes for each connection point 20, a section 28 of riser duct 22. In the case of the tower upper section, the riser duct sections have a portion of their lengths disposed within the interior of
25 body 35, but have their lower portions located outside the body so that the upper riser duct sections are arranged to mate with the riser duct sections carried by the tower central section immediately therebelow in the manner described above. The upper end of each riser duct upper
30 section is connected within tower body 35 to a corresponding connection point 20.

The body 35 of tower upper section 18 defines therein a buoyancy chamber. This buoyancy chamber is connected to the buoyancy control means previously described. Because of
35 the substantially greater internal volume of body 35, it is

1 apparent that the tower upper section is arranged to
provide, in the assembled tower, substantially greater
positive buoyancy than can be provided by any one of the
tower central sections having buoyancy chambers therein.

5 FIG. 6 illustrates the installation, completed (free
standing), drilled, and produced stages of tower 10 in water
having a depth in the range of from 2,000 to 10,000 feet
(606-3030 meters). Preferably, the installation of tower 10
is carried out by use of a floating derrick barge 45.
10 However, before arrival of the derrick barge at the intended
site of the tower, the sea floor immediately below the
installation site is prepared by the use of a floating
drilling platform such as a dynamically positioned drillship
12. Preparation of the ocean floor to receive tower 10 may
15 include the drilling of a hole of desired depth and diameter
into the ocean floor. The hole as so drilled preferably has
a diameter at its upper end which is less than the diameter
of the circle associated with the location of the lower ends
of riser ducts 22 at tower base structure 21. This hole is
20 drilled through a guide structure which is placed permanently
on the ocean floor. The guide includes an upwardly-open
funnel type structure having a diameter at its lower end
somewhat larger, but not much larger, than the diameter of
tower base structure 21. The desired hole is drilled cen-
25 trally through this funnel-type structure. When the hole
has been drilled to the desired depth into a stable geo-
logical formation below the ocean floor, the hole is filled
with a slow setting grout or cement.

 Derrick barge 46 or the like (e.g., a semi-submersible
30 construction platform as shown in FIG. 11) is then brought
into position over the grout-filled hole for use in assem-
bling and lowering the tower structure to the ocean floor.
The tower lower section 16 is floated in a horizontal atti-
tude to the desired offshore location, and then is ballasted
35 so that it occupies a vertical floating attitude at the

1 ocean surface. The upper end of the tower lower section is
suitably guyed to barge 45 to have its upper end held at a
predetermined position to the side of the barge within the
range of a crane 46 carried by the barge. Then the lower-
5 most tower central section 17 is lowered into registry with
and mated to the upper end of the tower lower section, and
this assembled pair of tower sections is then controllably
lowered, relative to the derrick barge, so that the upper
end of the lowermost central section assumes a position
10 above the water surface. Then, in sequence, further tower
central sections are mated with and connected to the tower
sections previously interconnected. Throughout this process,
the assembled tower sections are maintained in a floating
vertical attitude by controllably ballasting the assembled
15 tower sections, so that the combination of the several
assembled sections has slight net positive or neutral
buoyancy with a center of gravity disposed substantially
below its center of buoyancy. After connection of the
last tower central section into place, the tower upper
20 section 18 is mated to the tower. At this point the tower
has been completely assembled, but its lower end is still
about 300 feet (90 meters) or so above ocean floor 11.

The assembled tower is rendered negatively buoyant in
such a manner that the center of buoyancy of the tower
25 remains a substantial distance above its center of gravity.
The negatively buoyant tower is then suitably lowered from
the derrick barge into registry with the guide cone previ-
ously disposed on the ocean floor at the time the pre-
installation preparation operations at the sea floor were
30 performed. As the tower is lowered into the submerged cone
at the sea floor, the grouting stub assembly 24 at the lower
end of the tower penetrates into the slow setting grout in
the prepared hole. The tower is maintained in a negatively
buoyant condition and in a vertically erect attitude for
35 such time as is necessary for the slow setting grout to

1 harden around grouting stub assembly 24, thereby to securely
anchor the tower to the ocean floor. When the grout has
hardened, air is forced into the several buoyancy chambers
of the installed tower to render the tower strongly posi-
5 tively buoyant with the center of buoyancy of the installed
tower disposed substantially above its center of mass.

In this manner, an unguyed, positively buoyant,
compliant tower structure is assembled and installed on the
ocean floor. This is the condition of affairs shown at 50
10 in FIG. 6 in which the upper end of tower 10 is disposed a
selected distance, say about 300 feet (90 meters), below
water surface 13. At such a depth, the upper end of the
tower is essentially isolated from the dynamic effects of
wave action on the ocean surface. In this condition the
15 pressure of air contained in the several buoyancy chambers
of the tower is at substantially the same pressure as
ambient water pressure. Accordingly, the buoyancy chambers
present in the tower need be designed only as buoyancy
chambers, not as pressure vessels designed to withstand
20 exploding or imploding pressure differentials. The positive
buoyancy of the installed tower is greater than the immersed
weight of all structures and equipment which may thereafter
be landed upon the tower as it is thereafter used in the
drilling and production of subsea wells. This positive
25 buoyancy assures that the tower will not be subjected to
any net downward load at its upper end so as to balance as
a column loaded in compression.

Dynamically positioned drillship 12 is then brought
into position over the upper end of the tower, as shown in
30 FIG. 6, for the drilling of that number of subsea wells
below the tower as there are connection points 20 defined at
the upper end of the tower. These wells are drilled in
sequence, using equipment and procedures of the type which
have been developed and perfected for use in the drilling of
35 wells in substantially shallower water depths. After the

1 wells have been drilled and completed, a dynamically positioned production vessel 55 is brought into position over the tower for the production of oil or gas from the subsea wells which have been drilled and completed through the tower.

5 Tower 10 may be installed and used to advantage in waters 2,000 to 10,000 feet (600-3000 meters) or more in depth. The tower can be used for the drilling and production of subsea oil and gas using surface equipment taken from the worldwide inventory of offshore equipment designed for use
10 in substantially shallower depths of water.

FIGS. 7, 8 and 9 illustrate another manner of coupling a riser duct 41 in a tower 42 according to this invention. In tower 10, described above, the several riser ducts 22 are assembled together as the several tower sections are inter-
15 connected during assembly of the tower body. In the case of tower 42, however, the riser ducts 41 (only one of which is shown) are installed in the tower after the tower is at least partially assembled. Tower 42 has its sections cooperatively structured and interconnected either in accord
20 with the foregoing description pertinent to tower 10 or in accord with the tower structure modification illustrated in FIG. 10 and described below.

Tower 42 is composed of base, upper and central sections, the base section 43 and some of the central sections
25 44 being shown in FIG. 7. Base section 43 defines, at selected locations around its axis which correspond to the locations of the connection points 20 in the upper section of the tower, a plurality of receivers 47 for the lower ends of respective ones of risers 41. Each receiver 47 includes
30 an upwardly open, upwardly flared guide bell 48 for cooperation with the lower end of the respective riser for guiding the riser end, as it is lowered along the tower body toward the receiver, into a desired form of engagement between the riser end and the receiver. The riser ends and
35 the receivers are cooperatively structured, as by threads or

1 the like, so that the lower end of each riser can be axially
inserted into and securely connected to its respective
receiver, and so that the resulting connection can hold the
riser end against upward motion when tension is applied to
5 the riser.

Selected ones of the tower central sections 44, but
not necessarily each central section, also carry riser guide
assemblies 49 which, as shown in FIG. 8, are substantially
in the form of tubes 51 having flared upper ends 52;
10 the tubes generally resemble funnels having their axes
aligned parallel with the length of the tower. The
tubes are fixedly mounted by suitable support arms to
the exterior of each adjacent tower section. The guide
assemblies are arranged in a pattern about the tower
15 section which corresponds to the pattern of connection
points at the upper end of the tower upper section.
Each tube 51 has an inner diameter which is a sufficiently
small amount greater than the diameter of the adjacent
part of a riser duct 41, as installed in the tower, to
20 both loosely cooperate with the adjacent riser and
enable the riser portion therebelow to pass through the
tube. Each guide assembly 49 functions to hold the riser
duct from significant movement laterally relative to the
tower body while affording axial movement of the riser in
25 the tube as required in response to bending of the tower
body.

If tower 42 is, say 8000 feet (2424 meters) long, it
may be desirable to secure the riser ducts to the tower body
against axial motion at one or more spaced locations along
30 the lengths of the risers. In such event, one or more riser
guide assemblies 53 are provided on the exterior of corre-
sponding tower body sections. As shown in FIG. 9, each
guide assembly 53 is generally in the form of a guide
assembly 49, but has a gradually tapering lower section 54

1 (instead of a constant diameter tube 51) below its flared
upper end 52. The minimum internal diameter of tapered
section 54 preferably is no smaller than any tube 51 below
it in the tower.

5 A coupling, such as threaded coupling 59 shown in
FIG. 9, is provided in each riser duct at each guide
assembly 53 to facilitate tensioning of the riser
therebelow and tensioned connection of the portion of the
riser thereabove to the tensioned portion of the riser
10 having its upper end connected to the guide assembly.
For example, assume that guide assemblies 53 are disposed
in an 8000 foot (2424 meter) long tower at the 4000 foot
(1212 meter) level above the lower end of the tower, thereby
dividing each riser into upper and lower halves which are
15 affixed to the tower body at their lower 56 and upper 57
ends. At the appropriate time during or after the assembly
of the tower, after connection to the tower of the body
section carrying guide assemblies 53, the lower half of each
riser duct is passed through guide assemblies 53 and 49 into
20 secure connection of its lower end with a corresponding
receiver 47. The upper end 57 of each lower half of each
riser is then subjected to an upward load to establish a
desired tension in the riser lower half, and such upper end
is secured to its guide assembly 53 to maintain such tension;
25 such a connection can be established using conventional oil
drilling techniques and equipment such as slips 58 shown in
FIG. 9. Thereafter, at the appropriate time, the lower end
56 of the upper half of each riser duct can be connected to
riser half end 57 and can have its upper end secured under
30 tension in a similar manner to the respective connection
point at the upper end of the tower.

