CELLULAR TENDONS FOR TLP

ABSTRACT

Tendon systems described herein may include a cellular tendon main body system having at least two essentially parallel pipe strings and may be used to moor a floating structure to a seabed. Hybrid tendon systems may include one or more tendon modules, where at least one tendon module includes a cellular tendon main body system. Where more than one module is used, the modules may be different types or designs of tendon systems, such as conventional single-string tendon or cellular tendon, according to the performance requirements of the module. Cellular tendon main body systems described herein enable the overall tendon, and subsequently the floating structure, to be used in ultra-deep waters and/or with heavy topsides.
CELLULAR TENDONS FOR TLP

FIELD OF THE DISCLOSURE

[0001] Embodiments disclosed herein relate to a tendon system for use with tension leg platforms (TLP). More specifically, embodiments disclosed herein relate to a tendon system that includes Cellular Tendon arrangement as the main body of at least one tendon or tendon module or a portion of one tendon or tendon module, designed and configured to enable use of the tendon, and thus use of TLPs, in ultra-deep waters and/or for heavy topsides, or to improve constructability and transportation and installation and/or project cost for any water depth.

BACKGROUND

[0002] One type of offshore drilling and production platform is a tension leg platform, generally called a TLP, which utilizes tendons to support the platform. The tendons have lower terminations that connect to pilings on the sea floor. The upper ends connect to top connectors on the platform. The platform is de-ballasted after connection to the top connector, placing the tendons in tension.

[0003] One type of tendon includes a main body that is a single steel tubular formed of multiple segments connected together with mechanical connections. The pipes in the tendon segments have hollow interiors that are sealed from sea water to provide buoyancy. Ballheads may be located within the interior, dividing the hollow interior in separate compartments sealed from each other. Use of conventional single steel pipe design for the tendon main body has technical and practical limitations in meeting the combined stiffness and the tension-collapse resistance requirements, limiting the depth and topside payload at which conventional tendon systems may be used.

[0004] U.S. Pat. No. 6,851,894 discloses tubular sections having three different wall thicknesses. The upper section has a greater diameter but lesser wall thickness than an intermediate section, and the intermediate section has a greater diameter but lesser wall thickness than the lower section.

[0005] As TLP platforms are located in deeper waters, providing steel tubular tendons that can resist the hydrostatic pressure becomes an increasingly difficult problem. For example, U.S. Pat. No. 7,422,394 discloses use of a tendon having a varied diameter, decreasing in diameter with depth, and limiting the diameter to thickness ratio at depth to overcome crushing force and hydrostatic pressure increases.

[0006] Various methods have been proposed to overcome this hindrance to use of TLPs in extremely deep water. For example, another type of tendon is a solid cable, formed of composite fibers, such as carbon fibers (often called a tether). Typically, a composite tendon, such as disclosed in U.S. Pat. No. 7,140,807, has an elastomeric jacket that encloses several bundles of fibers. A spacer or filler fills the interior space surrounding the fibers. Steel terminations are located on the ends of the separate rods or sections of a composite tendon for connecting the sections to each other.

[0007] Composite fiber tendons are generally smaller in diameter than steel tubular tendons and weigh less. However, they are less buoyant, such as their specific gravities being around 0.85 where 1.00 is considered neutral. Having solid interiors, composite fiber tendons are able to withstand high hydrostatic pressures. However, the lack of buoyancy limits the usefulness of composite fiber tendons in very deep water because a larger and more buoyant hull for the TLP is required in order to maintain the required tension at the bottom connector. Also, fatigue of the upper portion of a composite fiber tendon can be a concern because of the high bending moments caused by TLP lateral motion. U.S. Pat. No. 4,990,030 discloses use of composite fibers in the interior of a steel pipe section, which may provide the buoyancy, but as noted above, the use of the single pipe would be unsuitable for deep waters due to the high hydrostatic pressures.

SUMMARY OF THE DISCLOSURE

[0008] Various aspects, embodiments disclosed herein relate to a cellular tendon system that may be used to moor or a floating structure to a seabed. The tendon system may include a top tendon section configured to attach to a floating structure and a tendon bottom section configured to attach to a foundation. The tendon system may also include an upper transition unit connected to the top tendon section, and a bottom transition unit connected to the tendon bottom section. One or more tendon modules may be disposed intermediate the upper and bottom transition units, at least one tendon module including a tendon main body system comprising at least two pipe strings connected proximate their upper ends to a first module transition unit, which can be the same or different than the upper transition unit, and proximate their bottom ends to a second module transition unit, which can be the same or different than the bottom transition unit. A tendon leg platform may be moored to a seabed using such a tendon system.

