

**Device for verifying the bearing capacity of a pile of an offshore
foundation construction**

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The present invention relates to the technical field of offshore foundation constructions, in particular offshore foundation constructions intended to support an offshore wind turbine. More specifically, the invention relates to a device for verifying the bearing capacity of a pile of such an offshore foundation construction.

Offshore devices such as offshore wind turbines usually rest on an offshore foundation construction including a structure and foundation piles. The offshore foundation construction is secured to a seabed by the foundation piles driven into the seabed. An upper end of the foundation piles is attached to the structure optionally by means of pile sleeves.

Traditionally, the foundation piles are driven into the seabed by the so-called impact driving technique including the application of a large load on a foundation pile to be driven during a short duration, for instance less than one second and repeating the application of this load. Once the foundation pile is inserted, the dynamic testing method is implemented. According to the dynamic testing method, the application of a load is still repeated with a hammer while acceleration and strains in the pile are monitored. By matching the modelled pile behavior during a hammer stroke with the recorded signals (so-called signal matching method), the pile bearing capacity can be back-calculated based on the monitored data. A major drawback of the dynamic testing is that it generates an important noise or important vibrations which may be harmful to the wildlife surrounding the offshore foundation construction and the offshore device. Moreover, the correlation or safety factors to be used in conjunction with the dynamic testing method are generally larger than for static testing, increasing the pile bearing capacity that

has to be measured by means of dynamic testing, increasing pile diameter and therefore material cost.

In order to avoid these drawbacks, it has been proposed various improved methods of driving a pile into the seabed. Nonetheless, these methods do not allow verifying whether the pile has been driven with the required capacity. Currently, the only way to verify the bearing capacity of a foundation pile driven by such an improved method is still to implement the dynamic testing method after the pile has been inserted. Accordingly, there is still a need for allowing to verify the bearing capacity of a foundation pile without requiring to implement the dynamic testing method.

The invention aims at overcoming the above-mentioned drawbacks.

More specifically, the invention aims at allowing to verify the bearing capacity of a foundation pile of an offshore foundation construction in a way more respectful of the surrounding wildlife.

According to a first aspect of the invention, it is proposed a device for verifying the installation of a first pile of an offshore foundation construction, comprising a body, a first means for connecting the body to a referential element, a second means for connecting the body to the first pile, a means for applying a load on the first pile in a direction parallel to the axis of the first pile.

According to one of its general characteristics, the device further includes a means for measuring a displacement of the first pile.

By virtue of such a device, the insertion of the first pile may be verified without implementing the dynamic testing technology. More specifically, the first and second means for connecting allow the means for applying to apply a lighter load under static conditions compared to dynamic testing. The generation of noise or vibrations is thus considerably decreased.

Preferably, the device is suitable for verifying the bearing capacity of the first pile.

Said first pile is any one of the piles of the offshore foundation construction. It may be the first one that has been installed or any of the following ones.

5 In one embodiment, the first means for connecting includes a contact surface intended to rest against a frontal surface of the referential element.

According to another embodiment, the second means for connecting includes a contact surface intended to rest against a frontal surface of the first pile.

10 In a specific embodiment, the first means for connecting is intended to fasten the body to a structure or to an adapter of the offshore foundation construction.

In one embodiment, the first means for connecting is configured to connect the body to a second pile of the offshore foundation construction.

15 Preferably, the first means for connecting and the second means for connecting are substantially identical.

In another specific embodiment, the first means for connecting includes a first means for securing a second pile of the offshore foundation construction to the body.

20 Preferably, the first means for securing is further configured to secure at least a third pile of the offshore foundation construction to the body.

In one embodiment, the first means for securing is configured to grip the second pile.

25 Such designs of the first means for connecting allow using a structure, an adapter or a second pile, as the case may be, as a counterweight for the load applied. It is thus avoided to use cumbersome ballast weights. This is particularly advantageous for a subsea equipment because of the more important buoyancy of a ballast weight in the seawater.

30 In a further embodiment, the second means for connecting includes a second means for securing the first pile to the body.

Preferably, the second means for securing is configured to grip the first pile.

In a specific embodiment, at least one of the first and the second means for securing includes at least two radially movable clamping
5 chucks.

In another embodiment, the means for applying is so configured to apply a load in a way tending towards pushing the first pile into the seabed.

