

Description

Title: Pile installation facility and methods thereof.

FIELD OF THE INVENTION

- 5 The present invention relates to an installation facility for installing a pile, in particular a tubular wind turbine pile, on a seabed and methods thereof.

BACKGROUND AND PRIOR ART

- Installation of wind turbine monopiles (MP), i.e. substructure of offshore wind turbines, in sea, has been performed for decades. See for example patent publication
10 JP 2001-207948.

- As exemplified in patent publication WO 2018/117846 A1, the MPs are normally transported horizontally on a deck of a vessel to their installation site. When the vessel is in place and stabilized, the MP is lifted to a vertical position and then lowered down to the seabed, typically by use of a heavy lift crane and a dedicated
15 up-ending tool. See for example figure 14 in WO 2018/117846 A1. When the MP is positioned in the correct position the MP is typically hammered into the seabed by use of a hammering tool.

In order to achieve sufficient stabilization prior to lifting of the MP a jack-up rig or jack-up vessel is typically employed.

- 20 During the installation, it is of utmost important that both the horizontal position and the vertical orientation of the MPs stay within acceptable ranges.

- Patent publication EP 3'517'479 A1 describes a device and a method for installing an MP which achieves a high accuracy in horizontal position and vertical orientation by arranging the MP in an upending tool in form of a basket consisting
25 of two enclosing rings for bringing the MP from a horizontal transport position to a vertical orientation. This upending tool works together with a gripping tool in keeping the MP under control and prevent oscillation of the MP during lowering.

One disadvantage with this known solution is its complexity and weight since it requires a high amount of moveable parts. The unit cost will consequently be high.

- 30 It is therefore an objective of the invention to provide an alternative installation facility and methods that may achieve the required horizontal position and vertical orientation with less complexity.

Another objective of the invention is to provide an installation facility and methods that effectively suppresses dynamic movements of the pile during vertical lowering.

Yet another objective of the invention is to provide an installation facility and methods that may increase control and redundancy of positional data of the MP
5 during installation.

Yet another objective of the invention is to perform a successful pile installation onto the seabed with a minimum amount of human interference.

SUMMARY OF THE INVENTION

The present invention is set forth and characterized in the main claims, while the
10 dependent claims describe other characteristics of the invention.

In a first aspect, the invention concerns an installation facility suitable for installing an elongated object such as a pile in a vertical orientation on a target pile position into or onto a seabed. The vertical orientation is defined hereinafter relative to global positioning coordinates at the target pile position. The elongated object / pile
15 is preferably a straight tube having an inner diameter *ID* and an outer diameter *OD*.

The installation facility comprising the pile having a longitudinal center axis, preferably in the form a tube being hollow along the entire pile length, a vessel comprising a deck for storing a plurality of piles, a lifting crane fixed to the vessel and capable of lifting the pile from the stored position on the deck, a global
20 positioning system for receiving global positioning coordinates from a navigation system and a vessel motion sensor, preferably a vessel accelerometer, installed on the vessel for measuring the vessel's excursions (typically heave, surge and pitch) and rotations (typically roll, yaw and sway) during operation at sea.

Examples of a navigation system are a global navigation satellite system, a local
25 three-point navigation or a combination thereof.

The vessel motion sensor comprises a vessel motion data transmitter allowing transmittal of measurement data.

The installation facility further comprises an installation tool fixed to an outer boundary of the deck such that the pile is located outside the deck boundaries when
30 oriented vertically relative to the seabed / global coordinates.

The installation tool comprises a suspending structure fixed (preferably removably) to an upper end of the pile, a pile motion sensor suitable for measuring at least the

position and direction of the pile relative to the global positioning coordinates at the target pile position and a pile gripper suitable for holding the pile in a desirable horizontal position during vertical lowering.

5 The suspending structure comprises means to fix (removably or non-removably) a first end of one or more crane cables handled by the lifting crane.

The pile motion sensor comprises a pile motion data transmitter allowing transmittal of measurement data and is preferably installed on at least one of the suspending structure and the pile.

10 Moreover, the pile motion sensor is preferably a pile accelerometer enabling measurement of velocity vectors, and even more preferably both velocity vectors and acceleration vectors. The desired pile position relative to the global coordinates is then achieved by integration over the measured velocity vectors and/or double integration over the measured acceleration vectors.

15 The pile motion sensor may in addition, or alternatively, be arranged in other locations such as on the vessel and/or on the pile gripper, and the desired pile orientation may be achieved by for example laser measurements. However, such measurements of orientation are considered inferior since it may be difficult to detect rapidly changing movements / instability in the pile during installation.

20 The pile gripper comprises a pile enclosing structure configured to enclose at least a part of an outer circumference of the pile within an enclosing space, preferably more than 50 % of the outer circumference, more preferably more than 80 %, for example the entire outer circumference, a pile gripper positioning system configured to re-position horizontally the pile during vertical lowering towards the seabed while the pile enclosing structure is in closed position and a control system
25 configured to regulate the pile gripper positioning system based on received measurement data from the vessel motion data transmitter and the pile motion data transmitter. The regulation of the control system is set to stabilize / control / suppress any movements of the pile during the vertical lowering such that the movements stays within a predetermined horizontal tolerance range from the global
30 positioning coordinates of the target pile position. Such undesired movements are typically pendulum movements. The purpose is thus to balance the movements sufficiently to avoid that excessive forces are allowed to develop during the installation.

35 The pile enclosing structure may comprise at least one receiving arm movable between an open position forming a pile receiving opening into the enclosing space

equal or larger than an outer diameter of the pile and a closed position wherein the pile receiving opening is at least partly closed and preferably completely closed.

In one embodiment of the invention, at least a part of the pile gripper positioning system is force controlled, i.e. where the components such as hydraulic cylinders and/or linear actuators are inflicting controllable force. Further, in this embodiment at least a part of the control system constitutes a force control system allowing setting and controlling the force of the force-controlled pile gripper positioning system. Specifically, the force control system may be configured to receive measured velocity vector data and/or measured acceleration vector data (i.e. including both magnitude and direction) from the pile motion sensor and to convert by integration measured data from the pile motion sensor (and alternatively also the vessel motion sensor) into force vectors having a size and a direction allowing the desired stabilization of the movements of the pile via the force-controlled pile gripper positioning system.

In another exemplary configuration of the invention, the pile enclosing structure comprises two receiving arms arranged mirror symmetrically relative to each other across a vertical mirror plane centered in the enclosing space.