[0009] In another aspect, embodiments disclosed herein relate to a cellular tendon system that may include a top tendon section configured to attach to a floating structure and a tendon bottom section configured to attach to a foundation. The tendon system may also include an upper transition unit connected to the top tendon section, and a bottom transition unit connected to the tendon bottom section. A tendon main body system including at least two pipe strings is connected proximate their upper ends to the upper transition unit and proximate their bottom ends to the bottom transition unit. The tendon system may be fully assembled onshore and transported to an offshore location, where it may be submerged and connected at its top end to a floating structure and at its bottom end to a foundation in the seabed. The floating structure may be, for example, a tension leg platform.

[0010] In another aspect, embodiments disclosed herein relate to a method of assembling a tendon system. The method may include assembling a tendon main body section having two or more pipe strings. The two or more pipe strings may be connected at their top end and bottom ends to a tendon top segment and a tendon bottom segment, which may be, for example, configured to connect to a floating structure, a foundation, or another tendon module.

[0011] In another aspect, embodiments disclosed herein relate to a hybrid tendon system, including: an upper tendon module and a lowermost tendon module. The upper tendon module includes a top tendon section configured to attach to a floating structure. The lowermost tendon module includes a bottom transition unit configured to attach to a foundation. At least one of the tendon modules include a tendon main body system comprising at least two pipe strings connected proximate their upper ends to an upper transition unit and proximate their bottom ends to a lower transition unit. A tension leg platform may be moored to a seabed using such a tendon system.
In another aspect, embodiments disclosed herein relate to a method of mooring a floating structure. The method may include: transporting a tendon system according to embodiments herein from an onshore assembly location to an offshore location; submerging the tendon system; connecting the tendon system to a foundation and connecting the tendon system to the floating structure.

Other aspects and advantages will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is an elevation view of a tension leg platform anchored with tendons according to embodiments herein.
FIG. 2 is a side view of a tendon according to embodiments herein.
FIG. 3 is a top cross-sectional view of a tendon according to embodiments herein.
FIG. 4 is a detail view of a portion of the tendon illustrated in FIG. 2.
FIG. 5 is an elevation view of a tension leg platform anchored with hybrid tendons according to embodiments herein.
FIG. 6 is a side view of a lower portion of a tendon according to embodiments herein.
FIG. 7 is a side view of a lower portion of a tendon according to embodiments herein.
FIGS. 8-10 are cross-sectional views of a tendon or portion thereof according to embodiments herein.

DETAILED DESCRIPTION

Embodiments disclosed herein relate to a tendon system for use with a tension leg platform (TLP). More specifically, embodiments disclosed herein relate to a tendon system having at least one cellular tendon main body portion designed and configured to enable use of the tendon, and thus use of TLPs, in ultra-deep waters and/or with heavy topside payload. Where the use of conventional tendons is technically and practically possible, the advantages of the cellular tendon over conventional tendons reside in the technical robustness, and, depending on platform geographical and economical characteristics, local fabrication, and cost savings.

The cellular tendon system includes the tendon main body, and for a single-module tendon system, an upper transition unit to interface with the tendon top interface, and a bottom transition unit to interface with the tendon bottom connection. Unlike the single carbon steel pipe used as the main body in a conventional tendon design, a cellular tendon consists of multiple metallic or composite tubular strings that are bundled together acting as one single body. Each individual string consists of multiple tubes or pipe segments connected to each other at the ends of the tubes, such as by welding or mechanical connections. The strings may be arranged in parallel and assembled on-shore.

Centralizers or frames may be used to bundle the strings together. Buoyancy modules are used partially or fully along the cellular tendon length to provide buoyancy necessary for the installation of the tendons. The TTS and TBS are assembled onshore and connected to the cellular tendon top transition unit and bottom transition unit, respectively. The cellular tendons, once fully assembled, may then be towed out to the site, upended, and installed.

A tendon system according to embodiments herein, such as a single-module tendon system described further below with respect to FIGS. 1-4, may include a top tendon section configured to attach to a floating structure, such as a TLP, and a tendon bottom section configured to attach to a foundation in the seabed. An upper transition unit may be connected to the top tendon section, and a bottom transition unit may be connected to the tendon bottom section. The tendon main body system includes at least two pipe strings connected proximate their upper ends to the upper transition unit and proximate their bottom ends to the bottom transition unit.

A tendon system according to embodiments herein, such as a multiple-module tendon system described further below with respect to FIGS. 5-7, may include a top tendon section configured to attach to a floating structure, such as a TLP, and a tendon bottom section configured to attach to a foundation in the seabed. The tendon main body system includes two or more modules, including an upper tendon module, a lowermost tendon module, and optionally one or more intermediate tendon modules. At one of the tendon modules includes a tendon main body system that includes at least two pipe strings connected proximate their upper ends to a first module transition unit and proximate their bottom ends to a second module transition unit.

The pipe strings are connected to the upper and bottom transition units such that the pipe strings are mechanically coupled. The coupling (connection) may be made by welding or other means of mechanical coupling such as treated connections. For example, the pipe strings may be welded to the upper and bottom transition units at the upper and lower ends of the individual pipe strings, respectively. Alternatively, the upper and lower ends of the pipe strings may be mechanically coupled to the upper and bottom transition units, respectively.

