A freestanding hybrid riser system includes a steel pipe riser having a bottom end anchored to a foundation on a seabed through a flexible joint and a diverless pipe connector. A tube is mounted to the foundation and connected to the diverless pipe connector for providing a static connection to a subsea pipeline on the seabed for a flow of fluid between the steel pipe and the subsea pipeline and through the flexible pipe joint and through the diverless pipe connector and through the tube. In a preferred implementation, the flexible pipe joint includes alternate elastomer layers and metal layers reinforcing the elastomer layers, and a receptacle of the diverless connector is mounted on a foundation such as a suction pile on the seabed, or a pile grouted in a bore in the seabed.
FREESTANDING HYBRID RISER INSTALLATION

INSTALL A FOUNDATION STRUCTURE UPON THE SEABED. THE FOUNDATION STRUCTURE INCLUDES A RECEPTACLE FOR A DIVERLESS PIPE CONNECTOR, AND A J-TUBE FROM THE RECEPTACLE TO A STATIONARY SUBSEA PIPELINE END TERMINATION. THE J-TUBE PROVIDES A VERTICAL-TO-HORIZONTAL TRANSITION FROM THE RECEPTACLE TO THE SUBSEA PIPELINE END TERMINATION.

ATTACH A FIRST END OF A FLEXIBLE PIPE JOINT TO A BOTTOM END OF THE STEEL PIPE OF THE RISER. THE FLEXIBLE PIPE JOINT HAS A SECOND END TERMINATED BY A DIVERLESS PIPE CONNECTOR HUB.


INCREASE THE BUOYANCY OF THE FLOATING TANK TO PLACE THE VERTICAL STEEL PIPE OF THE RISER IN A STATE OF TENSION FOR STABILITY.

INSTALLATION FINISHED

FIG. 4
FREESTANDING HYBRID RISER SYSTEM INCLUDING A BOTTOM CONFIGURATION WITH A FLEXIBLE PIPE JOINT AND A DIVERLESS PIPE CONNECTOR

RELATED APPLICATIONS

[0001] This application claims the benefit of Bao Duy Povaloski, U.S. Provisional Application Ser. 61/699,544 filed Sep. 11, 2012, incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to a freestanding hybrid riser system (FHRS) having a bottom configuration including a flexible pipe joint and a diverless pipe connector.

BACKGROUND OF THE INVENTION

[0003] A freestanding hybrid riser comprises a vertical steel pipe supported at its top end by a floating tank, the pull from which provides the system with stability. The floating tank is at a depth at which the effects of surface currents and waves are significantly attenuated. A length of pipe or flexible riser in a double catenary connects the top of the vertical steel pipe to a production platform. A tie bar or mooring connection provides a link between the floating tank and the top of the vertical steel pipe. The anchor or base for the riser typically is a suction pile in the seabed, or a drilled steel pipe grouted to the seabed.

[0004] A freestanding hybrid riser system (FHRS) may be used for the production (gathering) or export of oil or gas. The fluids produced or exported pass through the vertical steel pipe, which also performs the structural function of supporting the system. At its bottom end the vertical steel pipe has a component which makes a connection between the vertical steel pipe and a gathering or export line. This component is a length of pipe located at the base of the riser and made of steel, known as a rigid jumper, or a length of a flexible line.

[0005] The basic architecture of the freestanding hybrid riser system has been known for decades; for example, as described in Panicker et al. U.S. Pat. No. 4,423,984, issued Jan. 3, 1984. Panicker describes a freestanding hybrid riser system having a vertical rigid section which extends from a base on the seabed to a floating tank at a fixed position below the zone of turbulence that exists near the surface of the water, and a flexible section, which is comprised of flexible flowlines that extend in a catenary configuration from the floating tank to a surface facility.

[0006] Recently there has been a trend towards extending free standing risers from deep water (at least 1,000 feet or 300 meters) to ultra deep water (at least 5,000 feet or 1,500 meters). The increasing depth raises problems of loading upon the foundation and the jumper from the vertical steel pipe to the gathering or export line. These problems are discussed in S. A. Halton et al., Hybrid Riser Foundation Design and Optimization, OTC 17199, Offshore Technology Conference, Houston, Tex., May 2-5, 2005, Offshore Technology Conference Organization, Richardson, Tex. In deep water, the axial tension from the riser upon the foundation can be significant (70-1000 kN or 690-9800 kN). This tension must be reliably reacted into the seabed over the life of the development. Depending on the configuration of the selected foundation there may be, in addition to axial tension, bending moments, shear loads, and loads arising from flexure of rigid base jumper spools. The result is a complex set of load conditions, which, when combined with installation issues, can lead to a foundation system that is a significant cost element in the overall riser system.

SUMMARY OF THE INVENTION

[0007] In accordance with a first aspect, the invention provides a freestanding hybrid riser system. The freestanding hybrid riser system includes a vertical steel pipe having a top end and a bottom end, a floating tank coupled to the top end of the vertical steel pipe for supporting the vertical steel pipe, a flexible pipe joint, a diverless pipe connector attached to the flexible pipe joint, a foundation mounted on a seabed, and a tube mounted to the foundation. The bottom end of the vertical pipe is anchored to the foundation through the flexible pipe joint and the diverless pipe connector. The tube is connected to the diverless pipe connector for providing a static connection to a subsea pipeline on the seabed for a flow of fluid between the vertical steel pipe and the subsea pipeline and through the flexible pipe joint and through the diverless pipe connector and through the tube.

[0008] In a preferred implementation, the freestanding hybrid riser system includes a vertical steel pipe having a top end and a bottom end, a floating tank coupled to the top end of the vertical steel pipe for supporting the vertical steel pipe, a flexible pipe joint having an upper end attached to the bottom end of the vertical steel pipe, a diverless pipe connector hub attached to a lower end of the flexible pipe joint, a foundation mounted on a seabed, a diverless pipe connector receptacle attached to the foundation and engaging the diverless pipe connector hub, and a J-tube having an upper end attached to the diverless pipe connector receptacle and a lower end for providing a static connection to a subsea pipeline on the seabed so that fluid may flow between the vertical steel pipe and the subsea pipeline and through the flexible pipe joint, through the diverless pipe connector hub, and through the J-tube.