If the riser duct mounting arrangement illustrated
in FIGS. 7, 8 and 9, for example, is used in a tower ac-
cording to this invention, the vertical distance between

1 locations at which each riser is fixed to the tower body
should be sufficiently great to keep riser duct stresses,
due to elongation of the riser relative to the tower body
in response to bending of the tower, at acceptable levels.
5 For example, if the centerline of a riser duct is 8 feet
(2.42 meters) off the centerline of the tower body which
is subjected to 6° bending over a 4000 foot (1212 meters)
length of riser between fixed points along the riser, the
differential elongation of the riser will be 9.6 inches
10 (24.38 centimeters) which can be accommodated over such
length of the riser without adverse effect.

It will be appreciated that any tower according to this
invention will be subjected to lateral forces in use due to
one or more ocean currents flowing past the installed tower.
15 Such forces will cause the tower to bend, i.e., not be truly
vertical in use. Such bending loads have been accommodated
in prior submerged tower proposals by the use of hinge
connections between the tower and its base at the ocean
floor; Carden joints or other freely movable joints or con-
20 nections have been proposed. The disadvantage of a freely
movable connection at the lower end of a tower according to
this invention would result in very high bending stresses
being developed in the risers which extend along the tower
to its base and into the ocean floor. To avoid the genera-
25 tion of high bending stresses in the present riser ducts,
while also providing accommodation for current loads applied
to the tower, a tower of this invention may incorporate a
resilient hinge characteristic in its lower portion as shown
in FIG. 10.

30 FIG. 10 illustrates a tower 60 according to this
invention in which the several body sections immediately
above base section 61 define a resilient hinge arrangement
62. These body sections, in one form of the resilient
hinge which has been analyzed, may encompass 424.2 meters
35 of the total height of the tower. These body sections

1 differ in diameter so that, proceeding upwardly from base
section 61, the tower body progressively diminishes in
diameter to a minimum diameter at 63 and then progressively
increases to a larger diameter at 64 above which the tower
5 body diameter preferably is constant to the tower upper
section. Thus, the tower body proximately above its base
section has a reduced bending resistance characteristic in
which the transverse moment of inertia of the body first
diminishes and then increases. However, because the in-
10 stalled tower has substantial net positive buoyancy, the
lower tower sections must be able to withstand the substan-
tial upward loads due to such buoyancy; for this reason and
others, it is desired that as the diameters of the tower
body sections change, the wall thicknesses of the sections
15 also vary inversely with the diameters. In FIG. 10, data is
given for the relation between tower section diameter in
meters and wall thickness in centimeters for a resilient
hinge arrangement which has been analyzed for a 6000 foot
(1818 meter) tower. Such hinge arrangement is composed of 26
20 tower sections (arranged in groups of 2 sections each), with
each section 50 feet (15.15 meters) in length.

Tower 60 has an hourglass configuration over its lower-
most extent. Tower 60 relies upon buoyant forces to keep
the tower generally vertical in use. The resilient hinge
25 arrangement has the further advantage that the overturning
moment at the base of the tower is substantially reduced,
thus reducing the complexity and extent of the structure
required to secure the tower to the ocean floor. The con-
ductor tubing on the circumference of the base, which extends
30 into the sea floor as a necessary element of an oil or gas
well, can provide the necessary piles to hold the base
against this reduced overturning moment due to current
forces.

1 A tower structure according to this invention is a
long, slender structure. Accordingly, during the assembly
procedure described generally above, the assembled sections
of the tower form a floating unit which has low waterplane
5 area relative to total volume, and such area is defined
by cylindrical elements. As a result the floating unit
of assembled tower sections has a low tons-per-inch
characteristic, which means that it experiences a substan-
tial increase in draft for each ton of applied load.
10 Such a low tons-per-inch characteristic can be a problem
during the tower assembly process which is performed at
sea over the location where the tower is to be installed.
For example, the low tons-per-inch characteristic means
that the unit of assembled sections does not move ver-
15 tically in response to waves moving past it, and also any
miscalculations or unexpected situations concerning the
buoyancy of the unit (such as unexpected sea water
temperature or salinity at the surface or below) can
cause the unit to be more sensitive to applied loads than
20 expected. For these reasons, and also for other reasons
which will be made apparent, it is preferred that the
tower assembly process (illustrated generally in FIG. 6
and described briefly above) be carried out at a floating
work station (such as semi-submersible crane barge 45)
25 in conjunction with an auxiliary floatation structure 70
shown in FIGS. 11-14.

Floatation structure 70 (also called a float)
preferably is a positively buoyant, vertically elongate
body 71 having a central passage 72 axially through it
30 sized to permit the passage of the tower central and upper
sections vertically through it. The body is generally
hollow, so as to define internal buoyancy controlling
ballast chambers 73, and suitable machinery 74 is provided
in the body for pumping sea water into and out of the ballast
35 chambers. Body 71 itself preferably has a relatively low

1 tons-per-inch characteristic so that it is relatively insen-
sitive to heave due to wave action, thereby providing a
stable work platform at the upper end of the unit of
assembled tower sections. The float body, however, has
5 sufficient positive buoyancy that it can support the
assembled tower sections in the event that such unit should
become negatively buoyant by a small amount. If, as may be
the case, a tower central section has a length of 70 feet
(21.2 meters) between flanged upper and lower ends, the
10 float body may have a length of 80 feet (24.24 meters) or so
to provide a base for vertical tracks 75 along which holding
devices 76 may move. The holding devices (see FIGS. 12, 13
and 14) cooperate between the upper portion of the unit of
assembled tower sections and the float body and serve to
15 keep the unit centrally aligned in float passage 72 and to
hold the unit vertically relative to the float as the
buoyancy of the unit is periodically adjusted and as the
unit is lowered relative to the float. The holding devices
also enable the unit and the float to be locked together to
20 float as an entity in the event of a storm requiring the
unit and the float to be released from barge 45.

Preferably there are three sets of vertical tracks 75
and vertically drivable holding devices 76 provided at
equally spaced intervals around the circumference of float
25 passage 72; only one of these sets is shown in FIGS. 12-14.
Tracks 75 are defined by a pair of laterally spaced vertical
rails 77 which define a vertical path of movement for a cart
78 over a distance a selected amount greater than the length
of a tower central section, such as section 17. The cart
30 is mounted to the rails via rollers 79 and is driven up and
down along the rails by a loop of chain or wire rope 80, to
which the cart is connected as at 81, reeved over an idler
pulley 82 adjacent the lower end of passage 72 and over a
drive wheel 83 located near the upper end of the float body
35 and driven by a suitable motor 84. The cart drive system is
positive and can be locked.

1 The cart has a slide member 85 which is movable
radially toward and away from the axis of passage 72 in
response to operation of a double-acting linear actuator 86
coupled between the slide and the cart body. The slide
5 carries a support block 87 which is engageable with the
underside of the peripheral flange 32 around the upper
end of a tower central section 17 and by which the section
is connected to the next-adjacent central section of the
tower via its lower flange 31. Cooperation of block 87
10 with a flange 32 holds the unit of assembled tower sections
in the float passage from moving downward past the cart.
Upward movement of the unit past the cart is prevented by
engagement of a hold-down dog 88 with the upper side of a
flange 31 mated with flange 32. Dog 88 is rotatable into
15 and out of overlying relation with flange 31 in response to
operation of a bidirectional rotary actuator 89 carried on
slide 85 near block 87. The slide is movable radially of
the passage by an amount adequate to allow mated flanges 31
and 32 to pass downwardly past the cart at the appropriate
20 time.

 Preferably, float 70 also includes vertically fixed
holding devices near its upper end which are also engage-
able with a pair of mated flanges 31 and 32 for holding
the unit of tower sections in the float in the interval
25 while holding devices 76 are being released from the next
lowest set of flanges and raised into engagement with the
flanges held by the vertically-fixed holding devices.
There can be three vertically-fixed holding devices at
equally spaced locations around passage 72 intermediate
30 tracks 75. In this way, a unit of assembled tower sections
can be securely held in the float as a further tower
section is added to the unit, and as the enlarged unit is
then ballasted to have the desired amount of positive
buoyancy and as the enlarged unit is lowered through the
35 float so that the upper end of the enlarged unit is

1 positioned closely above the upper end of the float as
shown in FIGS. 11 and 12.

If desired, each of tracks 75 and the related cart
drive mechanisms, and also the vertically-fixed holding
5 devices if present, can be mounted on rams or the like
for movement radially toward and away from the axis of
passage 72. In this way the float can be defined to be
useful with tower sections of different diameter, such
as the tower sections defining the resilient hinge
10 feature shown in FIG. 10.

In the event of a storm during the process of
assembling tower 10, e.g., it may become prudent to cast
the partially assembled tower and its auxiliary
floatation structure off from barge 45. In such event,
15 the float 70 is deballasted to have substantial positive
buoyancy, and the partially assembled tower and the
float are secured together via holding devices 76, carts
78 and the cart drive mechanisms.

After all sections of the desired tower have been
20 assembled in the desired serial order, the tower will
still be disposed above the ocean floor by an amount
about equal to the desired submergence of the upper end
of the installed tower. To safely lower the assembled
tower to the sea floor, and to facilitate further ballast-
25 ing of the tower as described above, a plurality of
temporary lowering spools 90 (see FIG. 15) can be con-
nected serially to the tower upper section. The lowering
spools are substantially dummies of the tower central
sections, and may be of substantially the same diameter as
30 the central sections (see FIG. 15) or of the same diameter
as the upper section. The spools are provided for tempo-
rarily establishing a substantial physical connection
between the top of the landed tower and the water surface,
such as to enable operation of the manipulator shown in FIG.
35 16 to operate the tower ballast system during the course of

1 rendering the tower negatively buoyant and then finally
strongly positively buoyant. The connection of the lower-
most lowering spool to the upper end of the tower preferably
is remotely releasable, as by use of explosive bolts to
5 define such connection.

It was earlier noted that at least some of the bodies
26 of the tower central section 17 are arranged to define
airtight buoyancy chambers which are controllably ballasted
during serial interconnection of the tower sections and
10 thereafter to impart desired conditions of buoyancy to
the assembled sections. While the compressed air for use
in operating such a ballast system can be supplied to the
several tower buoyancy chambers by ducting installed
within the interior of the tower, it may be more conve-
15 nient to use an external air supply system 93 of the
character shown in FIG. 17 in combination with an external
submersible manipulator 94 as shown in FIGS. 16 and 18.

Where an external compressed air supply system and
manipulator are used in conjunction with the buoyancy
20 chambers of the tower, the use of temporary lowering
spools 90 is especially advantageous; such spools are not
disconnected from the installed tower until the final
buoyancy condition of the tower has been established.

