

CLAIMS

1. An installation facility (100) for installing a pile (10) in a vertical orientation on a target pile position (30a) into a seabed (30), the vertical orientation being defined relative to global positioning coordinates at the target pile position (30a), the installation facility (100) comprising
- the pile (10) having a longitudinal center axis,
 - a vessel (200) comprising a deck (205) for storing a plurality of piles (10),
 - a lifting crane (400) fixed to the vessel (200), capable of lifting the pile (10),
 - a global positioning system for receiving global positioning coordinates from a navigation system,
 - a vessel motion sensor (8) installed on the vessel (200) for measuring the vessel's (200) excursions and rotations during operation at sea, the vessel motion sensor (8) comprising a vessel motion data transmitter allowing transmittal of measurement data and
 - an installation tool (1) fixed to an outer boundary of the deck (205), the installation tool (1) comprising
 - a suspending structure (4) removably fixed to an upper end (10a) of the pile (10), the suspending structure (4) having means to fix a first end of one or more crane cables (403),
 - a pile motion sensor (9,9a,9b) installed on at least one of the suspending structure (4) and the pile (10) for measuring at least the position and orientation of the pile (10) relative to the global positioning coordinates at the target pile position (30a), the pile motion sensor (9,9a,9b) comprising a pile motion data transmitter allowing transmittal of measurement data,
 - a pile gripper (2) comprising a pile enclosing structure (2a,b) configured to enclose at least a part of an outer circumference of the pile (10) within an enclosing space, the pile enclosing structure (2a,b) comprising at least one receiving arm (2a) movable between an open position forming a pile receiving opening into the enclosing space equal or larger than an outer diameter of the pile (10) and a closed position wherein the pile receiving opening is at least partly closed, a pile gripper positioning system (2e-i) configured to re-position horizontally the pile (10) during vertical lowering and a control

- 5 system configured to regulate the pile gripper positioning system (2e-i) based on received measurement data from the vessel motion data transmitter and the pile motion data transmitter to stabilize movements of the pile (10) during a vertical lowering towards the seabed (30) within a predetermined horizontal tolerance range from the target pile position (30a).
- 10 2. The installation facility (100) in accordance with claim 1, wherein the pile motion sensor (9,9a,9b) is an accelerometer allowing measurements of magnitude and direction of the pile's (10) acceleration during the vertical lowering towards the seabed (30), wherein the position and orientation of the pile (10) is achieved by double integration of the measured acceleration vector.
- 15 3. The installation facility (100) in accordance with claim 1 or 2, wherein at least a part of the pile gripper positioning system (2e-i) are force controlled, and
- 20 - wherein the control system comprises a force control system for setting and controlling the force of the force-controlled pile gripper positioning system (2e-i), the force control system being configured
- to receive at least one of
 - measured velocity vector data and
 - measured acceleration vector datafrom the pile motion sensor (9,9a,9b) and
 - to convert measured data from at least the pile motion sensor (9,9a,9b) into force vectors having a size and a direction allowing the stabilization
- 25 of the movements of the pile (10).
4. The installation facility (100) in accordance with any one of the preceding claims, wherein the pile enclosing structure (2a,b) comprises two receiving arms (2a) arranged mirror symmetrically relative to each other.
- 30 5. The installation facility (100) in accordance with any one of the preceding claims, wherein the pile gripper positioning system (2e-i) comprises
- a first displacement device (2f) configured to displace the pile enclosing structure (2a,b) in direction perpendicular to a hull of the vessel (200) and
 - a second displacement device (2g) configured to rotate the pile enclosing
- 35 structure (2a,b) with a rotational axis perpendicular to the deck (205).

6. The installation facility (100) in accordance with any one of the preceding claims, wherein the pile gripper positioning system (2e-i) comprises
- two independently displaceable first displacement devices (2f) configured to displace the pile enclosing structure (2a,b) in a direction perpendicular to a hull of the vessel (200), wherein the two first displacement devices (2f) are fixed to opposite sides of the pile enclosing structure (2a,b) extending from the deck (205).
7. The installation facility (100) in accordance with any one of the preceding claims, wherein the pile gripper (2) further comprises
- a plurality of pile supporting devices (2c,d) arranged within the pile enclosing structure (2a,b) for suppressing movements of the pile (10) within the enclosing space during lowering,
- and wherein the pile gripper positioning system (2e-i) comprises
- a plurality of displacement devices (2e) coupled between the enclosing structure (2a,b) and the plurality of pile supporting devices (2c,d) to allow displacement of the pile supporting devices (2c,d) between
 - a contact position in which at least a part of each pile supporting device (2c,d) exerts a pressure onto an outer wall of the pile (10) and
 - a retracted position in which each pile supporting device (2c,d) exerts no or insignificant pressure onto the outer wall of the pile (10).
8. The installation facility (100) in accordance with claim 7, wherein each pile supporting device (2c,d) comprises
- a vertical pile displacement wheel (2c) having a rotational axis parallel to a pile gripper plane (A_{PG}) set by the pile enclosing structure (2a,b) and
 - a horizontal pile displacement wheel (2d) having a rotational axis perpendicular to the pile gripper plane (A_{PG}),
- wherein the plurality of pile supporting devices (2c,d) is further configured to displace the vertical pile displacement wheel (2c) and the horizontal pile displacement wheel (2d) relative to each other such that, when in contact position, either the vertical pile displacement wheel (2c) or the horizontal pile displacement wheel (2d) or both, exert(s) pressure onto the outer wall of the pile (10).
9. The installation facility (100) in accordance with any one of the preceding claims, wherein the lifting crane (400) comprises