[0009] In accordance with a second aspect, the invention provides a bottom configuration for a freestanding hybrid riser system. The bottom configuration includes a flexible pipe joint, a diverless pipe connector attached to the flexible pipe joint, and a tube connected to the diverless pipe connector for conveying fluid when the fluid flows through the flexible pipe joint and through the diverless pipe connector and through the tube.

[0010] In a preferred implementation, the bottom configuration includes a flexible pipe joint having an upper end for attachment to a lower end of a vertical steel pipe of a riser, a diverless pipe connector hub attached to a lower end of the flexible pipe joint, a diverless pipe connector receptacle configured for engaging the diverless pipe connector hub, and a J-tube having an upper end attached to the diverless pipe connector receptacle for conveying fluid when the diverless pipe connector hub is engaged in the diverless pipe connector receptacle and fluid flows through the flexible pipe joint, through the diverless pipe connector hub, through the diverless pipe connector receptacle, and through the J-tube.

[0011] In accordance with a final aspect, the invention provides a method of installing a freestanding hybrid riser to assemble a freestanding hybrid riser system. The freestanding hybrid riser includes a steel pipe having a top end and a bottom end. The method includes installing a foundation structure upon a seabed. The foundation structure includes a foundation mounted on the seabed and a tube mounted to the foundation and extending to a static connection to a subsea
pipeline on the seabed. The method further includes orienting the bottom end of the steel pipe over the foundation structure, and engaging a diverless pipe connector to anchor the bottom end of the steel pipe on the foundation structure and to complete a connection between the bottom end of the steel pipe and the foundation structure. The connection includes a flexible pipe joint and the diverless pipe connector between the bottom end of the steel pipe and the tube for a flow of fluid between the steel pipe and the subsea pipeline and through the flexible pipe joint and through the diverless pipe connector and through the tube.

[0012] A preferred implementation includes installing a foundation structure upon a seabed, the foundation structure including a receptacle for a diverless pipe connector, and a J-tube extending from the receptacle to a stationary subsea pipeline end termination, so that the J-tube provides a vertical-to-horizontal transition from the receptacle to the subsea pipeline end termination. The preferred implementation further includes attaching a first end of a flexible pipe joint to a bottom end of a steel pipe for the freestanding hybrid riser. The flexible pipe joint has a second end terminated by a diverless pipe connector hub. The preferred implementation further includes orienting the steel pipe over the foundation structure, and landing the diverless pipe connector hub into the receptacle to make a connection between the diverless pipe connector hub and the receptacle for the flow of fluid between the steel pipe and the subsea pipeline end termination and through the flexible pipe joint, through the diverless pipe connector hub, and through the J-tube.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Additional features and advantages of the invention will be described below with reference to the drawings, in which:

[0014] FIG. 1 shows a conventional freestanding hybrid riser system;

[0015] FIG. 2 shows a first example of a freestanding hybrid riser system in accordance with the present invention;

[0016] FIG. 3 shows a second example of a freestanding hybrid riser system in accordance with the present invention;

[0017] FIG. 4 is a flowchart of a method of installing a freestanding hybrid riser to assemble the freestanding hybrid riser system of FIG. 2 or FIG. 3;

[0018] FIG. 5 is an enlarged cross-section of the upper portion of the diverless collet-style pipe connector introduced in FIG. 2, shown in an open configuration;

[0019] FIG. 6 shows the upper portion of the diverless collet-style pipe connector of FIG. 5, shown in a closed configuration;

[0020] FIG. 7 is a cross-section view along section line 7-7 of FIG. 8 of the upper portion of a diverless clamp-style pipe connector, shown in an open configuration;

[0021] FIG. 8 is a top view of the diverless clamp-style pipe connector, shown in a closed configuration;

[0022] FIG. 9 is an oblique view of components of the diverless clamp-style pipe connector of FIGS. 7 and 8;

[0023] FIG. 10 is a cross-section view of a diverless collet-style pipe connector having an elastomeric flexible pipe joint integrated with the collet mechanism, shown in an open configuration;

[0024] FIG. 11 is a cross-section view of the diverless collet-style pipe connector of FIG. 10, shown in a closed configuration;

[0025] FIG. 12 shows an alternative arrangement, in which two diverless collet-collet style pipe connectors having integral flexible pipe joints are joined together;

[0026] FIG. 13 is a cross-section view of a diverless clamp-style pipe connector with a flexible pipe joint located on the riser side of the connection, shown in an open configuration;

[0027] FIG. 14 is a cross-section view of the diverless clamp-style pipe connector of FIG. 13, shown in a closed configuration;

[0028] FIG. 15 is a cross-section view of a diverless clamp-style pipe connector in a closed configuration joining two flexible pipe joints, one on the riser side of the connection, and the other on the foundation side of the connection;

[0029] FIG. 16 is a cross-section view of a diverless collet-style pipe connector including a first flexible pipe joint on the riser side of the connection, and joining a second flexible pipe joint on the foundation side of the connection;

[0030] FIG. 17 shows a flange-type pipe connector connecting a foundation structure to a horizontal rigid subsea pipeline;

[0031] FIG. 18 shows a diverless collet-style pipe connector connecting a foundation structure to a horizontal rigid subsea pipeline;

[0032] FIG. 19 shows a diverless collet-style pipe connector connecting a foundation structure to a vertical rigid jumper;

[0033] FIG. 20 shows a diverless collet-style pipe connector connecting a foundation structure to a horizontal flexible subsea pipeline; and

[0034] FIG. 21 shows a diverless collet-style pipe connector connecting a foundation structure to a vertical flexible jumper.

