

**A MODULAR SUB – SEA (LEVEL) STRUCTURE FOR SUPPORTING AN
OFFSHORE PRODUCTION FACILITY**

Related application data

5 [0001] The present patent application claims the benefit and priority of US provisional application number 60/782,766 filed on 16 March 2006, entitled "Sub-sea support structure for an oil and gas processing platform", the contents of which are hereby incorporated in entirety by reference.

10 Background

[0002] The present invention relates to the field of offshore structures, and more specifically, to a modular sub-sea (level) structure for supporting an off-shore production facility.

15 [0003] Conventional offshore production facilities, such as oil and gas production facilities, for example, are supported by a structure known as a "jacket" or "substructure". The term "substructure" or "subsea structure" will be used throughout this application to refer to such a structure.

20 [0004] These substructures are generally constructed from vertical or near vertical (battered) legs which are stabilized and restrained by a series of bracings between each two neighboring legs thereby forming braced frames, typically oriented perpendicular to each other, in three or more planes. The legs extend from the seabed and continue upwards past the waterline of a body of water and support
25 any topside structures, such a platform unit, for example. The substructures are typically of welded construction and are generally installed as a complete structure.

[0005] The legs bear the vertical forces resulting from the weight of the topside structure and the equipment arranged thereon. In addition, forces induced from
30 wave loading (hydrodynamic loads) are also borne by the legs. The hydrodynamic loads are greatest at the crest and trough of the wave. Said hydrodynamic loads create horizontal (or shear) forces on the substructure. These shear forces resolve into axial (vertical) forces within the legs due to the braced frame construction.

These shear forces, when axially resolved, are additive to the vertical loading forces contributed by the topside structure and thus increase in magnitude towards the base of the substructure.

5 [0006] Apart from creating additional vertical forces in the legs of the substructure, the shear forces of the waves, when the wave directions are normal to the planes in which the bracing frames lie in, also cause out of plane bending forces to be created in said bracing frames and legs. These out of plane bending forces in turn create internal stresses within the frames that are further additive to the (vertical)
10 axial loads already exerted by the topside unit and the hydrodynamic loading as mentioned above.

[0007] In addition to out of plane bending, it is also found that when hydrodynamic forces are exerted on a bracing frame of the substructure, joint displacements and
15 rotations typically occur within the plane of the frame. Joint displacements and rotations that take place within the plane of the frame give rise to in plane bending (i.e. bending within the plane of the frame) and create further internal stresses, which are also additive to the external loads (vertical and shear) and out of plane bending forces already experienced by the legs and members of the substructure.

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[0008] This combination of stresses from in plane bending, out of plane bending (due to the shear forces), and axial stresses (due to both the vertical loading and the shear forces) causes a build up of stress concentrations throughout the substructure, especially at perpendicular junctions of said structure. This build up of
25 stress concentrations produces fatigue in the welded connections between adjacent frames, the frames and the legs and/or the members (bracing) of the frames, thereby creating weakness in the overall substructure and may lead to catastrophic failure .

30 [0009] One example of a modular offshore production facility having a sub-sea supporting structure is described in European patent application EP 1 666 669 A2. The substructure is made up of a rigid trapezoidal base support structure and an upper pyramidal support structure. Both the base and the pyramidal support

structure are located just beneath the surface or waterline of a body of water. Piles connected to the substructure extend from the seabed beyond the waterline to support a topside structure (platform unit). The substructure includes a framework having four faces, wherein each face of the framework is defined by horizontal and diagonal bracing members. However, due to trapezoidal structure of the frames, the direction of the waves is still substantially normal to the planes of the bracing frames of said support structure, which therefore still gives rise to significant levels of stress being generated within the support structure.

10 **[0010]** Accordingly, there is still a need for a sub-sea structure (or substructure) for supporting an offshore production facility that is capable of bearing hydrodynamic forces by having a reduced occurrence of in plane and out of plane bending, that is portable and of simple construction and is yet cost effective to manufacture. In this respect, a sub-sea structure of the present invention, and as defined in the
15 appended claims, overcomes the aforesaid difficulties.

Description

[0011] The modular sub-sea (level) structure of the present invention includes at least one frame module. The frame module includes at least three triangular
20 frames. The triangular frames are arranged around or about a central longitudinal axis where bases of the triangular frames are connected to each other to form a horizontal frame comprising a closed polygonal ring, hereinafter also described as a "closed polygonal frame". Each triangular frame has a base and an apex opposite to said base. The apex of each triangular frame of the frame module is
25 connected to or adapted to be connectable to a corresponding vertex of another closed polygonal frame belonging to a subsequent frame module, if any, stacked thereon. This closed polygonal frame of the subsequent frame module is likewise formed by connecting the bases of the triangular frames of the subsequent frame module to each other. By stacking frame modules one above another successively
30 in this manner, subsea structures of varying heights can be formed.

[0012] The diametric dimension of each frame module is typically larger than that of the subsequent frame module stacked above it, so that the subsea structure gets

progressively smaller towards the top, thereby achieving an overall tapered or conical structure.

