

Some Innovations for Offshore and Harbor Berths Construction

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Abstract: Some new innovative constructions and piling technologies for improvement of offshore and port berthing structures are worked out and discussed. The aims of innovations are to decrease required power of construction (in particular, piling) equipment and, correspondingly, to improve environmental situation at the construction site. Another achieved goal is providing long tubular piles installation in hard soils conditions without application of very heavy and powerful driving machines. Worked out solutions are based on two approaches. One of them provides separate loading of driving force on pile's shaft and pile's tip concentrating the whole driving force on one of the mentioned parts of the pile. Another approach is focused on prevention of soil plug formation inside of the tubular pile tip facilitating the pile installation process. Also improved anchorage system for sheet piling seafront walls is presented and discussed. All considered innovations are patented and can be used in wide range of marine, offshore, coastal and harbor structures.

Key words: Offshore structures, port structures, tubular piles, piles installation, sheet-piling walls, anchor system.

1. Introduction

Essential water depth, unsupported column lengths, huge bending moments, and large lateral and axial forces all combine to make offshore piles large in diameter and long in length. Such piles in most offshore practice are steel pipe piles ranging usually from 1 m up to 4 m in diameter and in lengths from 40 to 300 m or more. Pile capacities for marine and offshore structures have design ultimate values of as much as 100,000 kn, far above those of conventional onshore piles.

For resisting axial compression, the pile transfers its load by skin friction along its outside perimeter and by end bearing on its tip, provided that the tip is either closed or plugged in such a way as not to yield in relation to the pile. Thus, for a natural plug of sandy clay, the internal skin friction must be adequate to

develop the full end-bearing resistance of the plug. Large-diameter tubular piles may not plug and thus the end bearing is lost. However, the interior surface will develop skin friction. Such high resistance is useful for structure's operation stage but it is not favorable at the stage of pile's installation. Very powerful and, correspondingly, expensive equipment should be applied to drive such piles to the target depth [1, 2].

One of the possible ways to solve the problem lies in overcoming of the soil resistance (both on shaft and on tip of the pile) without increase of piling equipment power and capacity. At the first part of this paper some innovative solutions related to facilitating of the long piles driving are considered and discussed. The problem of soil plug of open end pile is also well known [1, 2].

Our new solutions [3-6] presented below and based on some previous researches [7-11] aim to facilitate deep water pile driving operations, to provide target depth for long piles driving and to prevent initiation of

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soil plug during pile installation process.

Another technical problem of port piled berths construction (for example, quay walls made of sheet piles) is arduous conditions of anchorage. It stipulates necessity to install too high anchor plates or to drive anchor piles of high bearing capacity. At the second part of this paper a new approach and innovative solution aimed to avoid mentioned construction inconveniences is presented and analyzed.

2. Piles Driving Improvements for Hard Soil Conditions or In Case of Long Piles

In many cases essential soil resistance hampers driving of long piles and puts obstacles in the way of reaching their target depth of driving. Also rather often driving power of the available equipment (impact hammer/vibro hammer/press-in machine) is not sufficient to provide design parameters of piles installation. It makes necessary purchase or leasing of expensive pile driving equipment and correspondingly leads to increase of construction cost.

In this section some effective methods facilitating tubular piles installation procedure are considered.

They use such approaches as:

- division of pile's shaft and tip resistance and separate overcoming of them (so less powerful driving machine may be applied);
- prevention of the soil plug formation inside the tubular pile by two different techniques;
- combination of main tubular pile and auxiliary internal core pile step-by-step driving;
- application of tubular pile made of two semi-tubular piles which are connected by interlocks and driven alternately.