In a further embodiment, the means for applying includes a
10 cylinder and a piston.

Preferably, the means for measuring being able to measure directly the displacement of the piston with respect to the cylinder.

Such a design provides a simple and compact solution for applying the load and determining whether the first pile has moved.

15 In another embodiment, the means for measuring is able to measure the displacement of the first pile with respect to the body.

Such a configuration avoids a measurement offset due to the elasticity of the means for applying.

In a further embodiment, at least one of the first means for
20 connecting, the second means for connecting and the means for applying is actuated by a hydraulic energy and/or an electric energy.

Such energies are particularly preferable for subsea equipment because they allow having a power generation unit being distant, for instance on a vessel. The device is itself rendered more compact.

25 According to another aspect of the invention, an adapter for an offshore foundation construction includes a cylindrical sleeve for receiving a pile of the offshore foundation construction, and a device as set forth above.

In a specific embodiment, the cylindrical sleeve is so designed
30 to receive a pile having a circular radial cross-section with a diameter within a range 0,1 to 3,0 m, preferably 0,6 m to 1,5 m.

Such diameters allow limiting the load to be exerted by the means for applying of the device.

One may also foresee at least two cylindrical sleeves each intended to receive a pile of the offshore foundation construction, together forming an adapter.

Such an adapter allows increasing the number of foundation piles so as to decrease the diameter of each pile without jeopardizing the reliability of the attachment of the offshore foundation construction to the seabed and the combined bearing capacity.

According to a further aspect of the invention, it is proposed a method of testing the installation of a first pile of an offshore foundation construction, preferably of an offshore foundation construction intended to support an offshore wind turbine, including placing a device as set forth above on the offshore foundation construction so that the body is connected to a referential element, connecting the body to the first pile, applying a load to the first pile in a direction parallel to the axis of the first pile, measuring the load and measuring a displacement of the first pile.

The present invention and its advantages will be better understood by studying the detailed description of a specific embodiment given by way of nonlimiting examples and illustrated by the appended drawings on which:

- figure 1 is a side view of an offshore foundation construction including an adapter according to aspects of the invention,
- figure 2 is a tridimensional view of the adapter of figure 1,
- figure 3 is a cross sectional view of the adapter of figures 1 and 2 equipped with a device according to one aspect of the invention,
- figure 4 is a partial, cross sectional view of a first means for connecting of the device of figure 3,
- figure 5 is a detailed side view of a means for applying a load of the device of figure 3, and
- figure 6 is a detailed side view of a means for connecting equipping a variant embodiment of the device of figure 3.

With reference to figure 1, it is schematically depicted an offshore foundation construction 2. The offshore foundation construction 2 aims at resting on a seabed 3 and at supporting an

offshore device (not depicted), in particular an offshore wind turbine. Nonetheless, the offshore foundation construction 2 may be used for supporting another kind of offshore device, such as an offshore hydrocarbon platform.

5 It is defined an orthonormal direct vector base 4 attached to the offshore foundation construction 2. The base 4 consists of a vector $\vec{x}$, a vector $\vec{y}$ and a vector $\vec{z}$.

 In the present application, terms “low”, “down” and “up” will be understood as referring relative to the base 4 when the offshore foundation construction 2 is normally installed on a horizontal seabed, that is assuming that the vector $\vec{z}$ is vertically upwardly directed.

10 The word “cylindrical” will be understood according to its common definition, being namely that a cylindrical surface is a surface consisting of all the points on all the lines which are parallel to a given line and which pass through a fixed plane curve in a plane not parallel to the given line.

 The offshore foundation construction 2 includes a structure 6. The structure 6 includes four main legs 8, only two legs 8 being visible on the side view of figure 1. The structure 6 also includes a plurality of braces 10. The braces 10 connect mechanically a leg 8 with another leg 8. On the side view of figure 1, only four braces 10 are visible.

 In the depicted embodiment, the structure 6 is a jacket. However, it would be possible without departing from the scope of the invention to have a structure having a different design, being for instance a tripod.

