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(54) **Title:** PILE HANDLING FACILITY

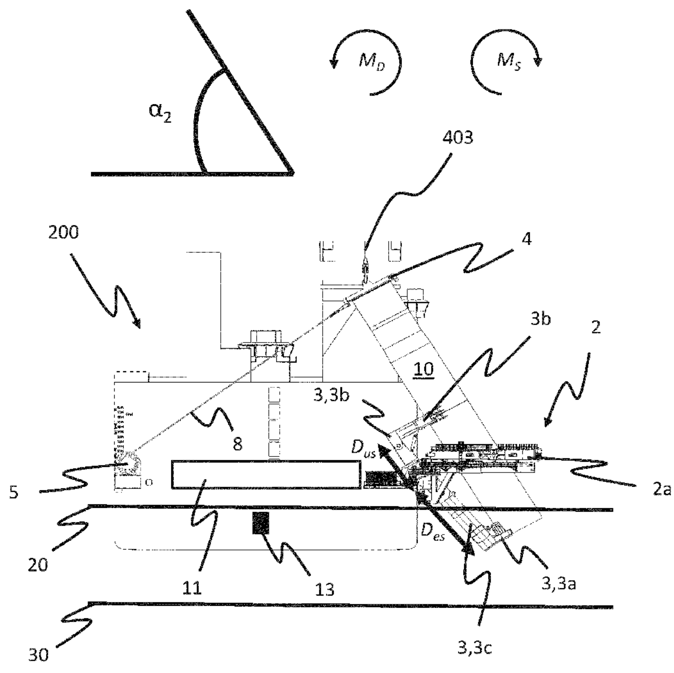

FIG. 7

(57) Abstract: The invention concerns a pile handling facility (100) for tilting a pile (10) from a laying orientation at least partly within a deck of a vessel (200) to an upright orientation outside an outer boundary of the deck and a method thereof. The pile handling facility (100) of comprises a pile (10), a vessel (200) comprising a deck (12) suitable for the pile, a lifting crane (400) fixed to the vessel, an upending tool (1) for supporting the pile during tilting from the laying orientation to the upright orientation and a winch system.

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Title: Pile handling facility

FIELD OF THE INVENTION

The present invention relates to a pile handling facility for tilting an elongated object / pile from a laying orientation on a deck of a floating vessel to a vertical orientation outside an outer boundary of the deck 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 JP 2001/1207948.

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 tilted to a vertical position and then lowered down to the seabed, typically by use of a heavy lift crane and a dedicated up-ending tool (UET). 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 tilting of the MP a jack-up rig or jack-up vessel is typically employed.

Due to the extensive weight and dimensions of the piles and the installation facility, it is of utmost important that the operator has full control of the pile position at any time during the tilting. Any unintentional situations such as unexpected change of torque direction may have severe consequences for personal and equipment.

Patent publication WO 2019/231329 A1 describes a pile handling facility and a method for controlled tilting of an MP from a parking position on deck to a vertical position outside the deck.

One disadvantage with this known solution is that any change of pile torque from inboard to outboard direction is handled chiefly by the crane, thereby making this pile handling facility vulnerable for sudden changes due to for example environmental forces on the vessel.

It is therefore an objective of the invention to provide a pile handling facility and a method that ensures low risk of pile instability during the entire tilting maneuver from a laying orientation to an upright orientation.

Another objective of the invention is to provide a pile handling facility and a method that ensures constant contact between the pile and the upending tool during tilting.

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

Yet another objective of the invention is to perform a successful tilting of a pile where the required control of the crane tension to ensure sufficient stability is kept at a minimum.

SUMMARY OF THE INVENTION

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

In a first aspect, the invention concerns a pile handling facility suitable for tilting a pile from a laying orientation at least partly within a deck of a vessel to an upright orientation outside an outer boundary of the deck, wherein the laying and upright orientations are defined as the orientation parallel and perpendicular to the deck respectively. Hereinafter, a pile shall be interpreted as any elongated object such as a monopile or a plurality of parallelly attached monopiles. Furthermore, a deck is defined as an exterior plane of the vessel onto which the vessel's superstructure is arranged.

The pile handling facility of the first aspect comprises during operation,

- one or more piles having longitudinal center axes C,
- a vessel comprising a deck suitable for storing the one or more piles,
- a lifting crane fixed to the vessel and dimensioned to lift a pile,
- an up-ending tool for supporting the pile during tilting from the laying orientation to the upright orientation and
- a winch system, preferably arranged on the deck.

The up-ending tool is rotatably fixed to the outer boundary of the deck via one or more pivot hinges around a rotational axis oriented parallel to the deck and perpendicular to the pile's longitudinal center axis C.

The upending tool comprises a contacting face configured to abut against a circumferential surface of the pile during tilting and an end-support configured such that a lower pile end of the pile may be supported on the end support.

Further, the lifting crane comprises a crane cable having, during tilting, a suspended end fixed, preferably removable, to or near an upper pile end of the pile. The suspended end may be indirectly attached to the upper pile end via a suspending structure removably fixed to the upper pile end during tilting.

In case such a suspending structure is present both the suspended end of the crane cable and the end of the winch cable may be fixed to the suspending structure.

During tilting, the crane cable should preferably be at any time in an upright orientation. Hence, a crane arm of the lifting crane (for example an outermost crane arm in case of several arms) must be raised coherent with the pile angle, thereby following the pile's tilting path. This may be achieved by adjusting the position of the fixation point between an outer crane tip of the lifting crane's outermost arm and the attached end of the crane cable both in direction parallel and perpendicular to the deck.

Any adjustments in order to keep the crane cable in an upright orientation will depend on the state of geometry of the crane and the pile. It may be done by visual inspection of the crane cable and/or by use of an inclinometer arranged on the crane cable. However, it is considered most advantageous to install a suitable crane motion sensor such as an accelerometer that allows measurements of the fixation point position during tilting. Such a sensor may for example be arranged at or near the outer crane tip. A combination of inclinometer, motion sensor and visual inspection may also be envisaged.

Finally, the winch system comprises a winch cable being fixed, during tilting, at an end to or near the upper pile end and a winch tension controller being configured to control a winch tension T_w in the winch cable. The attachment of the winch cable to the pile is, as for the crane cable, preferably removable. Moreover, the fixation may be indirectly via the suspending structure mentioned above.

The winch tension controller comprises a drum onto which the winch cable is spooled. The drum is preferably arranged on the deck of the vessel via suitable support(s), more preferably near or at the upper pile end when the pile is laying in a horizontal orientation on the deck. Moreover, the controller may comprise a winch tension sensor configured to measure (continuously and/or at set time intervals) the winch tension T_w within the winch cable during the tilting operation. The winch tension sensor may also be configured to transmit the measured tension data, wirelessly and/or wired, to a control system.

The winch tension may be determined by the winch tension sensor directly or by indirect measurements such as measuring the force acting on the winch cable and the geometry of the winch cable and the pile.

Said winch tension sensor may be a load cell interconnecting the end of the winch cable to the upper pile end, optionally via a suspending structure.

The winch tension controller may further comprise a drum motor configured to rotate the drum around a rotational axis perpendicular to the orientation of the winch cable. In this particular configuration, the winch tension controller may be configured to control (wireless and/or wired via signal communication lines) operation of the drum motor during operation.

Such a drum motor may be configured to control the rotational velocity of the drum during rotation, and thereby to control an angle velocity of the upper pile end (tilting velocity). This again ensures continuous, or near continuous, abutment against the contact face. Such control may be achieved by including in the winch tension controller means (such as one or more processors, located locally and/or remotely) suitable for calculating, using a software stored therein, a desired rotational velocity as function of the measured winch tension T_w. The means may also be made suitable for regulating the drum motor to achieve the desired rotational velocity as well as the position of the pile during tilting. The latter may alternatively, or in addition, be measured and/or estimated based on geometrical parameters (length of spooled winch cable, average angle of winch cable from drum to upper pile end or angles at specific locations, variation of winch cable length due to measured tension and physical properties, etc.).

The desired rotational velocity is herein defined as a time averaged rotational velocity obtained by accelerating / decelerating the drum speed and/or turning off / on the operation of the drum.

This time averaged desired rotational velocity is preferably set such that the actual winch tension T_w during tilting remains above a predetermined minimum tension, for example a minimum tension that ensures continuous abutment between the contacting face and the circumferential surface of the pile.

As mentioned above, the measurement of the winch tension T_w may be achieved directly by one or more dedicated winch tension sensors and/or more indirectly by geometric measurements (length / angle) of the winch cable(s) and measurement of another physical property such as the force acting on the winch cable(s).

The lifting crane may further comprise a crane tension sensor configured to measure a crane tension T_C in the crane cable. The measured tension data may be sent to a crane operator who may regulate the lifting force to ensure a minimum crane tension during the tilting operation.

Alternatively, or in addition, the winch tension controller may comprise means to receive the measured crane tension T_C and to calculate the desired rotational velocity as function of both the measured winch tension T_W and the measured crane tension T_C. The means may be a suitable receiver and the same processor as mentioned above.

The upending tool may also comprise a pivot base fixed to the at least one pivot hinge. Moreover, the end support may protrude from or near a lower end of the pivot base. The pivot base has preferably an elongated shape with a longitudinal axis oriented parallel, or near parallel, to the longitudinal axis C of the pile during tilting. The pivot base, the at least one pivot hinge and the end support are mutually arranged such that the lower pile end of the pile may be supported on the end support during tilting in order to prevent movement of the pile along its longitudinal center axis C.

In yet another advantageous configuration, the upending tool further comprises an upper support protruding from or near an upper end of the pivot base, wherein said contacting face forms part of this upper support.

Note that the terms ‘lower’ and ‘upper’ refer herein to a vertical orientation relative to global coordinate system.

In yet another advantageous configuration, the ratio of an end support distance D_{es} between the end support and the pivot hinge and an upper support distance D_{us} between the upper support and the pivot hinge is preferably at least 1, more preferably at least 1.5, for example 2, 2.5 or 3. However, the optimal ratio should be verified by simulations and/or model testing and depends inter alia on the pile’s length and weight. For example, it is considered advantageous to obtain a pivot point close to the pile’s center of gravity. Moreover, the upending tool and the pile’s length may be set such that the pile’s lower end is submerged into the sea at a desired stage of the tilting operation since the added mass of the water will increase the overall stability of the installation procedure.

In yet another advantageous configuration, the upper support is pivotably fixed to the pivot base such that the upper support may pivot (at least when the pile is in an upright orientation) between a contacting position where continuous contact is ensured between the contacting face and the circumferential surface of the pile and a release position displaying a horizontal spacing between the contacting face and the circumferential surface of the pile. The contacting face is preferably located above the upending tool’s center of gravity COG when the pile is in the upright orientation.

The shape of the contacting face when seen along the longitudinal center axis C of the pile may be concave with a radius equal, or near equal, to the radius of the relevant area of the pile, i.e. at the positions along the pile's length where such contact is established.

In yet another advantageous configuration, the winch system comprises a drum, preferably arranged onto the deck, and a plurality of winch cables spooled thereon. For example, the winch system may include one single drum arranged on the deck, two winch cables spooled onto the drum and a drum motor operably connected the drum to regulate e.g. the drum's rotational velocity (and thereby the winch tension T_W of the two winch cables when the free ends of the winch cables are connected at least indirectly to, or near, the upper pile end).

In yet another advantageous configuration the winch system comprises a plurality of drums and a corresponding plurality of winch cables, i.e. an equal number as for the drums. For example, the winch system may include two drums with winch cables spooled thereon. The end of each of the plurality of winch cables is in this configuration fixed to, or near, the upper pile end, for example via the above-mentioned suspending structure. Further, the plurality of drums may be arranged with spacings along a direction perpendicular to a tilting plane of the pile. At least two of the plurality of winch cables may be connected to the same winch tension sensor.

To ensure spooling of the winch cables correctly onto the drum, each of the drums should preferably be rotated relative to its base (usually the deck) such that a minimum length straight line oriented perpendicular to the spooling area of the drum is intersecting in, or near, the longitudinal center axis of the pile during tilting.

In the case of plurality of drums and winch cables, the pile handling facility may further comprise a pile motion sensor (such as an accelerometer) for measuring horizontal position of the upper pile end relative to corresponding global horizontal coordinates from the global position system. The winch tensions T_W from each of the plurality of winch cables (e.g. measured by at least one winch tension sensor) may then be transmitted to the winch tension controller for further control / analyzes, for example calculating and setting a new desired winch tension T_{wd} to ensure that the horizontal position of the upper pile end is within a threshold range from the corresponding global horizontal coordinates. Hence, a higher stability in the upper pile end's horizontal plane may be achieved.

In yet another advantageous configuration the upending tool constitutes part of a handling tool which also comprises a pile gripper *PG*. The pile gripper comprises at least one receiving arm, preferably at least two, configured to enclose the outer circumference of the pile within an enclosing space. The receiving arm(s) is/are 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. The pile gripper may further comprise a pile gripper positioning system configured to re-position horizontally the pile and a control system configured to regulate the pile gripper positioning system based on received measurement data from a vessel motion sensor and received measurement from a pile motion sensor. The purpose of the re-positioning may be to stabilize movements of the pile during a vertical lowering towards the seabed within a predetermined horizontal tolerance range from a target pile position. Both the vessel motion sensor and the pile motion sensors may be accelerometers.

In a second aspect, the invention concerns method for tilting a pile from a laying orientation at least partly within a deck of a vessel to an upright orientation outside an outer boundary of the deck by use of a pile handling facility in accordance with any of the features mentioned above. During tilting the vessel is floating in a body of water.