The pipe strings may be formed from steel, aluminum, or composite materials. The inner and outer diameter of the pipe in the pipe strings may be constant throughout the length of the pipe string in some embodiments. In other embodiments, the inner diameter, the outer diameter, or both, may vary along the length of the pipe string. For example, in some embodiments, the outer diameter of the pipes in the pipe string may remain constant, while the inner diameter decreases with depth, the thickness of the pipe thereby increasing with depth. Other variations in pipe diameter and thickness are also possible. The outer diameter and wall
thickness may be selected for each point along the length of a tendon to carry tension from the buoyant and partially submerged TLP (which consists of a nominal tension plus tension variations due to functional and environmental loads), to maintain a necessary tendon stiffness, to achieve a desired buoyancy, and to withstand the crushing forces of the surrounding sea.

0031] The tendon main body system may include one or more centralizers disposed along a length of the pipe strings. The centralizers may be, for example, metallic or non-metallic plates configured to space the pipe strings and arrange each of the pipe strings in a parallel configuration (substantially parallel, in some embodiments, as manufacturing process tolerances may provide for some minor deviation from parallel). The centralizers may also be connected to the pipe strings or otherwise configured such that the pipe strings are mechanically coupled. In this manner, the individual pipe strings form a single operative unit. In some embodiments, the centralizers may include a non-ferroic material associated with a metallic guide frame, described further below.

0032] To reduce consequences of flooding of the pipe strings, a plurality of bulkheads may be mounted in the pipe strings. The bulkheads may form sealed compartments so that leakage at any point along the length of a pipe section will flood only one compartment. The remaining sealed compartments would maintain sufficient buoyancy to support the weight of the tendon. Bulkheads may be placed according to the choice of the designer. The bulkheads may be located at the end of a designated joint of pipe, or at selected intervals, for example. Bulkheads may be secured in a variety of manners, and in some embodiments are secured by welding or mechanic locks.

0033] The tendon main body system may also include one or more buoyancy modules disposed around at least a portion of the pipe strings. In some embodiments, buoyancy modules may be disposed around the individual pipe strings in the tendon main body; in other embodiments, the buoyancy modules may be disposed around the joint of pipe strings forming the tendon main body. In some embodiments, the buoyancy modules may be formed from two or more sections disposed around respective portions of the pipe strings, and may be fastened to the pipe strings using non-ferroic or metallic straps. For example, the buoyancy modules may be banded to the pipe strings using metal strips or straps made of high-strength synthetic fiber or fabric, with a mechanical lock connecting the ends.

0034] The tendon main body system may also include one or more buoyancy arrest collars connected to the pipe strings. The buoyancy arrest collars may be provided to constrain the buoyancy modules to the cellular tendon. In some embodiments, the buoyancy arrest collar includes one or more mechanic parts configured to engage corresponding profiles in the buoyancy module.

0035] The physical requirements of the tendons may vary with depth. Thus, in some embodiments, the tendon may be formed by two or more modules. In some embodiments, for example, the tendon may include an upper tendon module and a lower tendon module; in other embodiments, the tendon may include an upper tendon module, a lower tendon module, and one or more intermediate tendon modules. As the design requirements (crush strength, etc.) of the shallower tendon modules may be lower than those used at depth, a hybrid tendon according to embodiments herein may include, for example, an upper tendon module, which may be a conventional tendon, such as a single-string tendon, and a lower tendon module or modules, which may be cellular tendons as described herein. In other embodiments, the tendon may include multiple cellular tendon modules. Where multiple cellular tendon modules are used along the length of the tendon, the design and physical requirements of the segments may be adjusted for operating depth.

0036] A hybrid tendon system according to embodiments herein, for example, may include an upper tendon module and one or more lower tendon modules, including a lowermost tendon module. The upper tendon module may include a top tendon section configured to attach to a floating structure. The upper tendon module may also include a lower tendon section configured to attach to one of the lower tendon modules, such as to an upper portion of an intermediate tendon module or the lowermost tendon module.

0037] The lower tendon modules may be configured to attach at their upper ends via an upper transition unit to either (a) the lower tendon section of the upper tendon module or (b) a lower tendon section of an axially higher lower tendon module. The lower tendon modules may also be configured to attach at their lower ends via a lower transition unit to either (a) a foundation or (b) an upper tendon section of an axially lower tendon module. The one or more lower tendon modules may be formed of a cellular tendon system, similar to that as described above, having a tendon main body system including at least two pipe strings connected proximate their upper ends to the upper transition unit and proximate their bottom ends to the lower transition unit.

0038] The above described tendons may be used to secure any variety of floating platform to a seabed.