[0013] The triangular frames of each frame module may be tilted (inclined) towards the central longitudinal axis of the polygonal frame, with the apex of each triangular frame being closer to the central longitudinal axis than the base. With this arrangement, each individual frame module becomes tapered towards the top end of the frame module. In exemplary embodiment, such a frame module comprises triangular frames that are uniformly inclined at an acute angle towards the central axis of the frame module, in a direction from the closed polygonal frame formed by the respective bases to the respective apexes of the triangular frames. In other words, in this embodiment, the apex of each triangular frame leans towards the central longitudinal axis of the frame module, so that the frame module is tapered towards the top.

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[0014] Instead of being tilted, the triangular frames in each frame module may also be arranged vertically, i.e. the plane of the triangular frame is parallel to the central longitudinal axis running through the center of the horizontal closed polygonal frame of the frame module. Frame modules comprising vertical triangular frames are also able to provide a tapering subsea structure. In this embodiment, the unique requirement that each subsequent frame module has the vertices of its closed polygonal frame connected to the apexes of the triangular frames of the frame module beneath results in frame modules that become successively smaller. The reason for this is that the distance between the apexes of adjacent triangular frames in a frame module is naturally smaller than the base of each triangular frame. This causes the triangular frames of the next frame module to have a smaller base length, and when they are connected together, they would form a smaller closed polygonal frame. In this manner, each closed polygonal frame becomes naturally smaller than the closed polygonal frame of the frame module beneath it. As the closed polygonal frame of each frame module becomes progressively smaller, a tapering or conical profile is achieved in each triangular frame in a direction from the base to the apex thereof, towards the central axis.

[0015] The sub-sea structure also includes a closing polygonal frame element having a number of vertices corresponding to the number of triangular frames of a top-most frame module (which may be only the frame module depending on the circumstances of use). The closed polygonal frame element comprises beams
5 connecting the apexes of each triangular frame of said top-most frame module. Essentially, the closing polygonal frame element serves to provide a structural support to the top-most frame module such that the apexes of the triangular frames of said top-most frame module are not left unsecured but are connected to the respective vertices of the closing polygonal frame element. In addition, the closing
10 polygonal frame element, as mentioned earlier, also provides a means for connecting the first plurality of sleeves to the sub-sea structure.

[0016] The sub-sea structure also includes a first plurality of sleeves, wherein each sleeve is connected to the closing polygonal frame element; and at least a
15 corresponding second plurality of sleeves, wherein each sleeve of said second plurality of sleeves is connected to the closed polygonal frame of the frame module most distant from said closing polygonal frame element. In other words, each sleeve of the second plurality of sleeves is connected to the bottom-most closed polygonal frame of the sub-sea structure. The corresponding sleeves of said first
20 and second pluralities of sleeves are adapted to slidably receive, in a pair wise manner, a plurality of piles, which either secure the sub-sea structure to the seabed or provide a means of supporting any topside structure.

[0017] In determining the number of frame modules required for the sub-sea
25 structure, operational parameters of or conditions under which the sub-sea structure is operated may be considered. Specifically, the depth of the body of water in which said sub-sea structure operates in is important. In one embodiment of the invention, where the depth of the body of water is considered to be shallow, the sub-sea structure may comprise a single frame module such that it forms the
30 top-most frame module. Under other operating environments where the depth of the body of water is greater, two, three, four or more frame modules may be utilized to achieve a desired height without a fixed upper limit.

[0018] In embodiments of the sub-sea structure having more than one frame module, the frame module at the very top of the entire assembled sub-sea structure, which is typically the frame module located just below the waterline of the body of water, is considered to be the top-most frame module. In one exemplary
5 embodiment, the top-most frame module terminates below the waterline, or more specifically, below the trough level of the wave. This is beneficial because the hydrodynamic forces are greatest in the wave zone located at or near the surface of the waterline. By minimizing the number of piles or beams that extend above the waterline and extend through the height of the waves, and not having the top-most
10 frame module penetrate the waterline, significant reductions to the forces experienced by the sub-sea structure may be achieved.

[0019] In the embodiment of the structure having a plurality (two or more) of frame modules, the height of each of the respective frame modules that form the subsea
15 structure may be equal or unequal depending on design, location and operational requirements. The first frame module, which typically forms the base (as shown in **Figure 1**) of the substructure, may be supported at and directly secured to the seabed by piles, for example.

20 **[0020]** Alternatively, the substructure may be supported by a frame module adapted to function as a gravity base structure of sufficient mass capable of resisting the sliding and overturning forces brought about by the waves, thereby being indirectly secured to the seabed.

25 **[0021]** In either case, whether the first (bottom-most) frame module is directly or indirectly secured to the seabed, the second frame module is stacked on the first frame module such that the apexes of the first frame module connect with the respective vertices of the closed polygonal frame of the second or subsequent framed stacked thereon. In this exemplary embodiment having a plurality of frame
30 modules, the uniform tapered nature of the triangular frames in a direction from the base to the apex thereof, and slanted towards the central axis of the polygonal frame results in an overall sub-sea structure that tapers towards the topside (or towards the waterline).

[0022] Accordingly, at any point along said height of the substructure, the combination of the tapering along the height of the structure and the polygonal nature of the frame module results in a minimum number of beams lying normal (at
5 ninety degrees to) the direction of the wave. A further effect of the tapering is that the diametric dimension of each subsequent frame module decreases along the height of the structure.