In yet another exemplary configuration of the invention, the pile gripper positioning system comprises one or more first displacement devices, for example hydraulic cylinders, configured to displace the pile enclosing structure in a direction perpendicular to a hull of the vessel at the position of the pile gripper and one or more second displacement devices, for example hydraulic cylinders, configured to rotate the pile enclosing structure with a rotational axis perpendicular to the deck. The resulting degree of freedom of the pile enclosing structure is in this embodiment thus a superposition of the first and second displacement devices. The first and/or second displacement devices may act directly onto the pile enclosing structure or via a support structure onto which the pile enclosing structure is supported.

In yet another exemplary configuration of the invention, the pile gripper positioning system comprises two independently displaceable first displacement devices configured to displace the pile enclosing structure in direction perpendicular to a hull of the vessel, wherein the two first displacement devices are fixed (directly or indirectly) to the opposite sides of the pile enclosing structure extending perpendicular from the deck. If these two first displacement devices are displaced at different length, the pile enclosing structure will rotate with a rotational axis perpendicular to the deck.

- In yet another exemplary configuration of the invention, the pile gripper further comprises a plurality of pile supporting devices arranged within the pile enclosing structure (i.e. on the side of the pile enclosing structure facing towards the pile when the receiving arm(s) is/are in closed position) suitable for suppressing movements of the pile within the enclosing space during lowering. Preferably, these pile supporting devices are placed symmetrically around the circumference of the pile in the plane extend by the pile enclosing structure when the pile is arranged therein. Further, the pile gripper positioning system comprises in this exemplary configuration a plurality of displacement devices coupled between the enclosing structure and the plurality of pile supporting devices to allow displacement of the pile supporting devices between a contact position in which at least a part of each pile supporting device exerts a pressure onto an outer wall of the pile and a retracted position in which each pile supporting device exerts no or insignificant pressure onto the outer wall of the pile.
- In yet another exemplary configuration of the invention, each pile supporting device comprises one or more vertical pile displacement wheels having a rotational axis parallel to a pile gripper plane A_{PG} set by the pile enclosing structure (i.e. within the enclosing space) and one or more horizontal pile displacement wheels having a rotational axis perpendicular to the pile gripper plane A_{PG} . In this exemplary configuration the plurality of pile supporting devices may be further configured to displace, via a displacement motor, the vertical pile displacement wheel and the horizontal pile displacement wheel relative to each other such that, when in contact position, either the vertical pile displacement wheel or the horizontal pile displacement wheel or both, exert(s) pressure onto the outer wall of the pile.
- In yet another exemplary configuration of the invention, the installation tool further comprises a rotatable up-ending tool with a rotational axis parallel to the deck of the vessel and preferably along the longitudinal direction of the vessel (i.e. along the bow-aft direction). The up-ending tool and the pile gripper are preferably separate units, thereby allowing inter alia independent operations.
- The up-ending tool comprises in this exemplary configuration an elongated member and an end-support configured to support a lower pile end of the pile. The end-support is fixed to a lower end of the elongated member, normally below the water line during operation at sea. An upper pile support is preferably fixed to an upper end of the elongated member to provide additional support in the longitudinal direction of the pile during up-ending / installation. The upper pile support may be

rotational with a rotational axis parallel to the deck. Further, the pile gripper may be located relative to the rotatable up-ending tool a distance D_{ue} from the end support.

In yet another exemplary configuration of the invention, the pile gripper is rotationally coupled via a fastening structure to the vessel with a rotational axis
5 parallel to the deck and preferably along the vessel's longitudinal direction.

In yet another exemplary configuration of the invention, the lifting crane comprises a crane arm onto which a second end of the crane cable is fixed at a fixation point. The installation facility may further comprise a crane motion sensor suitable for measuring at least a horizontal position of the fixation point relative to global
10 positioning coordinates at the target pile position acquired by the navigation system. As for the vessel and pile motion sensors, the crane motion sensor is preferably an accelerometer allowing measurements of at least velocity vectors and more preferably also accelerator vectors. The horizontal position is thus obtained by single integration (from velocity vector data) or double integration (from
15 acceleration vector data).

In yet another exemplary configuration of the invention, the installation facility further comprises one or more up-ending winches, one or more winch cables, one or more tension sensors (e.g. a load cell) configured to measure a tension in the winch cable(s) and one or more up-ending winch transmitters allowing transmittal of
20 tension data measured by the tension sensor(s). These data may e.g. be transmitted to the control system of the pile gripper and/or a dedicated winch control system for further processing. The winch cable(s) is/are fixed at one end to the suspending structure and fixed at an opposite end to the up-ending winch. The tension sensor(s) may for example be connected between the end of the winch cable and the
25 suspending structure.

In a second aspect, the invention concerns an installation method using an installation facility in accordance with the above description.

The method comprises the following steps:

- A. moving the at least one receiving arm of the pile enclosing structure into the
30 open position or alternatively controlling that the pile gripper is in the open position before continuing the method,
- B. aligning the pile relative to the deck-mounted pile gripper such that the pile's longitudinal center axis intersects an axis going through a center of the pile receiving opening (and thus also the center of the pile enclosing structure /
35 enclosing space),

- C. tilting the pile by use of the lifting crane until the longitudinal axis of the pile has reached the vertical orientation as defined for the first aspect above, wherein at least the orientation of the pile's longitudinal center axis relative to the vertical orientation is being monitored (continuously and/or in set time intervals) by measurement data transmitted from the pile motion sensor, preferably in form of velocity and/or acceleration vector data,
- D. moving the at least one receiving arm of the pile enclosing structure into the closed position,
- E. lowering the pile towards the target pile position (preferably by use of the lifting crane) while monitoring (continuously and/or in set time intervals) the movements of the pile using at least one of the pile motion sensor and the vessel motion sensor,
- F. if the movements of the pile within the closed pile enclosing structure during lowering are measured to be outside the predetermined horizontal tolerance range mentioned above for the first aspect, transmitting instruction signals to the control system of the pile gripper to adjust, via the pile gripper positioning system, the pile enclosing structure in order to force the movements of the pile to be within the predetermined horizontal tolerance range.

In an exemplary configuration of the second aspect of the invention, the installation facility further comprises a hammering structure comprising suspending means to suspend the first end of the crane cable(s) at one end.

The method may for this exemplary configuration further comprise the following step:

- G. removing the suspending structure, for example by using the lifting crane,
- H. suspending the hammering structure to the end of the crane cable(s) via the suspending means,
- I. arranging an end of the hammering structure opposite the suspending means onto the upper end of the pile, for example by using the lifting crane, and
- J. applying repeated impact force on the upper end of the pile to hammer the lower end into the seabed.

The hammering structure preferably comprises an insertion part at the end opposite the suspending means that is designed to create a tight fit within a hollow part of the upper end of the pile.