- a crane arm (404) onto which a second end of the crane cable (403) is fixed at a fixation point (405) and
wherein the installation facility (100) further comprises
 - 5 • a crane motion sensor (406) for measuring at least a horizontal position of the fixation point (405) relative to global positioning coordinates at the target pile position (30a).
10. An installation method using an installation facility (100) in accordance with any one of the preceding claims,
wherein the method comprises the following steps:
- 10 A. moving the at least one receiving arm (2a) of the pile enclosing structure (2a,b) into the open position,
- B. aligning the pile (10) with the pile gripper (2) such that the pile's longitudinal center axis intersects an axis going through a center of the pile receiving opening,
- 15 C. tilting the pile (10) by use of the lifting crane (400) until the vertical orientation of the pile (10) is achieved, wherein at least the orientation of the pile's longitudinal center axis relative to the vertical orientation is being monitored by measurement data transmitted from the pile motion sensor (9,9a,9b),
- 20 D. moving the at least one receiving arm (2a) of the pile enclosing structure (2a,b) into the closed position,
- E. lowering the pile (10) by use of the lifting crane (400) towards the target pile position (30a) while monitoring the movements of the pile (10) using at least one of the pile motion sensor (9,9a,9b) and the vessel motion sensor (8),
- 25 F. if the movements of the pile (10) within the pile enclosing structure (2a,b) during lowering are measured to be outside the predetermined horizontal tolerance range, transmitting instruction signals to the control system to adjust, via the pile gripper positioning system (2e-i), the pile enclosing structure (2a,b) in order to force the movements of the pile (10) to be within the predetermined horizontal tolerance range.
- 30 11. The installation method in accordance with claim 10, wherein the lifting crane (400) comprises
- a crane arm (404) onto which a second end of the crane cable (403) is fixed at a fixation point (405) and
 - 35 wherein the installation facility (100) further comprises
 - a crane motion sensor (406) arranged on the crane arm (404), and

wherein step E of the method further comprises

- measuring the horizontal position of the fixation point (405) relative to global positioning coordinates,
- subtracting the horizontal position of the fixation point (405) with the measured horizontal position of the pile (10) at one or more vertical positions and,
- 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 (10) via the pile gripper positioning system (2e-i) and
 - the horizontal position of the fixation point (405) via lifting crane (400)
- until the result of the subtraction is within the predetermined difference tolerance range.

12. A stabilization method enabling stabilization of movements of a pile (10) during lowering of the pile (10) towards a seabed (30) using an installation facility (100) in accordance with any one of claims 1-9, wherein the stabilization method comprises the following steps:

- (301) receiving global positioning coordinates from a navigation system,
- (302) setting reference state data based on the global positioning coordinates and vessel positioning coordinates,
- (304) transmitting the reference state data to a dynamic positioning system of the vessel (200),
- (303,305,307) adjusting the vessel positioning coordinates using the dynamic positioning system until vessel state data are achieved within a predetermined acceptance range relative to the global positioning coordinates,
- (307,310) setting the vessel state data as input reference data,
- (307,310-311,314) correcting the input reference data with initial pile state data to obtain initial set values,
- (310-311) transmitting the initial set values to the control system,
- (312) calculating initial instruction data based on the initial set values and a model of the installation facility (100) that forces the movements of the pile (10) to approach, or enter, into the predetermined horizontal tolerance range,

- (313,316-318) activating the pile gripper positioning system (2e-i) based on the initial instruction data,
 - (314,315,318) finding new pile state data relative to the vertical orientation by use of at least
 - 5 - the pile motion sensor (9,9a,9b),
 - measured and/or simulated disturbance data inflicting external force onto the pile (10) and
 - structural pile data,
 - (311,312) correcting the input reference data with the new pile state data to obtain new set values,
 - 10 - (310-311) transmitting the new set values to the control system,
 - (316) calculating new instruction data based on the new set values and the model of the installation facility (100) and
 - (313,316-318) activating the pile gripper positioning system (2e-i) based on the calculated new instruction data received from the control system.
 - 15 system.
13. The stabilization method in accordance with claim 12, wherein the method further comprises the following steps:
- 20 - (306) transmitting the vessel data or the vessel state data to a crane control system of the lifting crane (400),
 - (310) calculating initial input reference data based on crane state data and vector state data,
 - (310-311,314) correcting the initial input reference data with the initial pile state data to achieve initial set values and
 - 25 - (306,307,309,310,312) transmitting the initial set values to the control system.
14. The stabilization method in accordance with claim 12 or 13, wherein the lifting crane (400) comprises a crane arm (404) onto which a second end of the crane cable (403) is fixed in a fixation point (405) and wherein the installation facility (100) further comprises a crane motion sensor (406) arranged on the crane arm (404) for measuring at least a horizontal position of the fixation point (405) relative to the global positioning coordinates, and wherein the method further comprises the following steps:
- 30 - (306) transmitting the vessel coordinates or the vessel state coordinates to a crane control system of the lifting crane (400),
 - 35 coordinates to a crane control system of the lifting crane (400),

- (309,310) measuring the horizontal position of the fixation point (405),
 - (311,314) subtracting the horizontal position of the fixation point (405) with a horizontal position of the pile (10) at one or more
5 locations along the pile's longitudinal center axis,
 - (312) transmitting the result of the subtraction to the control system of the pile gripper (2) and/or the crane control system,
 - (316) calculating the initial instruction data based on the result of the subtraction to the pile gripper positioning system (2e-i) and
10 - (313,316-318) activating the pile gripper positioning system (2e-i) and/or moving the crane arm (404) based on instructions from the control system of the pile gripper (2) and/or the crane control system.
15. A computer-readable medium having stored thereon a computer program
15 comprising instructions to execute the method steps of any one of claims 12-14.