[0023] In one exemplary embodiment, the closing polygonal frame element may be
10 inscribed within a closing triangular frame. In this respect, the term "inscribed" means that the closing polygonal frame element is enclosed by and fits inside the closing triangular frame such that no other closing polygonal frame element similar to the inscribed closing polygonal frame may be enclosed within the closing triangular frame as well. In this exemplary embodiment, although the diameter of
15 the closing polygonal frame element may be smaller than that of the closed polygonal frame of the preceding frame module beneath, the closing triangular frame, within which the closing polygonal frame element is inscribed, is typically of a larger diametric dimension than the closed polygonal frame of the preceding frame module.

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[0024] As an illustrative example, the diametric dimension of the closing triangular frame may be equivalent to that of the closed polygonal frame of the frame module most distant from the closing polygonal frame element. In this illustrative embodiment, the first plurality of sleeves connected to the respective vertices of the
25 closing triangular frame, and each of the corresponding second plurality of sleeves connected to the respective vertices of the closed polygonal frame of the frame module most distant from said closing polygonal frame element, are arranged and aligned to allow each pile that is received in a pair wise manner by a sleeve of the first plurality of sleeves and a corresponding sleeve of the second plurality of
30 sleeves to be parallel to the central axis. In other words, the first plurality of sleeves which are connected to the respective vertices of the closing triangular frame of the are positionally matched by the corresponding second plurality of sleeves connected to the most distant frame module, so as to enable the plurality of piles to

be substantially vertical when received within said first and second pluralities of sleeves.

[0025] Alternatively, the closing polygonal frame element may include a closed
5 polygonal frame with each of its respective vertices connected to corresponding
apexes of the top-most frame module. In this alternative embodiment of the closing
polygonal frame element, the closing polygonal frame element may also include
beams extending from the respective vertices of the closed polygonal frame such
that its diametric dimension is again greater than the closed polygonal frame of the
10 preceding frame module and equivalent to that of the closed polygonal frame of the
frame module most distant from the closing polygonal frame element. In this
alternative embodiment, the first plurality of sleeves is connected to the beams
extending from the closed polygonal frame of each closing polygonal frame
element.

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[0026] As a further alternative, each of the first plurality of sleeves may also be
supported by a total of three beams where two of the three beams are connected
to adjacent vertices of the closing polygonal frame element, and the remaining
beam is connected to a vertex of the closed polygonal frame of the frame module
20 directly below said sleeve.

[0027] As mentioned above, each frame module includes at least three identical
triangular frames that form the closed polygonal frame of the frame module. The
triangular frames may be isosceles, equilateral, scalene, right, obtuse or acute with
25 each triangular frame being radially spaced (or arranged) around an origin (central
axis) such that their respective bases combine to form the horizontal closed frame
around said central axis.

[0028] In one exemplary embodiment, three triangular frames are used in the
30 fabrication of the frame module. The three triangular frames are arranged around
the central axis such that a horizontal closed triangular frame is formed. In another
exemplary embodiment, six triangular frames are used to form a horizontal closed

hexagonal frame. The exemplary embodiment where the frame module has six triangular frames will be described in greater detail below.

[0029] In general, there is no theoretical upper limit to the number of triangular frames, and hence no limit to the number of sides that the closed polygonal frame may have, i.e. the horizontal closed polygonal frame may be a n-sided polygonal frame. Having a polygonal frame having a larger number of sides is advantageous as the forces that are exerted on the subsea structure due to wave and hydrodynamic loading on each triangular frame that form the sub-sea structure are distributed over a larger number of triangular frames within each frame module. Furthermore, wave and hydrodynamic loading is also reduced as the changing angular face of the polygon provided by the larger number of triangular frames in each frame module does not present a common lateral plane that is completely normal to the wave direction, i.e. the number of instances when a wave is normal to a face of the sub-sea structure can be minimized by having a polygonal frame with a higher number of sides.

[0030] Each triangular frame that forms part of the closed polygonal frame of the frame module includes at least three individual beams. In the embodiment where the triangular frame is formed from three individual beams, a first individual beam may be a base beam (base). The remaining two beams each have one of their ends connected to either end of the base beam, such that the remaining two beams extend therefrom. The respective distal ends of said remaining two beams intersect opposite said base thereby forming the apex of the triangular frame.

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[0031] Alternatively, each individual beam of the triangular frame, such as the base beam for example may also be formed from a plurality (two or more) of further sub-beams, which in combination, still connect together to form the triangular frame, as described earlier.

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[0032] The cross-sectional shape of the individual beams that form the triangular frame also plays a role in minimizing the wave (drag) forces experienced by the substructure as a whole. In this regard, beams with inwardly increasing cross-

sectional areas may be used. Specifically, the individual beams of the triangular frames may be of a cross-sectional area that is circular, triangular, rectangular, elliptical or any combination thereof, for example.

5 **[0033]** As mentioned earlier, the sub-sea structure also includes a first and at least a corresponding second plurality of sleeves. In one embodiment, the first plurality of sleeves may be connected within the closing polygonal frame element, and proximate to the central axis, i.e. within the closing polygonal frame element. Similarly, in this embodiment the corresponding second plurality of sleeves are also
10 connected within the closed polygonal frame of the frame module most distant from the closing polygonal frame element. Both the first and second pluralities of sleeves, when connected to the structure, are in an equidistantly space-apart relationship from every other sleeve of their respective pluralities.