In another exemplary configuration of the second aspect, the pile gripper further comprises a plurality of pile supporting devices arranged within the pile enclosing

structure, suitable for suppressing movements of the pile within the enclosing space during lowering.

5 The pile gripper positioning system comprises a plurality of displacement devices coupled between the enclosing structure and the plurality of pile supporting devices to allow displacement of the pile supporting devices between a contact position in which at least a part of each pile supporting device exerts a pressure onto an outer wall of the pile and a retracted position in which each pile supporting device exerts no or insignificant pressure onto the outer wall of the pile.

10 For this exemplary configuration, step D of the method further comprises the step of locking the pile (or at least significantly restricting the movements of the pile) within the pile enclosing structure by transmitting instruction signals to the control system to displace, by use of the displacement devices, the pile supporting devices from a retracted position to a contact position. The pile is preferably locked / restricted with its longitudinal center axis aligned with the center axis of the enclosed space.

15 In yet another exemplary configuration of the second aspect, each pile supporting device comprises a vertical pile displacement wheel having a rotational axis parallel to a pile gripper plane A_{PG} set by the pile enclosing structure / enclosing space and a horizontal pile displacement wheel (also denoted rotational displacement wheel) having a rotational axis perpendicular to the pile gripper plane A_{PG} .

20 The plurality of pile supporting devices may for this exemplary configuration be further configured to displace, via a displacement motor, the vertical pile displacement wheel and the horizontal pile displacement wheel relative to each other such that, when in contact position, either the vertical pile displacement wheel or the horizontal pile displacement wheel or both, exert(s) pressure onto the outer wall of the pile.

25 Still for this exemplary configuration, step D of the method may further comprise:
- transmitting instruction signals to the control system to adjust, via the pile gripper positioning system, the pile displacement wheels such that only the horizontal pile displacement wheel is exerting pressure onto the pile and
30 - transmitting instructions signals to the control system to rotate, via a horizontal displacement wheel motor of the pile gripper positioning system, the pile an angle around its longitudinal center axis.

35 One purpose of the rotation of the pile within the enclosing structure in the pile gripper's closed position is to orient cable connection points or cable openings on

the pile in order to facilitate connection with external power and/or communication cables forming part of a subsea power distribution network, for example in a wind turbine offshore park.

5 In yet another exemplary configuration of the second aspect, the lifting crane comprises a crane arm onto which a second end of the crane cable(s) is fixed at a fixation point and the installation facility further comprises a crane motion sensor arranged on the crane arm. For this exemplary configuration step E of the method further comprises

- 10 - measuring the horizontal position of the fixation point relative to global positioning coordinates received by the navigation system,
- subtracting the horizontal position of the fixation point with the measured horizontal position of the pile at one or more vertical positions, for example within the pile gripper plane A_{PG} and,
- 15 - if the result of the subtraction is outside a predetermined difference tolerance range, transmitting instruction signals to the control system to adjust at least one of the horizontal position of the pile via the pile gripper positioning system and the horizontal position of the fixation point via the lifting crane until the result of the subtraction is within the predetermined difference tolerance range.

20 In yet another exemplary configuration of the second aspect, the installation tool further comprises a rotatable up-ending tool with a rotational axis parallel to the deck and preferably along the vessel's longitudinal direction (bow-aft).

The up-ending tool comprises an elongated member and an end-support configured to support a lower pile end of the pile. The end-support is fixed (for example rotationally with a rotation axis parallel to the deck) to a lower end of the elongated member. For this exemplary configuration step B of the method may further
25 comprise arranging the pile into the rotatable up-ending tool such that the pile's longitudinal center axis is parallel to the elongated member and the lower pile end is supported into the end-support. Moreover, step C of the method may further comprise tilting the up-ending tool with the pile supported therein.

30 In yet another exemplary configuration of the second aspect, the predetermined horizontal tolerance range varies depending on the vertical distance between the lower end of the pile and the seabed. For example, the predetermined horizontal tolerance range may be gradually less as said vertical distance is shortened.

35 In a third aspect, the invention concerns a stabilization method enabling stabilization of movements of a pile during vertical lowering of the pile towards a

seabed by use of an installation facility in accordance with the above description of the first aspect.

The stabilization method comprises the following steps:

- 5 - receiving global positioning coordinates from a navigation system, for example a global navigation satellite system or a local three-point navigation system or a combination thereof,
- setting a reference state data based on the global positioning coordinates at the position of the vessel and vessel positioning coordinates,
- 10 - transmitting the reference state data to a dynamic positioning system of the vessel,
- adjusting vessel coordinates using the dynamic positioning system until vessel state data are achieved that are within a predetermined acceptance range relative to the global positioning coordinates,
- setting the vessel state data as input reference data,
- 15 - correcting the input reference data with initial pile state data to obtain initial set values,
- transmitting the initial set values to the control system,
- calculating initial instruction data (typically force correcting instruction data) based on the initial set values (for example by use of Euler-Lagrange equation) and a model of the installation facility (for example a 2D or a 3D double pendulum model) that forces the movements of the pile to approach, or enter, into the predetermined horizontal tolerance range,
- 20 - activating the pile gripper positioning system based on the initial instruction data,
- finding a new pile state data including horizontal position and orientation relative to the vertical orientation by use of measured data from the pile motion sensor, measured and/or simulated disturbance data from external forces such as added mass, waves, current, wind, etc. and structural data of the pile such as length, diameter(s) and mass,
- 25 - correcting the input reference data with the new pile state data to obtain new set values,
- 30 - transmitting the new set values to the control system,
- calculating new instruction data (typically force correction instruction data values) based on the new set values and the model of the installation facility (e.g. by use of Euler-Lagrange equation and/or by use of double pendulum model) that result in a stabilization of the movements of the pile within the predetermined horizontal tolerance range and
- 35 - activating the pile gripper positioning system based on the calculated new instruction data received from the control system.

As for the first and second aspects, the motion vector(s) is/are preferably measuring the velocity vector and/or the acceleration vector, and the position / orientation is obtained by integration.

5 Note that state data may involve vectors / matrixes (magnitude and direction), for example velocity, acceleration, forces, etc.