[0035] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown in the drawings and will be described in detail. It should be understood, however, that it is not intended to limit the invention to the particular forms shown, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0036] With reference to FIG. 1, there is shown a conventional freestanding hybrid riser system (FHR) 10 in a deep water environment. The freestanding hybrid riser 10 comprises a vertical steel pipe 11 supported at its top end by a floating tank 12. The floating tank 12 is often called a buoyancy can or air can. The floating tank 12 is at a depth of at least 50 meters so that the effects of surface currents and waves upon the floating tank 12 are significantly attenuated. The floating tank 12 is filled with air so that it supports the weight of the vertical steel pipe 11 and also maintains the vertical steel pipe 11 in tension for stability. A length of pipe or flexible riser 13 in a catenary connects the top of the vertical steel pipe 11 to a production platform 14 on the surface. A mooring connection 15 such as a length of chain provides a link between the floating tank 12 and the top of the vertical steel pipe 11.

[0037] In FIG. 1, the bottom configuration of the riser system 10 on the seabed 16 is shown at a larger scale than the floating tank 12 and the production platform 14 near the surface. The base for the riser 10 is a suction pile 17 in the seabed 16. A bottom connector receptacle 18 is mounted on
the top of the suction pile 17 to receive a bull nose 19 on an extension 20 welded to the bottom end of the vertical steel pipe 11.

[0038] When guided into the receptacle 18 by an alignment cone 21, the bull nose 19 latches into the receptacle 18 forming a bottom connector assembly. The bull nose 19 has a flexible joint 22 permitting riser motion 23 with some stiffness as the inclination of riser 11 deviates from a desired vertical orientation. The bull nose 19 is also mounted to the extension 20 for free rotation about the vertical axis of the steel pipe 11. Further details of the bottom connector assembly are described in Peppel U.S. Pat. No. 4,943,188 issued Jul. 24, 1990.

[0039] The bottom of the vertical steel pipe 11 has a branch pipe 24 to a bottom riser connector 25. The bottom riser connector 25 connects a jumper 26 to a stationary pipeline end termination (PLET) connector 27 mounted on a sled 28 resting on the seabed 16 and providing a connection to an export pipeline 29.

[0040] In the example of FIG. 1, the vertical steel pipe 11 conveys fluid such as oil or gas downward from the floating production facility 14 to the subsea pipeline 29. The subsea pipeline 30 may then convey the fluid to an on-shore facility. In an alternative configuration, the vertical steel pipe 11 conveys fluid from one or more wells on the seabed 16 upward to the floating platform 14 for transfer of the fluid to vessels for shipment.

[0041] The conventional freestanding hybrid riser system (FHRS) 10 in FIG. 1 has a problem of loading upon the branch pipe 24 and the jumper 26 from the vertical steel pipe 11 to the stationary pipeline end termination (PLET) connector 27. To reduce stress from pivoting of the vertical steel pipe 11, the jumper 26 may include a number of bends or loops between the vertical steel pipe 11 and the stationary pipeline end termination (PLET) connector 27. However, the required size of the jumper 26 and the required number of bends increase significantly with the pipe diameter. This is due to the need to maintain 3D bends for pigging, and the increase in stiffness of the pipe section increasing to the 4th power of the pipe diameter.

[0042] The present invention relates to an improved freestanding hybrid riser system (FHRS) and a method for installing it, in which the bottom connection at the base of the riser has a diverless pipe connector allowing the riser to connect to a mating foundation structure so that riser fluid may flow through the foundation structure such as a suction pile to a static jumper connection point. The base of the riser or the mating foundation structure has at least one flexible pipe joint that permits pivoting of the riser with respect to the foundation. This is a functional improvement for the bottom connection configuration of the FHRS system. This reduces the bending and deflection in the rigid jumper, and removes riser motion from the jumper, thus reducing the size of the jumper and simplifying the design of the jumper. This also eliminates the need for a bottom connector assembly of the kind shown in FIG. 1.

[0043] FIG. 2 shows a first example of a freestanding hybrid riser system 40 in accordance with the present invention. The freestanding hybrid riser system 40 includes a vertical steel pipe 41 supported at its top end by a floating tank 42. The floating tank 42 supports the weight of the vertical steel pipe 41 and also maintains the vertical steel pipe 41 in tension for stability. A length of pipe or flexible riser 43 in a double catenary connects the top end of the vertical steel pipe 41 to a production platform 44 on the surface. A mooring connection 45 such as a length of chain provides a link between the floating tank 42 and the top end of the vertical steel pipe 41.

[0044] The anchor or base for the riser 40 is a suction pile 47 in the seabed 46. A bottom connector receptacle 48 is rigidly mounted to the top of the suction pile 47 by ribs 49, 50 or other reinforcements welded to the bottom connector receptacle 48 and welded to the top of the suction pile 47. The bottom of the vertical steel pipe 41 is fixed to a hub 52 having a built-in flexible pipe joint 53. The flexible pipe joint 53 has an upper extension 39, which is welded to the bottom of the vertical steel pipe 41. The flexible pipe joint 53 includes alternate elastomer layers and metal layers reinforcing the elastomer layers. Further details regarding the construction of such a flexible pipe joint 53 are found in Moses et al., U.S. Pat. No. 7,341,283 issued Mar. 11, 2008, entitled High Temperature Flexible Pipe Joint, incorporated herein by reference.

[0045] The hub 52 and the bottom connector receptacle 48 together form a diverless pipe connector 54. The bottom connector receptacle 48 has an alignment cone 55 for guiding the hub 52 into the bottom connector receptacle 48. The hub 52 mates with a hub 56 on an upper end of a J-tube 57. The upper end of the J-tube 57 is attached to the diverless pipe connector receptacle 48, and the J-tube has a lower end for providing a static connection to a subsea pipeline 59 on the seabed 46 so that fluid may flow between the vertical steel pipe 41 and the subsea pipeline 59 and through the flexible pipe joint 53, through the diverless pipe connector hub 52 and through the J-tube 57. The J-tube 57 provides a smooth bend of at least three pipe diameters and more preferably five or more pipe diameters transitioning from vertical at the bottom connector receptacle 48 to a horizontal pipeline end connector 58 connecting the J-tube to the subsea pipeline 59. The pipeline end connector 58 is stationary, and the pipeline end connector 58 can be a flanged connector or a diverless pipe connector.