15 **[0034]** Alternatively, the first plurality of sleeves and its corresponding second plurality of sleeves may be connected on or beyond the periphery of said closing polygonal frame element and on or beyond the periphery of the closed polygonal frame of the frame module, respectively. As above, the sleeves of the respective pluralities are also in an equidistant and spaced-apart relationship.
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[0035] The arrangement of the sleeves, as described above, is also such that it permits said sleeves to slidably receive, in a pair wise manner, a plurality of piles. In this respect, the first plurality of sleeves and its corresponding second plurality of sleeves may be vertically aligned with each other. In such an embodiment, the
25 piles received by the respective pairs of sleeves are also vertically aligned with the central axis.

[0036] Alternatively, the plurality of piles may also be received, in a pair wise manner, with the piles being oriented at an angle from the central axis. The piles
30 may be received such that they form a "teepee" configuration. An example of such a configuration of the piles is defined and described in US patent application 2006/0237600 A1, for example.

[0037] In a specific embodiment, the structure may include three piles that are slidably received by the sub-sea structure. In this embodiment where three piles are received either vertically or in a "teepee" configuration, the centroid of the three piles and the origin of the closed polygonal frame(s) of the frame module(s) are coincident. This feature allows for the regular and uniform loading of said three vertical piles. Additionally, in this embodiment, any one, or all of the three piles may be driven into the seabed, leaving the top-most, or any intermediate frame modules of the structure slidably engaged to the piles. In this respect, it should be noted that typically, the bottom-most frame module, i.e. the frame module resting on the seabed, may be connected in a fixed or rigid manner to the piles.

[0038] In general, at least one pile of the plurality of piles slidably received, pairwise, by the first and second pluralities of sleeves has a section thereof protruding through and extending above the waterline to support topsides facilities. This is in line with the concept of minimizing the number of piles or beams protruding above the waterline, as described earlier. Where a plurality (two or more) of piles protrude above the waterline, said plurality of piles are adapted to bear a substantial amount of any vertical loading due to topside facilities. It should be noted that the frame module does not bear any substantial vertical load but instead, is adapted to substantially bear lateral loads and to transmit said lateral loads axially along the individual beams of the triangular frames and towards the seabed. This is possible as the top of the sub-sea structure (i.e. the closing frame element) terminates below the water line and below the trough level of the waves. In this respect, and since the hydrodynamic forces are at a maximum at the surface of the water line, significant reductions to the forces experienced by the sub-sea structure are achieved, as the number of piles or beams penetrating the waterline and extending through the height of the waves is minimized.

[0039] As mentioned earlier, the sub-sea structure may be formed from a series of individual frame modules stacked one atop another or as a unitary structure. Accordingly, where the structure is a series of the individual frame modules, the individual frame modules are fabricated in a releasable manner, where the apex of each triangular frame is adapted to be connectable to a corresponding vertex of a

respective closed polygonal frame in a releasable manner. Examples of a releasable manner of connection include bolting, or alternatively, the use of self latching connectors, for example.

5 **[0040]** Alternatively, where the structure is formed as a unitary structure, the individual frame modules are connected to each other by to form a single entity, i.e. the individual frame modules are connected to each other in a non-releasable manner. In this respect, non-releasable manners of connection include swaging, welding and/or grouting, for example.

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[0041] In an illustrative embodiment of the present invention, the modular sub-sea (level) structure for supporting an offshore production facility includes five frame modules. Each frame module comprises six identical triangular frames, wherein each triangular frame has a base and an apex opposite to said base. The bases of
15 the six triangular frames are connected to each other (end to end) to form a horizontal closed hexagonal frame. Each triangular frame of the frame module may be tilted at an acute angle towards the central longitudinal axis of the frame module, or it may be vertically arranged. The apex of each triangular frame of the frame module is adapted to be connectable to a corresponding vertex of another
20 horizontal closed hexagonal frame of a subsequent frame module stacked thereon.

[0042] This illustrative embodiment also includes a closing hexagonal frame element comprising a closed hexagonal frame inscribed within a horizontal triangular frame, wherein the apex of each triangular frame of a top-most frame
25 module is connected to a respective vertex of the closed hexagonal frame of said closing hexagonal frame element. In addition, the structure also includes a first plurality of three sleeves, each sleeve being connected to a respective vertex of the triangular frame of said closing hexagonal frame element. The structure further includes a second plurality of six sleeves, each sleeve being connected to a
30 respective vertex of the closed hexagonal frame of the frame module most distant from said closing hexagonal frame element. The sleeves of the first plurality (all three) and three corresponding sleeves of the second plurality are adapted to

slidably receive, in a pair wise manner, at least three piles, said piles being oriented parallel to the central axis.

[0043] The remaining three sleeves of the second plurality of sleeves may either
5 remain empty or they may include additional piles that are driven into the seabed. The additional piles, however, may not extend fully over the entire length of the sub-sea structure. Rather, the additional piles may be restricted to merely securing the frame module furthest from the closing hexagonal frame element to the seabed, either rigidly or via a slidable engagement.

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[0044] In the above illustrative embodiment having five frame modules, the first and second pluralities of sleeves are connected along the periphery and at the vertices of the triangular frame of the closing hexagonal frame element, and the closed hexagonal frame furthest from the closing hexagonal frame element, respectively.
15 In addition, each sleeve of the first and second pluralities are also connected in an equidistantly spaced apart relationship when connected to the closing hexagonal frame element and the closed hexagonal frame of the frame module most distant from the closing hexagonal frame element, respectively.