25 The offshore foundation construction 2 includes, for each main leg 8, an adapter 12. That is, in the embodiment of figure 1, the offshore foundation construction 2 includes four adapters 12, only two of them being visible on the side view of figure 1. The adapters 12 are intended to form the mechanical connection between the structure 6 and foundation piles 22, 22a (see figure 3). The foundation piles 22, 22a have an axis along which they extend and are cylindrical about the direction of said axis. The foundation piles 22, 22a also have a circular radial cross section with a diameter d_{22} . In the following description, unless indicated otherwise, the words “radial” and “axial” will be

understood as referring to the axis of revolution of a pile 22 or 22a. The piles are not depicted on figures 1 and 2 for a better clarity of the drawings. For each main leg 8, an adapter 12 is attached to a lower end of the main leg 8. In the depicted embodiment, the adapters 12 are
5 welded to the legs 8 before the offshore foundation construction 2 is launched in the sea.

With reference to figure 2, the adapter 12 includes a central sleeve 14 and five peripheral sleeves 16. Nonetheless, a different number of peripheral sleeves 16 may be foreseen, for instance six
10 peripheral sleeves. The sleeves 14 and 16 are cylindrical about the direction of the vector $\vec{z}$. The sleeves 16 are all located on a circle about the axis of the sleeve 14. Nonetheless, a different geometrical arrangement of peripheral sleeves 16 may be foreseen. The sleeve 14 and the sleeves 16 have a circular radial cross-section. The diameter d_{16}
15 of the radial cross section is substantially the same for all the sleeves 16. The diameter d_{14} of the radial cross section of the sleeve 14 is approximately twice the diameter d_{16} . More specifically, the diameter d_{16} is so chosen that the adapter 12 is adapted to receive piles having a diameter d_{22} within a range 0,6 m to 1,5 m. The diameter d_{16} is then
20 within a range 0,6 m to 1,8 m.

Each adapter 12 includes a metallic subframe 18. The metallic subframe 18 includes a plurality of metallic hollow sections (not referenced) and metallic plates (not referenced). For each adapter 12, the metallic subframe 18 aims at connecting the sleeve 14, the sleeves
25 16 and a joining portion for attaching the adapter 12 with a lower end of the main leg 8.

As visible on figure 2, each sleeve 16 includes an upper portion 20. For each sleeve 16, the portion 20 is frustoconical about the axis of the peripheral sleeve 16. More specifically, the portion 20
30 vertically extends between a lower circular end with a diameter d_{20d} and an upper circular end with a diameter d_{20u} . The diameter d_{20d} equals the diameter d_{16} and the diameter d_{20u} is larger than the diameter d_{20d} . Preferably, the angle of the frustoconical shape of the portion 20 is within a range 40° to 55° . The frustoconical shape of the portion 20

helps inserting a foundation pile 22, 22a in a sleeve 16 in order to secure the offshore foundation construction 2 to the seabed 3.

Figure 3 is a cross sectional view about the plane III-III of figure 1. As visible on figure 3, each peripheral sleeve 16 includes a lower, enlarged portion 23. More particularly, the portion 23 includes a lower frontal surface 24 intended to rest on the seabed 3. The surface 24 forms a disc perpendicular to the vector $\vec{z}$. The portion 23 includes a plurality of, for instance eight, vertical uprights 25 intended to increase the rigidity of the connection between the portion 23 and the sleeve 16.

The offshore foundation construction 2 includes a device 26. The device 26 is intended to verify the bearing capacity of the piles 22, 22a after their insertion. The device 26 is not shown on the figures 1 and 2 for a better clarity of the drawings.

The device 26 includes a body 28. The body 28 is substantially flat and perpendicular to the vector $\vec{z}$. In the embodiment of Fig. 2, the body 28 includes five through holes (not referenced) so located to receive the five piles 22, 22a. The body 28 rests axially on an upper end of the portion 20 of the peripheral sleeves 16.

For each pile 22, 22a to be verified, the device 26 includes a sub-assembly 27. In the depicted embodiment, the sub-assemblies 27 are identical. Accordingly, only the sub-assembly 27 associated to the pile 22a will be detailed in the following description. It will be understood that, unless indicated otherwise, the below description concerning the sub-assembly 27 associated to the pile 22a also applies to the sub-assemblies associated to the piles 22. The number of piles to be verified may be lower than the total number of piles to be installed.