As shown in FIG. 17, an external air supply system
25 includes a single compressed air and vent line 95
extending along the exterior of the tower over the length
of the tower extending to the lowermost internal buoyancy
chamber. Near the lower end of each tower section defin-
ing a buoyancy chamber, a branch air line 96 extends
30 from main line 95 into the adjacent chamber via a control
valve 97 located outside the chamber in a predetermined
position. An isolation valve 98 is located in the main
line a selected distance below each branch line 96.

Inside each chamber, each branch line extends upwardly
35 to a discharge end located closely adjacent to the closed

1 upper end of the chamber. Also, each chamber is equipped
adjacent its lower end with a water flood and discharge
line 99 controlled by a valve 100 located outside the
chamber. Valves 97, 98 and 100 for all of the chambers
5 are vertically aligned with each other on the exterior
of the tower, and the valves for one chamber are disposed
in a predetermined pattern which is repeated in the valve
patterns for all other chambers. Each valve has a rotary
actuator which is especially configured to be engaged and
10 operated by a respective operating head on manipulator 94.

As shown in FIGS. 16 and 18, a pair of light-weight,
nonstructural rails 101 are mounted to the exterior of the
tower and extend upwardly along the tower from adjacent the
lowermost set of valves 97, 98, 100 to the top of the tower
15 and also along the lowering spools, if used. The rails are
nonstructural in that their presence is not relied upon to
define any of the strength or structural integrity of the
tower. The rails are located on either side of the line of
valves 97, 98, 100, and provide a track for guiding vertical
20 movement of manipulator 94. The manipulator is provided as
a cart-like assembly 102 which is held captive between the
rails by rollers 103. Cart 102 is negatively buoyant so
that it is urged downwardly by gravity along the rails; the
cart is connected to the lower end of a power, control, and
25 hoist cable assembly 104 which extends up the tower to a
suitable winch mechanism located on barge 45. The cart
carries three rotary actuator heads 105, one for each of
valves 97, 98 and 100 (only two of these heads are shown
in FIG. 16), in the same pattern on the cart as is defined
30 by the relative positions of each set of valves 97, 98, 100.
Each actuator head 105 is connected to a suitable actuator
drive mechanism 106 operable to turn the corresponding head
in either direction. The actuator drives may be electrical
mechanisms powered by power supplied via cable 104 and con-
35 trolled by suitable control signals supplied via the cable
to a suitable control circuit carried by the cart.

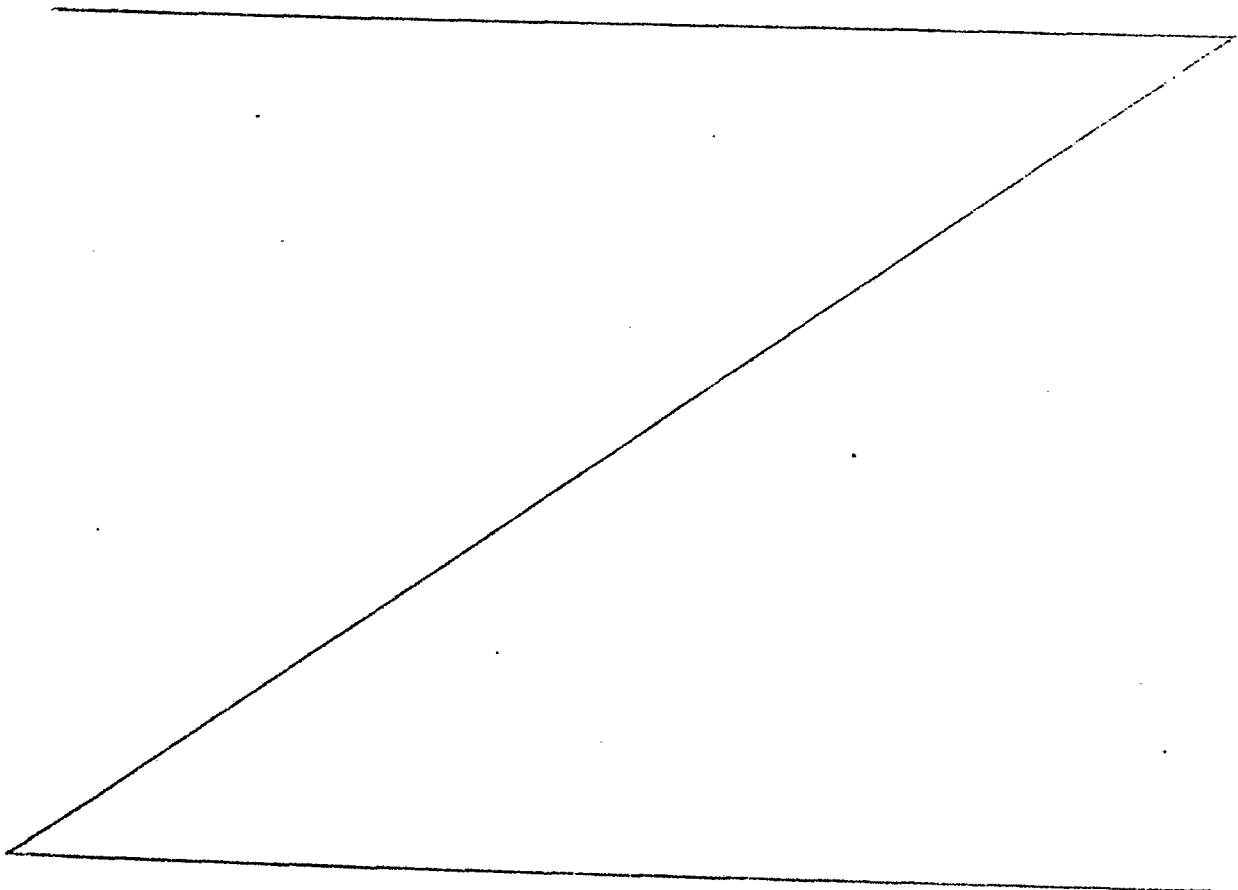
1 Cart 102 can be located at a desired position adjacent
each set of valves 97, 98, 100 by cooperation of a pair of
retractable detent dogs 107 carried by the cart with position
stop members 108 carried by rails 101. The dogs can be
5 turned between stop-engaging and stop-clearing positions
by a suitable rotary actuator (not shown) located on the
cart and powered and controlled in the same manner as
actuators 106. In this way, the manipulator can be
precisely positioned adjacent each set of valves along
10 the tower so that the several actuator heads register with
their respective valve actuators for operation of the
valves in response to operation of actuator mechanisms 106.

As each tower section is added to the tower during
the assembly process, main air line 95 is extended and
15 connected to a compressed air supply line 109 which is,
in turn, connected to an air compressor 110 aboard barge
45 (see FIG. 11) or to atmosphere, as appropriate at
any time.

As set forth above, adjustment of the buoyancy of
20 all interconnected tower sections is required during the
assembly and lowering of the tower, and during and after
the course of securing the tower to the ocean floor.
All necessary adjustments to the buoyancy of the tower
can be made readily and safely by manipulator 94 and
25 air supply and vent system 93. To increase the buoyancy
of a desired tower section, the manipulator is lowered
along rails 101 until it is positioned correctly by
dogs 107 and stops 108 adjacent the valves for that
tower section. Main tower air line 95 is connected to
30 compressor 110, all isolation valves 98 in line 95 above
the tower section of interest being open and the isolation
valve for the section of interest being closed. Valves 97
and 100 of the section of interest are opened so air can
flow into the section buoyancy chamber through branch
35 line 96 and so water in the chamber can be forced out

via line 99. When sufficient water has flowed out of the chamber, valves 97 and 100 are closed; the interior of the adjacent buoyancy chamber is then pressurized to or substantially to ambient pressure conditions. On the other hand, if the buoyancy of a tower section is to be reduced, main tower air line 95 is vented to atmosphere so that similar operation of valves 97 and 100 results in water being forced by ambient pressure into the chamber with air being expressed from the top of the chamber via branch line 96 and line 95; if necessary, main line 95 can be connected to the suction side of compressor 110 to create a reduced pressure in line 95 to assist flooding of a chamber.

If desired, lights and a television camera can be mounted to manipulator cart 102, to enable visual monitoring of the operation of the manipulator aboard barge 45.



CLAIMS:

1. An installation for use in drilling subsea hydrocarbon wells in substantial water depths, the installation providing a drilling wellhead at a submerged location substantially above an ocean floor and enabling the use of equipment normally useful only in waters of substantially shallower depth, and being characterised by an elongate, slender, unguyed, positively buoyant tower structure (10 or 42 or 60) having a lower end secured to the ocean floor at a site at which at least one subsea well is to be drilled and having an upper end disposed a substantial distance above the ocean floor and a selected distance below the water surface, the tower having a center of buoyancy located along its length a substantial distance above its midlength whereby the tower structure stands erect on the ocean floor, and at least one drilling riser duct (22 or 41) coupled to the tower structure and extending therealong from a duct lower end disposed in association with the tower structure lower end to a duct upper end associated with the tower structure and accessible from above the tower structure.
2. An installation according to claim 1 wherein the riser duct, if disposed other than coaxially of the tower, is secured from lateral movement relative to the tower yet is afforded limited axial movement relative to the tower.
3. An installation according to claim 1 or 2 wherein the tower has substantial net positive buoyancy distributed principally along the upper extent of the tower.
4. An installation according to any preceding claim including guide means (40) at the upper end of the tower

and accessible from thereabove for guiding equipment lowered to the tower into a selected position on the upper end of the tower relative to the upper end of the tower relative to the upper end of the riser duct.

5 5. An installation according to any preceding claim wherein the tower (60) is of tubular configuration along its length and has a diameter along a substantial central portion (62) of its length which is reduced relative to the diameter of the tower adjacent its upper and lower ends.