20 **[0045]** Another aspect of the present invention relates to an offshore production facility. The offshore production facility includes a modular sub-sea (level) structure having piles; and a platform unit, wherein the platform unit is mounted onto sections of the piles protruding above the waterline of the sea. In this arrangement, the piles substantially bear vertical load of the platform unit and transmit said loads
25 to the seabed.

[0046] In this aspect of the invention, the sub-sea structure as described above is substantially independent of the vertical axial loading from the topside facilities such as the platform unit, for example. The vertical load passes directly along the
30 piles to the seabed but not via the sub-sea structure. This separation is achieved by ensuring the that the top-most unit of the substructure provides only lateral support to the pile by means of the sleeves that closely contain the legs, in a slidable manner, as described previously. As such, the transfer of vertical forces

from pile to substructure or substructure to pile is not entirely permitted. The contact area between the sleeve and the pile is also minimized in order to minimize the transfer of bending moments from the leg to the substructure and vice versa. This connection, via the sleeve, is in essence a "sliding guide" support and is
5 designed such that it does not have the ability to transfer or receive axial (vertical) forces into or from the piles, respectively.

[0047] In one exemplary embodiment of the production facility, the platform unit is adapted to carry out oil and gas exploration. In this exemplary embodiment, it is to
10 be expected that the platform unit may be equipped with drilling equipment, and pipe handling measures in order to carry out its designated functions.

[0048] In order to aid in the further understanding of the various aspects of the present invention, the following exemplary embodiments are illustrated in the
15 accompanying drawings and are described in greater detail below in which:

[0049] Figure 1 shows a perspective view of an exemplary embodiment of a frame module;

20 **[0050]** Figure 1A shows a wireframe perspective view and side view of a frame module;

[0051] Figure 2 shows a perspective view of an exemplary embodiment of a subsequent frame module connected to a previous frame module;

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[0052] Figure 3 shows a perspective view of an exemplary embodiment of a closing frame element unit;

[0053] Figure 4 shows a perspective view of a plurality of piles;

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[0054] Figure 5 shows a perspective view of a generic platform unit;

[0055] **Figure 6** shows a perspective view of an assembly sequence of an exemplary embodiment of a sub-sea structure;

[0056] **Figure 7** shows a perspective view of an assembled exemplary embodiment
5 of a sub-sea structure;

[0057] **Figure 8** shows a perspective view of an exemplary embodiment of an offshore production facility;

10 [0058] **Figure 9** is a side view of the exemplary embodiment of **Figure 8** during use in a body of water;

[0059] **Figure 10** is another side view of the exemplary embodiment of **Figure 8** during use in a body of water; and

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[0060] **Figure 11** is a top view of the exemplary embodiment of **Figure 8**.

[0061] **Figure 1** shows a perspective view an exemplary embodiment of frame module **10**. The frame module **10** includes six closed triangular frames. Each
20 triangular frame is made up of three individual beams namely, base beam **11a** and two other beams **12** and **13** extending from either end thereof. The two other beams **12** and **13** extend from both ends of said base beam **11a** to form an apex **16** (singular vertex of a triangle opposite the base beams **11a – 11f**) thereby completing the closed triangular frame. The base beams **11a – 11f** of the six
25 triangular frames are arranged in a horizontal closed hexagonal structure with the apexes **16** of the respective triangular frames positioned substantially vertically above their respective base beams **11a – 11f**.

[0062] Each apex **16** is adapted to be connectable to the closed hexagonal frame
30 **14** of another or subsequent frame module **20** (not shown) stacked thereon. The diametric dimension of the closed hexagonal frame **14** of the subsequent frame module **20** (not shown) connected thereto is smaller than that of the closed hexagonal frame formed by base beams **11a – 11f**.

[0063] In addition, the frame module includes six sleeves **15**. Each of the six sleeves **15** is located at a corresponding vertex of the closed hexagonal frame formed by the base beams **11a – 11f**. As shown in the embodiment of **Figure 1**,
5 the sleeve **15**, ends of two base beams and the other beams **12** and **13** meet at a junction (which is the vertex of the closed hexagonal frame) and said sleeve **15** is integrally formed with the ends of two base beams and the other beams **12** and **13**.

[0064] **Figure 1A** shows a wireframe perspective view and side view of a frame
10 module. As in the above exemplary embodiment, the frame module is formed from six triangular frames. Each triangular frame includes a base member **1a** and two other members **2a** and **3a** that extend from either end of the base member **1a**. The members **2a** and **3a** intersect to form an apex **6a** of the triangular frame, opposite the base member **1a**. Each of the six triangular frames are identical and are
15 arranged around a central axis, denoted by the intersection of the axes X-X and Y-Y, to form a closed polygonal frame with their respective bases **1a – 1f**. In this exemplary embodiment, the six triangular frames are orientated to be perpendicular to the closed polygonal frame.