In an exemplary configuration of the third aspect, the method further comprises the following steps:

- transmitting the vessel data or the vessel state data to a crane control system of the lifting crane,
 - 10 - calculating initial input reference data based on crane state data and vector state data,
 - correcting the initial input reference data with the initial pile state data to achieve initial set values and
 - transmitting the initial set values to the control system and/or the crane control system.
- 15

In another exemplary configuration of the third aspect, the method further comprises the following step:

- adjusting a heave compensation system of the lifting crane based on the vessel data or the vessel state data to keep the vertical position of the pile stationary within a predetermined vertical tolerance range with respect to the vertical position of the vessel, or alternatively to force the vertical position of the pile to enter within this predetermined vertical tolerance range.
- 20

In yet another exemplary configuration of the third aspect, the lifting crane comprises a crane arm onto which a second end of the crane cable(s) (or any other means allowing suspension of the pile via the suspending structure) is fixed in a fixation point. The installation facility further comprises a crane motion sensor, for example a crane accelerometer, arranged on the crane arm for measuring at least a horizontal position of the fixation point relative to the reference state data.

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Alternatively, or in addition, the horizontal position may be calculated by measuring the angle of the outermost arm and using measurement data from the vessel motion sensor.

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For this exemplary configuration, the method may further comprise the following steps:

- transmitting the vessel coordinates or the vessel state coordinates to a crane control system of the lifting crane,
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- measuring the horizontal position of the fixation point,
- subtracting (or in any other way correcting) the horizontal position of the fixation point with a horizontal position of the pile at one or more locations along the pile's longitudinal center axis, for example in a plane set by the pile enclosing structure,
- 5 - transmitting the result of the subtraction / correction to the control system of the pile gripper and/or the crane control system,
- calculating the initial instruction data based on the result of the subtraction/correction to the pile gripper positioning system and/or displacement device(s) on the crane arm to minimize the result of the subtraction (or optimizing
- 10 the result of the correction) and
- activating the pile gripper positioning system and/or the displacement device(s) on the crane arm based on instructions from the control system of the pile gripper and/or the crane control system.

15 In a fourth aspect, the invention concerns a computer-readable medium having stored thereon a computer program comprising instructions to execute the above-mentioned stabilization method of the third aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

20 The following drawings depict alternatives of the present invention and are appended to facilitate the understanding of the invention. However, the features disclosed in the drawings are for illustrative purposes only and shall not be interpreted in a limiting sense.

25 Figure 1 illustrates an installation facility in accordance with the invention and an initial phase of an installation process in accordance with the invention, where fig. 1A shows a vessel transporting a plurality of piles on deck to an installation site and fig. 1B shows an intermediate phase of an upending process from horizontal to vertical orientation.

Figure 2 illustrates an intermediate phase of the installation process in accordance with the invention in which a vertical oriented pile is arranged within a pile gripper of the up-ending tool.

30 Figure 3 illustrates the pile gripper constituting part of the inventive installation facility into which a vertical oriented pile is arranged, where fig. 3A and fig. 3B show the pile gripper in an open position and in a closed position, respectively.

Figure 4 illustrates another intermediate phase of the installation process in accordance with the invention, in which the vertical oriented pile is arranged within

the closed pile gripper as depicted in fig. 3B, where fig. 4A shows a perspective view of the closed pile gripper and fig. 4B shows a detailed drawing of the pile supporting devices locking the pile in the horizontal plane.

5 Figure 5 illustrates another intermediate phase of the installation process in accordance with the invention, where fig. 5A shows the vessel seen from in front and fig. 5B shows a detailed drawing of an end support of the up-ending tool on which a lower end of the pile is supported.

10 Figure 6 illustrates the pile gripper of figs. 3-5 seen from above, where fig. 6A and fig. 6B show the pile gripper tilted in two different directions around a rotational axis perpendicular the vessel's deck and fig. 6C and fig. 6D show the pile gripper in a retracted and an extended position, respectively, parallel to the vessel's deck.

15 Figure 7 illustrates the installation facility from behind of yet another intermediate phase of the installation process in accordance with the invention, in which the end support of the up-ending tool has been removed from the lower end of the pile, where figs. 7A and 7B shows the pile before and after horizontal displacement, respectively.

Figure 8 illustrates yet another intermediate phase of the installation process in accordance with the invention, in which the pile is lowered vertically towards the seabed by use of a lifting crane attached to an upper end of the pile.

20 Figure 9 illustrates yet another intermediate phase of the installation process in accordance with the invention, in which the pile is rotated around its longitudinal center axis within the pile gripper.

Figure 10 illustrates yet another intermediate phase of the installation process in accordance with the invention where the pile is contacting the seabed.

25 Figure 11 illustrates yet another intermediate phase of the installation process in accordance with the invention where the lower end of the pile has self-penetrated a distance below the seabed due to its weight.

30 Figure 12 illustrates a final phase of the installation process in accordance with the invention, where fig. 12A shows removal of the suspending structure at the upper end of the pile and fig. 12B shows the insertion of a hammering structure at the same pile location.

Figure 13 illustrates another final phase of the installation process in accordance with the invention where the pile is penetrated further below the seabed using the hammering structure.

5 Figure 14 illustrates a flowchart of a stabilization method in accordance with the invention showing data communication and control systems involved during an installation process.

Figure 15 illustrates adjustment of verticality based on the double pendulum principle.

DETAILED DESCRIPTION OF THE INVENTION

10 In the following, embodiments of the invention will be discussed in more detail with reference to the appended drawings. It should be understood, however, that the drawings are not intended to limit the invention to the subject-matter depicted in the drawings.

15 Installation of a pile 10 from a deck 205 of a vessel 200 onto a seabed 30 can be divided into the following operational phases:

- 20 1. (Fig. 1) A, first, up-ending phase where a pile 10 is initially lifted from a pile cradle 12 on the deck 205 and arranged in an installation tool 1 via a height controllable pile bench 11. The pile 10 is subsequently tilted from a horizontal position where most of the pile length is arranged within the boundaries of the deck 205 to a vertical position arranged fully outside the boundaries of the deck 205. In the example shown in fig. 1, the tilting (up-ending) of the pile 10 takes place into a dedicated up-ending tool 3 for providing sufficient support. The force necessary for the tilting process are mainly provided by a lifting crane 400 mounted onto the vessel 200. The
25 lifting crane 400 is fixed via one or more crane cables 403 to a suspending structure 4 on an upper end 10a of the pile 10. At this initial phase, the pile's lower end 10b is supported on an end-support 3a of the upending tool 3 to prevent undesired vertical pile movements during upending to vertical orientation.
- 30 2. (Figs. 2-5) A second horizontal alignment phase where the pile 10 has been oriented vertically relative to its longitudinal center axis and is further stabilized / locked in the horizontal plane by

- enclosing the circumference of the pile 10 using a pile gripper 2 of the installation tool 1 and