10 6. Apparatus useful for defining an installation as claimed in claim 1 characterised by

15 a. a tubular tower base section (16 or 43 or 61) defining at a lower end thereof, means (24) adapted for connecting the section to the ocean floor and for holding the section from upward movement when subjected to substantial upwardly directed force, the base section having an upper end adapted to mate coaxially with and be secured to a lower end of one of a plurality of tower structure central sections (17 or 44 or 63),

20 b. a tubular tower upper section (18) having a lower end adapted to mate coaxially with and be secured to an upper end of one of the tower central sections and having an upper end defining at least one connection point (20) for the drilling of a subsea hydrocarbons well, the connection point being arranged for access thereto and for connection of selected equipment thereto from above,

25 c. A plurality of tower structure tubular central sections (17 or 44 or 63) each adapted at upper and lower ends thereof to mate coaxially with and to be secured to the lower and upper ends of others of the central sections or the upper end of the base section or the lower end of the upper section, as appropriate, the central sections being sufficient in number and aggregate length that when the central sections are connected in series between

30

the base and upper sections there results a tower structure having a length equal to the distance between the selected depth and the ocean floor at said offshore location,

5 d. buoyancy means (35) within the upper section and buoyancy means (26) within at least some of the other tower sections operable for controlling the buoyancy of the corresponding tower section,

10 e. whereby, upon serial interconnection of all of the tower sections and connection of the lower section to the ocean floor, there results a submerged tower as aforesaid, and

15 f. at least one tubular riser duct (22 or 41) carried by the tower in a selected position relative to the tower and extending along the entire length of the tower, each duct being coupled to the tower at selected locations therealong to be secure from significant lateral movement relative to the tower, there being the same number of riser ducts as there are connection points (20) defined at the upper end of the tower upper section, the ducts
20 being connected at their upper ends to the respective connection points.

25 7. Apparatus according to claim 6 wherein the buoyancy means includes means (95 to 100) for varying the amount of positive buoyancy of at least some of the tower sections with which the buoyancy means is associated.

30 8. Apparatus according to claim 6 wherein the buoyancy means includes means (93) for introducing air into the tower sections with which it is associated and for maintaining air pressure in at least some of the tower sections at a pressure substantially equal to the ambient pressure outside the tower section.

9. Apparatus according to claim 8 wherein the tower

upper section is defined to contain air at a pressure greater than the ambient pressure outside the section.

10. Apparatus according to claim 6 wherein the tower upper section has an average cross-sectional area transversely of its length which is greater than the average transverse cross-sectional area of the other tower sections.

11. Apparatus according to claim 6 wherein the tower upper section defines a plurality of connection points at its upper end in a predetermined pattern relative to the axis of the section.

12. Apparatus according to claim 6 wherein the riser ducts are disposed externally of the tower central sections and at least partially externally of the tower upper and lower sections.

13. Apparatus according to claim 12 wherein each riser duct is defined by a plurality of duct sections (28), there being one section of each riser duct for each tower section, each duct section being carried by the corresponding tower section for mating at at least one end thereof with an adjacent end of an adjacent section of the corresponding riser duct upon mating of the related tower section with another tower section.

14. Apparatus according to claim 13 wherein the riser duct sections associated with the tower central sections include connection means for interconnecting the duct sections with duct sections associated with an adjacent tower section, the connection means affording limited axial movement between interconnected duct sections.

15. Apparatus according to claim 13 including connections (29, 30) means for connecting the riser duct sections (28) to the corresponding tower sections, the connection means securing the duct sections from lateral movement while affording limited axial movement relative to the corresponding tower sections.

16. Apparatus according to claim 6 wherein the tower central sections (at 62) have an average transverse area per unit length less than the average transverse area per unit length of the tower upper and lower sections.

17. Apparatus according to claim 6 wherein the tower lower section includes means (24) at the lower end thereof adapting the section to be cemented to the ocean floor.

18. Apparatus according to claim 6 wherein the aggregate length of all of the tower sections is approximately 300 feet (90 meters) less than the water depth at said offshore location.

19. Apparatus according to claim 6 wherein the riser ducts (41) are under tension between lower ends thereof connected to the tower base section and upper ends thereof connected to the tower upper section, and riser guide assemblies (49) carried by selected ones of the tower sections externally thereof loosely co-operating with the riser ducts for constraining the riser ducts from significant lateral movement relative to the respective tower sections while affording axial motion of the riser ducts relative to the respective tower section.

20. Apparatus according to claim 19 wherein at least one of the riser guide assemblies (53) for each riser duct, at a location along the riser duct intermediate its upper

and lower ends, is structured in co-operation with the structure of the riser duct for holding the riser duct secure from axial motion relative to the respective tower section and for providing a support relative to which the riser duct therebelow may be subjected to tension.

21. Apparatus according to claim 19 or 20 wherein each riser guide assembly (49 or 53) comprises a tubular structure sized for the passage of the riser duct there-through and having an upwardly open flared upper end (52).

22. Apparatus according to claim 6 wherein the tower central sections (at 62) for defining a selected portion of the length of the tower structure proximately adjacent the base section (61) are co-operatively related in structure and dimension to cause the tower structure centrally of such selected portion to have a reduced bending resistance characteristic, which characteristic progressively increases proceeding in opposite directions along such selected portion of the tower structure.

23. Apparatus according to claim 22 wherein said tower central sections for defining said selected portion of the length of the tower are co-operatively arranged to define a resilient hinge section of the tower structure in which, proceeding upwardly along the tower structure from the lower end to the upper end of the hinge section, the tower sections are first of progressively decreasing diameter and then of progressively increasing diameter.

24. Apparatus according to claim 23 wherein, throughout the tower hinge section, the wall thicknesses of the several tower central sections are inversely related to the diameters of the central sections.

25. Apparatus according to claim 6 further comprising

an auxiliary floatation structure (70) useful in the serial interconnection of the several tower sections to define the tower structure, the floatation structure having substantial positive buoyancy and including holder means (76) releasably engageable with selected portions of vertically disposed interconnected tower sections for holding such interconnected tower sections from movement vertically relative to the floatation structure, and drive means (80 to 84) for controllably moving the holder means vertically relative to the floatation structure.

26. Apparatus according to claim 25 wherein the auxiliary floatation structure is substantially annular and is arranged for interconnection of the tower sections and for movement of the interconnected sections therethrough.

27. Apparatus according to claim 25 including ballast means (73, 74) operable for controlably varying the positive buoyancy of the auxiliary floatation structure.

28. Apparatus according to claim 7 wherein the means for varying the amount of positive buoyancy comprises a main air flow duct (95) extending along the length of the tower from the top thereof to the lowermost tower section which is to have its buoyancy varied, a valved branch air flow line (96) from the main line into each section which is to have its buoyancy varied, each branch line having an open end adjacent the top of the interior of the respective tower section, and a valved water flow line (99) communicating from the lower interior portion of each respective tower section to the exterior thereof, the main air flow line being connectible alternately to a source of compressed air and to either a source of air at subatmospheric pressure or to atmosphere.

29. Apparatus according to claim 28 wherein the valves

(97, 98, 100) for each branch air flow line and each water flow line are operable from the exterior of the respective tower sections.

5 30. Apparatus according to claim 29 wherein the valves associated with each tower section are disposed in the same relative positions in a pattern common to all such sections, and the patterns are vertically aligned along the tower, and including a remotely controlled manipulator (94) movable along the tower from pattern to pattern for
10 operating the valves in each pattern in a desired manner.

 31. Apparatus according to claim 30 including a vertical guide (101) mounted to the tower along said length for guiding the manipulator vertically along the tower, and releasable stop and detent means (107, 108)
15 co-operable between the manipulator and the guide adjacent each pattern of valves for defining a predetermined position of the manipulator relative to each pattern.

 32. A method for installing an installation according to claim 1 using apparatus according to claim 25
20 characterised by the steps of

 a. providing at the offshore location a floating work station and the several tower sections in the appropriate sequence,

25 b. providing adjacent the work station the positively buoyant auxiliary floatation structure,

 c. disposing the tower base section in a partially immersed vertical attitude in the ocean adjacent the floatation structure and coupling the base section to the floatation structure for control of further immersion of
30 the base section from the floatation structure,

 d. adjusting the buoyancy of the base section to have a selected small positive buoyancy and sufficient stability to float vertically,

 e. lowering from the work station to the upper end

of the base section the tower central section to be interconnected to the base section, interconnecting the base and central sections, and adjusting the buoyancy of the interconnected sections so that as a unit they have a selected small positive buoyancy and sufficient stability to float vertically while maintaining the coupling of such unit to the floatation structure,

5 f. adjusting the location of coupling of said unit to the floatation structure from the original location to a higher location associated with the uppermost section of the unit,

g. repeating the substantive aspects of steps e and f mutatis mutandis with the remaining tower central sections and upper section in sequence and with a plurality of temporary installation sections having a collective length a selected amount greater than said selected depth, whereby the tower structure is assembled in serial order from bottom to top and is progressively lowered toward and into engagement with the ocean floor at the offshore location from the work station,

15 h. upon engagement of the assembled tower structure with the ocean floor, adjusting the buoyancy thereof to be negative but with a center of buoyancy substantially higher in the tower structure than its center of mass, and securing the base section to the ocean floor,

25 i. following securing of the tower structure to the ocean floor, adjusting the buoyancy of the tower structure to be substantially positive with its center of buoyancy substantially higher in the tower structure than its center of mass, and

30 j. disconnecting the temporary installation sections from the tower upper section.

33. A method as claimed in claim 32 including the further step of installing the riser ducts in the tower

structure following completion of step i.

34. A method as claimed in claim 33 wherein the step of installing the riser ducts includes the steps of

a. passing each desired riser duct from the work station through the respective connection point and through guide structures located at selected points along the tower structure into engagement by the lower end of the riser duct with the tower base section,

b. securing the lower end of the riser duct to the base section sufficiently to thereafter withstand tension in the riser duct, and

c. applying tension of selected amount to the riser duct at least at the respective connection point and securing the riser duct to the respective connection point adequately to maintain such tension in the riser duct.