0039] FIG. 1 is an elevation view of a floating platform 1, such as a TLP, moored to seabed 2 using tendon systems according to embodiments herein. Platform 1 may have a plurality of columns 4, and a horizontal section 6 may extend between the columns 4. Columns 4 and horizontal pontoons 6, to provide buoyancy, and may be adapted to be selectively ballasted with water. Platform 1 may also include one or more decks 8 for supporting a variety of equipment for offshore operations, such as drilling and/or production, such as through top tensioned risers 10.

0040] Upper tendon supports 12 are mounted to platform 1 at each column 4 for attachment to an upper end 13 of each tendon 14. A minimum of two tendons 14 may be used to support at each tendon support 12, and thus a platform 1 with four corners would have at least eight separate tendons 14. The lower end 16 of each tendon 14 is secured to a piling or foundation 18.

0041] FIG. 2 illustrates a tendon 14 according to embodiments herein. Tendon 14 includes a tendon top segment 20, tendon main body section 22, and a tendon bottom segment 24. The top of the uppermost pipe segment in tendon top segment 20 may be terminated with a connector assembly 25, commonly referred to as a length adjustment joint (L AJ) that is arranged and designed to connect to the TLP hull.

0042] The top of tendon main body section 22 is axially connected to the bottom of tendon top segment 20, and the bottom of tendon main body section 22 is axially connected to the top of tendon bottom segment 24. The bottom of the tendon bottom segment 24 is terminated with a connector assembly 27, commonly referred to as a bottom latch assembly that is arranged and designed to be received and locked into a piling 18 or other foundation structure on the seabed.
Tendon main body section 22 includes multiple (i.e., two or more, small quantities for large diameter sean pipes and large quantities for small diameter seamless pipes) metallic pipe strings 38. Each individual pipe string is formed from multiple pipe sections (segments, stands, or joints) welded or mechanically coupled end-to-end. Alternatively, tendon main body section 22 may include multiple composite pipe sections.

To facilitate connection of tendon main body section 22 to top and bottom segments 20, 24, an upper transition unit 26 and a bottom transition unit 28 may be used. Transition units 26, 28 may include tapered sections 30, 32 expanding in diameter from the diameter of the tendon top segment and the tendon bottom segment, respectively, terminating at a larger than the tendon bottom section 34, 36. Large diameter sections 34, 36 are sized appropriately for connection with the main body section 22. The top and bottom of pipe strings 38 forming main body section 22 may be welded or mechanically connected to transition units 26, 28, respectively.

For example, pipe strings 38 may be attached to the upper transition unit 26 that interfaces with the tendon top segment 20. The pipes in the pipe strings 38 are welded to, or mechanically connected to, the upper transition unit 26. A short taper 30 may or may not be used at the pipe top ends where the transition is made. At the top, the upper transition unit 26 may include a weld profile to be welded at the bottom of the tendon top segment 20. The pipe strings 38 may also be attached to the bottom transition unit 28 that interfaces with the tendon bottom segment 24. The pipes in the strings 38 are welded to, or mechanically connected to, the bottom transition unit 28. A short taper 32 may or may not be used at the pipe bottom ends where the transition is made. At the bottom, the transition unit 28 may have a weld profile to be welded to the top of the tendon bottom segment 24.

The physical arrangement of pipe sections 38 may vary, and may depend on the depth of service, the expected environmental conditions, and other factors. In some embodiments, the pipe strings 38 may be arranged such that the pipe strings run alongside each other. In other embodiments, the pipe strings 38 may be spaced apart from each other.

For example, in some embodiments, the pipe strings 38 may be spaced apart using a centralizer 40, a guide frame 42, or a combination of the two. Centralizers 40 may be made of non-ferric material, with or without the metallic guide frames 42, and may be used to bundle the pipe strings together and keep all the strings acting as a mechanically composite unit to meet the tendon strength and fatigue requirements.

Compartmentalization of the pipes may be used to reduce the in-water weight of the tendon when a leak occurs in one pipe string 38. For example, as shown in FIG. 4, single or multiple compartments 44, 46 may be formed inside the pipe strings, as well as the tendon top segment 20 and the tendon bottom segment 24, by using bulkhead 48. The bulkheads 46 may be used together with the guide frame 42 in some embodiments. For example, the guide frames 42 and bulkheads 48 may be inserted proximate an end of a pipe segment, facilitating connection to the next pipe segment forming the pipe string 38, spacing of the pipe strings, as well as segregation of the pipe segments into sealed chambers 44, 46.

Buoyancy modules 50 may be used partially or fully along the Cellular Tendon length to provide buoyancy necessary for installation of the tendons. Material used to form the buoyancy modules may be synthetic foams or other suitable light material. Open-bottom air cans or other types of buoyancy devices may also be used. Further, the buoyancy of the buoyancy modules 50 may vary along the length of pipe strings 38.