[0046] In the example of FIG. 2, the bend of the J-tube 57 is contained within the suction pile 47. A horizontal section of the J-tube 57 passes through a hole 60 in the outer circumference of the suction pile 47. Any gap between this hole 60 and the outer circumference of the J-tube 57 is closed by a fillet weld around the outer circumference of the J-tube 57 in the vicinity of the hole 60. In a similar fashion, a vertical section of the J-tube 57 passes through a hole 61 in the top of the suction pile 47, and any gap between this hole 61 and the outer circumference of the J-tube 57 is closed by a fillet weld around the outer circumference of the J-tube 57 in the vicinity of the hole 61. Therefore the interior of the suction pile 47 remains sealed from the external sea water, so that suction may be applied to the interior of the suction pile in order to drive the suction pile into the seabed 46 in the usual fashion.

[0047] The diverless pipe connector 54 may use a non-articulated connector or an articulated connector depending on whether the suction pile 47 has or has not been driven vertically into the seabed 46. If the suction pile 47 has been driven vertically into the seabed 46, then a non-articulated connector can be used. If the suction pile 47 has not been driven vertically into the seabed, then an articulated connector can be used to make up for the deviation from the desired vertical orientation of the suction pile 47. In any event, it is desired for the hub 52 on the bottom of the vertical steel pipe 41 to have a vertical orientation regardless of whether the suction pile 47 and the receptacle 48 are tilted.
An articulated connector, for example, has the hub 52 terminating in a quasi-spherical ball that engages a matching socket in the hub 56. When an engagement mechanism 63 is actuated, the ball is locked into a fixed position with respect to the socket, forming a metal-to-metal seal. The ball remains locked into the fixed position with respect to the socket while the flexible pipe joint 53 permits some pivoting 62 of the vertical steel pipe 41 about a true vertical orientation.

An annular sealing element may be interposed between the hub 52 on the bottom of the vertical steel pipe and the hub 56 on the top of the J-tube 57. For example, the hubs 52, 56 have relatively hard polished metal surfaces, and the sealing element is made of a relatively softer metal that may deform slightly under pressure to complete a fluid-tight metal-to-metal seal with the relatively hard polished metal surfaces of the hubs. Further details of such an annular sealing element are described in Tarlton U.S. Pat. No. 7,677,799 issued Dec. 23, 2008, incorporated herein by reference.

The diverter pipe connector 54 may use various kinds of engagement mechanisms to engage the hub 52 on the bottom of the vertical steel pipe 41 with the hub 56 on the top of the J-tube 57. For example, the engagement mechanism is a clamp-style mechanism, or the engagement mechanism is a collet-tone mechanism. A collet-style mechanism is described in Wittman et al., U.S. Pat. No. 4,477,105 issued Oct. 16, 1984, incorporated herein by reference. The use of such a collet-style mechanism for a subsea termination pipeline connection is described in Tarlton et al., U.S. Pat. No. 6,142,708 issued Nov. 7, 2000, incorporated herein by reference. A clamp-style mechanism for an articulated connector is described in Spiering et al. U.S. Pat. No. 6,305,720 issued Oct. 23, 2001, incorporated herein by reference, and Spiering et al. U.S. Pat. No. 6,698,800, issued Mar. 2, 2004, incorporated herein by reference.

The engagement mechanism 63 is sized to provide a sufficient level of force upon the hubs 52, 56 to contain the fluid pressure within the vertical steel pipe 41 and the J-tube 57 and also to react to the tension from the vertical steel pipe 41. For example, the fluid pressure is up to 15,000 psi (103 MPa). In general, the tension upon the suction pile 47 from the vertical steel pipe 41 will be a fraction of the weight of the vertical steel pipe 41. For example, the length of the vertical steel pipe 41 is 1,300 meters for a seabed depth of 1350 meters, and for a 22 inch (55.9 cm) pipe diameter, the maximum tension upon the suction pile 47 is 450 kN (4410 kN). In this case, the suction pile 47 has a weight of at least 190 kN (1862 kN), a length of 32 meters, and a diameter of eight meters, in order to sustain the maximum tension.

Fabrication of the assemblies for the freestanding hybrid riser 40 is performed on-shore or on the deck of a surface vessel. Two basic assemblies are: (1) the assembly of the steel pipe 41 and the flexible pipe joint 53 and diverter pipe connector hub 52; and (2) the subsea foundation structure including the suction pipe 47 and the components welded or otherwise mounted to the suction pipe 47.

The foundation structure is assembled by welding the upper end of the J-tube to the hub 56 in the diverter pipe connector receptacle 48. Then the J-tube 57 is inserted through the holes 61, 60 in the suction pipe in order to mount the receptacle 48 to the top of the suction pipe 47, and then the receptacle 48 is welded to the top of the suction pipe 47 via the ribs 49, 50. Then the J-tube 57 is welded to the suction pipe 47 to close the gaps between holes 61, 60 and the J-tube. Then a hub of the connector 58 is welded to the lower end of the J-tube 57.

The suction pile 47 is then shipped and sunk so that it is delivered to a desired position on the seabed 46, and then driven into the seabed, so that the lower end of the J-tube is aligned with the end of the subsea pipeline 59. Then the J-tube 57 is connected via the connector 58 to the subsea pipeline 59. At this point, the subsea foundation structure has been installed, and the steel pipe 41 of the riser is ready to be connected over the subsea foundation structure and landed into the receptacle 48. The steel pipe 41 is oriented over the subsea structure and the diverter pipe connector hub 52 is landed into the receptacle 48 by control of the buoyancy of the floating tank 42, and control of the position of the floating tank 42 by surface vessels, while a remotely operated vehicle (ROV) on the seabed guides the hub 52 into the receptacle 48. The engagement mechanism 63 of the diverter pipe connector 54 is actuated once the floating tank 42 has been positioned so that the steel pipe 41 is oriented in a vertical position.