The method comprises the following steps:

A. arranging the pile into the upending tool such that the contacting face abuts against the circumferential surface area of the pile and the lower pile end is supported onto the end-support,
B. lifting the upper pile end by use of the lifting crane such that the pile and the upending tool is tilted around the rotational axis while the contacting face remains in abutment with the circumferential surface area and,
C. during at least a part of the tilting, regulating operation of the drum by use of the winch tension controller in order to maintain the winch tension T_w above a minimum winch tension value T^w_{min}.

To measure the winch tension T_w the winch tension controller may include a winch tension sensor such as a load cell mounted in the fixation point to the upper pile end / suspending structure and/or measuring / estimating the length and angle of the winch cable. Note that a winch tension sensor may be mounted anywhere on the winch system as long as the winch tension T_w is achieved, for example within the winch cable or at the drum.

The method may also comprise one or both of the following steps:

- prior and/or during step C, measuring a crane tension in the crane cable by use of a crane tension sensor and,
- during step C, regulating the lifting crane in order to maintain the tension in the crane cable above a minimum crane tension value T^c_{min}.

The measured crane tension may for example be transmitted to an operator which may regulate the lifting crane in order to ensure a minimum crane tension during tilting.

If the winch tension controller further comprises a drum motor configured to rotate the drum around a rotational axis perpendicular to the orientation of the winch cable and a winch tension sensor configured to measure the winch tension T_w, continuously and/or in time intervals, the method may further comprise the steps:

- measuring the winch tension T_w by use of the winch tension sensor,
- calculating, using for example a processor within the winch tension controller, operational instructions for the drum motor(s) as function of the measured winch tension(s) T_w to achieve desired winch tension(s) T_{wd} in the winch cable(s) and
- setting the drum motor(s) in accordance with the calculated operational instructions.

The setting of the drum motor(s) may be performed wireless via transmitter(s) and/or wired via signal communication line(s).

If the lifting crane comprises a crane tension sensor configured to measure a crane tension T_C in the crane cable, the method may further comprise the steps:

- measuring the crane tension T_C by use of the crane tension sensor and
- calculating, for example by a processor within the winch tension controller, operational instructions for the drum motor as function of the measured winch tension T_w *and* the measured crane tension T_C to achieve the desired winch tension T_{wd} in the winch cable.

The step of regulating the operation of the drum (step C) is performed at least during time periods of the tilting where

- an absolute value of an inboard directed torque M_d induced by the pile's weight, length and distance between the upper pile end and the abutting circumferential surface area, as well as the vessel's movements due to environmental forces, is equal to, or near equal (for example ± 20 %) to,
- an absolute value of a corresponding outboard directed torque M_s) within the same range (for example ± 20 %).

The rotating direction of M_s is opposite of M_d and due to similar parameters.

Both the inboard directed torque M_d and the outboard directed torque M_s may be determined / estimated by a combination of measurements and calculation.

If the pile handling facility comprises a plurality of drums and winch cables as described in one exemplary configuration above, the method may further comprise the following steps during tilting:

- calculating a new desired winch tension T_{wd}, for example by use of a processor within the winch tension controller, to ensure that the horizontal position of the upper pile end stays within a threshold range from the corresponding global horizontal coordinates mentioned above and
- setting the new winch tension T_{wd} by use of one or more of the drums.

The choice drum(s), and the subsequent regulations, is determined by the outcome of the calculations.

During tilting, the method is preferably also comprising the step of measuring a position of the upper pile end relative to an initial position in the laying orientation by measuring and/or calculating a length of the winch cable between the drum and a fixation point of the winch cable on the upper pile end and a length of the crane cable between a fixation point on the lifting crane and a fixation point of the upper pile end. The fixation point of both the winch cable and the crane cable may either be directly on the upper pile end or indirectly via the suspending structure.

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

BRIEF DESCRIPTION OF THE DRAWINGS

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.

Figure 1 shows a perspective view of a pile handling facility in accordance with the invention including a vessel, a plurality of piles arranged side-by-side on the vessel's deck and a handling tool for transferring a pile from the vessel to the sea.

Figure 2 shows a perspective view of a handling tool constituting part of a pile handling facility in accordance with the invention.

Figure 3 shows a perspective view of the handling tool of fig. 2, wherein fig. 3a and fig. 3b shows the handling tool in a transport position and in a pile receiving position, respectively.

Figure 4 shows a perspective view of a pile arranged within a handling tool constituting part of the pile handling facility in accordance with the invention, wherein fig. 4A shows an arrangement of the handling tool in a pile receiving position into which a pile is installed, and fig. 4B shows coupling of a winch system to an upper end of the pile.

Figure 5 shows a side view of handling tool in a pile receiving position into which a pile is installed parallel to the vessel's deck.

Figure 6 shows a side view of the handling tool in fig. 5, wherein a lifting crane has tilted the pile an angle α_1 relative to the orientation of the deck.

Figure 7 shows a side view of the handling tool in figs. 5 and 6, where the lifting crane has tilted the pile an angle $\alpha_2 > \alpha_1$ relative to the orientation of the deck.

Figure 8 shows a side view of the handling tool in figs. 5-7, where the lifting crane has tilted the pile to a upright orientation relative to the deck.

Figure 9 shows a side view similar to fig. 7, where various geometrical parameters and force / momentum vectors are indicated.

Figure 10 shows a perspective view of part of the handling tool and a vertically oriented pile arranged therein, where figs. 10A and 10B show a pile gripper in an open position and in a closed position, respectively, and an upending tool in contact position with the pile.

Figure 11 shows a side view of a pile handling facility in accordance with the invention with a vertically oriented pile arranged within a handling tool, wherein an upper support of an up-ending tool constituting part of the handling tool has been retracted from the pile wall.

Figure 12 shows another side view of the pile handling facility of fig. 11, where an end-support of the up-ending tool has been retracted from the lower end of the pile.

Figure 13 shows a perspective view of the pile handling facility in fig. 1, wherein a upright oriented pile is arranged within the handling tool, and where the pile gripper is arranged in a closed position around the pile and the up-ending tool has been retracted.

Figure 14 show a side views of a pile handling facility in accordance with the invention, wherein figs. 14A-14I shows different tilting stages of the pile and wherein figs. 14G-I also shows the up-ending tool in further details.

DETAILED DESCRIPTION OF THE INVENTION

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.

The invention concerns a pile handling facility 100 suitable for transporting piles 10 to an installation sites and installing these piles 10 into the sea. The piles 10 may be adapted for arrangement on a seabed 30 or on floating platforms.

With particular reference to fig. 1, the inventive pile handling facility 100 comprises

- a vessel 200 having an aft part 201, a bow part 202 and a deck 205,
- a lifting crane 400,
- a plurality of pile cradles 12 for accommodating the piles 10 in transport position,
- a height adjustable pile bench 11 for lifting the pile 100 perpendicular to the deck 205,
- a handling tool 1 for providing support when the pile 10 is tilted from a laying orientation parallel to the deck 205 to an upright orientation *U* perpendicular to the deck 205 and outside the deck boundaries and
- a winch system 5-8 for stabilizing the pile 10 within the handling tool 1 during the tilting.

An exemplary configuration of a handling tool 1 is depicted in further details in fig. 2. The main parts of the handling tool 1 comprises an upending tool 3 chiefly responsible for supporting the pile 10 during tilting from the laying orientation to the upright orientation *U* and a pile gripper 2 chiefly responsible for aligning the pile in a horizontal plane after the upright orientation *U* is achieved. The pile gripper 2 may also be configured to allow vertical lowering of the pile 10 while horizontal alignment is maintained.

The pile gripper 2 comprises

- receiving arms 2a configured to embrace the circumference of the pile 10 when in upright position,

- two linear support structures 2b supporting the receiving arms 2a and
- a pivot structure 2c coupled to the deck 205 and the linear support structures 2b to allow the latter to pivot along planes along the deck 205 and perpendicular to the deck 205.

Further, the receiving arms 2a and the linear support structures 2b are configured such that the arms 2a may displace the pile 10 away from the deck 205.

The upending tool 3 is arranged between the linear support structures 2b and comprises

- pivot base / elongated base 3c rotatably fixed to or near the deck boundary via one or more pivot hinges 3d having a rotational axis parallel to the deck 205 and perpendicular to a longitudinal center axis *C* of the pile 10 during tilting,
- an end-support 3a extending out from a lower end of the elongated base 3c and configured to allow support of a lower pile end 10b,
- an upper support 3b rotationally coupled to an upper end of the elongated base 3c and configured to provide contact support to a circumferential part of the pile 10 during tilting via a contacting face 3e and
- a control hydraulic cylinder or linear actuator 3f to inter alia ensure positional control of the elongated base 3c.

The longitudinal orientation of the elongated base 3c is parallel, or near parallel, to the longitudinal center axis *C*. Moreover, both the upper support 3b and the end-support 3a is oriented away from the deck 205.

The process of tilting the pile 10 from the laying orientation *L* into the upright orientation *V* outside the outer boundary of the deck 205 can be divided into the following five operational phases:

1. (Fig. 3) An initial preparation phase where the pile gripper 2 and a lower part of the up-ending tool 3, both constituting part of the handling tool 1 (see fig. 2), are rotated from a transport position perpendicular to, or near perpendicular to, the deck 205 to a receiving position parallel, or near parallel, to the deck 205.

2. (Figs. 4-5) A second loading phase where a pile 10 is transferred from the pile cradle 12 on the deck 205 into the handling tool 1 via the height controllable pile bench 11. After transfer the longitudinal center axis *C* of the pile 10 intersects a center axis of the pile gripper 2 and the longitudinal axis of the upending tool 3. The pile 10 is then displaced in a direction along the elongated base 3c of the upending tool 3 until the lower pile end 10b is

supported onto or into the lower end-support 3a protruding from the lower end of the elongated base 3c. In this second loading phase, the upper support 3a protruding from the upper end of the elongated base 3c is oriented such that the circumferential part of the pile 10 is resting onto the contacting face 3e of the upper support 3a. The transfer of the pile 10 from the pile cradle 12 to the pile bench 11 may for example be performed by the lifting crane 400.

3. (Figs. 6-7) A third up-ending phase where the pile 10 is tilted by use of the lifting crane 400 from the laying position where at least a part of the pile length is arranged within the boundaries of the deck 205 to the upright position where the pile 10 is perpendicular to the laying position / the vessel's deck 205 and where the entire pile length is arranged fully outside the deck boundaries. The tilting of the up-ending tool 3 around the rotational axis perpendicular to the pile's longitudinal axis *C* and parallel to the deck 205 is achieved by the one or more pivot hinges 3d rotatably connecting the up-ending tool 3 to the vessel 200.

4. (Fig 8-9). A fourth upright phase where the receiving arms 2a of the pile gripper 2 is moved from an open position forming an opening in the plane perpendicular to the longitudinal pile axis *C* that is larger than the diameter *OD* if the pile 10 at that height to a closed position closing, or near closing, said opening. As is apparent from fig. 8, the upright orientation U (perpendicular to the deck 205) may be different from the vertical orientation V (relative to a global coordinate system) due to e.g. rolling of the vessel 200.

5. (Figs. 10-12) A fifth release phase where the upper support 3b is retracted from a position abutting against the circumferential part of the pile 10 and where either a lower end-support 3a is retracted from a lower pile end 10b of the pile 10 or the pile gripper 20 is moving the pile 10 away from the deck 205 by use of the linear support structures 2b or a combination thereof. Both retractions may be performed by rotations. In fig. 11 this is exemplified by rotating the upper support 3b counterclockwise (inboard direction) relative to its elongated base 3c, while rotating the base 3c clockwise (outboard direction) such that its longitudinal axis becomes parallel, or near parallel with the longitudinal center axis *C* of the pile 10 and perpendicular to the deck 205. As best seen in fig. 9, movement of the pile away from the deck 205 to avoid hitting the lower end support 3a during lowering is achieved by sliding the receiving arms 2a with the pile 10 along the linear support

structures 2b oriented parallel to, and away from, the deck 205 (when in upright position).

In order to ensure full control of the upending tool 3, the hydraulic control cylinder 3f (see fig. 13F) may be fixed at one end to the vessel's deck 205 and the other end to the elongated base 3c above the pivot hinge 3d. Such a configuration ensures that the elongated base 3c do not fall uncontrolled towards the vessel's hull when the upper support 3b is detached from the pile 10. Moreover, it may aid the tilting of the upending tool 3 and the pile 10 by regulating its pushing force onto the elongated base 3c.

As mentioned above, the tilting (up-ending) of the pile 10 from a laying position parallel to the deck 205 to an upright position outside the deck 205 takes place in a dedicated up-ending tool 3 in order to allow enough pile support. The force required for carrying out the tilting process are chiefly provided by the lifting crane 400 mounted onto the vessel 200.

This lifting crane 400 is connected via one or more crane cables 403 to a suspending structure / plate 4 on an upper pile end 10a of the pile 10. During tilting the lower pile end 10b is supported on the lower end-support 3a of the upending tool 3 to prevent undesired vertical pile movements during upending to the upright orientation. Further, the suspended end of the crane cable(s) 403 is in the depicted configurations fixed to the plate 4 via a crane tension sensor 407, thereby enabling continuous and/or on-demand measurements of the crane tension T_C.

Fig. 4 shows an exemplary configuration of a lifting crane 400 with only one crane arm 404.

In case of a lifting crane 400 with multiple crane arms 404, the crane cable(s) 403 is/are preferably fixed to the outermost arm 404. However, a configuration where the crane cable(s) 403 is/are fixed to another crane arm 404, located further towards the lifting crane's 400 upright column 405, may also be envisaged.