The buoyancy modules 50 may be used as a fabrication aid when the pipe strings 38 are assembled on shore. For example, using a centralizer 40, internal to a pipe segment group, encapsulation of multiple pipe segments with a buoyancy module 50 may facilitate disposition of the ends of the pipe segment for connection of guide frames 42, bulkheads 44, and/or connection of the pipe segment to the subsequent pipe segment. In some embodiments, the buoyancy modules 50 may be fastened to the pipe strings 38 by non-ferric or metallic straps 52, which may be recessed within a buoyancy module or may be placed at the surface around a buoyancy module.

A buoyancy arrest collar 54 may be used, such as with the metallic guide frames 42 as shown in FIG. 4, to facilitate placement and retention of the buoyancy module 50 around the pipe strings 38, both during construction and in service. For example, buoyancy arrest collar 54 may include one or more mechanical parts configured to engage corresponding profiles in the buoyancy module. In other embodiments, buoyancy arrest collar may include a disc-like structure encompassing the pipe strings 38, the outer portions of the disc engaging circumferential grooves in the buoyancy modules 50, or engaging a terminal end of the buoyancy modules 50.

Referring now to FIG. 5, an elevation view of a floating platform 1, such as a TLP, moored to seabed 2 using hybrid or modular cellular tendon systems according to embodiments herein is illustrated, where like numerals represent like parts. As described above with respect to FIG. 1, the platform 1 may have a plurality of columns 4, and a horizontal section 6 may extend between the columns 4. Columns 4 and horizontal pontoons 6 provide buoyancy, and may be adapted to be selectively ballasted with water. Platform 1 may also include one or more decks 8 for supporting a variety of equipment for offshore operations, such as drilling and/or production, such as through top tensioned risers 10.

Similar to the cellular tendon system described above, upper tendon supports 12 are mounted to platform 1 at each column 4 for attachment to an upper end 13 of each tendon 14. Minimum two tendons 14 may be supported at each tendon support 12, and thus a platform 1 with four corners would have minimum eight separate tendons 14. The lower end 16 of each tendon 14 is secured to a piling or foundation 18.

FIG. 5 illustrates two possible hybrid cellular tendons according to embodiments herein. Hybrid tendons 70 include an upper tendon module 72 that is a conventional, single string, tendon connected to a lower tendon module 74 that is a cellular tendon, such as that described above with respect to FIG. 2. Hybrid tendons 76 include an upper tendon module 78 that is a cellular tendon section, such as that described above with respect to FIG. 2, connected to a lower tendon module 80, which may also be a cellular tendon similar to that as described above with respect to FIG. 2, where the modules 78, 80 may be of the same or different design, which may be varied to appropriately meet design criteria for intended depth of use.
[0065] FIG. 6 is a side view of a hybrid tendon 70 according to embodiments herein, where like numerals represent like parts. Tendon 70 may include an upper tendon module 72 that is a conventional, single string, tendon connected to a lower tendon module 74 that is a cellular tendon. Upper tendon module 72 may include a tendon module top segment 81, a tendon module main body section 82, and a tendon module bottom segment 84. The top of the uppermost pipe segment in tendon top segment 81 may be terminated with a connector assembly 25, commonly referred to as a length adjustment joint (LAJ) that is arranged and designed to connect to the TLP hull. Conventional tendon module 72 main body section 82 may be formed from a single pipe string 86 including one or more segments 88 of pipe axially connected end-to-end. The top of tendon main body section 82 is axially connected to the bottom of tendon top segment 81, and the bottom of tendon main body section 82 is axially connected to the top of tendon bottom segment 84. The bottom of the tendon bottom segment 84 is terminated with a connector assembly 87, which may be similar to a bottom latch assembly. The connector 87 may be designed to be received and locked into a receiver assembly 90, having a receptacle 92, which may be designed similar to connector assemblies for attachment of a tendon to a piling, for example. The receiver assembly 90 may be connected, directly or indirectly, to bottom tendon module 74. For example, receiver assembly 90 may be part of a transition module (not shown) for latching connector assembly 87 and likewise latching to a connector assembly (not shown) forming an upper terminal end of bottom tendon module 74. In other embodiments, such as illustrated in FIG. 6, connector assembly 87 may form the upper terminal end 94 of bottom tendon module 74.

[0068] FIG. 7 is a side view of a hybrid tendon 76 according to embodiments herein, where like numerals represent like parts. Tendon 76 may include an upper tendon module 78 that is a cellular tendon connected to a lower tendon module 80 that is also a cellular tendon. Upper tendon module 78 may include a tendon module top segment 101, a tendon module main body section 102, and a tendon module bottom segment 104. The top of the uppermost pipe segment in tendon top segment 101 may be terminated with a connector assembly 25, commonly referred to as a length adjustment joint (LAJ) that is arranged and designed to connect to the TLP hull. The top of tendon main body section 102 is axially connected to the bottom of tendon top segment 101, and the bottom of tendon main body section 102 is axially connected to the top of tendon bottom segment 104. The bottom of the tendon bottom segment 104 is terminated with a connector assembly 107, which may be similar to a bottom latch assembly.