The foundation structure installation procedure just mentioned above may be modified to suit the required size of the foundation, the depth of foundation, and availability of materials and any pre-existing foundation on the seabed. For example, for a large foundation, it may be convenient to install the foundation on the seabed separate from the other foundation structure, and then mount the other foundation structure to the foundation. In this case, the foundation could include a number of suction piles or cemented casing structures, which could be installed separately and then joined together by the mounting of the other foundation structure. One or more of the suction piles or cemented casing structures could be a pre-existing foundation.

FIG. 3 shows a second example of a freestanding hybrid riser system 80 in accordance with the present invention. The freestanding hybrid riser system 80 includes a vertical steel pipe 81 supported at its top end by a floating tank 82. The floating tank 82 supports the weight of the vertical steel pipe 81 and also maintains the vertical steel pipe 81 in tension for stability. A length of pipe or flexible riser 83 in a double catenary connects the top end of the vertical steel pipe 81 to a production platform 84 on the surface. A mooring connection 85 such as a length of chain provides a link between the floating tank 82 and the top end of the vertical steel pipe 81.

The anchor or base for the riser 80 is a drilled and grouted pile 87 in the seabed 86. In other words, the pile 87 is a length of pipe or well casing that has been placed is a well bore 107 in the seabed 86, and then the annulus between the pipe and the well bore is filled with grout 88 that sets over time. If a subsea field already has a dry wellbore at a convenient location for use as a riser base, then a drilled and grouted pile 87 may be the most convenient base for a riser.

The foundation structure includes a flanged or diverter pipe connector 89 on the top of the pile 87, a forged branch fitting 90 such as a Y-fitting coupled by the connector 89 to the pile 87, and a receptacle 91 of a diverter pipe connector 92. The branch fitting 90 has a first arm 105 mounted to the upper end of the pile 87 via the pipe connector 89. The branch fitting 90 has a second arm 106 that provides an upper portion of a J-tube, which further includes a lower portion 93 coupling the branch fitting to a stationary pipeline end termination connector 94. The pipeline end termination...
connector 94 couples the lower portion 93 of the J-tube to a subsea pipeline 95. The pipeline end termination connector 94 can be a flanged connector or a diverless pipe connector.

[0059] The branch fitting 90 provides a fluid path from a hub 96 within the connector receptacle 91 to the lower portion 93 of the J-tube, but the branch fitting does not provide a fluid path to the pipe connector 89. For example, the branch fitting 90 is a forged or cast body Y-fitting with a curved bore machined to match a typical 5D bend and a pipe wall thickness. The hub 96 is welded to a short piece of straight pipe 97, which is inserted into the top of the Y-fitting 90, and then the short piece of pipe 97 and the connector receptacle 91 are welded to the body of the Y-fitting 90. Then the curved pipe 93 is inserted into the Y-fitting 90 and welded to the Y-fitting. Then a hub of the connector 94 is welded to the curved pipe 93. Then a short piece of straight pipe 98 is inserted into the bottom of the Y-fitting 90 and welded to the Y-fitting. Then a hub of the connector 89 is welded to the pipe 98. The connector 89 need not contain fluid pressure, but the connector 89 is subject to the tension from the vertical steel pipe 81 and bending moment from pivoting 102 of the vertical steel pipe 81.

[0060] The diverless pipe connector receptacle 91 receives a hub 99 having an integral flexible pipe joint 100. The flexible pipe joint 100 has an upper extension 101, which is welded to the bottom of the vertical steel pipe 81. The flexible pipe joint 100 permits a limited range of motion of the lower end. When the hub 99 is locked in a vertical orientation in the receptacle 91.

[0061] The hub 99 is guided into the receptacle 91 by an alignment cone 103. Once the steel pipe 81 of the riser is aligned in a vertical orientation, an engagement mechanism 104 in the receptacle 91 is actuated to lock the hub 99 into engagement with the hub 96. The engagement mechanism is sized to provide a sufficient level of force upon the hubs 96, 99 to contain the fluid pressure within the vertical steel pipe 81 and the J-tube 90, 93 and also to react to the tension from the vertical steel pipe 81. For example, the fluid pressure is up to 15,000 psi (103 MPa).

[0062] The three basic assemblies of components for the riser system 80 in FIG. 3 are: (1) the pile 87 capped with a hub for the connector 89; (2) the steel pipe 81 having a lower end attached to the flexible pipe joint 100 and diverless pipe connector receptacle 91; and (3) the subsea structure including the connector receptacle 91, the branch fitting 90, and the other components welded or otherwise mounted to the branch fitting 90 including the curved pipe section 93 attached to a hub for the subsea pipeline end termination connector 94, and the straight pipe section 98 attached to a hub for the pile connector 89. The second and third of these three assemblies are assembled on-shore or on the deck of a surface vessel.

[0063] If a pile capped with a connector hub is not already found at the desired location of the riser base, then a pipe string capped with a connector hub is inserted into a wellbore at the desired location of the riser base, and the annulus between the wellbore and the pipe string is filled with grout.

[0064] The hub 99 is secured to the bottom of the steel pipe 81 by welding the extension 101 to the bottom of the vertical steel pipe 81.

[0065] The assembly of the diverless pipe connector receptacle 91, the branch fitting 90, and the other components attached to the branch fitting is fabricated or delivered to a surface location above the pile 87, and then this assembly is sunk and aligned over the pile 87. Then the connector 89 is engaged to mount this assembly to the top of the pile 87. Then the connector 94 is engaged to connect the lower portion 93 of the J-tube to the subsea pipeline 95.