○ horizontally displacing a plurality of pile supporting devices (PSDs) 2c,d such that vertical displacement wheels / rolling means 2c of each PSD 2c,d are contacting the pile's 10 outer wall symmetrically around the pile's 10 circumference. Each of these vertical displacement wheels 2c has a horizontally oriented rotational axis, thereby enabling both vertical displacement and horizontal restriction of the pile 10
- 3. (Fig. 6-7) A third release and displacement phase where the end-support 3a of the up-ending tool 3 is firstly removed from the lower pile end 10b, leaving the pile 10 suspended in the lifting crane 400, and secondly that the pile 10 is displaced horizontally away from the vessel's deck 205 (and thus also the end-support 3a) using a pile gripper positioning system 2e-i of the pile gripper 2 comprising a set of hydraulic cylinders and/or linear actuators 2f,2g.
- 4. (Fig. 8) A fourth vertical displacement phase where the pile 10 is lowered vertically a distance L_4 towards the seabed 30 relative to the vertical position of the third phase.
- 5. (Fig. 9) A fifth rotational phase where

 - the vertical displacement wheels or vertical displacement rolling means 2c of the PSDs allowing vertical pile displacement are retracted,
 - rotational displacement wheels / rolling means 2d of the PSDs are advanced such that the rotational displacement wheels 2d are contacting the pile's 10 outer wall symmetrically around the pile's 10 circumference, wherein each of the rotational displacement wheels 2d has a vertical rotational axis allowing rotational movements of the pile 10 around its longitudinal center axis, and
 - the pile 10 is rotated by rotating the rotational displacement wheels 2d using rotational displacement wheel motors 2i.

The relative displacements of the vertical displacement wheels 2c accepting vertical pile movements and the rotational displacement wheels 2d enabling rotational pile movements may be performed by a dedicated displacement motor. The surface of at least the rotational displacement wheels 2d should be made in order to provide sufficient friction to enable the desired pile rotation.

6. (Fig. 10) A sixth vertical displacement phase where the pile 10 is lowered further until the lower end 10b of the pile 10 is adjacent to, or contacting, the seabed 30.
7. (Fig. 11) A seventh self-penetration phase where the pile 10 is penetrating a distance L_7 into the seabed 30 due to the pile's 10 self-weight.
8. (Figs. 12-13) An eighth hammering phase where the suspending structure situated on the upper end of the pile is replaced with a hammering structure 7 allowing hammering of the pile 10 a distance L_8 into the seabed 30. Note that Fig. 13 shows a pile 10 which has penetrated the seabed 30 only partly. In order to achieve sufficient pile stability after installation, the percentage of penetration length relative to total pile length is typically significantly higher.

If nothing else is specified, the orientations 'horizontal' and 'vertical' are herein defined relative to global positioning coordinates.

- The main purpose of implementing the above mentioned operational phases is to enable installation of a pile 10 on a predetermined pile target position 30a on the seabed 30 within an acceptable horizontal range from global horizontal coordinates and within an acceptable orientation of the pile's longitudinal center axis from global vertical coordinates.
- In order to achieve a successful installation, i.e. within the acceptable ranges, the main purpose can be divided into three sub-purposes:
 1. Ensure that positions and movements of the pile 10 are continuously compensated for movements of the vessel 200 (i.e. disattaching the vessel movements from the pile movements).
 2. Ensure that any pendulous movements of the pile 10 are sufficiently suppressed, inter alia to avoid build-up of hazardous forces onto the installation tool 1 during operation.
 3. Ensure that the lower end 10b of the pile 10 hits and penetrates the seabed 30 at the target pile position 30a with sufficient vertical and horizontal accuracy.

The importance of *horizontal* precision (sub-purpose 1), and thereby also the importance of frequent and accurate measurements, followed by possible

adjustments, typically increases as the lower pile end 10b approaches the target seabed position 30a. Increased requirements of positional and directional accuracy necessitate not only increased number and accuracy of measurements, but also increased need of ensuring high data reliability.

- 5 When the lower pile end 10b is submerged below the water surface 20, the surrounding water both outside and inside a tubular pile 30 (which is normally used in offshore installations such as wind turbines) increases the inertial forces, thereby suppressing any continuous pile movements from verticality.

- 10 Hence, while the need for horizontal and vertical corrections due to static deviations from desired horizontal and vertical pile coordinates (sub-purposes 1 and 3) may increase when approaching the seabed 30, the need for regulating dynamic movements such as pendulum movements (sub-purpose 2) may abruptly decrease during the same operation, typically when the lower end 10b of the pile 10 reaches the water surface 20 and the seabed 30.

- 15 These different requirements affect the magnitude of forces that the pile gripper 2 needs to transfer to the pile's 30 outer wall to achieve all sub-purposes (and thereby also the main purpose).

The different installation phases will in the following be described in more detail:

- 20 Again with reference to fig. 1, the up-ending tool 3 comprises an elongated member 3c, an end-support 3a rotatably mounted onto the lower end of the elongated member 3c and configured to receive and support the lower end 10b of the pile 10 and an upper support 3b rotatably mounted onto the upper end of the elongated member 3c and configured to support the outer wall of the pile 10 at a location above the pile gripper 2.

- 25 In the first phase of the installation, one of a plurality of piles arranged parallel to the deck 205 is placed onto a height adjustable pile bench 11 such that the longitudinal center axis of the pile 10 is intersecting a center axis of a pile enclosing structure 2a,b of the pile gripper 2 and a longitudinal axis of the elongated member 3. In this phase, at least the upending tool 3 has been rotated to a position where
30 the upper support 3b is near the deck 205 and the pile bench 11, and preferably such that the elongated member 3c is parallel, or near parallel, to the deck 205.

The pile 10 is then displaced in a direction along the elongated member 3c until the lower end 10b is supported onto or into the end-support 3a. The upper support 3a is

oriented / displaced such that the pile 10 is resting onto the contact surfaces of the upper support 3a.

5 In addition to the crane cable 403, the suspending structure 4 may be attached to an end of a winch cable 6 which other end is fixed to a suitable upending winch 5 such as a tugger winch. Such a winch system 5,6 may include a tension sensor such as a load cell connected between the suspending structure 4 and the winch cable 6 to enable tension measurements during the upending process.

10 The second phase of the installation involves stabilizing the pile 10 in a horizontal position within the pile gripper 2 when a sufficient verticality of the pile 10 is achieved relative to global vertical coordinates.

As best illustrated in figs. 3 and 4, such horizontal stabilization is achieved by closing a pile enclosing structure 2a,b around the outer circumferential wall of the pile 10. The pile enclosing structure 2a,b comprises two movable arms 2a having ends being rotatably connected to respective ends of two fixed arms 2b, wherein the arms 2a,2b are extending in a common pile gripper plane A_{PG} . When the movable arms 2a are in closed positions, the two movable arms 2a and the two fixed arms 2b forms an enclosing space having a diameter equal or larger than an outer diameter OD of the pile 10. When the movable arms 2b are in a fully open position a pile receiving opening into the pile enclosing structure 2a,b is formed having a size in the pile gripper plane A_{PG} equal or larger than the outer diameter OD .