[0063] The connector 107 may be designed to be received and locked into a receiver assembly 110, having a receptacle 112, which may be designed similar to connector assemblies for attachment of a tendon to a piling, for example. The receiver assembly 110 may be connected, directly or indirectly, to bottom tendon module 80. For example, receiver assembly 112 may be part of a transition module (not shown) for latching connector assembly 117 and designed to connect to a connector assembly (not shown) forming an upper terminal end of bottom tendon module 80. In other embodiments, such as illustrated in FIG. 7, connector assembly 107 may form the upper terminal end 114 of bottom tendon module 80.

[0064] The top of bottom tendon main body section 122 is axially connected to the bottom of upper tendon module 72, as described above, via a connection 124. The bottom of bottom tendon main body section 122 is axially connected to the top of a tendon bottom segment 124. The bottom of the tendon bottom segment 124 is terminated with a connector assembly 127, commonly referred to as a bottom latch assembly that is designed to be received and locked into a piling 18 or other foundation structure on the seabed.

[0065] Upper tendon module 78 and bottom tendon module 80 may otherwise be similar to the cellular tendons as shown and described above with respect to FIGS. 2-4, where like numerals represent like parts.

[0066] In the various tendon modules 78, 80, as well as for intermediate modules that may be placed between and connecting modules 78, 80 for embodiments including more than two tendon modules, the size, number, and physical arrangement of pipe sections 38 may vary, and may depend on the depth of service, the expected environmental conditions, and other factors. In some embodiments, the pipe strings 38 may be designed such that the pipe strings run alongside each other. In other embodiments, the pipe strings 38 may be spaced apart from each other. For example, as described above with respect to FIGS. 2-4, in some embodiments, the pipe strings 38 may be spaced apart using a centralizer 40, a guide frame 42, or a combination of the two, as well as with a buoyancy module 50.

[0067] Upper tendon modules, such as modules 72, 78, as well as the bottom tendon modules, such as modules 74, 80, may include transition units 130, similar to transition units 26, 28, connecting the respective tendon modules 22, 82, 102, 122 to the tendon top segments and tendon bottom segments, as well as any intermediate connector segments used along the length of the hybrid tendon system.

[0068] Assembly of the cellular tendons according to embodiments herein may be performed in any number of manners. The main body section 22 may be assembled pipe segment by pipe segment. In some embodiments, the main body section 22 may be assembled pipe segment by pipe segment. In some embodiments, the main body includes a main body transition, and the main body includes a pipe string. In other embodiments, the two or more pipe strings forming the tendon main body may be individually assembled by axially connecting two or more pipe segments to form a pipe string. The two or more pipe strings, having roughly equivalent length, may be axially
connected at the respective ends to a tendon top segment and a tendon bottom segment. An upper transition unit and a bottom transition unit may be used to facilitate connection of the tendon main body section with the tendon top segment and the tendon bottom segment. As noted above, the tendon bottom segment and the tendon top segment may each be terminated with a connector assembly.

[0070] As noted above, it may be desired to space the pipe strings forming the tendon main body section apart from one another. Guide frames, centralizers, and/or a buoyancy module may be used to achieve the desired spacing, either during collective manufacture of the individual pipe strings or following manufacture of the individual pipe strings individually. A bulkhead may periodically be disposed in the pipe strings during assembly, and buoyancy arrest collars may be disposed along the length of the pipe strings, either during collective manufacture of the guides strings or following manufacture of the individual pipe strings individually.

[0071] In some embodiments, the main tendon body pipe strings may be assembled collectively as follows. A buoyancy module section, such as a semi-circular section, may be placed horizontally, with the interior of the module facing upward. The buoyancy module section may be configured, similar to that as illustrated in FIG. 3, having pockets 60 in which the pipe segments may be disposed or laid. Centralizer 40 may then be disposed on the pipes and buoyancy modules, such as into a groove in the buoyancy module section or by welding to pipes 38. The upper pipe segments may then be disposed on or connected to centralizer 40, subsequently encapsulated with a second buoyancy module section, and then the buoyancy module sections may be cinched or secured to the structure using straps 52. Disposing of a centralizer and buoyancy module proximate each end of a pipe segment, such as within a couple feet of an end, may thus allow for disposal of guide frames 42, bulkheads 48, and buoyancy arrest collars 54, as required, and connection of two corresponding pipe segments forming an individual pipe string to be welded or otherwise connected to each other with relative ease.

[0072] One possible arrangement for buoyancy modules 50 is thus as illustrated and described with respect to FIG. 3, which may be used to facilitate tendon fabrication as described above. Other various arrangements for buoyancy modules that may facilitate fabrication and spacing of strings 38 during fabrication are illustrated in FIGS. 8-10.

[0073] As illustrated in FIG. 8, for example, a buoyancy module 150 may include two or more arms defining two or more recesses 154 in which the strings 38 may be disposed. Non-ferric or metallic straps 52 may be placed at the surface around the buoyancy module 150 and the strings 38. As illustrated, buoyancy module 150 includes four arms 152, recesses 154; other embodiments may include three, five, six or more arms/recesses for placement of the strings 38.