The sub-assembly 27 includes a collar 30 radially surrounding the pile 22a. The collar 30 is cylindrical about the direction of the axis of the pile 22a, which in the depicted embodiment is in the direction of vector $\vec{z}$. The collar 30 is also visible on figure 4 which is a cross section along the plane IV-IV. As well as the sleeves 16, the collar 30 is adapted to receive the pile 22a having a diameter d_{22} within a range 0,6 m to 1,5 m. More specifically, the collar 30 is radially inwardly delimited by a cylindrical surface having a circular radial cross-section. The circular

radial cross section of the collar 30 has a diameter d_{30} bigger than the diameter d_{22a} :

$$d_{22} < d_{30} < 1,5 \times d_{22}$$

5 The collar 30 includes three radially movable clamping chucks 32. The chucks 32 are depicted in detail on the radial, cross-sectional view of figure 4. The chucks 32 are provided for centering and gripping the pile 22a to the collar 30. To do so, the chucks 32 are regularly spread over the internal circumference of the collar 30. The chucks 32 are able to move radially inward so as to grip the pile 22a. In this way, there is provided a means for mechanically connecting the body 28 to the pile 22a.

10 The sub-assembly 27 includes a pair of hydraulic actuator 34. The actuators 34 are depicted on the detailed view of figure 5. Each actuator 34 includes a cylinder 36 attached to the body 28 and a piston 38 attached to the collar 30. In the depicted embodiment, each actuator 34 is able to exert an axial, downward load within a range 3,75 Mega Newtons to 30 Mega Newtons. By virtue of such actuators, an axial load within a range 7,5 Mega Newtons to 60 Mega Newtons may be exerted on the pile 22a.

20 In the depicted embodiment, the chucks 32 and the hydraulic actuators 34 are in hydraulic connection with a hydraulic power generation unit (not shown) arranged on a vessel in the vicinity of the offshore foundation construction. The hydraulic connection may be provided by means of hydraulic ducts (not depicted). Nonetheless, it is possible to use a different energy, for instance electric energy, for actuating the chucks 32 and/or the actuators 34.

25 The sub-assembly 27 further includes displacement sensors 40 and 41 (there are two in the depicted embodiment). The sensors 40 and 41 are provided for measuring whether the pile 22a moves or not. The sensor 40 is attached to the body 28. The sensor 40 is able to measure directly the axial displacement of the pile 22a and to compare the measured displacement with a predefined threshold as per standard EAP/ASTM D1143. The sensor 41 is attached to the cylinder 36. The sensor 41 may also be mounted in a recess of the cylinder 36 (not

represented). The sensor 41 is able to measure directly the displacement of the piston 38 and to compare the measured displacement with a predefined threshold. For instance, the sensors 40 and 41 may include an end of stroke sensor.

5 In the depicted embodiment, two displacement sensors are provided for each sub-assembly 27. This allows performing a redundant metering so as to increase the reliability of the detection of a displacement of the pile 22a. Nonetheless, it may be foreseen only one of the two sensors 40 and 41 or more than two sensors 40 and 41 per
10 sub-assembly 27 without departing from the scope of the invention.

 In the depicted embodiment, the means for connecting the piles 22, 22a to the body 28 are the same for all the piles 22 and 22a. In particular, the means for connecting the pile 22a to be tested is the same as the means for connecting the piles 22 not to be tested. It is
15 particularly advantageous because it does not require to displace the device 26 each time that a different pile 22, 22a has to be tested.

 Hence, the body 28 is connected to a referential element, being namely, in the illustrated embodiment, at least two piles 22 different from the pile 22a to be tested. Nevertheless, one may possibly use a
20 different referential element, such as a single pile 22 different from the pile 22a to be tested or the adapter 12 or the structure 6. Besides, when the referential element includes at least one pile 22 different from the pile 22a to be tested, the pile 22 may be secured, for example by swaging or grouting, in order to be attached to the adapter 12 or to the structure
25 6, as the case may be.

 In a variant embodiment, it may be foreseen a means for connecting the pile 22a different than the means for connecting the piles 22. For instance, the means for connecting the pile 22a may include a contact surface (not depicted) axially contacting an upper end of the pile
30 22a. In another variant embodiment, the means for connecting the piles 22 includes a contact surface 50 axially contacting an upper end of the piles 22 and the actuator 34 of the sub-assembly 27 associated with the pipe 22a is intended to apply an axial, upward load.