20 [0065] **Figure 2** shows a perspective view of an exemplary embodiment of subsequent frame module **20**. As above, the frame module **20** includes six triangular frames. Each triangular frame includes a base beam (any of base beams **21a – 21f**). The base beams **21a – 21f** each have two other beams **22** and **23** extending from both ends of said base beams **21a – 21f** to form an apex **26**
25 (singular vertex in a triangle usually opposite the base beams **21a – 21f**) thereby completing the closed triangular frame. As above, the base beams **21a – 21f** of the six triangular frames are arranged to form a closed horizontal hexagonal frame with the apexes of the respective triangular frames positioned substantially vertically above their respective base beams **21a – 21f** and have a tapering from the closed
30 hexagonal frame. The closed hexagonal frame of frame module **20**, as formed by base beams **21a – 21f** is equivalent to the closed hexagonal frame **14** of **Figure 1**. In other words, the closed hexagonal frame formed by base beams **21a – 21f** is connectable to the respective apexes **16** of the frame module **10** as illustrated in

Figure 2. The closed hexagonal frame **24** of the next subsequent frame module is also shown to be connected to the apexes **26** of the frame module **20**.

[0066] Essentially, the frame modules **10** and **20** are similar except that the
5 diametric dimension of each subsequent closed hexagonal frame formed by the
respective base beams (**11a – 11f** and **21a – 21f**) is less than the closed
hexagonal frame preceding it. Accordingly, and as shown to a limited degree in
Figure 2, the apexes **16** and **26** are uniformly tapered. This feature of the structure
is better illustrated in **Figure 7** and will be described in more detail below.

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[0067] **Figure 3** shows a perspective view of an exemplary embodiment of a
closing frame element **30**. The closing frame element **30** is adapted to be
connectable to the respective apexes of a top-most frame module [which may be
any previous frame module (**10** or **20**), for example]. In **Figure 3** the closing frame
15 element **30** is shown to be connected to the apexes **26** of the frame module **20** via
a closed hexagonal frame **31**. In this embodiment, the closed hexagonal frame **31**
of the closing frame element **30** is inscribed within a triangular frame **32**.

[0068] The triangular frame **32** is essentially equilateral and is formed by three
20 beams. It is integrally formed with the closed hexagonal frame **31** of the closing
frame element **30** such that, both the frame **31** and the triangular frame **32** lie
within the same plane. The vertices of the closed hexagonal frame **31** of the
closing frame element **30** are further linked to the triangular frame **32** with three
separate beams **33** extending from three vertices of the closed hexagonal frame **31**
25 to corresponding vertices of the triangular frame **32**. The remaining three vertices
of the closed hexagonal frame **31** are coincident with the mid-point of the three
beams that form the triangular frame **32** due to the hexagonal frame **31** being
inscribed therein. It is to be noted that from the described arrangement, the closed
hexagonal frame **31** and the triangular frame **32** share a common central
30 longitudinal axis of rotation.

[0069] In addition, the closing frame element **30** further includes three sleeves **15**.
Each of the three sleeves **15** is connected to a corresponding vertex of the

triangular frame **32**. In this embodiment, the sleeves **15** are integrally formed with the triangular frame **32** of the closing frame element **30**. It is to be further noted that in this embodiment the distance, arrangement and alignment between the three sleeves **15** corresponds to three of the sleeves **15** of the frame module **10**. In other words, the three sleeves **15** of the closing frame element (i.e. a first plurality of sleeves) and three of the sleeves **15** of the frame module most distant from the closing frame element **30** (i.e. a at least corresponding second plurality of sleeves) are vertically aligned.

[0070] Figure 4 shows a perspective view of piles **40a**, **40b** and **40c**. The piles **40a**, **40b** and **40c** are of sufficient length to link a sleeve **15** of a frame module furthest from the closing polygonal frame element to a corresponding sleeve **15** of a closing polygonal frame element **30**. In one exemplary embodiment, which is described in greater detail later, said piles **40a**, **40b** and **40c** even have a section thereof extending vertically beyond the closing frame element **32** for supporting topside loads. When the piles **40a**, **40b** and **40c** are connected to the respective sleeves **15** of the frame module **10** and the closing frame element **30**, piles **40a**, **40b** and **40c** slidably engage the sleeves **15** in a pair wise manner. The piles **40a**, **40b** and **40c** may be either resiliently engaged or slidably engaged with the corresponding sleeves **15** of the frame modules **10**. However, the piles are always slidably engaged with the sleeves **15** of the closing polygonal frame element. The effects of this manner of engagement between the piles and the various units will be explained with respect to **Figure 9** below.

[0071] Figure 5 shows a perspective view of a generic platform unit **50** having a deck **51**. As mentioned above, a section of at least one of the piles **40a**, **40b** and **40c** extends beyond the closing frame element **32**. It is on said extended section of the piles **40a**, **40b** and **40c** that the platform **50** is mounted onto. The platform unit **50** may be adapted to carry out a variety of tasks such as oil and gas exploration services, for example.

[0072] Figure 6 shows a perspective view of an assembly sequence of an exemplary embodiment of sub-sea structure **70** (see **Figure 7**). The assembly

sequence may commence with either the frame module **10** or with the closing frame element **30**. In this illustrative example, taking the frame module **10** as the starting point, subsequent frame modules, such as frame module **20**, are stacked one atop the other till the required height of the sub-structure is attained. Finally,
5 the closing frame element **30** is placed atop the last stacked frame module **20**, thereby completing the sub-sea structure **70**.