[0074] As illustrated in FIG. 9, as another example, a buoyancy module 160 may be used to space strings 38 via corner recesses 162. Similarly, shapes having three, five, six or more corners may be used, where recessed corners are designed for placement and/or retention of strings 38 during fabrication and/or use of the cellular tendon or cellular tendon modules.

[0075] As illustrated in FIG. 10, as another example, a buoyancy module 170 may be used to space strings 38 via recesses 172. Recesses 172 may be located proximate a corner of the shaped buoyancy module, as well as along the length of the sides of the shaped buoyancy module. As illustrated in FIG. 10, the buoyancy module 170 includes a recess 172 proximate the top corner of the triangular buoyancy module 170, as well as two recesses 172 located along the sides of the triangular buoyancy module 170. In this manner, the bottom 174 of the buoyancy module may be used to support the strings 38 during fabrication, providing a flat surface for disposal of the buoyancy module and strings 38 during fabrication.

[0076] The buoyancy modules as illustrated in FIGS. 8-10 may provide for the desired buoyancy of the cellular tendon modules. Additionally, these and similar configurations provide openings along the length of the string, allowing access to the pipes in the strings for inspection. Additionally, such embodiments may allow for removal and/or replacement of one or more strings of the pipes.

[0077] Similar to the embodiments for buoyancy modules illustrated in FIGS. 3 and 8-10, guide frames may also be formed from a variety of shapes so as to properly space strings 38 and facilitate fabrication of the cellular tendons or tendon modules.

[0078] After assembly on shore, the cellular tendon system 14 as described above may be transported, or towed out, in single units, pairs, or other convenient connection numbers, to the offshore site. The towing can be carried out as surface tow or submerged tow. At the offshore site, the cellular tendon system 14 is upended and attached to the foundation 18. The tendon top segment 20 is pulled in and locked at the tension leg platform 1 tendon porch 12 via the length adjustment joint (L.A.J.) 25. After the tendon pretension reaches the design value, the tendon is ready for the in-place services.

[0079] To add flexibility in the TLP construction schedule, the Cellular Tendon system 14 can be pre-installed. In the pre-installed condition, a temporary tendon supporting buoy may be used to maintain the near vertical position of the tendons and meet the strength and fatigue requirements from the wave and current loads, similar to those used in conventional tendon systems.

[0080] When multiple tendon modules are used to form a single tendon, such as illustrated in FIGS. 5-7, the cellular tendon modules may be fabricated onshore as described above. After assembly onshore, the modules (such as 72, 74 or 78, 80) may be towed out, in single units or in pairs, to the offshore site. The towing can be carried out as surface tow or submerged tow. At the offshore site, the bottom tendon module may be upended and attached to the foundation. To add the flexibility in the TLP construction schedule, the bottom modules can be pre-installed prior to arrival of the upper modules. After towed to the site, the upper modules may be upended and latched, or otherwise attached, to the receiving module at the upper end of the lower module. The top tendon segment of the uppermost module is pulled in and locked at the TLP tendon porch via the length adjustment joint (L.A.J.). After the tendon pretension has reached the design value, the tendon is ready for the in-place services. In other embodiments, the upper and lower modules of the tendon system may be assembled offshore prior to submerging and upending.

[0081] As described above, tendons according to embodiments herein include a tendon main body section that includes multiple metallic or composite tubular members, bundled together acting as the main body of a tendon system for a Tension Leg Platform (TLP). These “cellular” tendons have unique features which enable the TLP technology and application in hydrocarbon production in ultra-deep water and/or with heavy topsides. In addition, the advantages of the
cellular tendon over the conventional tendons reside in the technical robustness, local fabrication, and cost savings.

The cellular tendon design has technical merits for actual field developments using TLPs with representative large, medium or small payloads in water depths between 1500 meters and 3000 meters, and possibly deeper. The cellular tendon system has the following advantages over the conventional tendons: provides sufficient vertical and lateral stiffness, while also ensuring sufficient resistance to tension collapse; provides more neutrally buoyant tendons that reduce TLP displacement and temporary buoyancy requirement during tendon installation; provides more structural redundancy for the tendon main body where the multiple tube construction in the Cellular Tendon warrants additional structural redundancy in the event of one string damaged; enhances (and in some cases enables) the local fabricating content, where applicable; provides material cost savings as a result of eliminating mechanical couplings; and provides installation cost savings as a result of eliminating the need for heavy lift vessels.

While the disclosure includes a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments may be devised which do not depart from the scope of the present disclosure. Accordingly, the scope should be limited only by the attached claims.