2.1 Division of Pile's Shaft and Tip Resistance

In order to simplify piled structure installation it is proposed to divide driving of pile's shaft and tip. For this purpose the shoe of the pile can be driven separately as advance element according to the invention [1]. Then the pile's tubular shaft may catch up with the shoe (also by separate driving). Such proposed procedure (multiple repeating of the mentioned two steps while reaching the target depth of penetration) is explained by Fig. 1. According to the last, three stages of pile's installation are foreseen. At

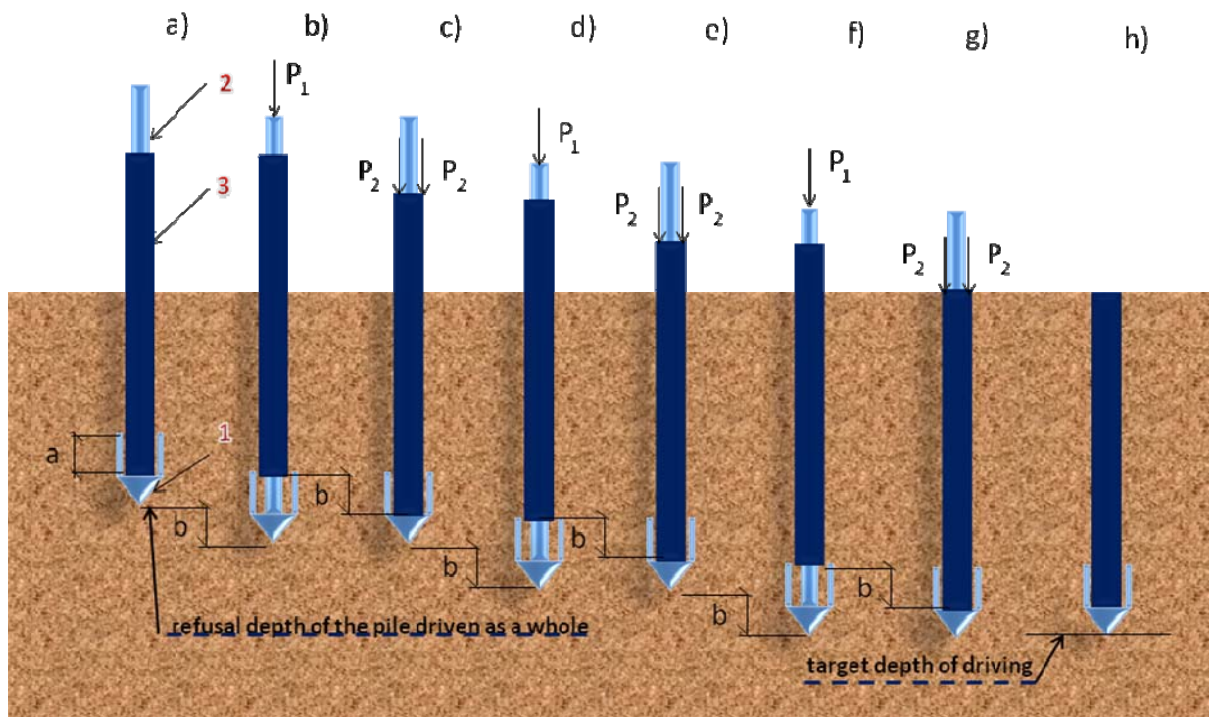


Fig. 1 Pile installation procedure by separate driving of the shoe (by driving force P_1) and the shaft (by driving force P_2).

the first stage the driving of the pile (as a whole element) is provided without separation of the shaft and the shoe (similarly to usual close-end pile penetration), Fig.1a.

On reaching the pile refusal the second stage of the procedure starts. It consists of separate alternate driving of pile's shoe (Fig.1b, d, f, etc.) and shaft (Fig.1c, e, g, etc.) as mentioned above. Driving of the shoe 1 is provided by transferring the driving force P_1 from the hammer via the rigid core element 2 (depth of penetration " b " is limited by height " a " of the guide casing of the shoe 1). Thus the hammer's energy is used just to drive only the shoe. Then only a shaft 3 is driven (as a usual tubular pile by impact or vibro hammer) and again the hammer's energy (driving forces P_2) is used just to drive the shaft (in general case $P_1 \neq P_2$). Total value of the forces P_2 as well as of the force P_1 corresponds to the maximal capacity of the available pile driving machine. Alternate use of the same hammer to drive pile's shaft or tip may be provided by application of specially shaped adapters.