A typical pile weight is between 1000 and 3000 tons and a typical pile size is between 50 and 120 meters in length and between 8 and 16 meters in diameter. Handling of such a massive weight and size of the pile 10 and its related installation equipment necessitates a high degree of control and a low risk of failure during tilting. For example, at a specific positional range of the upper pile end 10a along the tilting arc (see e.g. fig. 7) the outboard torque M_S of the pile 10 (i.e. forcing the pile 10 to rotate clockwise towards the sea) may become equal or similar to the opposite directed inboard torque M_d. At this situation it is considered highly advantageous that the pile 10 remains firmly supported in the up-ending tool 3. With other words, any rotation causing the pile 10 to lose contact with the contacting face 3e, and/or falling below a certain minimum abutment pressure, should be avoided or at least significantly suppressed.

The handling tool 1, and in particular the upending tool 3, is preferably adapted to allow arrangement of piles 10 having varying diameters, i.e. the handling tool 1 should provide sufficient support for a set of piles 10 parked on the vessel's deck 205 that have inequal average pile diameters *OD*.

Furthermore, the handling tool 1 may preferably also be adapted to allow support for a single pile 10 shaped with varying diameters along its pile length. A specific example of the latter is a conical shaped pile 10 having its largest diameter at the lower pile end 10b.

Construction of such a general-purpose handling tool 1 will affect the configuration of at least the contacting face 3e and the end-support 3a.

For the pile handling facility 100 described herein, this suppression of rotation away from the up-ending tool's contacting face 3e is achieved by installing a winch system 5-8 to the upper pile end 10a. With particular reference to figs. 4-8, a winch cable 8 spooled onto a motorized drum 5 has a free end fixed to the suspending structure / plate 4, which again is removably fastened onto the upper pile end 10a. To enable user-controlled operation of the drum 5, such as switching the rotation on/off and/or to adjust the drum's rotational velocity, the drum 5 is operatively coupled to a programmable drum motor 6 (see fig. 13d). As best seen in fig. 4, the free end of the winch cable 8 is connected to the plate 4 via a load cell 7, thereby allowing real-time measurement of the winch tension *Tw* during the tilting process.

The winch tension *Tw* may be measured directly via e.g. one or more load cells 7 and/or indirectly via geometrical considerations and e.g. measurement of forces acting on the winch cable 8.

An indirect determination of the latter type may proceed as follows (with reference to the idealized model shown in figure 9):

The pile inclination angle α is measured when rotating the pile 10 through the rotating point *Rp* by an inclinometer, e.g. arranged in or near *Rp*.

Throughout the measurements / calculations, the vessel's deck 205 is considered as the ground base. Moreover, the pile 10 and the up-ending tool 3 is geometrically fixed as a closed system.

This closed system is rotating around the pile's rotation point *Rp* fixed to the ground base, and the winch cable 8 are connected between the deck 205 and the upper pile end 10a / suspending structure 4. The rotation point *Rp* is coincident with the rotating point of the up-ending tool's rotating axis / pivot hinge 3d. Both the pile's center of gravity *Gpile* and the up-ending tool's center of gravity G_{UET} do not change. Furthermore, the position of the pile 10 relative to the upending tool 3 does not change.

During operation, and still with reference to the idealized model shown in fig. 9, the system is under the influence of two main forces, the crane lifting force *Tc* and a tension control force from the winch motor *M*. Both two forces are continuously measured during upending by suitable sensor(s). The basic geometrical distances i, g, L_p, L_{st}, D_p, R in this system do not change (see below) during the tilting operation. By considering the total sum of momentum balance $\Sigma M_j = 0$, it is possible to calculate *Tw*. Dynamic forces will be continuously calculated and added into the equation as well as friction and environmental effects.

In fig. 9, the following parameters are indicated:

α: inclination angle between ground base and longitudinal direction of pile 10

R: radius between center of drum 5 and outermost point of the winch cable 8 still spooled onto the drum 5

Rp: rotation point of up-ending tool 3 and pile 10

M: winch motor

Tw: winch tension

Tc: crane lifting force

Md: momentum pile

G_{pile}: center of gravity for pile 10

G_{UET}: center of gravity for up-ending tool 3

a: distance between *Rp* and G_{pile}

b: distance between G_{pile} and attachment point of winch cable 8 to upper pile end 10a

c: distance between said attachment point and center of drum

d: distance between *Rp* and G_{UET}

e: distance between G_{UET} and lower pile end 10b / end-support 3a

f: distance between center position of pile and said attachment point along the ground base

g: distance between the lower pile end 10b and G_{pile} along the longitudinal direction of the pile 10

h: distance between G_{UET} and the upper support 3b

i: distance between the lower pile end 10b / end-support 3a and G_{UET}

s: distance of a straight line extending perpendicular from a straight line between the winch and the upper pile end and the rotation point *Rp*

D_p: diameter of pile 10

L_p: longitudinal length of pile 10

L_{st}: thickness of suspending structure along the longitudinal direction of the pile 10

At least an approximate value of the winch tension Tw may be calculated based on momentum balance:

$$T_W * s + G_{PILE} * a - T_C * (a + b - f) - G_{UET} * d = 0$$

$$\downarrow$$

$$T_W = -(G_{PILE} * a - T_C * (a + b - f) - G_{UET} * d)*(1/s)$$

Instead of one winch cable 8 per drum 5, an alternative configuration having two or more winch cables 8 spooled on the same drum 5 may be envisaged. The drum 5 with the multiple winch cables 8 is preferably operated by a single programmable drum motor 6.

Independent of the pile's 10 abutment against the contacting face 3e, the winch system 5-8 contributes (together with the lifting crane 400) control of the pile's 10 angle velocity.

The upending tool 3 may be of any size as long as it provides sufficient support for the pile 10 during the tilting from the laying to the upright orientation. However, the overall size, and in particular its length along the pile's 10 longitudinal center axis *C*, is advantageously adapted such that the lower pile end 10b is submerged below the water surface 20 well before the upright orientation has been reached. Fig. 7 shows an example where the lower pile end 10b starts submerging when the orientation of the pile 10 is about $\alpha_2 = 60°$ relative to the orientation of the deck 205. The angle may vary according to parameters such as size and draft of the vessel 200, sea conditions, etc. But an angle range between $\alpha_2 = 50\text{-}70°$ is considered advantageous.

When submerged, the surrounding water will increase the inertial forces, thereby suppressing any undesired deviation from the pile's tilting arc. In case of a tubular pile, this suppressing effect will be enhanced since water then will enter the inside of the pile and thereby further increase the inertial forces.

The length of the elongated base 3c and the position of the pivot hinge 3d along the length can be determined based on model simulation and/or model tests. Typical parameters that enter into these kinds of simulations are pile properties such as pile length, pile diameter and weight distribution. Further, environmental parameters such as expected average and maximum significant wave height at the installation site may also prove important. The results of such simulations / tests are a ratio of an end support distance D_{es} between the end support 3a and the pivot hinge 3d and an upper support distance D_{us} between the upper support 3b and the pivot hinge 3d. To achieve the desired stability, this ratio is preferably at least 1 or probably better at least 1.5. Ratios of 2, 2.5 or 3 are envisaged. In general, it is considered advantageous to set a pivot point (i.e. at the location of the pivot hinge 3d) at or close to the pile's 10 center of gravity. Moreover, the upending tool and the pile's length may be set such that the pile's lower end 10b is submerged into the sea at a desired stage of the tilting operation since the added mass of the water will increase the overall stability of the installation procedure.

When the pile 10 has reached its upright orientation, it is further stabilized / locked in the horizontal plane by enclosing the circumference of the pile 10 using the receiving arms 2a described above. The receiving arms 2a are rotatably connected to fixed supports and extends in a common pile gripper plane A_{PG} (see fig. 9). When the receiving arms 2a are in closed positions, they form an enclosing space having a diameter equal or larger than the relevant outer diameter *OD* of the pile 10, i.e. the outer diameter OD at the position along the longitudinal center axis C being in vertical alignment with the pile gripper plane A_{PG}. In a fully open position, a pile receiving opening going into the enclosing space is formed having a size in the pile gripper plane A_{PG} equal or larger than the outer diameter *OD*.

After setting the receiving arms 2a in closed positions, a plurality of pile supporting devices (PSDs) are horizontally displaced such that vertical displacement wheels / rolling means of each PSD are contacting the pile's 10 outer wall symmetrically around the pile's 10 circumference. Each of these vertical displacement wheels has a horizontally oriented rotational axis, thereby enabling both vertical displacement and horizontal restriction of the pile 10 (see fig. 9).

The orientations 'horizontal' and 'vertical' are herein defined relative to global positioning coordinates, while 'laying' and 'upright are defined relative to the orientation of the vessel's deck 205.

After the fifth release phase, the pile 10 is fully suspended in the lifting crane 400, and the lowering towards the seabed 30 may commence. In case of seabed installed piles, the desired alignment precision by use of the pile griper 20 towards a global verticality is preferably increased during lowering, i.a. when time of contact of the lower pile end 10b with the seabed 30 is approaching. In figs. 11 and 12, the winch cable 8 is shown with no or insignificant winch tension T_w since the full weight of the pile 10 is handled by the lifting crane 400. However, a configuration may be envisaged where the winch system 5-8 is actively aiding the adjustment of the upper pile end 10a towards vertical orientation during the lowering of the pile 10.

For example, the winch system 5-8 may comprise two drums 5, each with winch cables 8 spooled thereon. As for the configuration with one drum 5, the end of each winch cable 8 is fixed to the above-mentioned suspending structure / plate 4. The two drums 5 are arranged on the deck 205 with a separating spacing along a direction perpendicular to the tilting plane of the pile 10. The length of the spacing depends inter alia on the horizontal alignment force required set up by the two drums 5 on the upper pile end 10a.

The two winch cables 8 may be connected to the same load cell 7, alternatively to separate load cells 7.

The drums 5 should be arranged on the deck 205 with an angle in the deck place to ensure that a straight line perpendicular from the drum surface may be drawing between the drum 5 and the connection point on the suspending structure 4.

One or more pile motion sensors 9 (preferably an accelerometer) for measuring horizontal position of the upper pile end 10a relative to corresponding global horizontal coordinates from the global position system can be installed either on the suspending structure 4 or on the pile 10 itself or both. Such a pile motion sensor 9 is particularly useful for the configuration with a winch system including more than one drum 5. The winch tensions T_W from both winch cables 8 measured by attached load cells 7 are transmitted to a control system forming part of the winch system 5-8 for further control / analyzes. For example, a processor may calculate a new desired winch tension T_{wd} to ensure that the horizontal position of the upper pile end 10a is within a threshold range from the corresponding global horizontal coordinates. And this new winch tension T_{wd} is transmitted to the drum motors 6 which regulate the drums 5 accordingly. Hence, a higher stability in the upper pile end's 10a horizontal plane may be achieved.

The vessel 200 comprises one or more vessel motion sensors 13 allowing measurements of the vessel's 200 movements at sea such as rotational motions (roll, pitch, yaw) and translational motion (heave, sway, surge). Such vessel motion sensors 13 are preferably of type accelerometers allowing measurements of velocity vectors and acceleration vectors. Positional data may thus be obtained by single integration or by double integrations of the measurement data.

The vessel motion sensor 13 constitutes part of a dynamic positioning system (*DP*) on the vessel 200, enabling access of continuous or on-demand information concerning vessel dynamics for control systems of the handling tool 1, the winch system 5-8 and the lifting crane 400. For example, measurement data from the winch tension sensor 7, the crane tension sensor 407, the vessel motion sensor(s) 13 and/or the pile motion sensor 9 may be fed as input parameters to a control system comprising a processor. Based on these parameters, a desired winch tension T_W and/or a desired crane tension T_C may be calculated, thus forming instructional data to the drum motor 6 and the lifting crane 400, respectively. Also calculating and setting new movement patterns of the upending tool 3 and/or the pile gripper 2 are feasible, for example by setting new pressures on various hydraulic cylinders responsible for the movements of the handling tool 1.

Further, one may envisage a dynamic precision setting, where the processor calculates the inboard torque M_D and the outboard torque M_S during the tilting operation and where the measurements / calculations of the desired tensions T_W,T_C and the subsequent settings of the drum motor 6 / lifting crane 400 intensify when the estimated outboard torque M_S is within a predetermined range of the estimated inboard torque M_D, for example equal or near equal.

The pile handling facility 100 may also comprise one or more crane motion sensors 406 such as an accelerometer and/or an inclinometer that are configured to measure the exact position of the fixation point between the suspended end of the crane cable 403 and the upper pile end 10a / plate 4, 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 acceleration vectors of the fixation point. The position of the fixation point is thus achieved by single integration or double integration.

A pile handling 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. For example, a lifting system 400 that allows sensor-controlled movements in horizontal directions and/or in vertical direction (heave compensation) may be envisaged. This however sets higher demands on need for continuous / frequent collection of positional crane state data (position, velocity, acceleration).

Fig. 13A-F shows different stages in the tilting process from the second loading phase (fig. 13A), via the third up-ending phase (figs. 13B-E) and the fourth upright phase (fig. 13F) and to the fifth release phase (figs. 13G-I).

For all stages, the direction and size of the winch tension T_W and the crane tension T_C are indicated, as well as the center of gravity G_{PILE}, G_{UET} of the pile 10 and the upending tool 3 and the rolling movements of the vessel 200 (double arched arrow below).

In fig. 13A to 13C, the inboard torques M_D is indicated as dominating, while the outboard torques M_S become more prevailing in the stages shown in fig. 13E to 13G.

For the stages shown in fig. 13H and fig. 13I there are no or insignificant torques since the pile 10 is fully suspended in the crane cable 403.

For the specific stage shown in fig. 13D, the inboard torque M_D and the outboard torque M_S are of equal or similar size, thereby creating a potentially hazardous situation since the pile 10 may start rotating in outboard direction without sufficient aid by the lifting crane 400. As seen from fig. 13D, the winch tension T_W is in this situation significantly larger than the corresponding crane tension T_C in order to minimize the risk that the pile 10 loses its steady abutment against the contacting face 3e of the upending tool 3.