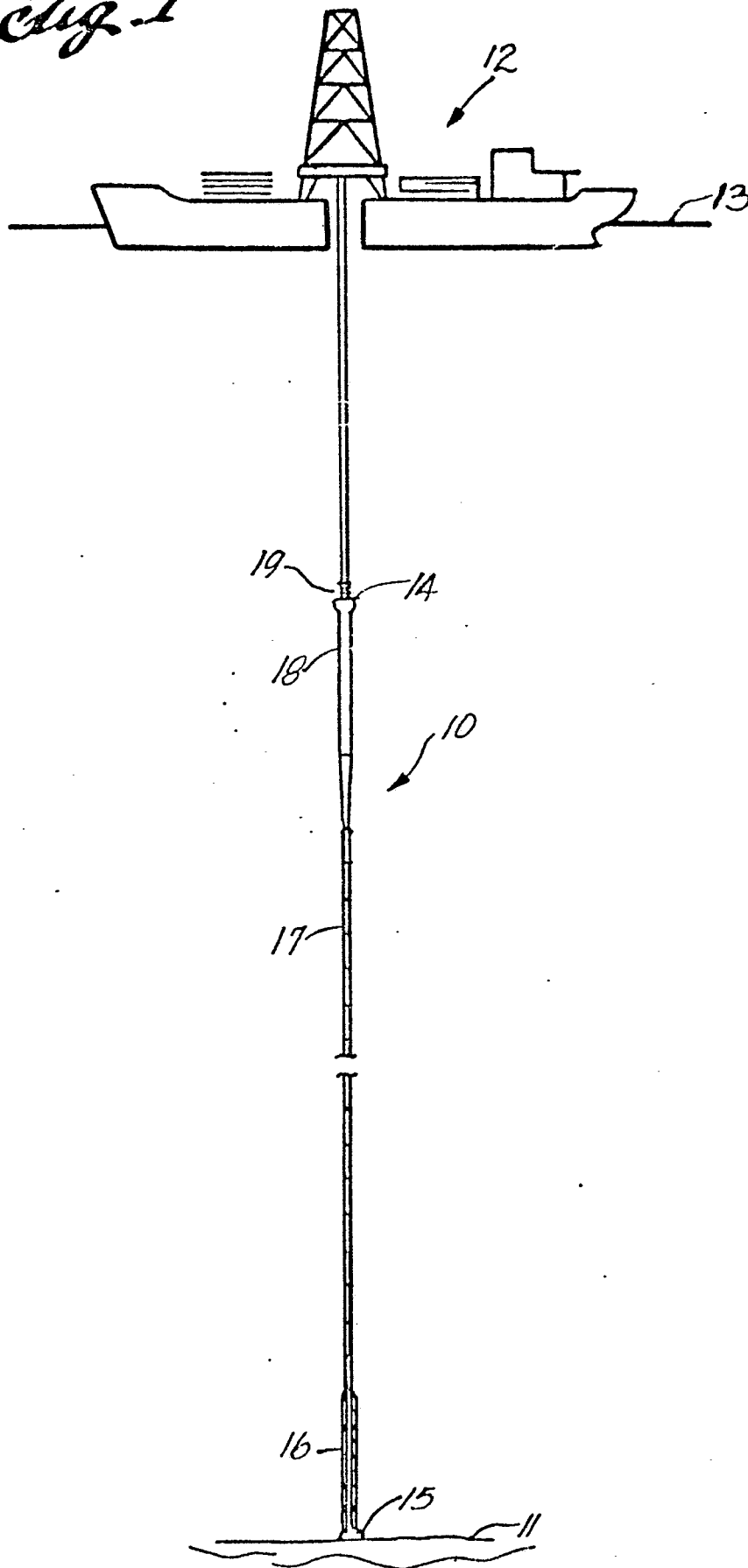
Fig. 1

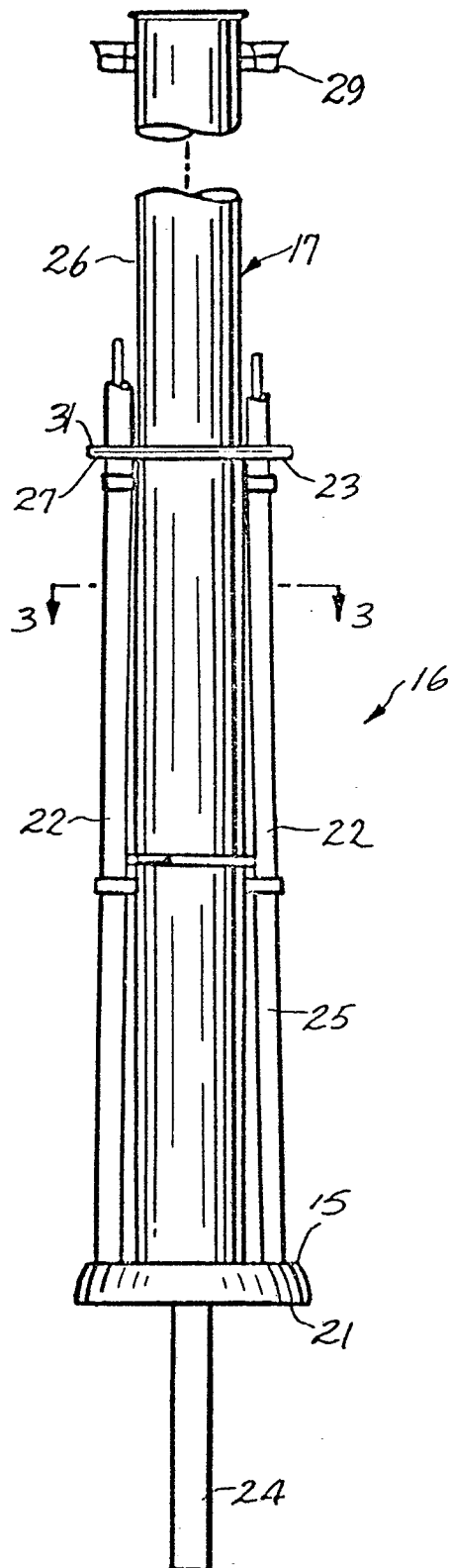
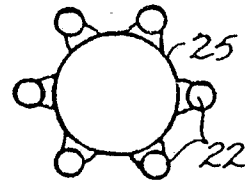
Fig. 2*Fig. 3*