In a further embodiment, the body 28 is not connected to the piles 22 but to a part of the adapter 12 or the structure 6. For instance, the device 26 includes a means for fastening the body 28 to the upper portion 20 of a sleeve 16.

5 On figure 6, it has been depicted a means for connecting that may be used as a variant of the clamping chucks 32. The means for connecting of figure 6 intend to attach the device 26 to an inner surface of the piles 22, 22a. In this variant, the collar 30 is replaced with a disc 42 having the same outer diameter and the same axial thickness than the
10 collar 30. The disc 42 may be mechanically connected to the body 28 via the same actuators 34 (not shown in figure 6). A rod 43 extends from the disc 42 in a direction perpendicular to the disc 42. In the depicted embodiment this direction is parallel to the vector $\vec{z}$. The rod 43 includes a cylindrical portion 44 proximal to the disc 42 and a tapered portion 46
15 distal to the disc 42. The portion 44 has a circular radial cross-section with a diameter d_{44} slightly smaller than the diameter d_{22} :

$$d_{22} \times 0,8 < d_{44} < d_{22}$$

The portion 46 is radially, outwardly delimited by a tapered surface forming a cone frustum about the axis of the portion 44. The
20 portion 46 extends between an upper end having a larger diameter d_{46u} being substantially equal to the diameter d_{44} and a lower end having a smaller diameter d_{46d} .

As may be seen on figure 6, the portion 44 includes eight radially movable pads 48. The pads 48 are actuated by a hydraulic force supplied
25 by the hydraulic power generation unit.

By means of such an arrangement, the rod 43 may be received within a pile 22, 22a. Then, the pads 48 are radially, outwardly moved so as to exert a pressure on the inner cylindrical surface of the pile 22, 22a. This clamps the rod 43 to the pile 22, 22a.

30 Such a means for connecting may also be used to secure the body 28 to the sleeve 14. In such case, it is no longer necessary to provide a means for connecting a pile 22 and it is possible to considerably improve the compacity of the device 26.

By means of the device 26, the following verifying method may be implemented. The verifying method is implemented after insertion of the foundation piles 22 and 22a of the offshore foundation construction 2 into the seabed 3. Driving the foundation piles 22 and 22a may be performed by any suitable method known in the art, preferably a method being different from the impact driving technique.

As a first step, one of the piles 22, 22a is chosen as being the pile to be tested. For the purpose of illustration, the pile 22a will be chosen as the pile to be tested.

Secondly, the device 26 is placed on an adapter 12 in the position as illustrated on figure 3.

Thirdly, the piles 22 and the body 28 are connected together. To do so, the chucks 32 of the sub-assemblies 27 associated to the piles 22 are radially inwardly moved so as to connect mechanically the piles 22 to the body 28.

Then, the pile 22a and the body 28 are connected together. To do so, the chucks 32 of the sub-assembly 27 associated to the pile 22a are radially inwardly moved so as to connect mechanically the pile 22a to the body 28.

An axial downward load corresponding to the required bearing capacity of the pile 22a is then exerted by the actuators 34 of the sub-assembly 27 associated to the pile 22a. Said load is measured and recorded. In the meantime, the sensors 40 and 41 monitor the displacement of the pile 22a relative to the body 28 and the displacement of the piston 38 relative to the cylinder 36, respectively. If one of these displacement is more important than the associated predefined threshold, the pile 22a is considered improperly installed.

In the depicted embodiment, it is considered that a displacement of the pile is detected when at least one of the displacements measured by the sensors 40 and 41 exceeds the associated predefined threshold. Nonetheless, it may be foreseen that the displacement of the pile is detected only if both displacements measured by the sensors 40 and 41 exceed the associated predefined thresholds.

Then, the first step is repeated by choosing another pile to be tested 22. The following steps are repeated. When all the piles 22, 22a of the adapter 12 have been tested, the device 26 is displaced to another adapter 12 and the verifying method is repeated on the piles of the other
5 adapter 12. The verifying method is complete when the number of piles of the offshore foundation construction defined in the standard EAP/ASTM D1143 has been verified.

The above detailed device 26 and method allow verifying whether the foundation piles 22, 22a have been properly installed
10 without exerting a large load on a short duration. In this way, the generation of important noise or vibrations is avoided.