The upending tool 3 is reproduced with enlarged drawings in figs. 13G-I for clarity reasons.

With particular reference to the enlarged drawing in fig. 13G, a dedicated upper support cylinder 3g is shown which allows pivot moments of the upper support 3b between a contacting position and a release position relative to the pile 10.

Still with reference to fig. 13G, a locking mechanism 3h is indicated which allows the contacting face 3e to lose its abutment towards the pile 10 without causing a sudden (and most likely undesired) rotation towards the vessel 400. Configurations where such sudden rotation is prevented *without* the locking mechanism 3h may be envisaged, for example by setting a sufficiently high retraction force on the control cylinder 3f. However, since the end-support 3b of the upending tool 3 experiences the full weight of the pile 10 during operation (see upward vertical line from the end-support in fig. 13G), the amount of force necessary to keep the angle of the elongated base 3c in position may be too high for a typical, reasonable prized hydraulic cylinder to ensure the required control of the operation.

The locking mechanism 3h may for example comprise a protruding structure fixed to the vessel's outer hull side, alignable holes going through the elongated base 3c and the protruding structure and a suitable bolt that may be inserted into the alignable holes.

When the gravitational force from the pile 10 is released by increasing the tension T_C from the lifting crane 400 (see fig. 13H), the locking mechanism 3h may be unlocked by removing the bolt from the through-going holes. After rotation of the elongated base 3c into its retracted position (see fig. 13I), a second locking mechanism 3h may be activated to keep the elongated base 3c into this position while the pile 10 is lowered towards the seabed 30. This second mechanism 3h may be at or near the same position as the first locking mechanism 3h and may for example comprise second alignable holes through the protruding structures and the elongated base 3c for insertion of another bolt or the same bolt used for the first locking mechanism 3h.

As mentioned above, in addition to the dedicated locking mechanism(s) 3h, a configuration may be envisaged where the control cylinder 3f also act as a locking mechanism for the elongated base 3c, either alone or in combination.

In the preceding description, various aspects of the pile handling facility 100 and associated methods of installation using the pile handling facility 100 have been described with reference to the illustrative embodiment. For purposes of explanation, specific numbers, systems and configurations were set forth in order to provide a thorough understanding of the facility 100 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 100, which are apparent to persons skilled in the art to which the disclosed subject matter pertains, are deemed to lie within the scope of the present invention.

REFERENCE NUMERALS

1	Handling tool
2	Pile gripper
2a	Receiving arms
2b	Linear support structure
2c	Pivot structure for pile gripper
3	Rotatable up-ending tool
3a	End-support
3b	Upper support
3c	Elongated base / pivot base
3d	Pivot hinge
3e	Contacting face
3f	Control cylinder
3g	Upper support cylinder
3h	Locking mechanism for upending tool
4	Suspending structure / plate
5	Drum
6	Drum motor
7	Winch tension sensor / load cell
8	Winch cable
9	Pile motion sensor / pile accelerometer
10	Pile / wind turbine pile / elongated object
10a	Upper pile end
10b	Lower pile end
11	Height adjustable pile bench
12	Pile cradle
13	Vessel motion sensor / vessel accelerometer
20	Water surface
30	Seabed
100	Pile handling facility
200	Vessel
201	Aft part of vessel
202	Bow part of vessel
205	Deck
400	Lifting crane
403	Crane cable
404	Crane arm
405	Upright column of lifting crane
406	Crane motion sensor
407	Crane tension sensor
C	Pile's longitudinal centre axis
L	Laying orientation parallel to the deck
U	Upright orientation perpendicular to the deck

V	Vertical orientation relative to global coordinate system
A_{PG}	Pile gripper plane set by the receiving arms
G_{PILE}	Gravitational force from pile
G_{UET}	Gravitational force from up-ending tool
T_C	Tension from crane
T_W	Tension from winch
T_{wd}	Desired tension from winch
M_S	Outboard torque
M_D	Inboard torque

CLAIMS

1. A pile handling facility (100) for tilting a pile (10) from a laying orientation (*L*) at least partly within a deck (205) of a vessel (200) to an upright orientation (*U*) outside an outer boundary of the deck (205), wherein the laying and upright orientations are defined as the orientation parallel and perpendicular to the deck (205) respectively,
the pile handling facility (100) comprising
    - the vessel (200) comprising the deck (205) for storing at least one pile (10),
    - a lifting crane (400) fixed to the vessel (200) and dimensioned to lift the pile (10), the lifting crane (400) comprising
        - a crane cable (403) having, during tilting, a suspended end fixed to or near an upper pile end (10a) of the pile (10), and
    - an up-ending tool (3) for supporting the pile (10) during tilting from the laying orientation to the upright orientation, the up-ending tool (1) being rotatably fixed to the outer boundary of the deck (205) via at least one pivot hinge (3d) around a rotational axis parallel to the deck (205) and perpendicular to a longitudinal center axis (*C*) of the pile (10),
    the up-ending tool (3) comprising
        - a contacting face (3e) configured to abut against a circumferential surface of the pile (10) during tilting,

characterized in that
the pile handling facility (100) further comprises
    - a winch system comprising
        - a winch cable (8) fixed, during tilting, at an end to or near the upper pile end (10a) and
        - a winch tension controller configured to control a winch tension (T_w) in the winch cable (8), comprising a drum (5) onto which the winch cable (8) is spooled.

2. The pile handling facility (100) in accordance with claim 1, wherein the winch tension controller (5,7) further comprises
    - a winch tension sensor (7) configured to measure the winch tension (T_w).

3. The pile handling facility (100) in accordance with claim 1 or 2, wherein the pile handling facility (100) further comprises
    - a suspending structure (4) removably fixed to the upper pile end (10a) during tilting,

wherein both the suspended end of the crane cable (403) and the end of the winch cable (8) are fixed to the suspending structure (4).

4. The pile handling facility (100) in accordance with claim 3, when dependent on 2, wherein the winch tension sensor (7) is a load cell interconnecting the end of the winch cable (8) with the suspending structure (4).

5. The pile handling facility (100) in accordance with any one of the preceding claims, wherein the winch tension controller (5,6) further comprising
   - a drum motor (6) configured to rotate the drum (5) around a rotational axis perpendicular to the orientation of the winch cable (8), and

   wherein the winch tension controller (5,6) is configured to control operation of the drum motor (6).

6. The pile handling facility (100) in accordance with claim 5,
   wherein the drum motor (6) is configured to control the rotational velocity of the drum (5) during rotation and
   wherein the winch tension controller (5,6) further comprising means
   for calculating a desired rotational velocity as function of the measured winch tension (T_w) and
   for regulating the drum motor (6) to achieve the desired rotational velocity.

7. The pile handling facility (100) in accordance with any one of the preceding claims, wherein the lifting crane (400) further comprises
   - a crane tension sensor (407) configured to measure a crane tension (T_C) in the crane cable (403).

8. The pile handling facility (100) in accordance with claim 7, when dependent on claim 6, wherein the winch tension controller (5-7) comprises means to receive the measured crane tension (T_C) and to calculate the desired rotational velocity as function of both the measured winch tension (T_w) and the measured crane tension (T_C).

9. The pile handling facility (100) in accordance with any one of the preceding claims, wherein the upending tool (3) further comprises
   - a pivot base (3c) fixed to the at least one pivot hinge (3d) and
   - an end support (3a) protruding from or near a lower end of the pivot base (3c),

wherein the pivot base (3c), the at least one pivot hinge (3d) and the end support (3a) are configured such that a lower pile end (10b) of the pile (10) may be supported on the end support (3a) during tilting.

10. The pile handling facility (100) in accordance with any one of the preceding claims, wherein the upending tool (3) further comprises
   - a pivot base (3c) fixed to the at least one pivot hinge (3d) and
   - an upper support (3b) protruding from or near an upper end of the pivot base (3c), wherein the upper support (3b) comprises the contacting face (3e).

11. The pile handling facility (100) in accordance with claim 10, when dependent on claim 9, wherein the ratio of

    an end support distance (D_{es}) between the end support (3a) and the pivot hinge (3d) and

    an upper support distance (D_{us}) between the upper support (3b) and the pivot hinge (3d)

    is at least 1.

12. The pile handling facility (100) in accordance with claim 10 or claim 11, wherein the upper support (3b) is pivotably fixed to the pivot base (3c) such that the upper support (3b) may pivot between

    a contacting position where continuous contact is present between the contacting face (3e) and the circumferential surface of the pile (10) and

    a release position displaying a horizontal spacing between the contacting face (3e) and the circumferential surface of the pile (10).

13. The pile handling facility (100) in accordance with any one of the preceding claims, wherein the contacting face (3e) has a concave form seen along the longitudinal center axis (C) of the pile (10) with a radius equal, or near equal, to the radius of the pile (10).

14. A method for tilting a pile (10) from a laying orientation at least partly within a deck (205) of a vessel (200) to an upright orientation outside an outer boundary of the deck (205) by use of a pile handling facility (100) in accordance with any one of the preceding claims,

    wherein the method comprises the following steps:

A. arranging the pile (10) into the upending tool (3) such that the contacting face (3e) abuts against the circumferential surface area of the pile (10),

B. lifting the upper pile end (10a) by use of the lifting crane (400) such that the pile (10) and the upending tool (3) is tilted around the rotational axis while the contacting face (3e) remains in abutment with the circumferential surface area and,

C. during at least a part of the tilting, regulating operation of the drum (5) by use of the winch tension controller in order to maintain the winch tension (T_w) above a minimum winch tension value ($T^w{}_{min}$).

15. The method in accordance with claim 14, wherein the winch tension controller (5-7) further comprising

- a drum motor (6) configured to rotate the drum (5) around a rotational axis perpendicular to the orientation of the winch cable (8) and
- a winch tension sensor (7) configured to measure the winch tension (T_w),

wherein the method further comprises the steps:

- measuring the winch tension (T_w) by use of the winch tension sensor (7),
- calculating operational instructions for the drum motor (6) as function of the measured winch tension (T_w) to achieve a desired winch tension (T_{wd}) in the winch cable (8) and
- setting the drum motor (6) in accordance with the calculated operational instructions.

16. The method in accordance with claim 15, wherein the lifting crane (400) further comprises

- a crane tension sensor (407) configured to measure a crane tension (T_C) in the crane cable (403),

wherein the method further comprises the steps:

- measuring the crane tension (T_C) by use of the crane tension sensor (407) and
- calculating operational instructions for the drum motor (6) as function of the measured winch tension (T_w) and the measured crane tension (T_C) to achieve the desired winch tension (T_{wd}) in the winch cable (8).

17. The method in accordance with any one of claims 14 to 16, wherein the step of regulating the operation of the drum (5) is performed during time periods of the tilting where

- an absolute value of an inboard directed torque (M_d) induced by the pile's (10) weight, length and distance between the upper pile end (10a) and the abutting circumferential surface area, as well as the vessel's (200) movements due to environmental forces, is equal to, or near equal to,
- an absolute value of a corresponding outboard directed torque (M_s).

18. The method in accordance with any one of claims 14 to 17, wherein the method further comprises the step:

- measuring a position of the upper pile end (10a) relative to an initial position in the laying orientation by measuring and/or calculating a length of the winch cable (8) between the drum (5) and a fixation point of the winch cable (8) on the upper pile end (10a) and a length of the crane cable (403) between a fixation point on the lifting crane (400) and a fixation point of the upper pile end (10a).

19. A computer-readable medium having stored thereon a computer program comprising instructions to execute the method steps of any one of claims 14 to 18.