[0066] At this point, the subsea foundation structure for the riser 80 has been installed, and the steel pipe 81 is ready to be oriented over the foundation structure and landed into the receptacle 91. The vertical steel pipe 81 is oriented over the subsea structure and the diverless pipe connector hub 99 is landed into the receptacle 91 by control of the buoyancy of the floating tank 82, and control of the position of the floating tank by surface vessels, while a ROV on the seabed guides the hub 99 into the receptacle 91. Then the engagement mechanism 104 of the diverless pipe connector 92 is actuated once the floating tank 82 has been positioned so that the steel pipe 81 is oriented in a vertical position. Then the buoyancy of the floating tank 82 is increased to put the vertical steel pipe 81 in a state of tension for stability.

[0067] FIG. 4 shows a freestanding hybrid riser installation method for the installation of the riser 40 in FIG. 2. This installation method is also applicable to the installation of the riser 80 in FIG. 3.

[0068] In a first step 110 of FIG. 4, a foundation structure is installed upon the seabed. The foundation structure includes a receptacle for a diverless pipe connector, and a J-tube from the receptacle to a stationary subsea pipeline end termination. The J-tube provides a vertical-to-horizontal transition from the receptacle to the subsea end termination. Next, in step 111, a first end of a flexible pipe joint is attached to a bottom end of the steel pipe of the riser. The flexible pipe joint has a second end terminated by a diverless pipe connector hub.

[0069] Then, in step 112, the steel pipe of the riser is oriented over the foundation structure, and the diverless pipe connector hub is landed into the receptacle. Once the diverless pipe connector hub has been landed and the steel pipe of the riser has been oriented in a vertical position, the engagement mechanism of the diverless pipe connector is actuated, in order to make a connection between the diverless pipe connector and the receptacle for the flow of fluid between the vertical steel pipe and the subsea pipeline end termination and through the flexible pipe joint, through the diverless pipe connector hub, and through the J-tube. The engagement mechanism also locks the diverless pipe connector hub into a fixed engagement position with respect to the receptacle for the diverless pipe connector. Finally, in step 113, the buoyancy of the floating tank is increased to place the vertical steel pipe of the riser in a state of tension for stability.

[0070] FIG. 5 shows an open configuration of the collet connector engagement mechanism 63 introduced in FIG. 2. The engagement mechanism 63 includes a cylindrical housing 121 mounted via a cover 122 to the hub 52. The housing 121 serves as a hydraulic cylinder for a cylindrical and tubular piston 123 that reciprocates in an axial direction to open and close the engagement mechanism 63 by rocking fingers 124, 125, 126, etc., in a circular array of the fingers.

[0071] FIG. 6 shows the engagement mechanism 63 in a closed configuration. A reversible pump 127 removes hydraulic fluid such as oil or water from an annular region 128 between the housing 121 and the piston 123 in order to switch the engagement mechanism 63 from the open configuration in FIG. 5 to the closed configuration shown in FIG. 6. The pump 127 supplies hydraulic fluid to the annular region 128 in order to switch the engagement mechanism back to the open configuration.
Fig. 7 and 8 show the upper portion 131 of a clamp style diverless pipe connector. The upper portion 131 includes an upper hub 132 having a lower flange 133 and a pair of split ring clamps 134, 135 mounted to the upper hub around the lower flange.

As shown in Fig. 8, the split ring clamps 134, 135 are held together by a pair of screws 136, 137. Each screw 136, 137 includes a respective hexagonal head 138, 139 configured for engagement with a wrench tool of a remotely operated submersible vehicle (ROV) (not shown). Each screw 136, 137 also includes a respective left-hand thread 141, 142 engaging a respective pin 143, 144 in the clamp 134, and a respective right-hand thread 145, 146 engaging a respective pin 147, 148 in the clamp 135. Consequently, when the ROV wrench tool turns any one of the screws 136, 137 in a clockwise direction, the clamps 134, 135 are drawn together toward the flange 133, and when the ROV wrench tool turns any one of the screws 136, 137 in a counter-clockwise direction, the clamps 134, 135 are pulled apart away from the flange 133.

In order to mount the clamps 134, 135 to the hub 132, each clamp is slotted for receiving a respective C-shaped guide 151, 152. Each guide 151, 152 is secured to a respective half 153, 154 of a split ring that is received in an annular groove 155 cut in the periphery of the hub 132. The split ring is clamped to the hub 132 by bolts 156, 157. A respective helical compression spring 158, 159 is disposed between each of the clamps 134, 135 and its respective guide 151, 152 in order to center the clamps 134, 135 about the flange 133.

Fig. 10 shows a diverless collet-style pipe connector 170 having an elastomeric flexible pipe joint 175 integrated with the collet mechanism, shown in an open configuration. The collet-style pipe connector includes a top flange 171 for connection to the bottom end of a riser, and a bottom flange 172 for connection to foundation structure such as a suction pile or branch fitting. The top flange 171 is attached to an extension pipe 173 having a semispherical lower flange 174. An annular elastomeric flex element 175 is bonded to the semispherical lower flange 174. The flex element 175 includes alternate elastomer layers 176, 177 and annular metal layers 178, 179 reinforcing the elastomer layers. The elastomer layers 176, 177 are formed by embossing the metal layers 178, 179 in elastomer during a molding process. The elastomer, for example, is made of natural rubber or nitrile butadiene rubber (NBR).

The flex element 175 is also bonded to an inner cylindrical housing 180 that is attached to an outer cylindrical housing 181. A cylindrical and tubular piston 182 for the collet mechanism is disposed within the outer cylindrical housing 181 and between the inner housing 180 and the outer housing 181. The outer housing 181 serves as a hydraulic cylinder in cooperation with the piston 182 for actuating the collet mechanism. The inner housing 180 is attached to an internal pipe 183 terminated with an upper pipe connector hub 184. The internal pipe 180 and the extension pipe 183 together provide a lumen for the flow of riser fluid between the upper flange 171 and the upper pipe connector hub 184. The upper pipe connector hub 184 has been landed on a lower pipe connector hub 185 of an extension pipe 186 terminated by the lower flange 172.