What is claimed:

1. A tendon system, comprising:
   a top tendon section configured to attach to a floating structure;
   a tendon bottom section configured to attach to a foundation;
   an upper transition unit connected to the top tendon section;
   a bottom transition unit connected to the tendon bottom section; and
   one or more tendon modules disposed intermediate the upper and bottom transition units, at least one tendon module including a tendon main body system comprising at least two pipe strings connected proximate their upper ends to a first module transition unit, which can be the same or different than the upper transition unit, and proximate their bottom ends to a second module transition unit, which can be the same or different than the bottom transition unit.

2. The tendon system according to claim 1, comprising one tendon module disposed intermediate the upper and bottom transition units, the tendon module including a tendon main body system comprising at least two pipe strings connected proximate their upper ends to the upper transition unit and proximate their bottom ends to the bottom transition unit.

3. The tendon system according to claim 1, comprising two or more tendon modules, including an upper tendon module, a lowermost tendon module, and optionally one or more intermediate tendon modules.

4. The tendon system of claim 3, wherein the lowermost tendon module includes a tendon main body system comprising at least two pipe strings connected proximate their upper ends to a module transition unit and proximate their bottom ends to the bottom transition unit.

5. The tendon system of claim 3, further comprising one or more intermediate tendon modules, comprising:
   the upper tendon module including the top tendon section configured to attach to the floating structure and a lower tendon section configured to attach to one of the intermediate tendon modules;
   the intermediate tendon module:
   attached at their upper ends via an upper transition unit to the lower tendon section of the upper tendon module;
   attached at their lower ends via a lower transition unit to an upper tendon section of an axially lower tendon module;
   the lowermost tendon module:
   attached at its upper end to a lower tendon section of an axially higher tendon module;
   attached at its lower end via the bottom transition unit to the foundation.

6. The tendon system of claim 1, wherein the pipe strings are connected to the upper and bottom transition units such that the pipe strings are mechanically coupled.

7. The tendon system of claim 1, wherein the pipe strings are formed from steel, composite, or aluminum.

8. The tendon system of claim 1, the tendon main body system further comprising one or more centralizers disposed along a length of the pipe strings.

9. The tendon system of claim 8, the centralizers configured to space the pipe strings and mechanically couple the pipe strings.

10. The tendon system of claim 1, the tendon main body system further comprising one or more buoyancy modules disposed around at least a portion of the pipe strings.

11. The tendon system of claim 1, the tendon main body system further comprising a buoyancy arrest collar connected to the pipe strings.

12. The tendon system of claim 1, the tendon main body system further comprising one or more guide frames disposed along a length of the pipe strings.

13. The tendon system of claim 1, wherein each of the pipe strings are substantially parallel to each other.

14. The tendon system of claim 3, wherein one or more of the tendon modules comprises a single-string type tendon.

15. The tendon system of claim 3, wherein the upper tendon module comprises a cellular tendon.

16. A tension leg platform moored to a seabed using a tendon system as claimed in claim 1.

17. A method of mooring a floating structure, comprising:
    transporting a tendon system according to claim 1 from an onshore assembly location to an offshore location;
    submerging the tendon system;
    connecting the tendon system to a foundation; and
    connecting the tendon system to the floating structure.

18. The method of mooring a floating structure of claim 17, the tendon system comprising two or more tendon modules, including an upper tendon module, a lowermost tendon module, and optionally one or more intermediate tendon modules, the method comprising:
    submerging the lowermost tendon module;
    connecting the lowermost tendon module to the foundation;
    submerging an upper tendon module;
    connecting the upper tendon module to a lower tendon module; and
    connecting the upper tendon module to the floating structure.
19. The method of mooring a floating structure of claim 17, wherein the tendon modules of the tendon system are fully assembled onshore prior to transport.

20. The method of mooring a floating structure of claim 18, wherein the upper and lower modules of the tendon system are connected offshore prior to submerging.

21. A method of assembling a tendon system, comprising: assembling a tendon main body section comprising two or more pipe strings; axially connecting the top and bottom ends of the two or more pipe strings to a tendon top segment and a tendon bottom segment, respectively.

22. The method of claim 21, further comprising: disposing an upper transition unit intermediate the top end of the two or more pipe strings and the tendon top segment; and disposing a bottom transition unit intermediate the bottom end of the two or more pipe strings and the tendon bottom segment.

23. The method of claim 21, further comprising terminating the tendon bottom segment with a connector assembly; and terminating the tendon top segment with a connector assembly.

24. The method of claim 21, wherein assembling the tendon main body system comprises axially connecting two or more pipe segments to form a pipe string.

25. The method of claim 24, the assembling the tendon main body system further comprising spacing apart the two or more pipe segments or the two or more pipe strings using at least one of a guide frame, a buoyancy module, and a centralizer.

26. The method of claim 21, further comprising disposing a bulkhead in at least one of the two or more pipe strings, the tendon top segment, and the tendon bottom segment.

27. The method of claim 21, further comprising disposing a buoyancy arrest collar in at least one of the two or more pipe strings, the tendon top segment, and the tendon bottom segment.

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