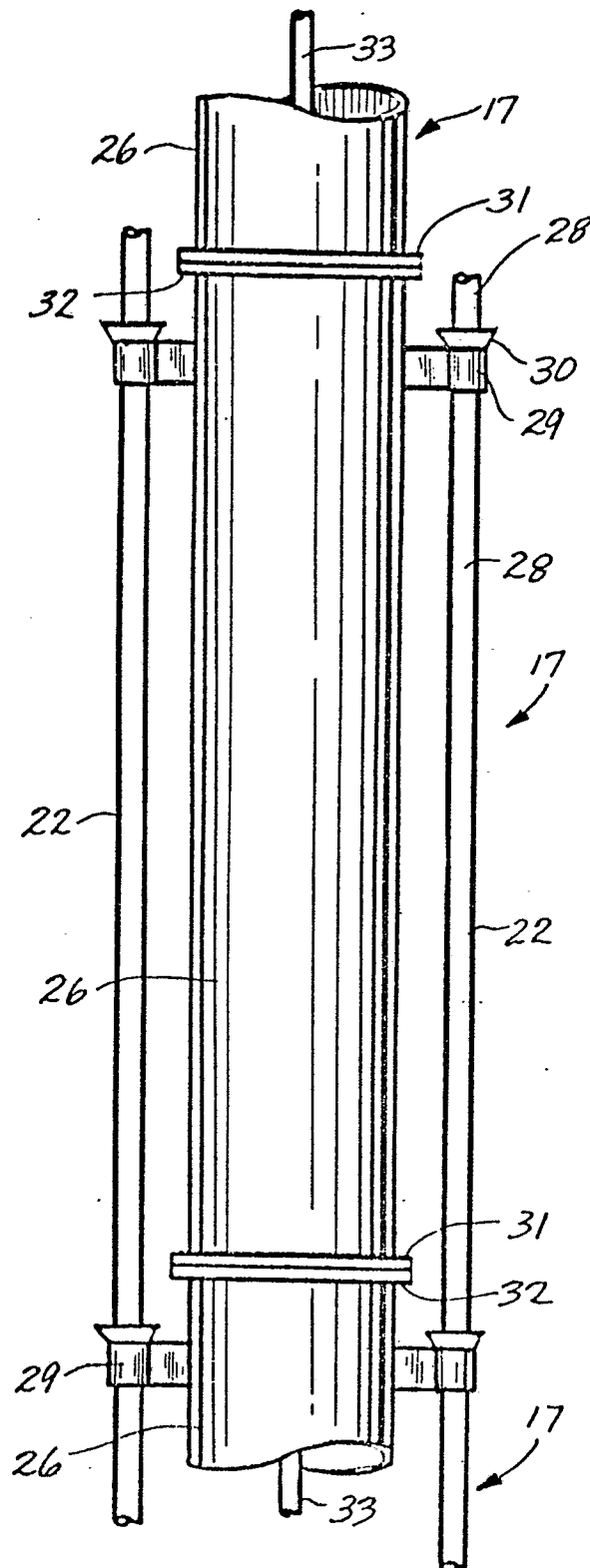
Fig. 4

Fig. 5

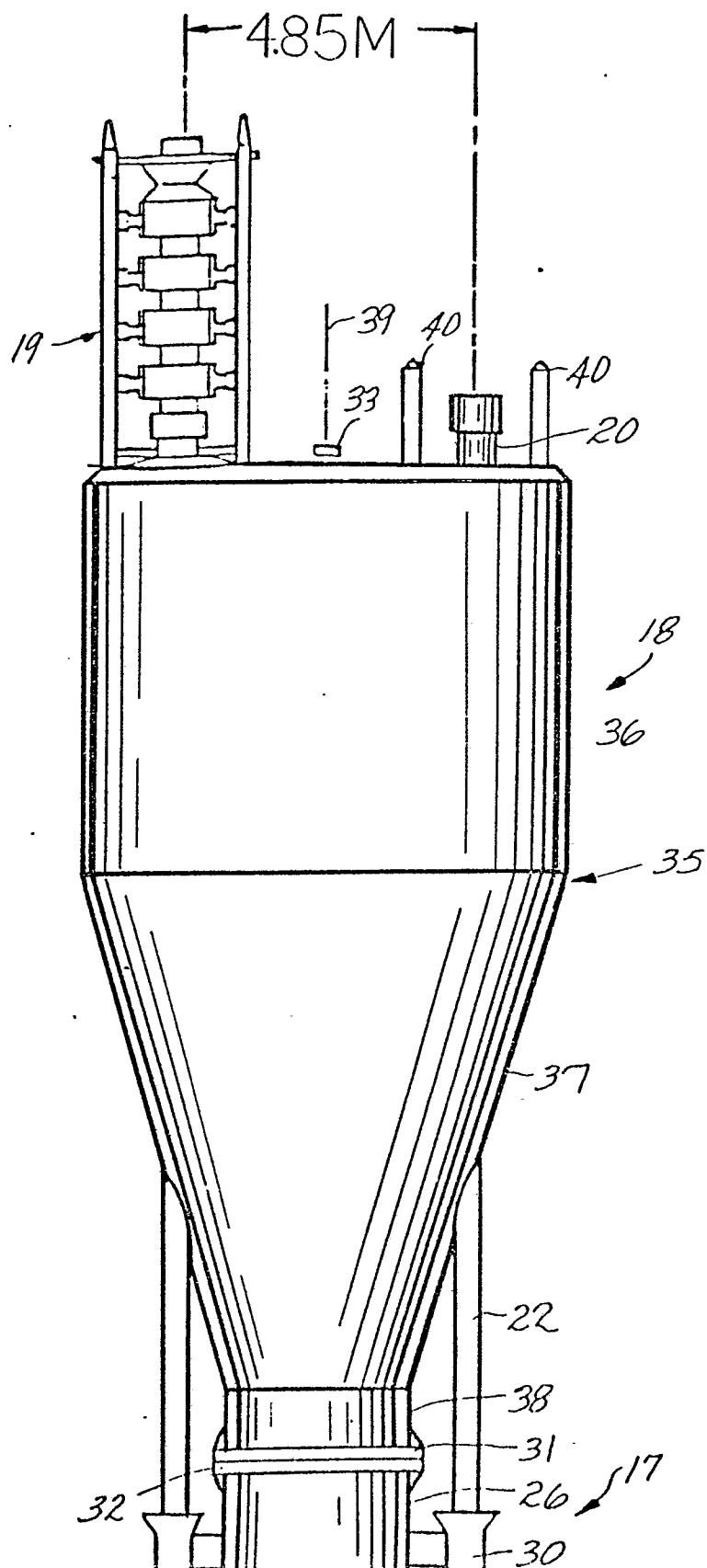
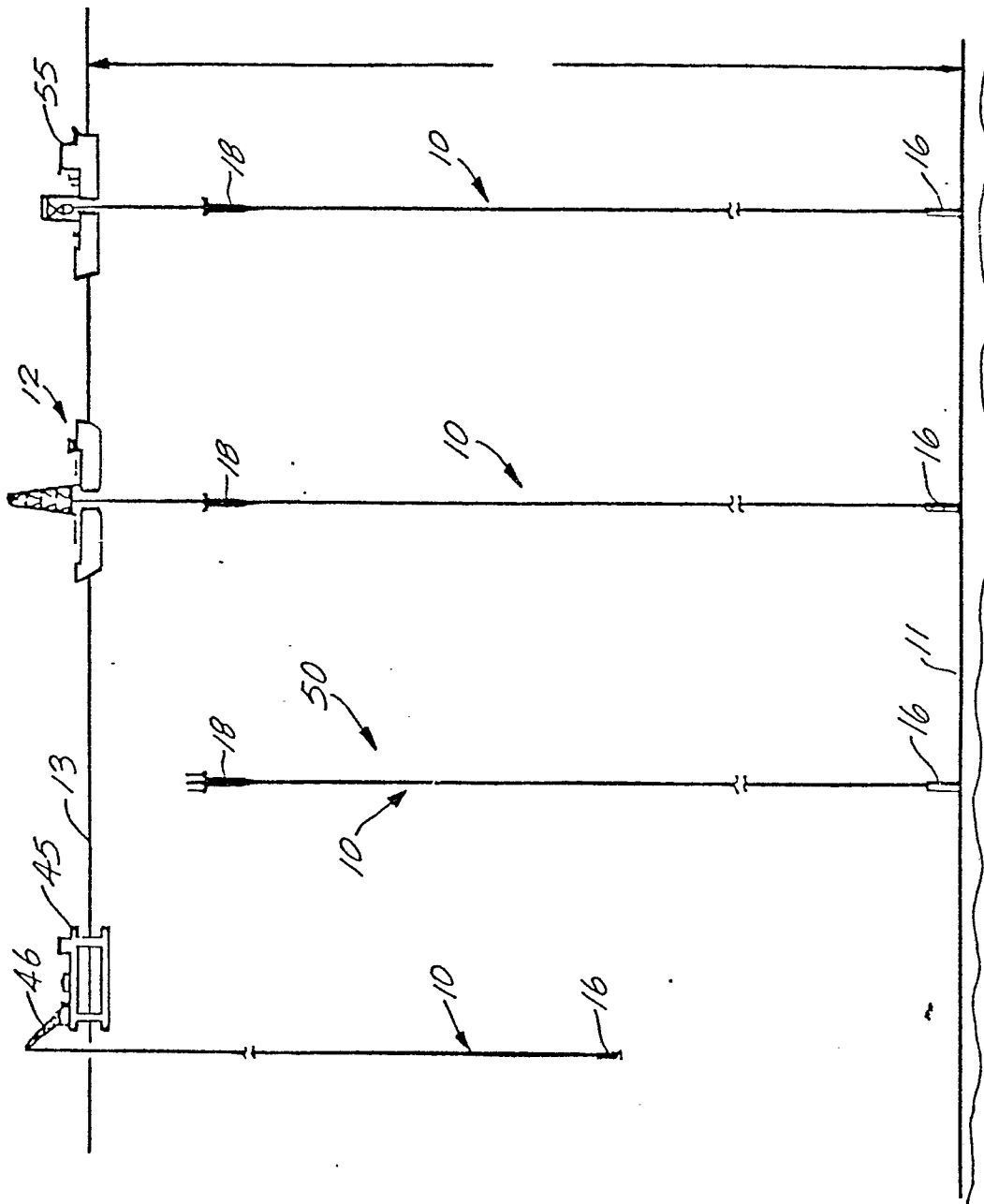
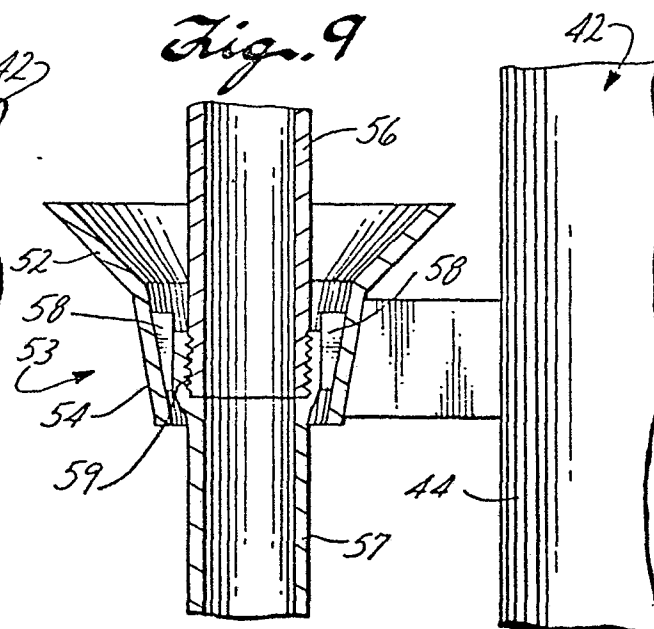
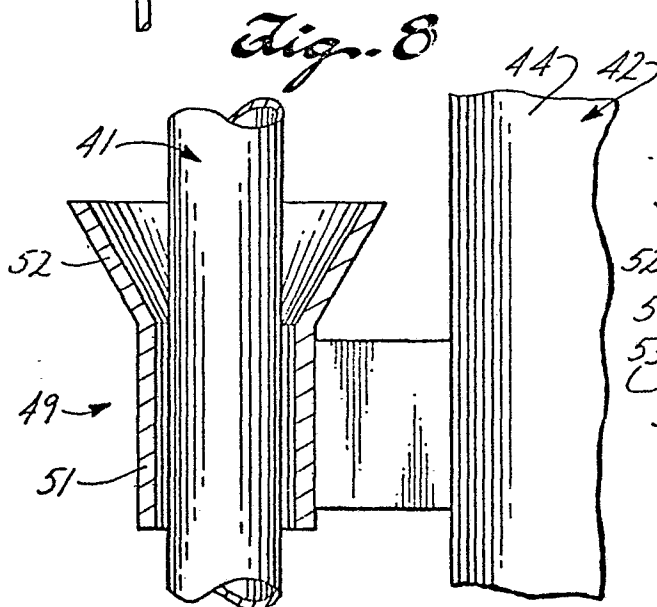
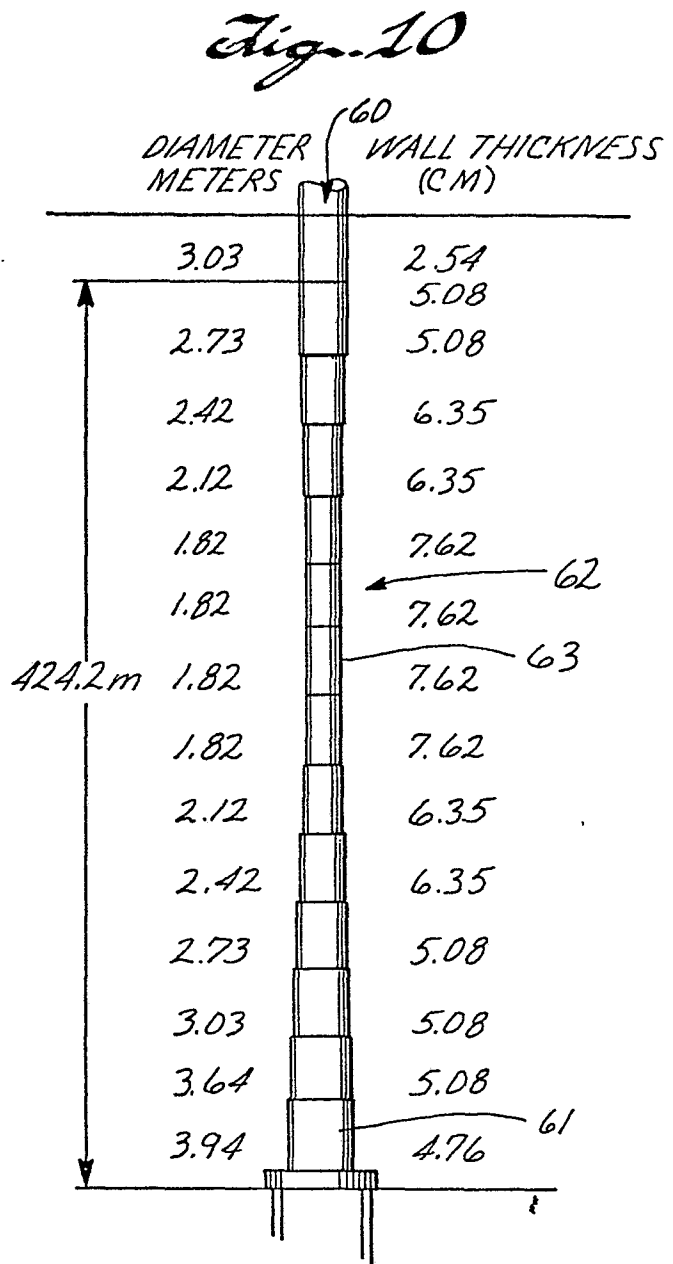
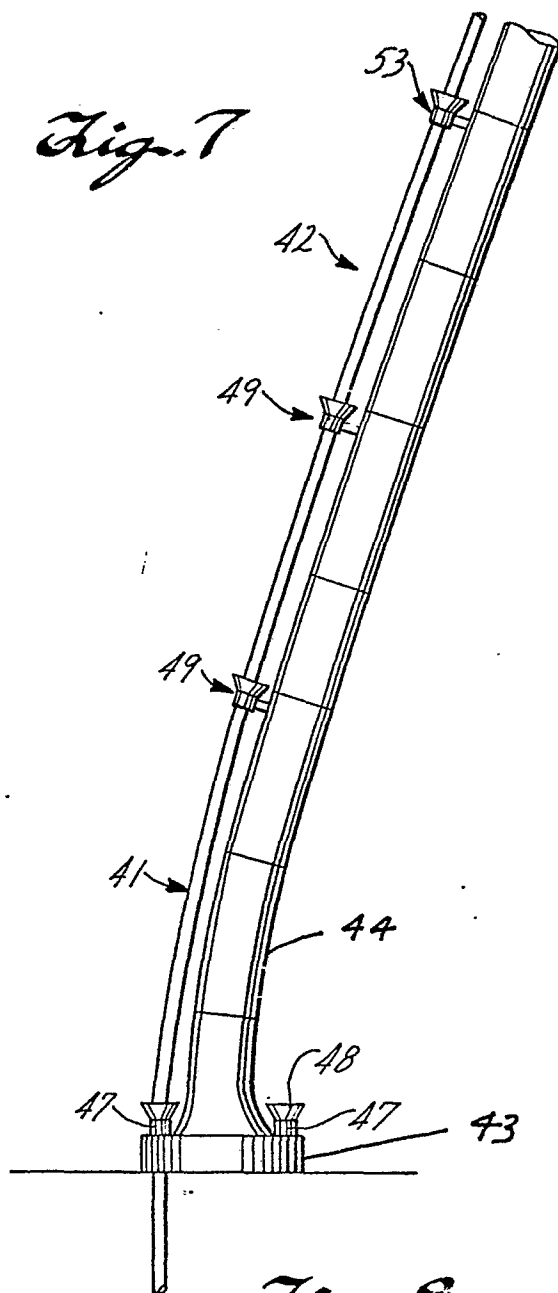