Fig. 11 shows the closed configuration of the diverless collet-style pipe connector 170. The piston 182 has been extended downward to rock the fingers 187, 188 to forcibly engage the upper pipe connector hub 184 with the lower pipe connector hub 185.

Although the FIGS. 10 and 11 show the flange 171 as the upper flange and flange 172 as the lower flange, the diverless collet-style pipe connector 170 is just as operable for anchoring the bottom end of the riser to foundation structure when the diverless collet-style pipe connector 171 is turned upside down. In this case, the flange 171 would be connected to the foundation structure such as a suction pile or branch fitting, and the flange 172 would be attached to the bottom end of the riser pipe. When a single flexible pipe joint is used between the bottom end of the riser and the foundation, the choice between these two alternatives is a matter of which one is more convenient for installation and possible removal of the flexible pipe joint. In other cases, it is desirable to use more than one flexible pipe joint between the bottom of the riser and the foundation in order to accommodate an increased deflection angle of the riser from a vertical orientation. In these other cases, depending on the availability of diverless pipe connectors and flexible pipe joints, it may be most convenient to use at least one flexible pipe joint attached to the foundation below the diverless pipe connection.

Fig. 12 shows such an alternative arrangement, in which two diverless collet-style pipe connectors 191, 192 having respective integral flexible pipe joints 193, 194 joined together by an extension pipe 195 having an upper hub 196 and a lower hub 197. In this case, the flexible pipe joint 193 of the upper diverless collet-style pipe connector 191 would be attached to the bottom end of the riser pipe and would be above the diverless pipe connections, and the flexible joint 194 of the lower diverless collet-style pipe connector 192 would be attached to the foundation and would be below the diverless pipe connections.

Fig. 13 shows an open configuration of a diverless clamp-style pipe connector 201 with a flexible pipe joint 202 located on the riser side of the connection. Fig. 14 shows the same assembly in a closed configuration. In this example, a bottom flange 203 of the flexible pipe joint 202 is configured to serve as an upper hub 203 of the clamp-style pipe connector 201. The upper hub 203 mates with a lower hub 204 of an extension pipe 205. When two split-ring clamps 206, 207 are drawn together, for example by a screw mechanism as described above with reference to FIGS. 7, 8, and 9, the upper hub 203 becomes clamped to the lower hub 204 as shown in Fig. 14.

For connecting the bottom end of a riser to a foundation, the bottom end of the riser is secured to an upper flange 208 of the flexible pipe joint 202, and a lower flange 209 of the extension pipe 204 is mounted to the foundation. In an alternative configuration, the assembly shown in FIGS. 13 and 14 is turned upside down so that the bottom end of the riser is connected to the flange 209 of the extension pipe 205, and the flange 208 of the flexible pipe joint 202 is mounted to the foundation.

Fig. 15 shows a closed configuration of a diverless clamp-style pipe connector 211 joining two flexible pipe joints 212 and 213. The flexible pipe joint 212 is on the riser side of the connection, and the flexible pipe joint 213 is on the foundation side of the connection. A lower flange 214 of the flexible pipe joint 212 is configured as an upper hub for the pipe connector 211, and an upper flange 215 of the flexible pipe joint 213 is configured as a lower hub for the pipe.
connector. Two split ring clamps 216, 217 have been drawn together in order to clamp the flanges 214, 215 together.

FIG. 16 shows a closed configuration of a diverless collet-style pipe connector 221 joining two flexible pipe joints 222 and 223. The flexible pipe joint 222 is on the riser side of the connection, and the flexible pipe joint 223 is on the foundation side of the connection. A lower flange 224 of the upper flexible pipe joint 222 is configured as an upper hub for the pipe connector 221, and an upper flange 225 of the lower flexible pipe joint 223 is configured as a lower hub for the pipe connector. The collet actuation mechanism of the connector 221 is built around the upper flexible pipe joint 222.

For connecting the bottom end of a riser to a foundation, the bottom end of the riser is secured to an upper flange 226 of the upper flexible pipe joint 222, and a lower flange 227 of the lower flexible pipe joint 223 is mounted to the foundation. In an alternative configuration, the assembly shown in FIG. 16 is turned upside-down so that the bottom end of the riser is connected to the flange 227 of the flexible pipe joint 223, and the flange 226 of the flexible pipe joint 222 is mounted to the foundation.

FIGS. 2 and 3 have shown static connections of the foundation structures to horizontal rigid subsea pipelines. There are various other ways that a foundation structure may provide a static connection to a subsea pipeline.

FIG. 17 shows a flange type connector 241 connecting a foundation structure 242 to a horizontal rigid subsea pipeline 243. The foundation structure 242 includes a hub 244 and an alignment cone 245 for the riser connection. The foundation structure 242 also includes a J-tube 246 providing a connection between the hub 244 and the flange connector 241 for the flow of riser fluid.

FIG. 18 shows a horizontal diverless collet-style pipe connector 251 connecting a foundation structure 252 to a horizontal rigid subsea pipeline 253.

FIG. 19 shows a first vertical diverless collet-style pipe connector 261 connecting a foundation structure 262 to a first end of a vertical rigid jumper 263. A second vertical diverless collet-style pipe connector 264 connects a second end of the vertical rigid jumper 263 to a pipeline end termination (PLET) 265 of a horizontal rigid subsea pipeline 266. This particular configuration provides a way of accommodating considerable misalignment between the foundation structure 262 and the horizontal rigid subsea pipeline 266.

FIG. 20 shows a horizontal diverless collet-style pipe connector 271 connecting a foundation structure 272 to a horizontal flexible subsea pipeline 273. This is a way of accommodating more misalignment between a foundation structure and a subsea pipeline.