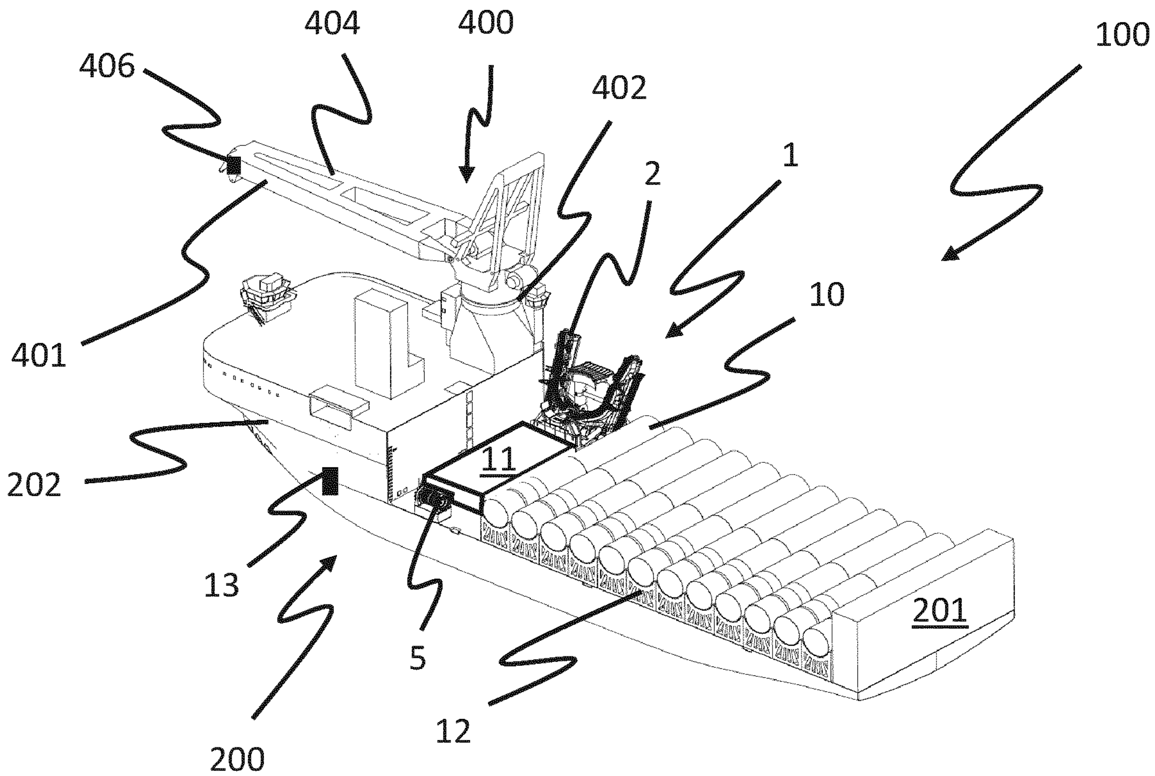


FIG. 1

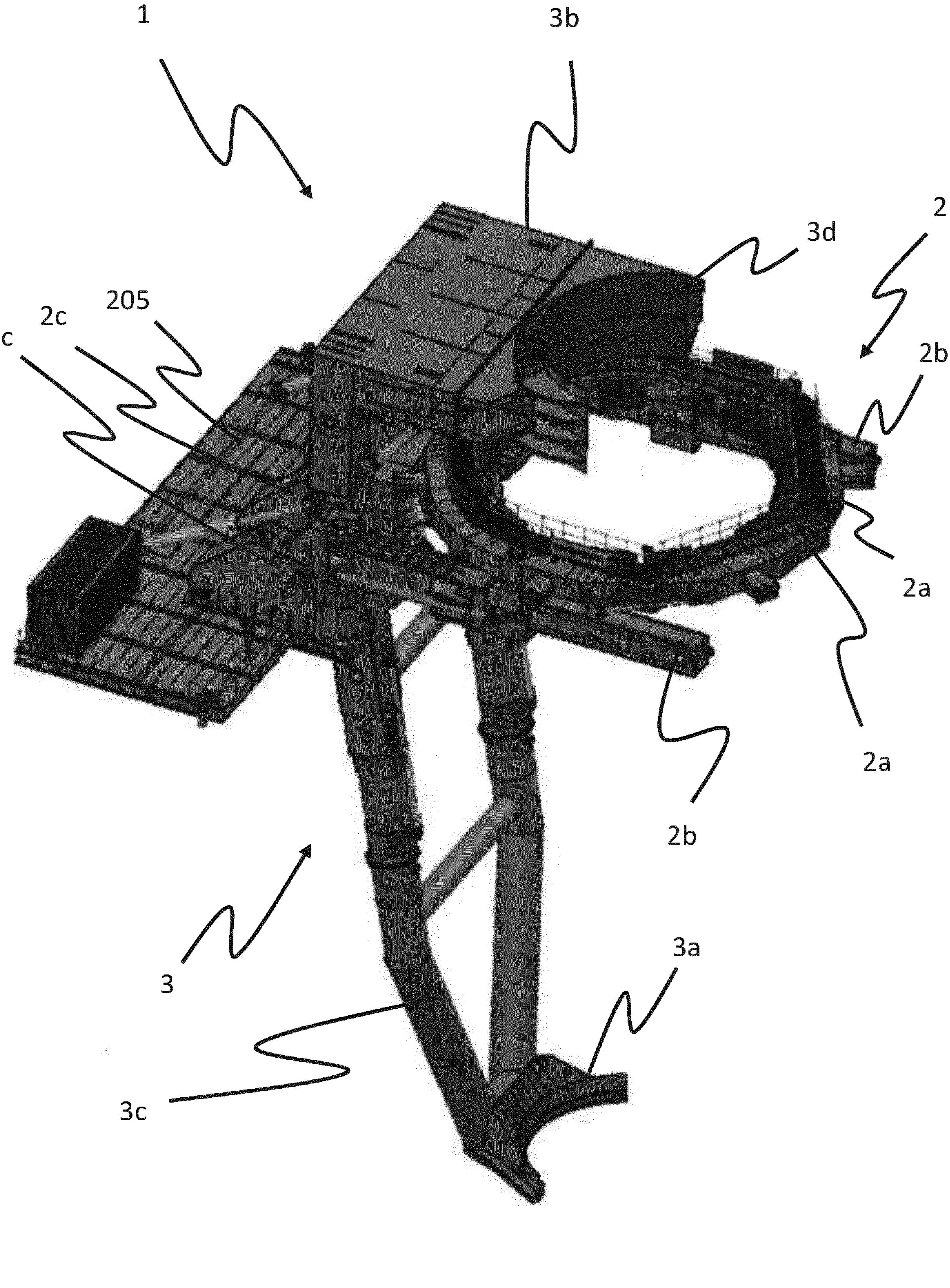
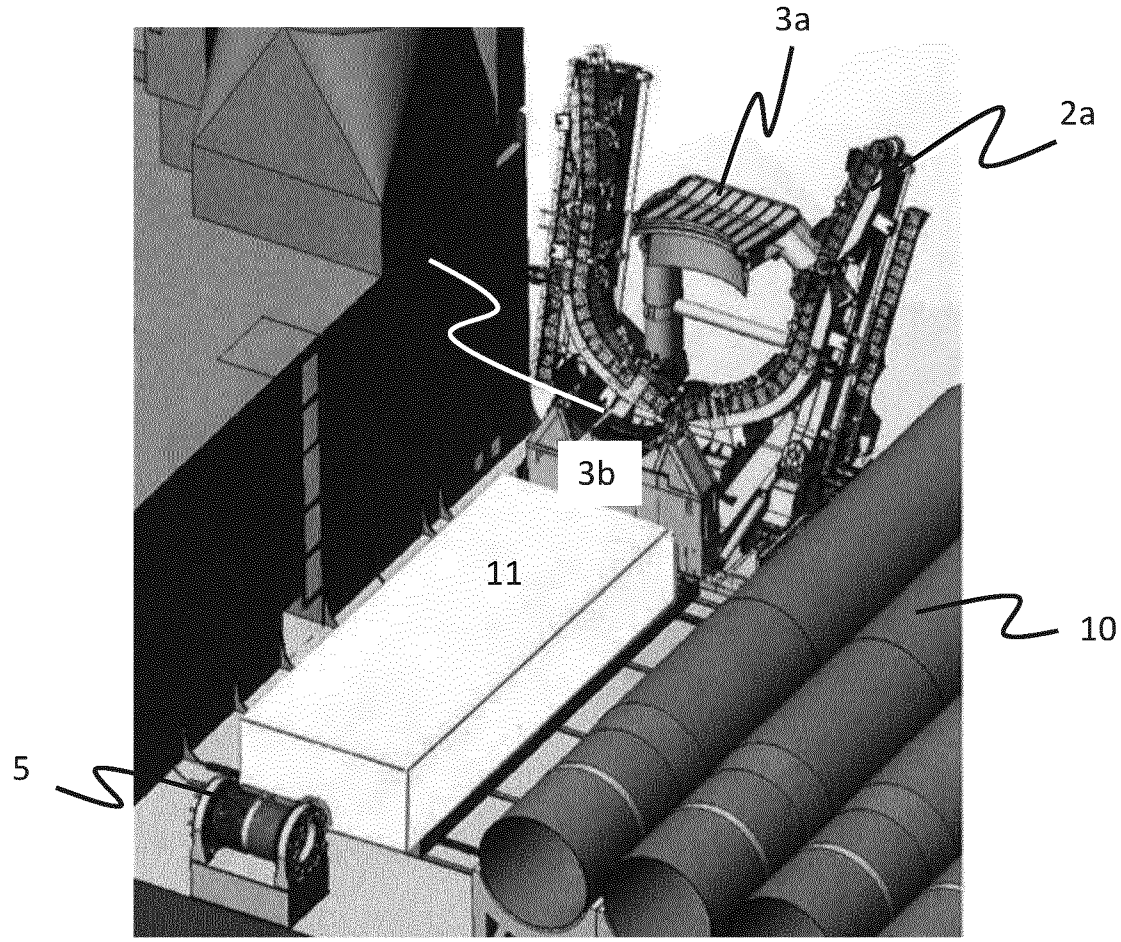


FIG. 2



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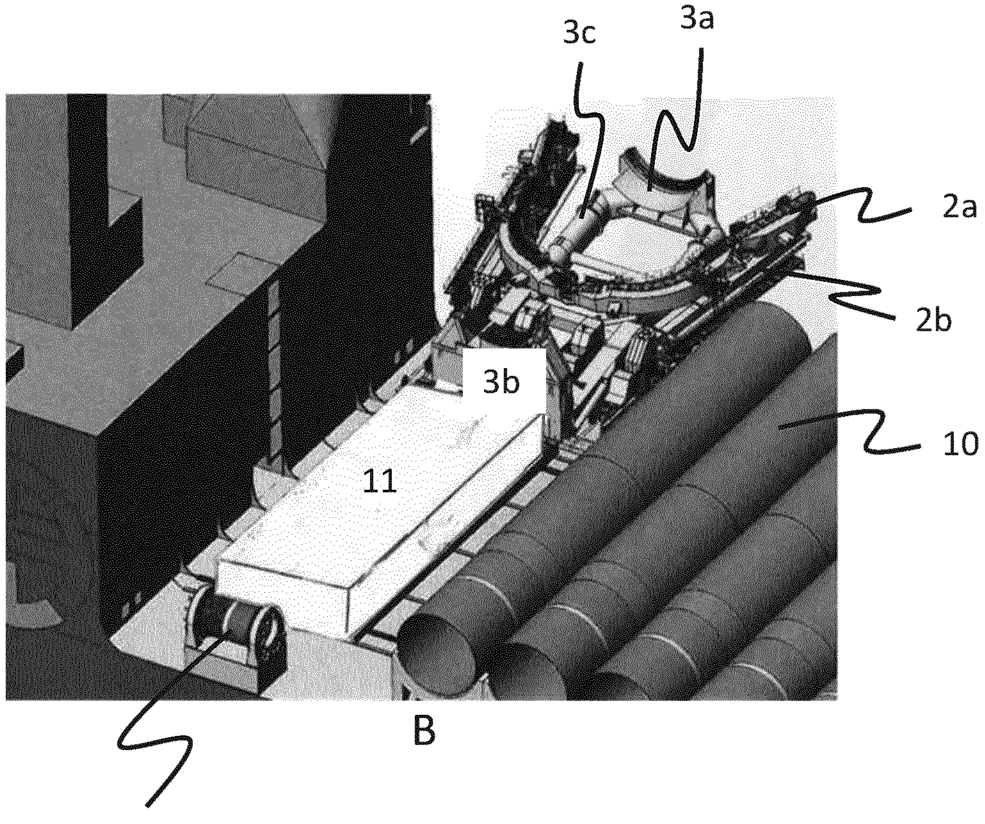

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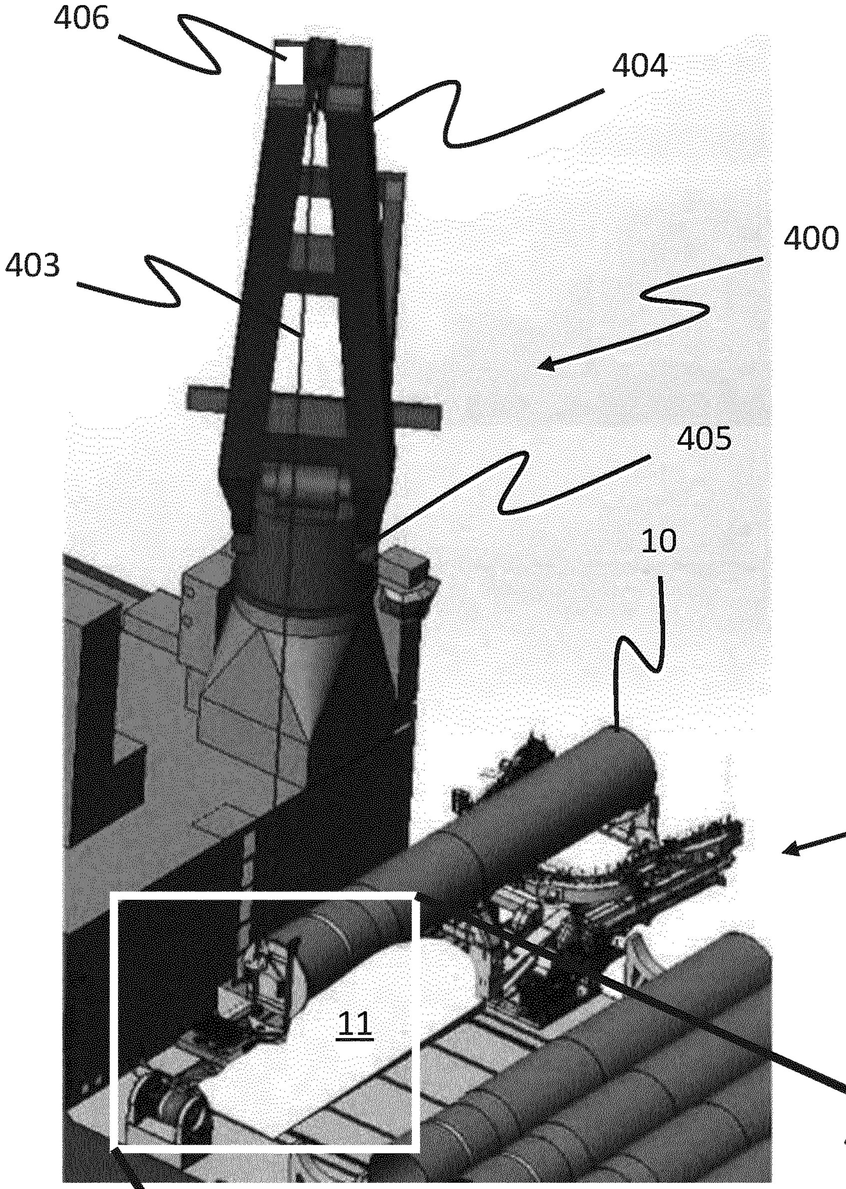
FIG. 3