[0073] **Figure 7** shows a perspective view of the assembled exemplary embodiment of sub-sea structure **70**. The frame module **10a** of the structure **70**
10 may be supported at or anchored to the seabed using the plurality of piles **40a**, **40b** and **40c** (not shown here). Alternatively, the frame module **10a** may be a gravity base that is sufficiently heavy enough to resist the sliding and overturning forces while supporting the subsequent frame modules **10b – 10e**, and the closing frame element **30**. The subsequent frame modules **10b – 10e** may be stacked in a
15 releasable or non-releasable manner. As mentioned, the diameter of the substructure reduces towards the closing frame element **30** due to the uniform tapering of the respective triangular frames of the frame modules beginning with those of the frame module **10a**, most distant from the closing frame element **30**, towards said closing frame element **30**. It is to be noted that in the exemplary
20 embodiment of **Figure 7**, the three sleeves **15** of the closing frame element **30** are in vertical alignment with three corresponding sleeves **15** of the frame module **10a**.

[0074] As a result of the geometric arrangement described in relation to **Figure 7**, there are a minimum number of triangular frames lying at 90 degrees (normal) to
25 the wave direction and the forces within the individual beams of the triangular frames are found (by analysis) to be predominantly axial forces, i.e. forces that are transmitted along the beam. This leads to a reduction in overall stress levels and an improvement in the fatigue performance (life) of the substructure. External loads, such as those imposed by the topside structure, are resisted predominantly
30 by axial forces within the beams and this minimizes any in and out of plane bending moments and stresses. This reduction in bending stress leads to an improved (increased) fatigue life for the beams and joints of the structure.

[0075] **Figure 8** shows a perspective view of an offshore production facility **80**. The offshore production facility **80** includes the sub-sea structure **70**, which supports the platform unit **50** having a deck **51** via three piles **40a – 40c**. As shown, the three piles **40a – 40c** utilized in facility **80** are slidably engaged with both the sleeves **15** of the frame module **10a** and the closing frame element **30**. In addition, the remaining sleeves of the frame module **10a** may be anchored to the seabed using piles of considerably shorter length than that of piles **40a – 40c** or said sleeves **15** may simply be left disengaged.

10 [0076] **Figure 9** is a side view of the embodiment of **Figure 8** during use in the sea. The facility **80** includes the sub-sea structure **70**, which is secured (either directly or via its weight) to the seabed **92** and below the waterline **91**. The facility **80** also includes platform unit **50** having a deck **51** mounted on said sub-sea structure **70** via the plurality of piles **40a – 40c**. The structure **70** includes the frame modules 15 **10a – 10d** and closing frame element **30**.

[0077] Although only four frame modules are shown, it is to be noted that more than four frame modules may be utilized according to operating environment, as long as the final height of the sub-sea structure **70** remains below the waterline of the sea. More specifically, the top of the substructure (i.e. the closing frame element) should terminate below the water line and below the trough level of the waves. As explained earlier, it is at the waterline level that hydrodynamic forces are at a maximum, i.e. the waves at the surface of the waterline are strongest. Accordingly, in the exemplary embodiment of **Figure 8**, and as shown in **Figure 9**, 25 by minimizing the number of piles or beams that penetrate the waterline and extend through the height of the waves, significant reductions to the forces experienced by the substructure are achieved.

[0078] **Figure 10** is another side view of the embodiment of **Figure 8** during use in 30 the sea. As mentioned above, the sub-sea structure **70** is secured (either directly or via its weight) to the seabed **92** and below the waterline **91**, with only three piles **40a, 40b** and **40c** protruding beyond the waterline **91**.

[0079] Figure 11 is a top view **110** of the exemplary embodiment of **Figure 8**. From this view **110**, the closing frame element **30** is shown and the most distant hexagonal frame therefrom, formed from base beams **11a – 11f**, is also shown. As mentioned earlier, the sleeves **15** of the most distant closed hexagonal frame
5 (second plurality of sleeves) serve as junctions between the various base beams **11a – 11f** that make up said closed hexagonal frame. As shown, three sleeves **15** of the second plurality of sleeves correspond to three sleeves **15** of the first plurality of sleeves.

10 **[0080]** It should be noted that the exemplary embodiments described above merely serve to aid in the better understanding of the present invention. As such, the present invention is not to be construed as being limited to the described exemplary embodiments but rather, as defined in the appended claims that follow.

Claims

What is claimed is:

1. A modular sub-sea (level) structure for supporting an offshore production facility, comprising:
 - at least one frame module, wherein each frame module comprises at least three triangular frames arranged around a central axis of the frame module, each triangular frame having a base and an apex opposite to said base, wherein the bases of the triangular frames are connected to each other to form a closed polygonal frame, and the apex of each triangular frame of the frame module is adapted to be connectable to a corresponding vertex of another closed polygonal frame of a subsequent frame module, if any, stacked thereon;
 - a closing polygonal frame element having a number of vertices corresponding to the number of triangular frames of a top-most frame module, wherein each vertex of said closing polygonal frame element is connected to a respective apex of each triangular frame of said top-most frame module ;
 - a first plurality of sleeves, each sleeve being connected to a vertex of said closing polygonal frame element;
 - at least a corresponding second plurality of sleeves, each sleeve being connected to a corresponding vertex of the closed polygonal frame of the frame module most distant from said closing polygonal frame element; and
 - a plurality of piles, wherein the sleeves of the first plurality and the corresponding sleeves of the second plurality are adapted to slidably receive said plurality of piles in a pair wise manner.
2. The structure according to claim 1, said structure comprising two or more frame modules.
3. The structure according to claim 1 or 2, wherein each frame module is smaller than the preceding frame module arranged below it, such that the shape of said structure is tapered towards the top.