The rotational movements of the arms 2a are achieved by arm displacement device 2h such as hydraulic cylinders and/or linear actuators.

25 The pile enclosing structure 2a,b is supported onto a linear support structure 2l comprising two straight arms 2l extending on both sides of the pile enclosing structure 2a,b from respective pivot structures 2m with rotational axis perpendicular to the deck 205.

30 Now with particular reference to fig. 6, the rotation of the linear support structure 2l by the pivot structures 2m are seen to allow displacement of the pile enclosing structure 2a,b in the longitudinal direction of the vessel 200. Such rotation is activated by hydraulic cylinders and/or linear actuators 2g arranged with an angle in respect to the two arms of the linear support structure 2l and where one end is connected to a fastening structure 2k fixing the pile gripper 2 to the deck 205 and an opposite end is fixed to respective straight arms 2l. The fastening structure 2k may be rotationally fixed to the deck with a rotational axis parallel to the deck 205.

In addition, the two straight arms 2l are seen to be length adjustable by use of a displacement device 2f comprising hydraulic cylinders or linear actuators arranged parallel to the arms 2l and where one end is connected to the fixing structure 2k and an opposite end is connected to the respective straight arms 2l.

- 5 Now with particular reference to fig. 4, the pile gripper 2 further comprises a plurality of pile supporting devices (PSD) 2c,d allowing locking of the pile 10 into a center position within the pile enclosing structure 2a,b. The PSDs 2c,d are arranged rotationally symmetric within the enclosing space of the pile enclosing structure 2a,b. Each PSD 2c,d comprises vertical pile displacement wheels 2c and horizontal
10 pile displacement wheels 2d having rotational axes parallel and perpendicular to the pile gripper plane APG , respectively. Further, each PSD is fixed to an end of a PSD displacement device 2e which again is fixed to rotationally symmetric to the pile enclosing structure 2a,b, thereby enabling the PSDs 2c,d to be displaced within the pile gripper plane APG from a retracted position where no wheels of the PSD 2c,d
15 are contacting the pile 10 installed in the enclosing space and a contact position where the vertical pile displacement wheels 2c and/or the horizontal / rotational displacement wheels 2d are contacting the pile 10. Each rotational displacement wheel 2d in each PSD 2c,d is fixed to a rotational displacement wheel motor 2i allowing motorized rotation.
- 20 Moreover, each PSD 2c,d comprises another displacement motor for relative displacement of the vertical pile displacement wheels 2c and the rotational displacement wheels 2d. The displacement motor is configured such that, in contact position, the two types of wheels 2c,2d may be retracted / advanced in order for the control system of the pile gripper 2 to control which of the type of wheels 2c,2d
25 should inflict pressure onto the pile's 10 outer wall.

The arm displacement device(s) 2h enabling rotation of the arms 2a of the pile enclosing structure 2a,b, the displacement devices 2f,2g enabling both rotation and translational movements of the straight arms of the linear support structure 2l, the PSD displacement devices 2e enabling displacement of the PSDs 2c,d and the
30 rotational displacement wheel motors 2i enabling motorized rotation of the rotational displacement wheels 2d all constitute part of the pile gripper positioning system 2e-i controllable from the pile gripper's 2 control system.

35 With reference to fig. 7, the third phase of the installation involves using the displacement device 2f arranged parallel to the straight arms of the linear support structure 2l to displace the pile enclosing structure 2a,b, and thereby also the vertical oriented pile 10, further away from deck 205 when the end-support 3a of

the up-ending tool 3 has been removed from the lower pile end 10b, either by lifting of the pile 10 by the lifting crane 400 or rotating the end-support 3a downward or a combination of both. Further, at this phase, the upper support 3b is tilted upwards to release its support on the outer wall of the pile 10.

- 5 After completing the third phase, the pile 10 is only suspended in the crane cable 403 via the suspending structure 4. The fourth phase may thus commence in which the vertical pile displacement wheels 2c of the PSDs 2c,d are inflicting pressure onto the pile's outer wall to stabilize / lock the pile's horizontal position, following by a lowering of the pile 10 towards the seabed 30 by use of the lifting crane 400. In
- 10 the particular example shown in fig. 8, the pile 10 is lowered a certain distance L_4 before starting the optional fifth phase; rotation of the pile 10 around its longitudinal center axis C as disclosed above. The purpose of the rotation may be to align external power and communication cables forming part of a subsea power distribution network with respective connection points / openings within the pile 10.
- 15 When desired rotational position of the pile 10 is achieved, the sixth phase commences where the lowering of the pile 10 is continued until the lower end 10b is adjacent to, or contacting, the target pile position 30a of the seabed 30, see fig. 10. The seventh phase, self-penetration at distance L_7 below the seabed 30, will then occur due to the pile's 10 self-weight.
- 20 As the final, eight phase, the pile 10 is forced further into the seabed 30 to create a stable fixation. As exemplified in fig. 12 this phase is achieved by replacing the suspending structure 4 at the upper end 10a with a hammering structure 7 by use of the lifting crane 400. The hammering structure 7 is in fig. 12 depicted as a cylindrical block where one end of the block comprises means to connected to an
- 25 end of the crane cable 403. A section of the block which includes the opposite end has a reduced diameter that can be inserted into a hollow part of the upper pile end 10a. In order to enable hammering, the other section including the end attached to the crane cable 403 should have a diameter larger than the pile's inner diameter ID and preferably larger than the outer diameter OD .
- 30 The installation vessel 200 comprises one or more vessel motion sensors 8 allowing measurements of the vessel's 200 movements at sea such as rotational motions (roll, pitch, yaw) and translational motion (heave, sway, surge). The vessel motion sensors 8 are preferably of type accelerometers allowing measurements of velocity vectors and acceleration vectors. Positional data may thus be obtained by single or
- 35 double integrations of the measurement data.

The vessel motion sensor(s) 8 constitute(s) part of a dynamic positioning system (DP) on the vessel 200, enabling access of continuous (or near continuous) information concerning vessel dynamics for the control system of the pile gripper 2. As a response to these input data of the vessel movements, hydraulic cylinders and/or linear actuators forming part of the pile gripper's 2 positioning system 2e-i are activated by the control system to keep the horizontal position of the pile stationary with respect to the seabed. Hence, during operation, the pile gripper's 2 control system ensures that any movements involving horizontal displacements of the pile 10 become independent (or near independent) from movements involving the vessel's horizontal displacements. Hence, data communication between the vessel motion sensor(s) 8 and the pile-gripper's 2 control system makes it possible to reach sub-purpose 1.