Fig. 6





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Fig. 11

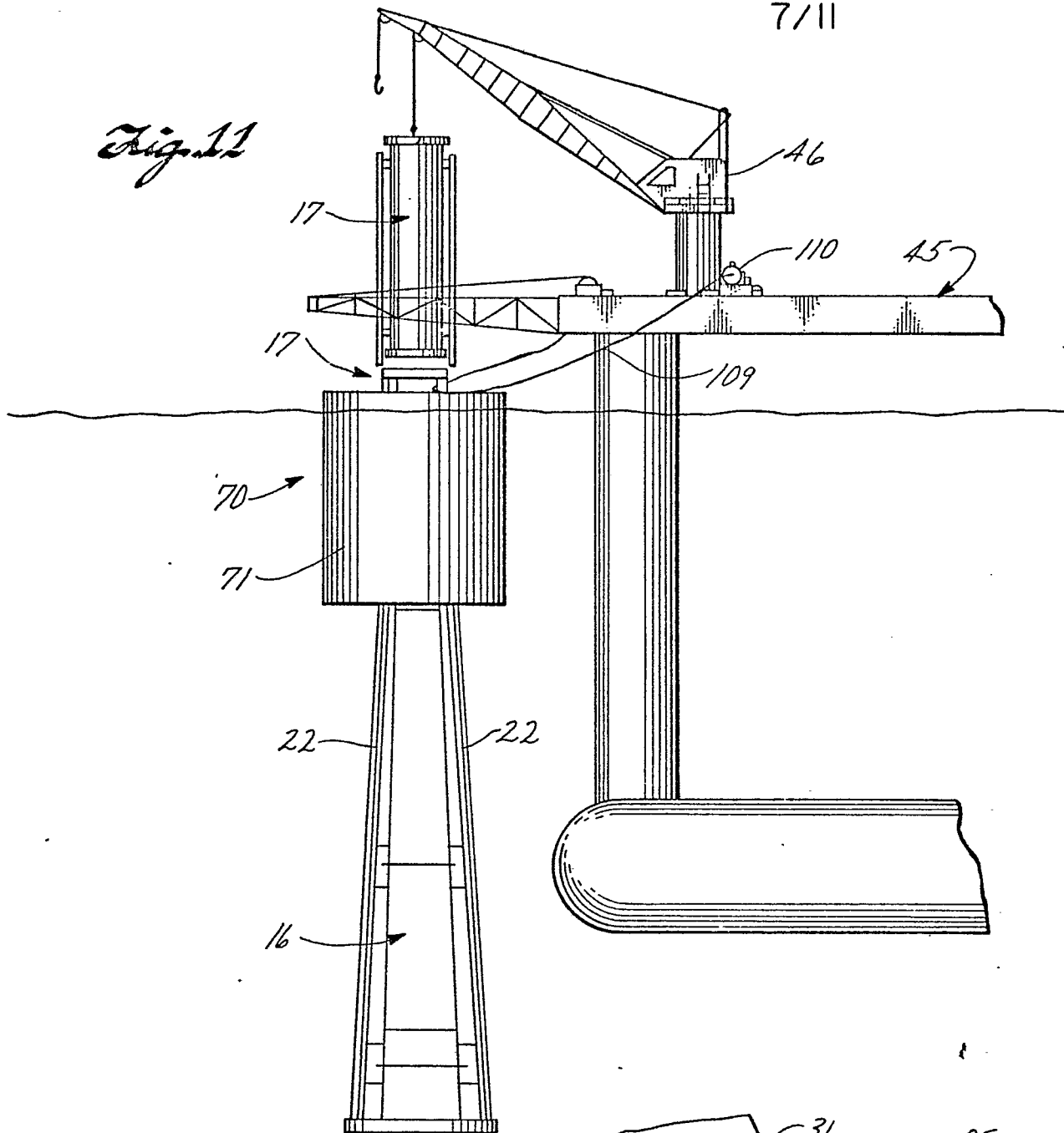
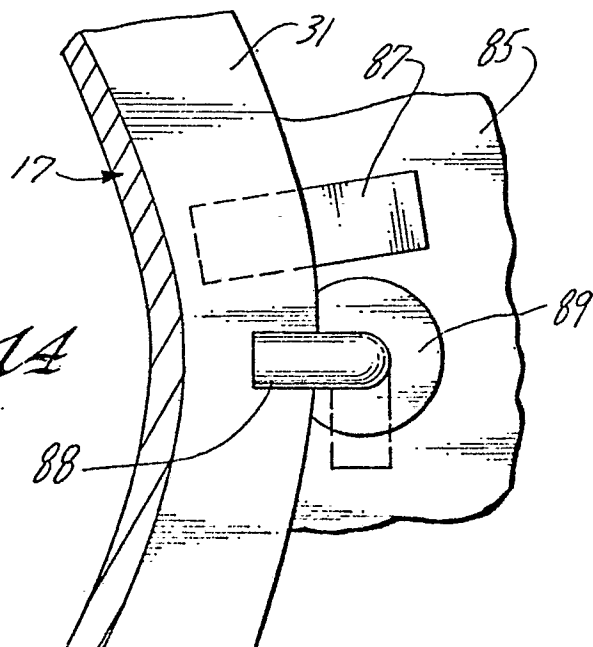