After reaching the pile's target penetration depth completing of the pile (stage 3, Fig. 1h) may be fulfilled by several ways: either (1) by concreting the space inside the pile between shaft 3, rigid core 2 and

shoe 1 with guide casing or (2) by removing the rigid core 2 and concreting the space inside the pile between shaft 3 and shoe 1, or (3) by removing the shaft 3 and creating the cast-in-place pile above the shoe 1 and around the core 2.

2.2 Prevention of the Soil Plug Formation inside the Tubular Pile

The first solution of this approach (let's name it "tube with core", Fig. 2) is based on the following. Driving of the open end pile "2" (tube) of diameter " D " follows the driving of the core pile "1". The core pile may be tube or any other pile of size/diameter " d " ($d < D$) inside the area limited by diameter " D ".

In case of unfavourable soil conditions and/or not powerful enough hammer, open end pile driving may be provided as multistep installation in accordance with invention [2] (Fig. 2). Driving of both piles (core before, tube after) is provided alternately and by stepping while achieving the target depth of open end pile installation. Step 1 (Fig.2a, b) includes driving of the core pile "1" and then driving of the open end pile "2" enclosed the core "1" driven before. On the step 2 (Fig.2c, d) the core pile "1" is driven first again and then tube "2" is driven too. Step 3 (Fig.2e, f) repeats

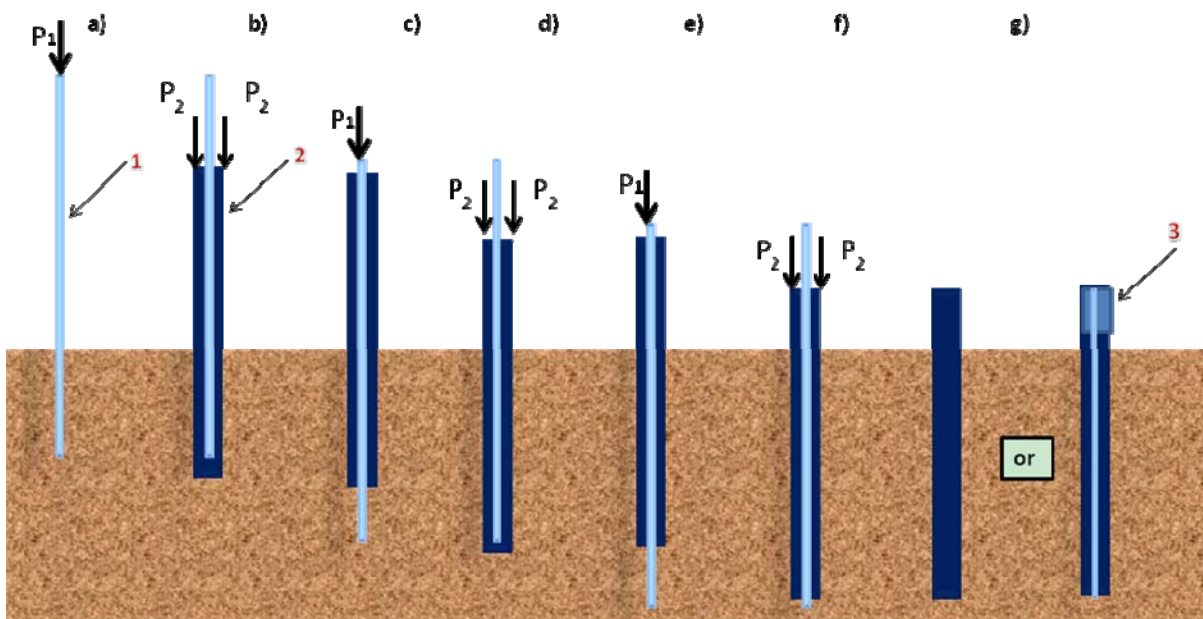


Fig. 2 Pile installation procedure applying multistep driving of core pile (1) and tubular pile (2).