However, motion compensation by the pile gripper 2 based on only vessel motion sensor measurements cannot achieve sub-purposes 2 and 3 within the desired accuracy since vessel compensation in itself does not take into account any misalignment of the pile 10 beyond its horizontal position within the pile gripper 2. These undesired misalignments can be a result of external forces inflicted onto the pile 10 during parts of the installation process, typically waves, currents, wind and added mass. Other external forces can also be envisaged such as earthquakes or mechanical instabilities on crane, pile gripper, etc.

To perform a pile installation that also take into account sub-purposes 2 and 3, and in particular for installation phases three to six, one or more pile motions sensors 9,9a,9b are mounted on the pile 10 and/or on the suspending structure 4 at the upper pile end 10a. Both configurations are exemplified in fig. 7 where the pile motion sensor(s) 9,9a,9b is/are fastened on top of the suspending structure 4 and on the outer wall near the upper end 10a.

As for the vessel motion sensors 8, the pile motion sensors 9 may be configured to measure numerous static and dynamical data, including orientation of the pile's 10 longitudinal center axis *C* relative to global vertical coordinates. And as for the measurement data from the vessel motion sensor 8, the measurement data from the pile motion sensor 9 are sent via transmitters to the control system of the pile gripper 2 which then calculates and transmits instructional data to the various force and/or positional regulatable components within the pile gripper positioning system 2e-i to perform necessary adjustments for minimizing the above-mentioned pile misalignments. The misalignments may include static misalignments, i.e. stable or near stable offsets from desired horizontal position and vertical orientation (sub-

purpose 3) and continuously varying misalignments due to e.g. induced pendulum pile movements during lowering towards the seabed 30, i.e. third to eighth phase and in particular third to sixth phase (sub-purpose 2).

As it will be explained below, the pile gripper's 2 control system is configured to receive input vectors / matrixes from vessel 200, lifting crane 400 and pile 10 related data (typically a combination of measured, estimated and structural data) and process these based on a chosen installation facility model and calculation method that results in new force vectors / matrixes for the pile gripper positioning systems 2e-i. The force vectors / matrixes in force are subtracted from the new force vectors / matrixes, and the results are transmitted as new set of values to the relevant hydraulic and/or electric components of the pile gripper positioning system 2e-i as described above.

In order to stabilize pile pendulum movements, it is of importance to know the exact position coordinates of the fixation point 405 of the crane cable 403.

Normally these position coordinates of the fixation point 405 may be determined by calculating horizontal and vertical coordinates of the fixation point 405 relative to positional coordinates of the vessel 200 measured by the vessel motion sensors 8.

However, as depicted in fig. 2, the installation facility 100 may also comprise one or more crane motion sensors 406 that are configured to measure the exact position of the fixation point 405 relative to global horizontal positioning coordinates. As for the vessel motion sensors 8 and the pile motion sensors 9, the crane motion sensors 406 are preferably accelerometers allowing measurements of velocity vectors and/or accelerator vectors of the fixation point 405. The position of the fixation point is thus achieved by single integration or double integration.

An installation facility 100 which includes such a crane motion sensor 406 is advantageous, in particular if the lifting crane 400 may perform controlled movements of the fixation point 405 that contributes to the above stated purposes. For example, a lifting system 400 that allows sensor-controlled movements in horizontal directions and/or in vertical direction (heave compensation) may be envisaged, thereby setting higher demands on continuous / frequent collection of positional crane state data (position, velocity, acceleration).

With particular reference to with flowchart shown in fig. 14 and the double pendulum model shown in fig. 15, a stabilization method for stabilizing the pile 10 when lowered towards the seabed 30 will now be described in further details:

Global geo position data 301 is received from a global or local navigation system. The current global geo position data 301 is compared with the reference position giving the reference state data 302 and transferred to a dynamic position system vessel DP system 304 by comparing 303 reference state data with the current measured vessel state data 307. Reference position is defined as the target (i.e. wanted) position of the vessel 200. The comparison 303 of the reference state data 302 with the measured vessel state data 307, gives a wanted correction of the vessel position by transmitting the offset (difference) between reference state data 302 and the current measured vessel state data 307 to the vessel DP system 304 on the vessel 305. The vessel DP system 304 includes a vessel motion sensor 8, typically an accelerometer. A more used term in the marine industry for an accelerometer is MRU (Motion Response Unit). There can be one or more accelerometers in one MRU and there can be one or more MRU, all together included in the vessel motion sensor 8. The vessel DP system 304 could be any system, of any kind and brand, capable of controlling the vessel 305. The vessel 305 controlled by the vessel DP system 304 may be any combinations of size and draft and configuration of marine propellers, such as propulsion propellers screws, azimuth thruster(s), tunnel thrusters and with/without rudders – one or several in different combinations – with the intention to control the position, direction and rotation of a vessel. The vessel motion sensor 8 may measure constantly, or in short time intervals, at least information about changes in the vessel position, thereby making possible calculations of current speed in all directions and computations of the current rotation and excitation directions, heading, heel and trim. The vessel state data 307 may contain the state data involving the vessel control of actuators powering, response and effect from the actuators and current position, heading, rotations and excitation (excursions) of the vessel 305. The current vessel current state data 307 may also be transferred to the lifting crane 306 for co-processing with the crane operation control system. Data transfer from the lifting crane 306 are continuously compared with the crane winch measurement system 308 and the crane arm measured position 309. The current crane arm position 309 is preferably measured with a crane motion sensor 406, typically of an accelerometer type. In addition, or alternatively, the crane arm position 309 can be measured by mechanical and/or optical angle and excitation instruments.

By transmitting current position from the crane arm measuring system 309 and computing this with the vessel state data 307, the input reference vector 310 constituting part of the inputs to force controller 312 of the pile gripper 2 may be determined. This input reference vector 310 is measured / determined at the tip of the crane arm 404, i.e. at the fixation point 405 for the crane cable 403. The input

reference vector 310 is expressing the resultant power/force needed in a specific direction based on the weight and inertia of the pile 10 and the crane cable 403 (included the crane block and hook), as well as the suspending structure / lifting tool 4 acting on the fixation point 405. The input reference vector 310 is mathematically in a matrix form and the array may also include information of position, angle, speed and acceleration at the fixation point 405. However, the input reference vector 310 is typically not including any effects of pendulum movements of the pile 10, the crane cable 403 (included the crane block and hook) and the lifting tool 4.