FIG. 21 shows a vertical diverless collet-style pipe connector 281 and a diverless vertical connector jumper 282 connecting a foundation structure 283 to a flexible pipeline 284. This is a way of accommodating still more misalignment between a foundation structure and a subsea pipeline.

In view of the above, there has been described an improved freestanding hybrid riser system and a method for installing it, in which the bottom connection at the base of the riser has a diverless pipe connector with a flexible pipe joint allowing the riser to connect to a mating tube and foundation structure, and allowing the riser fluid to flow through the foundation structure such as a suction pile to a static jumper connection point. This reduces the bending and deflection in the foundation structure, and eliminates the need for a jumper with multiple bends or loops between the lower end of the vertical steel pipe of the riser and the stationary pipeline end termination. Therefore there is a significant cost savings in the riser foundation structure, especially in deep and ultra-deep water.

What is claimed is:

1. A freestanding hybrid riser system comprising:
   - a vertical steel pipe having a top end and a bottom end;
   - a floating tank coupled to the top end of the vertical steel pipe for supporting the vertical steel pipe;
   - a flexible pipe joint;
   - a diverless pipe connector attached to the flexible pipe joint;
   - a foundation mounted on a seabed, and the bottom end of the vertical steel pipe being anchored to the foundation through the flexible pipe joint and the diverless pipe connector;
   - a tube mounted to the foundation and connected to the diverless pipe connector for providing a static connection to a subsea pipeline on the seabed for a flow of fluid between the vertical steel pipe and the subsea pipeline and through the flexible pipe joint and through the diverless pipe connector and through the tube.

2. The freestanding hybrid riser system as claimed in claim 1, wherein the flexible pipe joint includes alternate elastomer layers and metal layers reinforcing the elastomer layers.

3. The freestanding hybrid riser system as claimed in claim 1, wherein the flexible pipe joint has an upper end attached to the bottom end of the vertical steel pipe, and the flexible pipe joint has a lower end attached to the diverless pipe connector.

4. The freestanding hybrid riser system as claimed in claim 1, wherein the flexible pipe joint has an upper end attached to the bottom end of the vertical steel pipe, and the diverless pipe connector has a connector hub attached to a lower end of the flexible pipe joint, and the diverless pipe connector has a connector receptacle mounted to the foundation, and the tube has an upper end attached to the connector receptacle and provides a vertical-to-horizontal transition from the diverless pipe connector to the static connection to the subsea pipeline.

5. The freestanding hybrid riser system as claimed in claim 1, wherein the tube is a J-tube having an upper end attached to a receptacle of the diverless pipe connector, and the J-tube has a lower end for providing the static connection to the subsea pipeline.

6. The freestanding hybrid riser system as claimed in claim 1, wherein the foundation includes a suction pile, and the tube passes through the suction pile.

7. The freestanding hybrid riser system as claimed in claim 1, wherein the foundation includes a pile grouted in a bore in the seabed, and the tube extends from a branch fitting mounted on top of the pile.

8. A bottom configuration for a freestanding hybrid riser system, the bottom configuration comprising:
   - a flexible pipe joint;
   - a diverless pipe connector attached to the flexible pipe joint; and
   - a tube connected to the diverless pipe connector for providing a vertical-to-horizontal transition from the diverless pipe connector for conveying fluid when the fluid flows through the flexible pipe joint and through the diverless pipe connector.

9. The bottom configuration for a freestanding hybrid riser system as claimed in claim 8, wherein the flexible pipe joint includes alternate elastomer layers and metal layers reinforcing the elastomer layers.
10. The bottom configuration for a freestanding hybrid riser system as claimed in claim 8, wherein the flexible pipe joint has an upper end configured for attachment to a lower end of a vertical steel pipe of a riser, and the diverless pipe connector has a hub attached to a lower end of the flexible pipe joint, and the diverless pipe connector has a receptacle configured for engaging the diverless pipe connector hub, and the tube has an upper end attached to the diverless pipe connector receptacle for conveying the fluid when the diverless pipe connector hub is engaged in the diverless pipe connector receptacle and fluid flows through the flexible pipe joint, through the diverless pipe connector hub, through the diverless pipe connector receptacle, and through the tube.

11. The bottom configuration for a freestanding hybrid riser system as claimed in claim 8, further comprising a suction pile upon which the diverless pipe connector is mounted, and the tube passes through the suction pile.

12. The bottom configuration for a freestanding hybrid riser system as claimed in claim 8, further comprising a branch fitting upon which the diverless pipe connector is mounted, and the branch fitting has a first arm configured for attachment to an upper end of a pile, and the branch fitting has a second arm attached to the tube.

13. A method of installing a freestanding hybrid riser system comprising: installing a foundation structure upon a seabed; installing a foundation structure including a foundation on the seabed and a tube mounted on the foundation for providing a static connection to a subsea pipeline on the seabed; orienting the steel pipe in a vertical position once the diverless pipe connector hub has been landed into the receptacle, and then actuating the engagement mechanism to lock the diverless pipe connector hub into the fixed engagement position with respect to the receptacle.

14. The method as claimed in claim 13, which includes engaging a first end of the flexible pipe joint to the bottom end of the steel pipe, and wherein the enganging of the diverless pipe connector mounts a second end of the flexible pipe joint to the foundation structure.

15. The method as claimed in claim 14, wherein the second end of the flexible pipe joint is terminated by a diverless pipe connector hub, and a receptacle of the diverless pipe connector is mounted to the foundation structure, and the method includes landing the hub of the diverless pipe connector in the receptacle to mount the second end of the flexible pipe joint to the foundation structure.

16. The method as claimed in claim 15, wherein the receptacle for the diverless pipe connector has an engagement mechanism for locking the diverless pipe connector hub into a fixed engagement position with respect to the receptacle, and the method further includes orienting the steel pipe in a vertical position once the diverless pipe connector hub has been landed into the receptacle, and then actuating the engagement mechanism to lock the diverless pipe connector hub into the fixed engagement position with respect to the receptacle.