Fig. 14



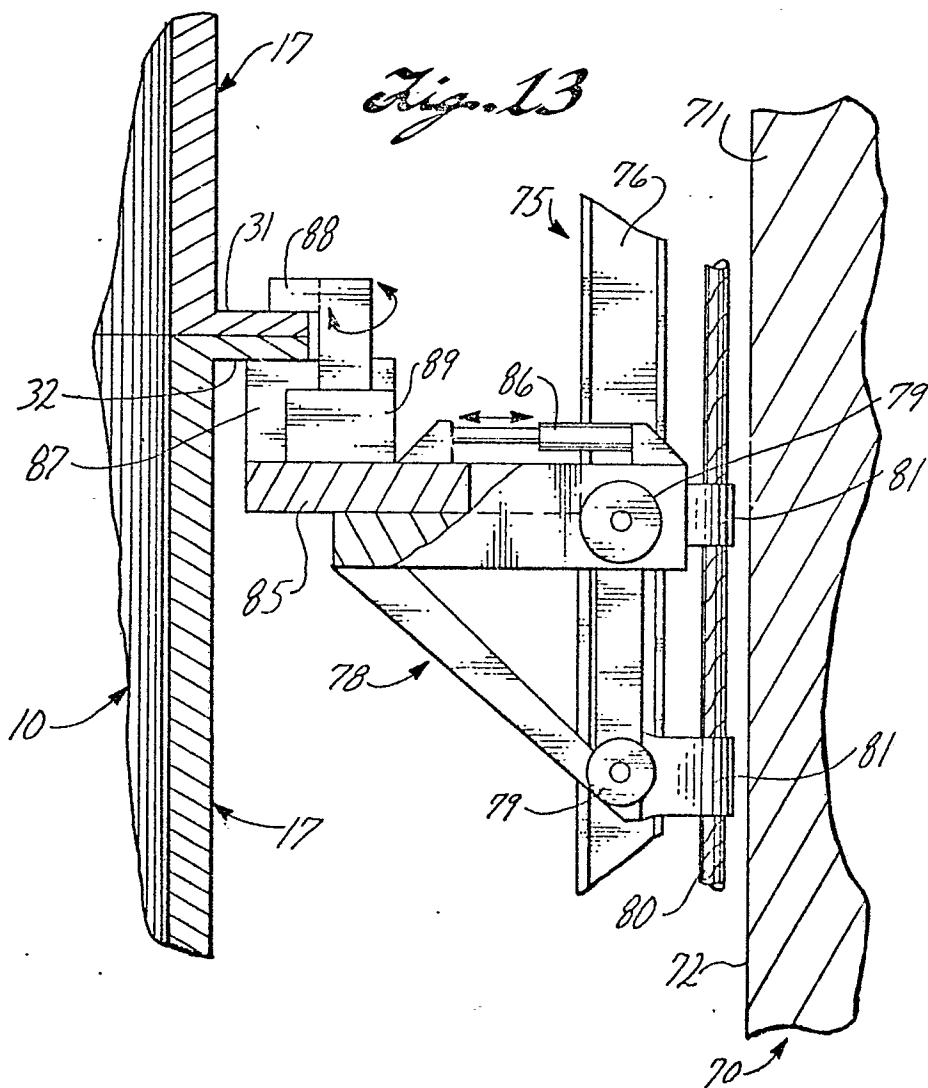
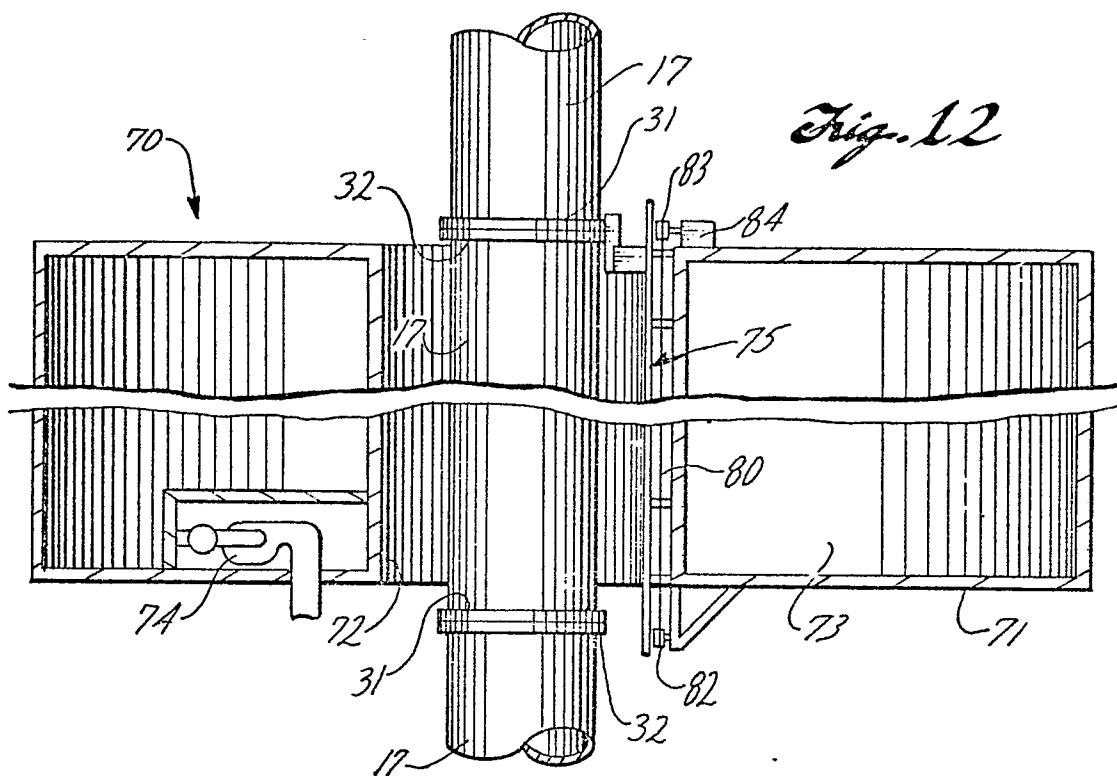


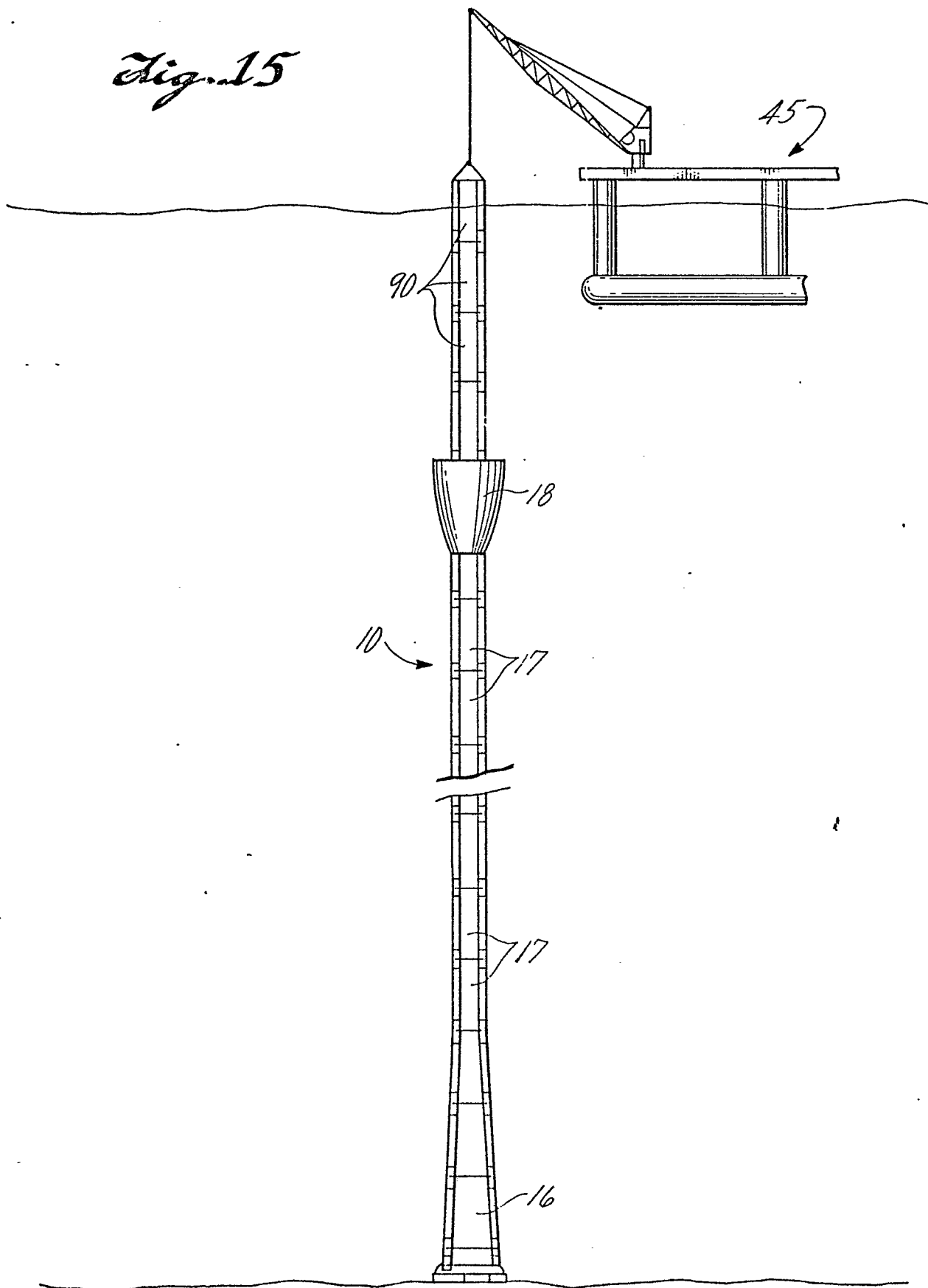
Fig. 15

Fig. 17

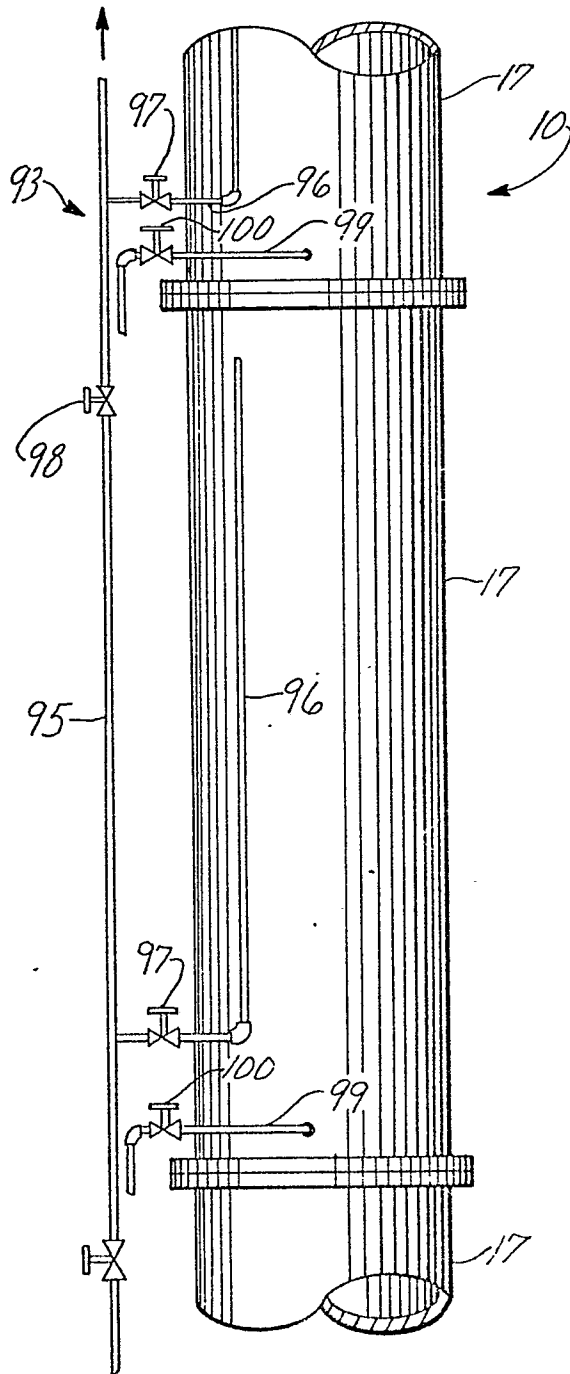


Fig. 18