The suspended pile 10, the crane cable 403 and the lifting tool 4 may be modelled as a dynamic double pendulum, with or without added mass on the pile 10 (typically as a water column) with or without a suspending structure 4 and with or without a hammering tool 7, depending on which phase the pile gripper launching operation is in (see description above and fig. 15).

To control such double pendulum movements and keep safe, stabilized conditions, active compensation forces and position corrections are performed in the pile gripper 2. Just before the lower end 10b of the suspended pile 10 is contacting the seabed 30, the required precision of the vertical inclination of the pile 10 is set higher than earlier installation phases. Also, the required horizontal precision may be set higher at this final phase.

In fig. 14, the crane winch measurement system (crane winch MS) 308 provides information concerning the location of the suspending structure / lifting tool 4 relative to the fixation point 405.

During the stabilization method, the following data are transmitted to the pile register state vector (MP) 318:

- lifting crane state data (lifting crane) 306,
- crane winch state data (Crane winch MS) 308,
- disturbances state data (Disturbances) 319,
- structural MP data 320 (for example pile length (L_p), inner diameter (ID), outer diameter (OD) and weight of pile (m_l) and
- current setting positional state data of pile gripper positioning system (PG System) 317.

By computing these data (MP) 318, and adding measurement data from the pile motion sensor 9,9a,9b, a pile state vector (MP state vector MS) 314 is determined comprising updated information of e.g. pile movements (position, velocity,

acceleration, forces, etc). This pile state vector 314 provides necessary correction data to the desired state vector given by the input reference vector 310. Corrective data are thus calculated using a summation block 311. By comparing input reference vector 310 with the measured pile state vector 314 in the summation block 311, new
5 instruction data for the force controller 312 are determined.

Furthermore, these instruction data are corrected in a summation block 313 for measured state vector of the pile gripper (PG MS) 315 (e.g. actual hydraulic cylinder positions) in order to achieve corrected set values (such as correction force) to the hydraulic components within the hydraulic positioning system 316.
10 With reference to the description above concerning the configuration of the pile gripper 2, corrected force values are sent to first and second displacement devices (typically hydraulic cylinders), alternatively, or in addition, to the PSD displacement device 2e and/or the rotational displacement wheel motor 2i.

Any variation of the predetermined horizontal tolerance range (including and
15 variations in the inclination tolerance range from global vertical coordinates) may be transmitted to the input reference vector 310 during the installation.

In the preceding description, various aspects of the installation facility and associated methods of installation and stabilization using the installation facility have been described with reference to the illustrative embodiment. For purposes of
20 explanation, specific numbers, systems and configurations were set forth in order to provide a thorough understanding of the facility and its workings. However, this description is not intended to be construed in a limiting sense. Various modifications and variations of the illustrative embodiment, as well as other embodiments of the facility, which are apparent to persons skilled in the art to
25 which the disclosed subject matter pertains, are deemed to lie within the scope of the present invention.

REFERENCE NUMERALS

1	Installation tool
2	Pile gripper
2a,b	Pile enclosing structure
2a	Movable receiving arm(s) on pile enclosing structure
2b	Fixed part of pile enclosing structure / fixed arms
2c,d	Pile supporting device (PSD)
2c	Vertical pile displacement wheel
2d	Horizontal pile displacement wheel / rotational displacement wheel
2e-i	Pile gripper positioning system
2e	Displacement device (e.g. hydraulic cylinder or linear actuator) / PSD displacement device
2f	First displacement device / first hydraulic cylinder
2g	Second displacement device / second hydraulic cylinder
2h	Receiving arm displacement device / hydraulic cylinder
2i	Rotational displacement wheel motor
2k	Fastening structure (for rotationally fixing pile gripper to deck)
2l	Linear support structure for pile enclosing structure
2m	Pivot structure for linear support structure (with rotational axis perpendicular to deck)
3	Rotatable up-ending tool
3a	End-support
3b	Upper support
3c	Elongated member
4	Suspending structure / plate
5	Upending winch / tugger winch
6	Winch cable
7	Hammering structure
7a	Suspending means / suspending structure to fix an end of the crane cable(s) to the hammering structure
8	Vessel motion sensor / vessel accelerometer
9	Pile motion sensor / pile accelerometer
9a	Pile motion sensor mounted on suspending structure
9b	Pile motion sensor mounted on pile
10	Pile / wind turbine pile / Tubular pile
10a	Upper end of pile
10b	Lower end of pile
11	Height adjustable pile bench
12	Pile cradle
20	Water surface
30	Seabed
30a	Target pile position
100	Installation facility
200	Vessel
201	Aft part of vessel
202	Bow part of vessel
205	Deck
300	Flowchart for stabilizing a pile during vertical lowering towards the seabed
301	Receiving global geo position data from a global or local navigation system.

302	Setting global geo position data as reference state data
303	Comparing reference state data with measured vessel state data
304	Transmitting reference state data to a dynamic position system (DP) on the vessel
305	Setting the vessel coordinates in accordance with the reference state data using the DP
306	Transmitting vessel coordinates to lifting crane
307	Setting vessel coordinates as vessel state data
308	Transmitting lifting crane state data to a measurement system of up-ending winch
309	Transmitting lifting crane state data to a measurement system of crane arm with crane cable
310	Setting the vessel state data and the crane arm state data as input reference vector for force controller in pile gripper.
311	Comparing input reference vector with measured monopile (MP) state vector / summation block
312	Transmitting comparison data to force controller and calculate instructional force data
313	Comparing instructional force data with setting of pile gripper positional system / summation block
314	Transmitting comparison data to hydraulic control system for setting hydraulic components
315	Transmitting positional state data of pile gripper positioning system
316	Adjusting hydraulic components of hydraulic control system based on comparison data
317	Setting / registering new positional state data of pile gripper positioning system
318	Setting / registering MP state vector based on set positional state data, set up-ending winch data, set lifting crane data, measured MP data and external disturbances.
319	Setting and transmitting disturbance data which impact the orientation and position of MP
320	Transmitting structural MP data such as length, inner diameter, outer diameter and mass.
400	Lifting crane
403	Crane cable
404	Crane arm
405	Fixation point
406	Crane motion sensor
C	Pile's longitudinal center axis
V	Vertical orientation relative to global positioning coordinates
OD	Outer diameter of pile
ID	Inner diameter of pile
A_{PG}	Pile gripper plane set by pile enclosing structure
θ_1	Angle between global vertical coordination and crane cable orientation between fixation point and suspending structure
θ_2	Angle between global vertical coordinates and pile orientation
ψ_1	Angle between global horizontal coordinates and horizontal position of crane cable
ψ_2	Angle between global horizontal coordinates and horizontal position of pile
m_1	Weight of pile
m_2	Weight of added mass