4. The structure according to claim 2 or 3, wherein the closed polygonal frame of each frame module is smaller than the closed polygonal frame of the preceding frame module below it.
5. The structure according to any of claims 1 to 4, wherein each triangular frame of a frame module is tilted uniformly at an acute angle towards the central axis of the polygonal frame, such that the frame module is tapered towards the top.
6. The structure of any of claims 1 to 5, wherein the closing polygonal frame element is inscribed within a closing triangular frame.
7. The structure of claim 6, wherein each of the first plurality of sleeves is connected to a respective vertex of the closing triangular frame, and thereby indirectly connected to a vertex of the closing polygonal frame element.
8. The structure according to any of claims 1 to 7, wherein each triangular frame comprises at least three individual beams.
9. The structure according to any of claims 1 to 8, wherein each triangular frame is isosceles, right – angled, scalene and/or equilateral.
10. The structure according to claim 9, wherein each individual beam of the triangular frame has a cross-sectional area that is circular, triangular, rectangular, elliptical or any combination thereof.
11. The structure according to any of claims 1 to 10, wherein at least one pile of the plurality of piles slidably received, in a pair wise manner, by one of the first plurality of sleeves and a corresponding one of the second plurality of sleeves is attached to the seabed, thereby securing the frame module most distant from the closing polygonal frame element to said seabed.
12. The structure according to claim 7, wherein the closing triangular frame is dimensioned such that each of the first plurality of sleeves connected to its

respective vertices, and each of the corresponding second plurality of sleeves connected to the respective vertices of the closed polygonal frame of the frame module most distant from said closing polygonal frame element, are arranged and aligned to allow each pile that is received in a pair wise manner by a sleeve of the first plurality of sleeves and a corresponding sleeve of the second plurality of sleeves to be parallel to the central axis.

13. The structure according to any of claims 1 to 12, wherein at least one pile of the plurality of piles has a section protruding above the waterline of the sea, said section being adapted to support a platform unit.
14. The structure according to any of claims 1 to 13, wherein the first plurality of sleeves and its corresponding second plurality of sleeves are connected within the periphery of the closing polygonal frame element, and within the periphery of the closed polygonal frame of the frame module, respectively.
15. The structure according to any of claims 1 to 13, wherein the first plurality of sleeves and its corresponding second plurality of sleeves are connected on or outside the periphery of said closing polygonal frame element and on or beyond the periphery of the closed polygonal frame of the frame module, respectively.
16. The structure according to any of claims 1 to 15, wherein the frame module is adapted to bear at least a substantial amount of lateral loading and to transmit said lateral loading axially along individual beams of the triangular frames, towards the seabed.
17. The structure according to any of claims 1 to 16, wherein the apex of each triangular frame is adapted to be connectable to a corresponding vertex of another closed polygonal frame in a releasable or non-releasable manner.
18. The structure according to claim 17, wherein the releasable manner of connection includes bolting and/or self-latching connectors.

19. The structure according to claim 17, wherein the non-releasable manner of connection includes swaging, welding and grouting.
20. A modular sub-sea (level) structure for supporting an offshore production facility, comprising:
- five frame modules,
 - wherein each frame module comprises six identical triangular frames, each triangular frame having a base and an apex opposite to said base, wherein the bases of the triangular frames are connected to each other to form a closed hexagonal frame, and
 - the apex of each triangular frame of the frame module is adapted to be connectable to a corresponding vertex of another closed hexagonal frame of a subsequent frame module stacked thereon;
 - a closing hexagonal frame element inscribed within a triangular frame, wherein the apex of each triangular frame of a top-most frame module is connected to a respective vertex of the closed hexagonal frame of said closing hexagonal frame element;
 - a first plurality of three sleeves, each sleeve being connected to a corresponding vertex of the triangular frame of said closing hexagonal frame element; and
 - a second plurality of six sleeves, each sleeve being connected to a corresponding vertex of the closed hexagonal frame of the frame module being most distant from said closing hexagonal frame element; and
 - at least three piles, wherein the sleeves of the first plurality and three corresponding sleeves of the second plurality are adapted to slidably receive said three piles, in a pair wise manner, such that said piles are parallel to the central axis.
21. The structure of claim 20, wherein each triangular frame of the frame module is tilted uniformly towards the central axis of the polygonal frame, such that the frame module is tapered.

22. The structure according to claim 20 or claim 21, wherein the three piles each have a section protruding above the waterline of the sea.
23. The structure according to any of claims 20 – 22, wherein the first plurality of sleeves and at least three corresponding sleeves of the second plurality of sleeves are connected within the periphery of the closed hexagonal frame of the closing hexagonal frame element and the frame module, respectively.
24. The structure according to any of claims 20 – 22, wherein the first plurality of sleeves and at least three corresponding sleeves of the second plurality of sleeves are connected on or outside the periphery of the closed hexagonal frame of the closing hexagonal frame element and the frame module, respectively.
25. An offshore production facility comprising:
a modular sub-sea (level) structure as defined in any of claims 13 – 19 and 22;
and
a platform unit, wherein the platform unit is mounted onto the section of the at least one pile protruding above the waterline of the sea, such that the at least one pile substantially bears the vertical load of the platform unit and transmits said load directly to the seabed.
26. The facility according to claim 25, wherein the platform unit is adapted to carry out oil and gas exploration works.