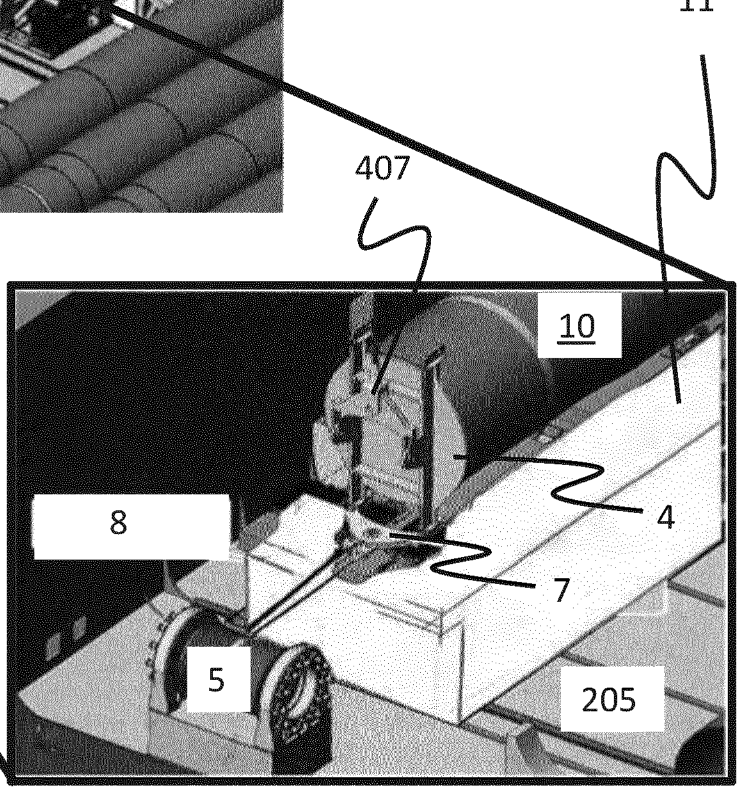


FIG. 4

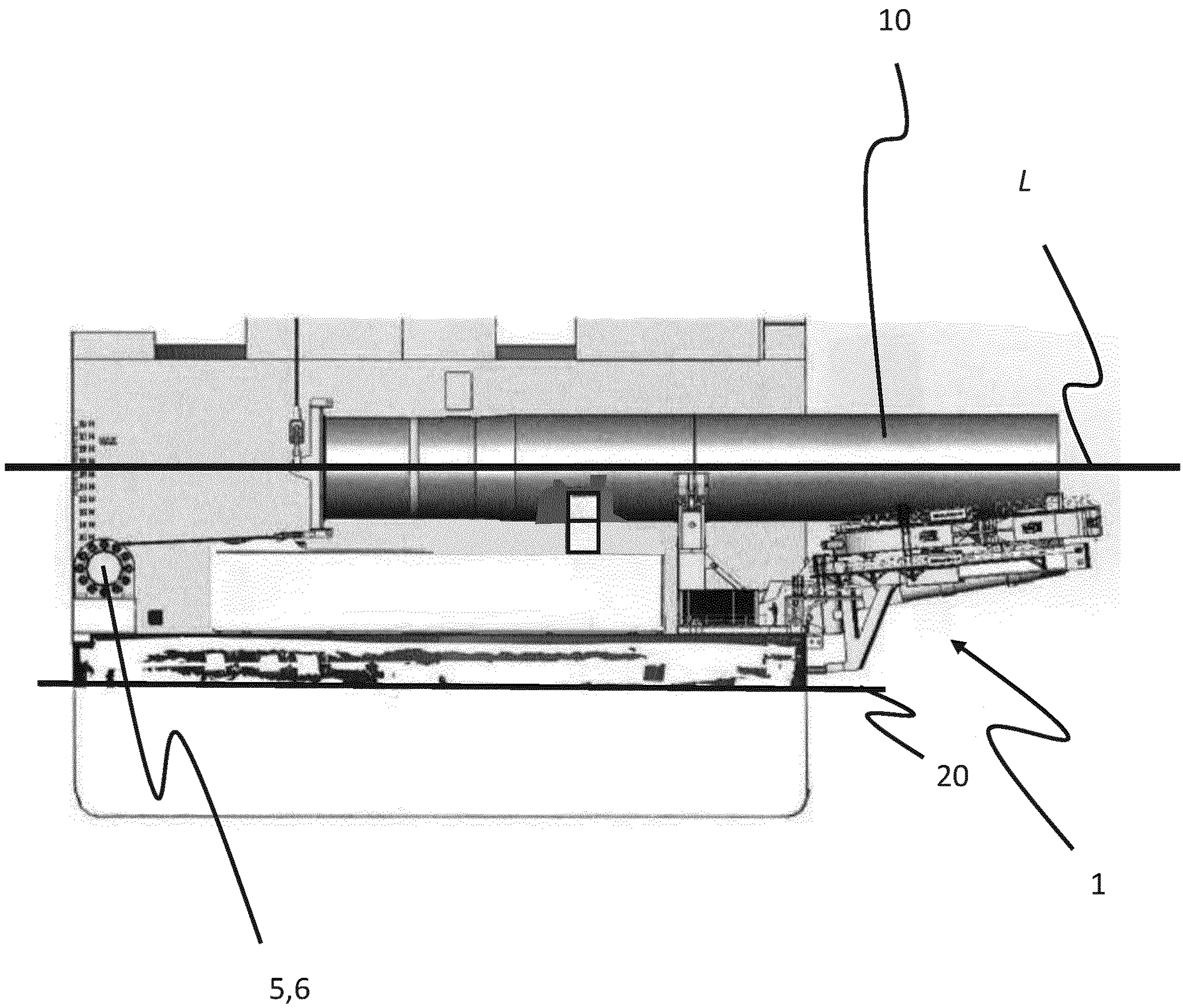


FIG. 5

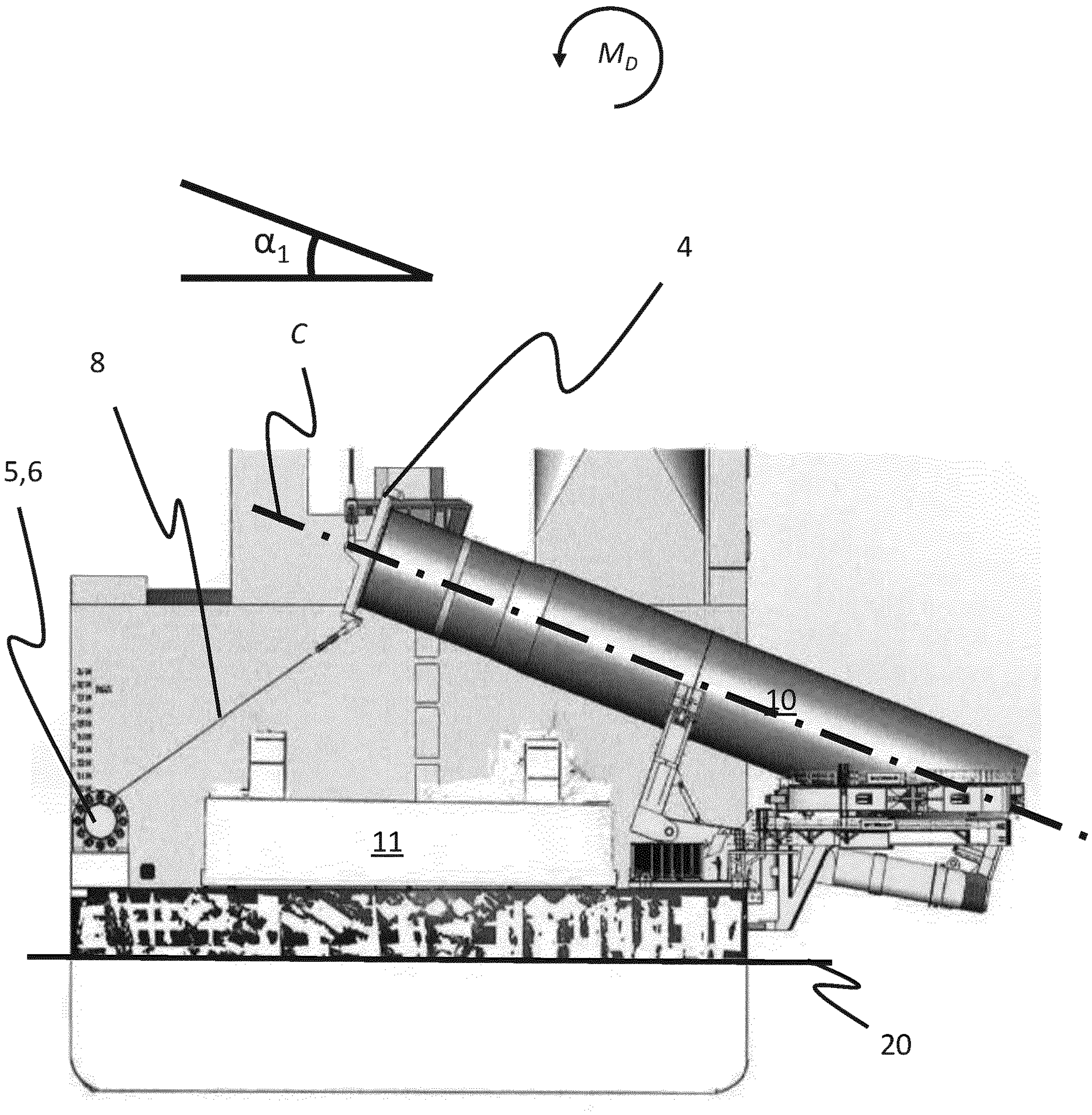


FIG. 6

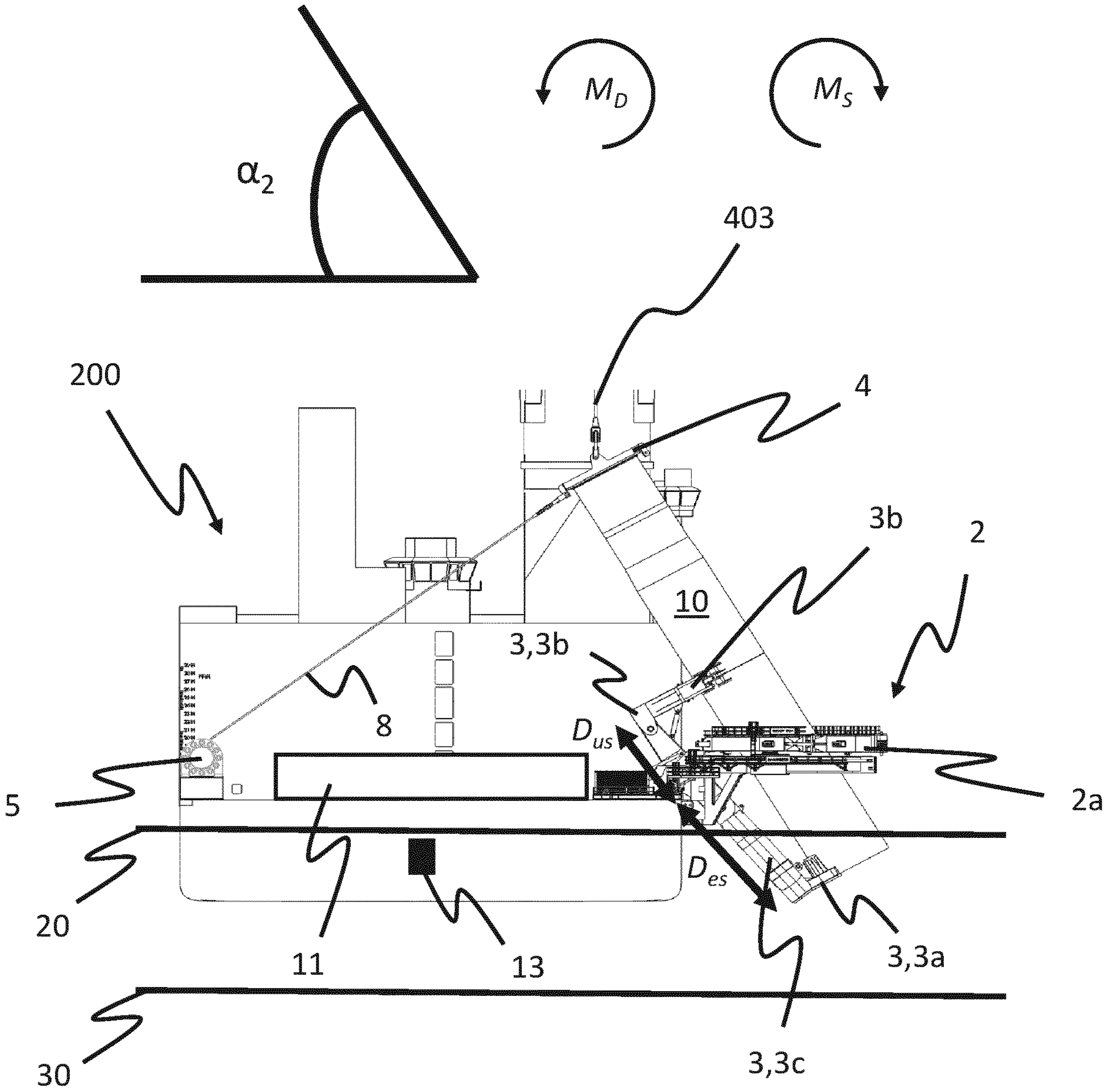


FIG. 7

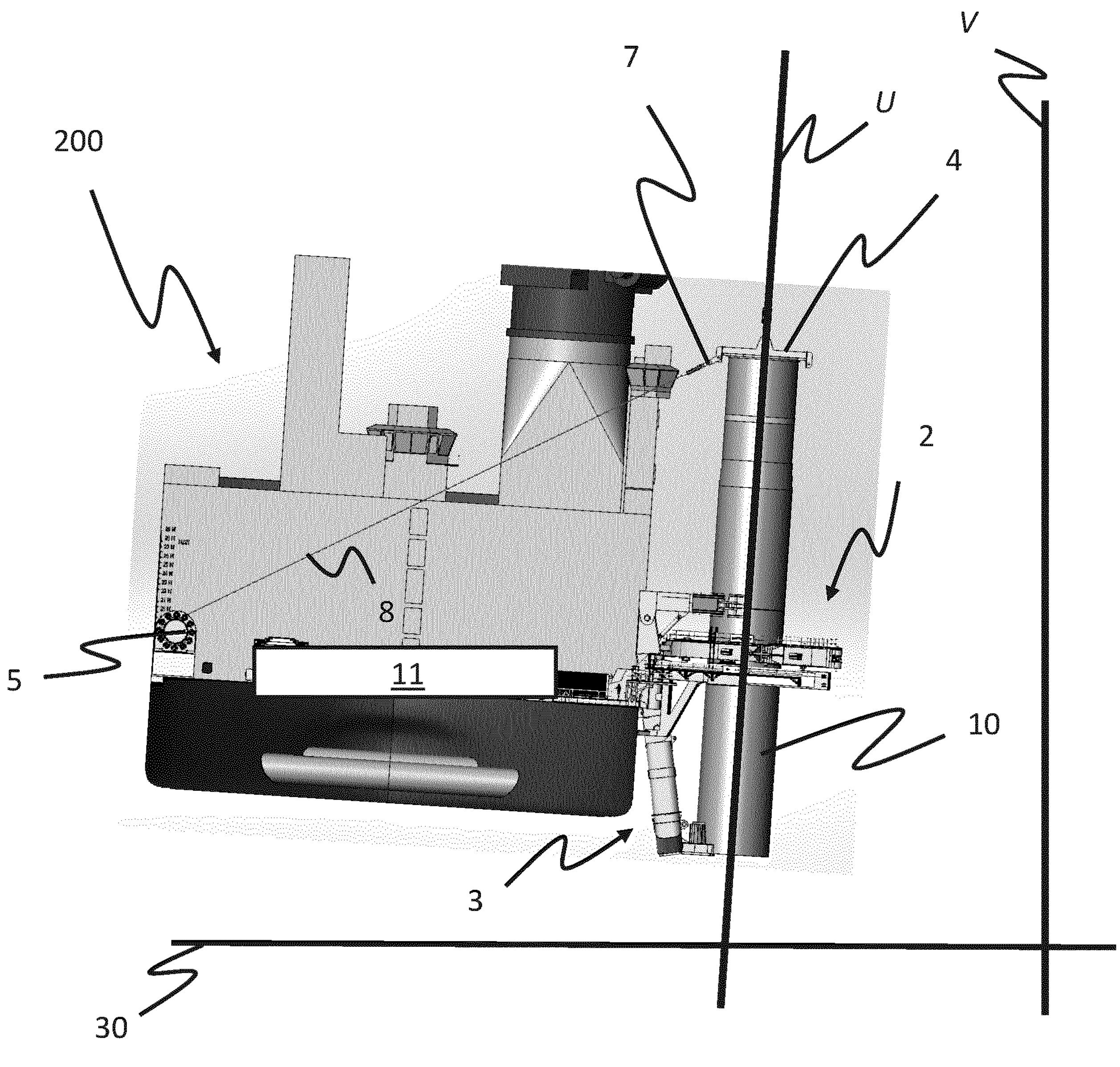


FIG. 8

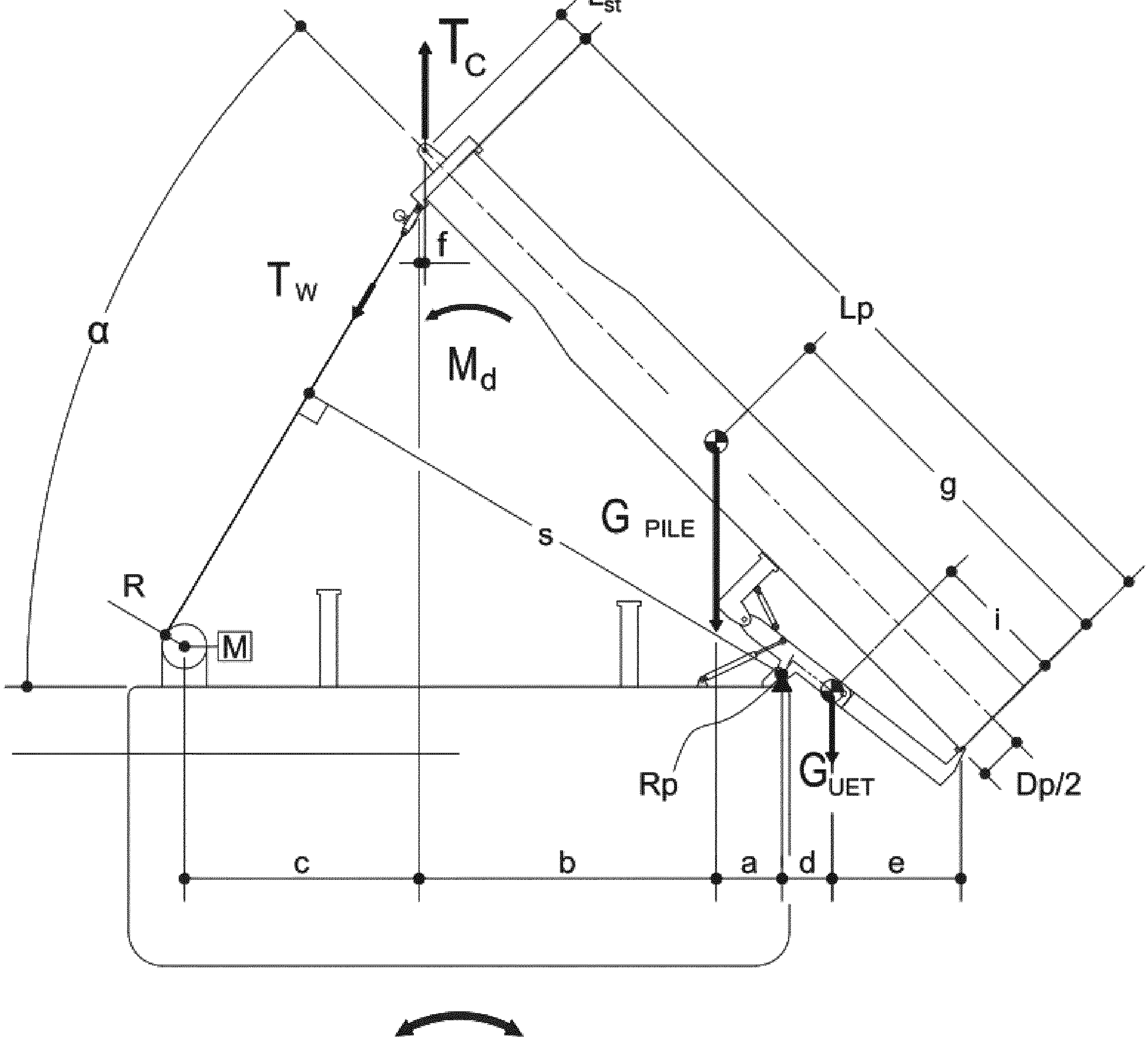


FIG. 9

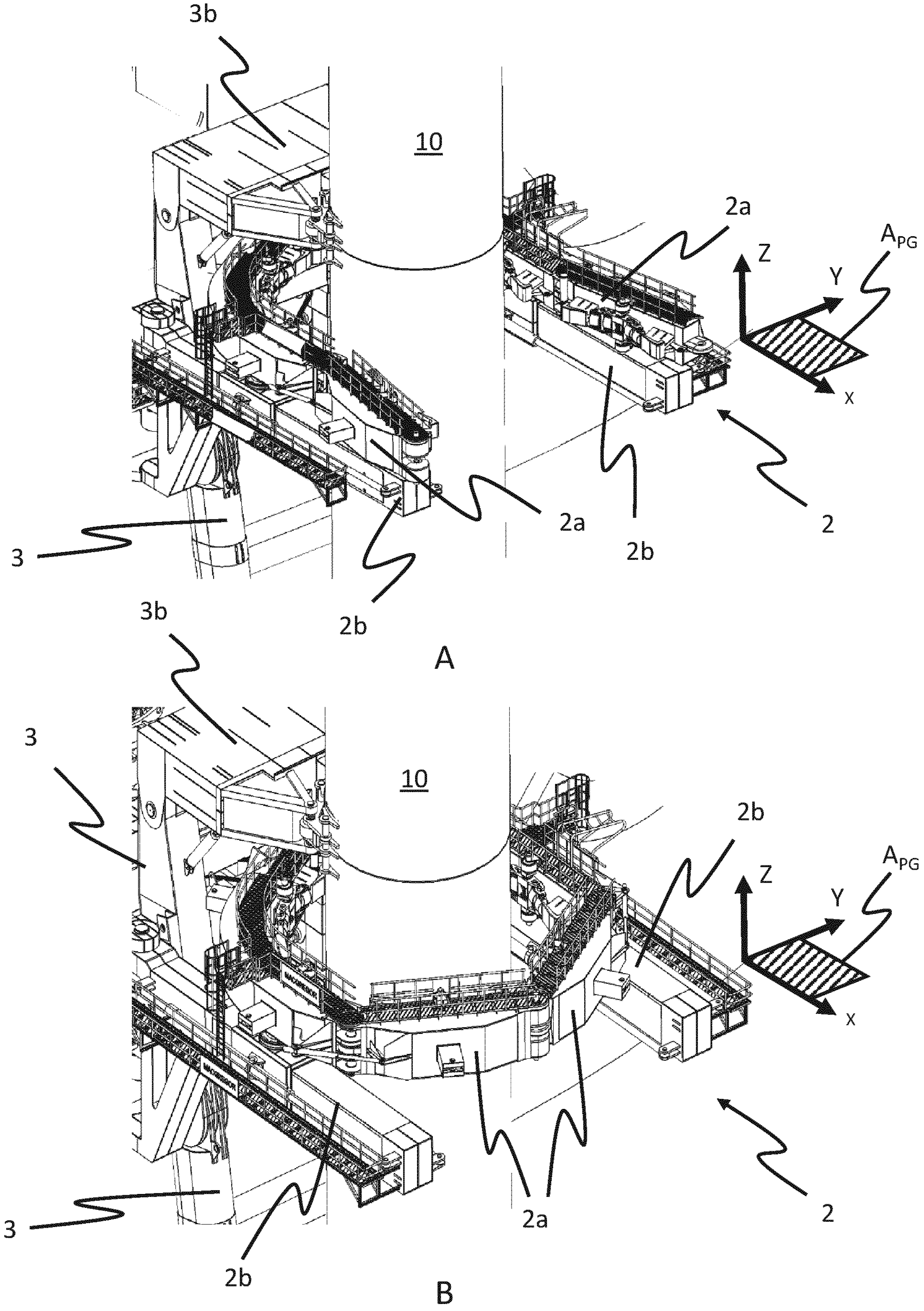


FIG. 10

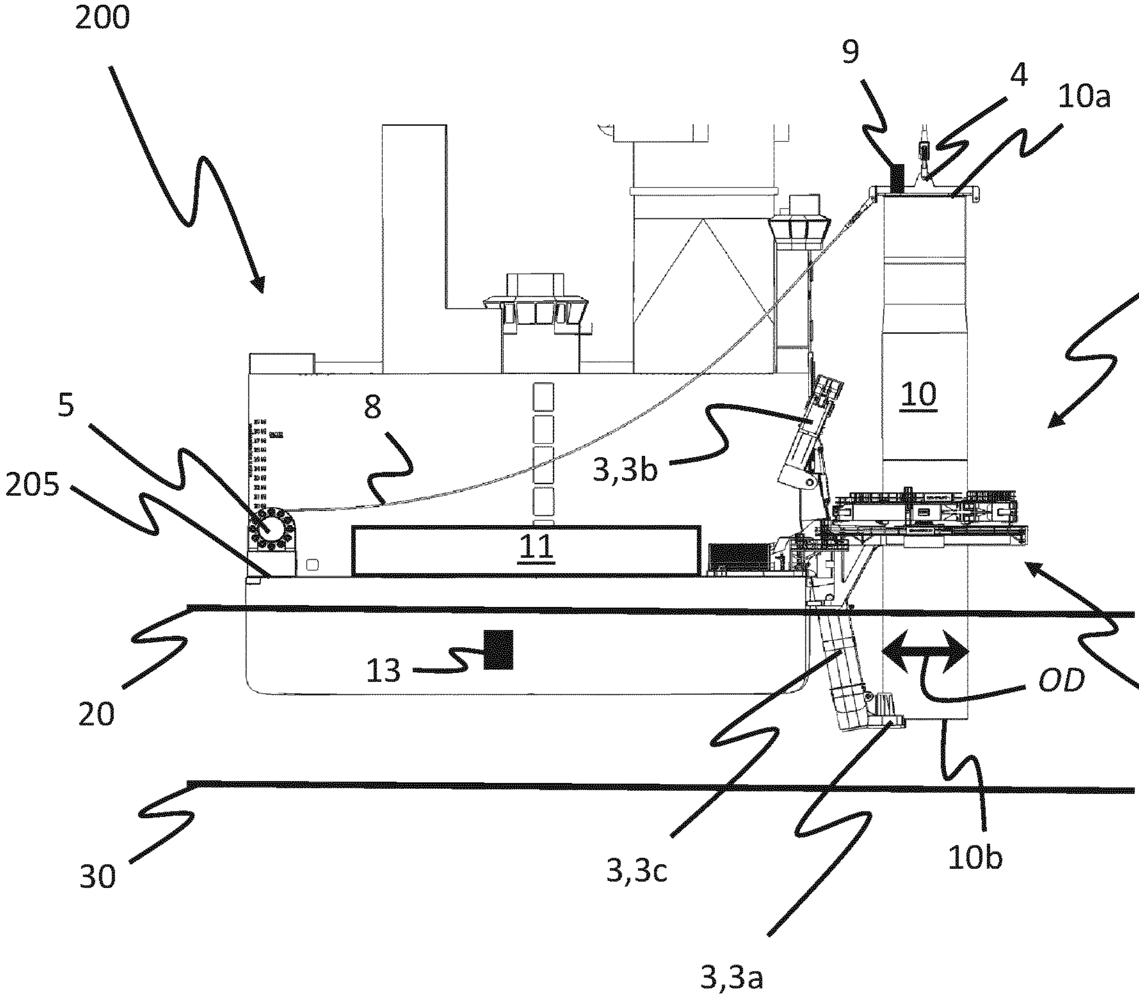


FIG. 11

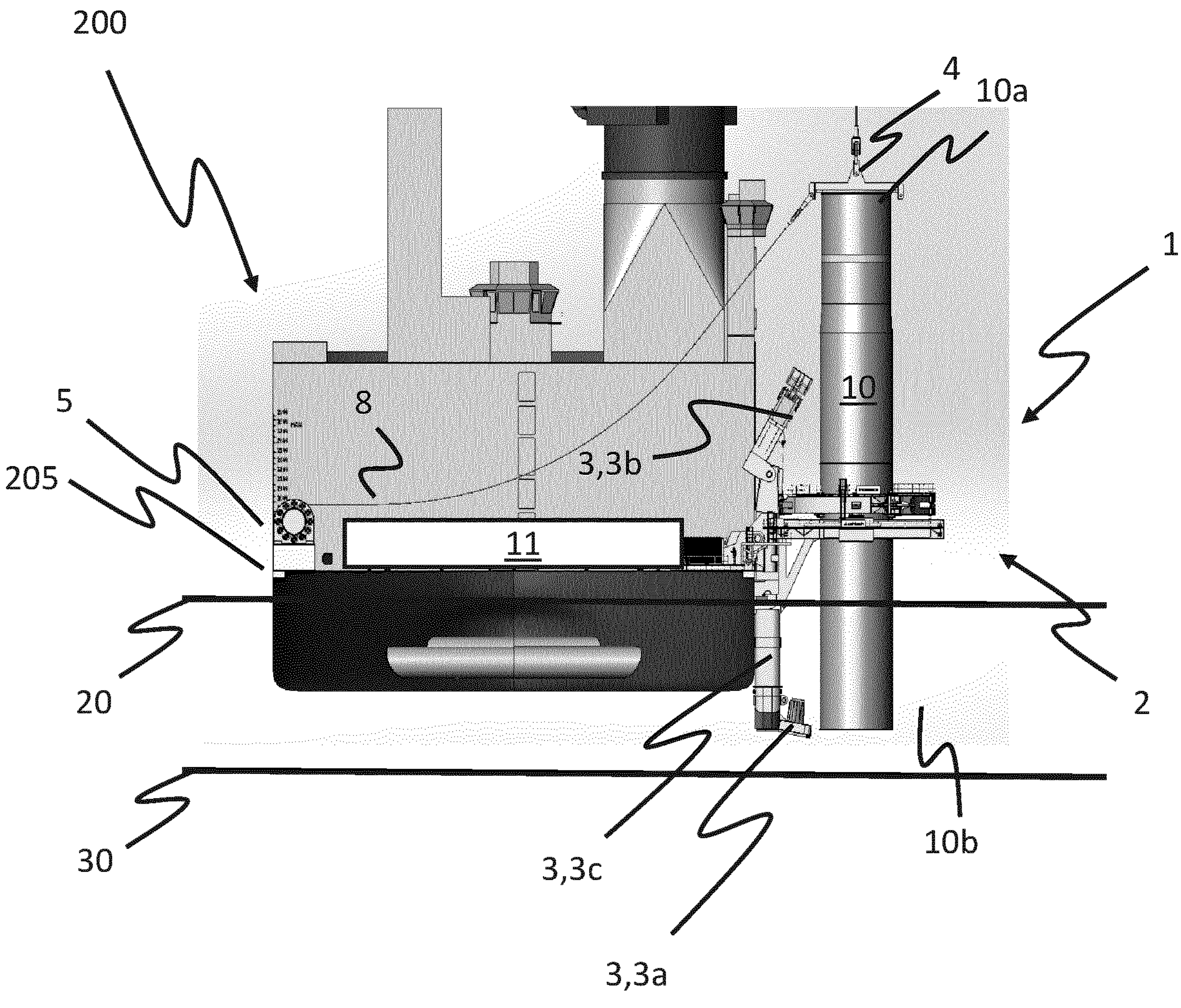


FIG. 12

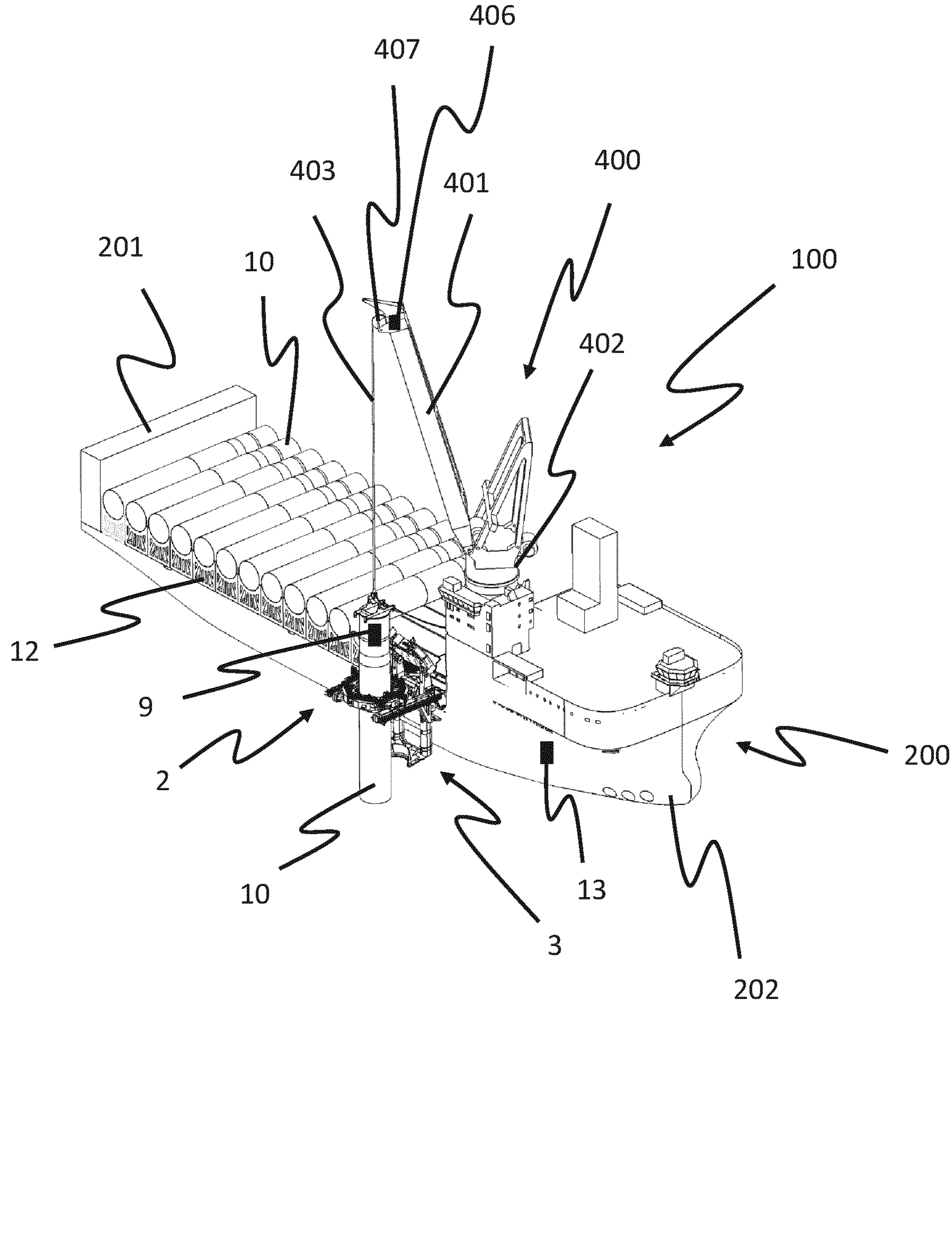
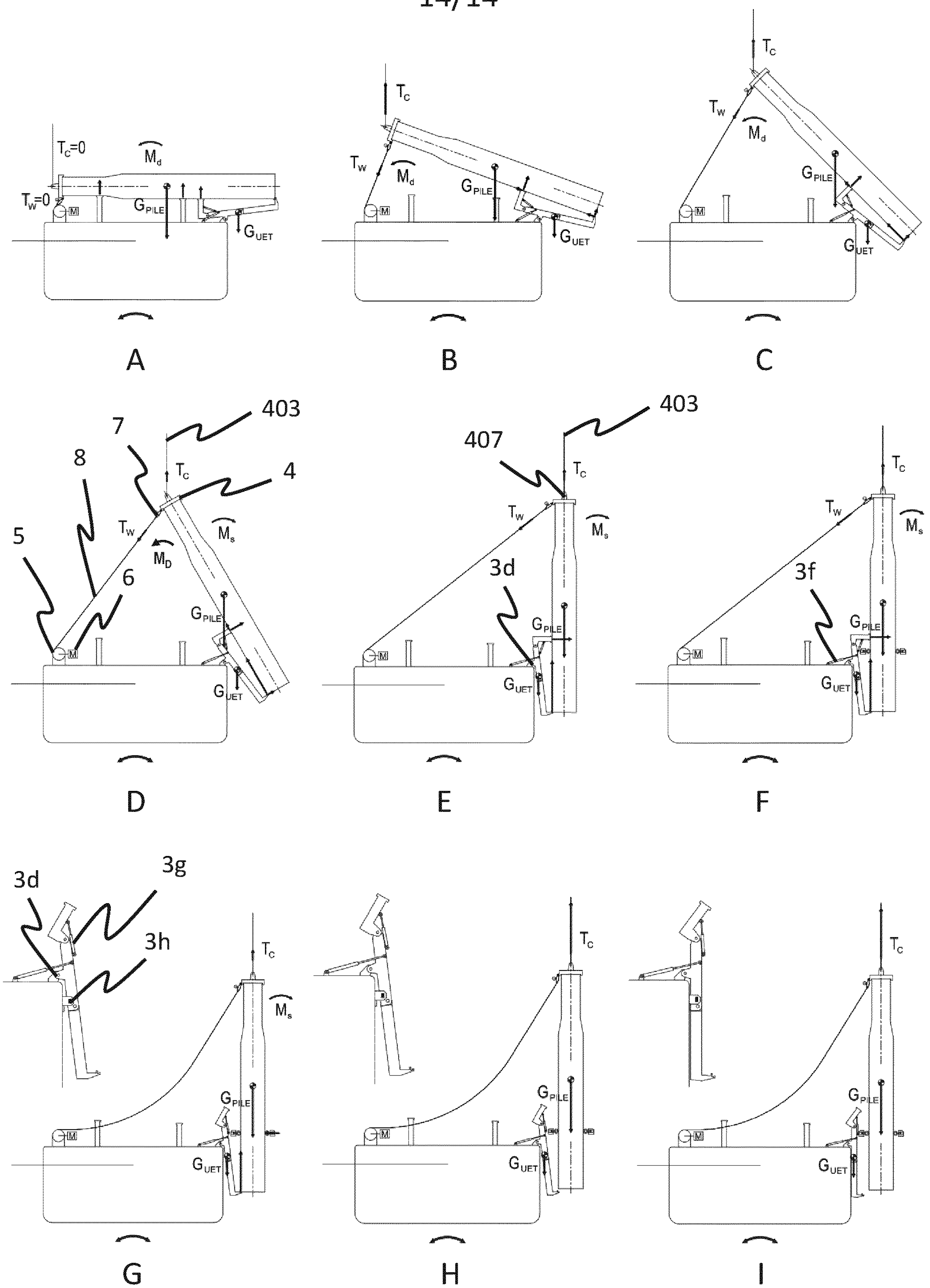


FIG. 13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C
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M_D
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D
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FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/065012

A. CLASSIFICATION OF SUBJECT MATTER
INV. B63B27/10 B63B35/00 B63B79/10 E02D13/04 E02D13/06
F03D13/10 F03D13/25
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B63B F03D B63J E02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 3 517 479 A1 (GEOSEA NV [BE]) 31 July 2019 (2019-07-31) Fig.1, 2, 4A, 6B, 6F, 6L and corresponding text; paragraphs [0053] - [0056], [0080]	1-19
Y	WO 2013/123383 A1 (BELINSKY SIDNEY [US]; BELINSKIY ALEKSEY [NL]) 22 August 2013 (2013-08-22) page 30, page 39 - last paragraph; figures 78, 80, 81	1-19
A	EP 2 372 143 A1 (GEOSEA NV [BE]) 5 October 2011 (2011-10-05) the whole document	1-19
A	WO 2020/043255 A1 (MAERSK SUPPLY SERVICE AS [DK]) 5 March 2020 (2020-03-05) the whole document	1-19

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 September 2021	07/10/2021

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Patrascu, Bogdan

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2021/065012

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			WO	2020043255	A1	05-03-2020