step 2 at another depth of driving and so on (number of steps depends on designed target depth and driving depth of core and tube at each step). So at this multistep installation process due to advance core's penetration, tube is driven without forming of soil plug. Besides due to advance tube's penetration (starting from the second step and further) the core pile driving is facilitated. After completing the tube driving at the last step the auxiliary core pile may be either removed (withdrawn) or connected with main open end pile using rigid coupling "3" to increase tube's strength and bearing capacity as shown on Fig. 2g. Total value of the forces P_2 (applied to the tubular pile) corresponds to the maximal capacity of the available pile driving machine (obviously we consider the case when these forces' value is not sufficient to drive the tubular pile without the core to the target depth). Maximal force P_1 (applied to the core pile) may be limited by the same value.

In order to simplify and to fasten considered multistep installation process the driving tandem (two machines) may be applied: for example, press-in piler

drives a tubular outer pile and vibro hammer drives an inner core pile. As option (to speed up the process) both machines may drive outer and inner piles simultaneously starting since the second step of installation. In general there may be used more than one inner core pile inside the outer tubular pile (it depends on outer tube diameter and driving hammer capacity). Besides proposed approach may be successively applied for several open end piles (placed concentrically) forming finally tube of required large diameter. In such a case each tube which was outer one relatively to the inner core, may be used as the core relatively to the other outer tube of larger diameter.

The second solution of the considered approach (let's name it "semi-tubes") is based on the following. To prevent initiation of soil plug of open end pile during press-in process in the invention [3] it is proposed to split the tube and to form two semi-tubes "1" connected by interlocks "2" (similar to sheet piles interlocks) as shown on the Fig. 3. Interlock connections are parallel to the longitudinal axis of the

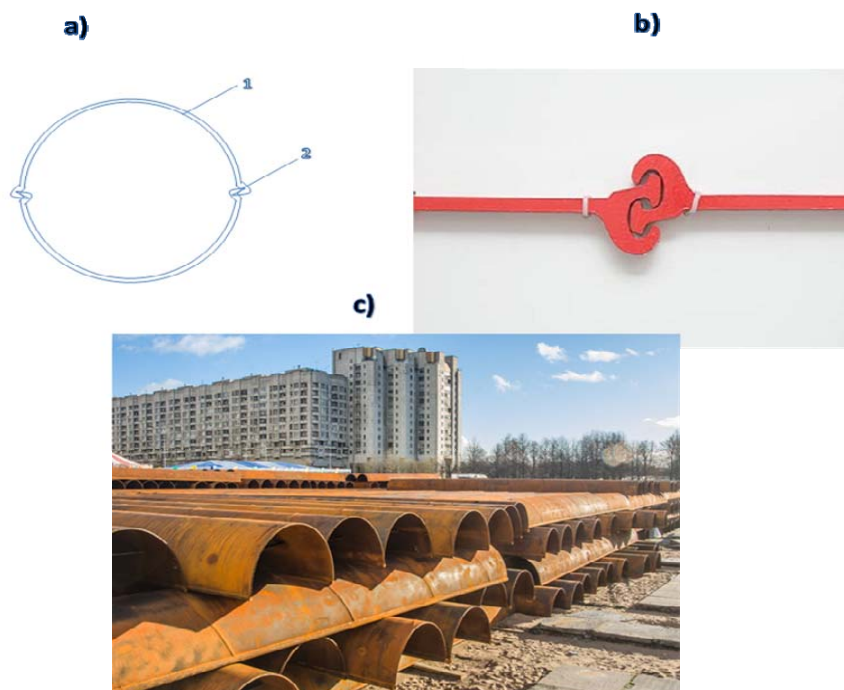


Fig. 3 Tubular pile made of two semi-tubes with interlock connections: (a) cross-section of the tubular pile; (b) variant of interlock connection; (c) semi-tubes with interlock connections.

1—semi-tube; 2—interlock.

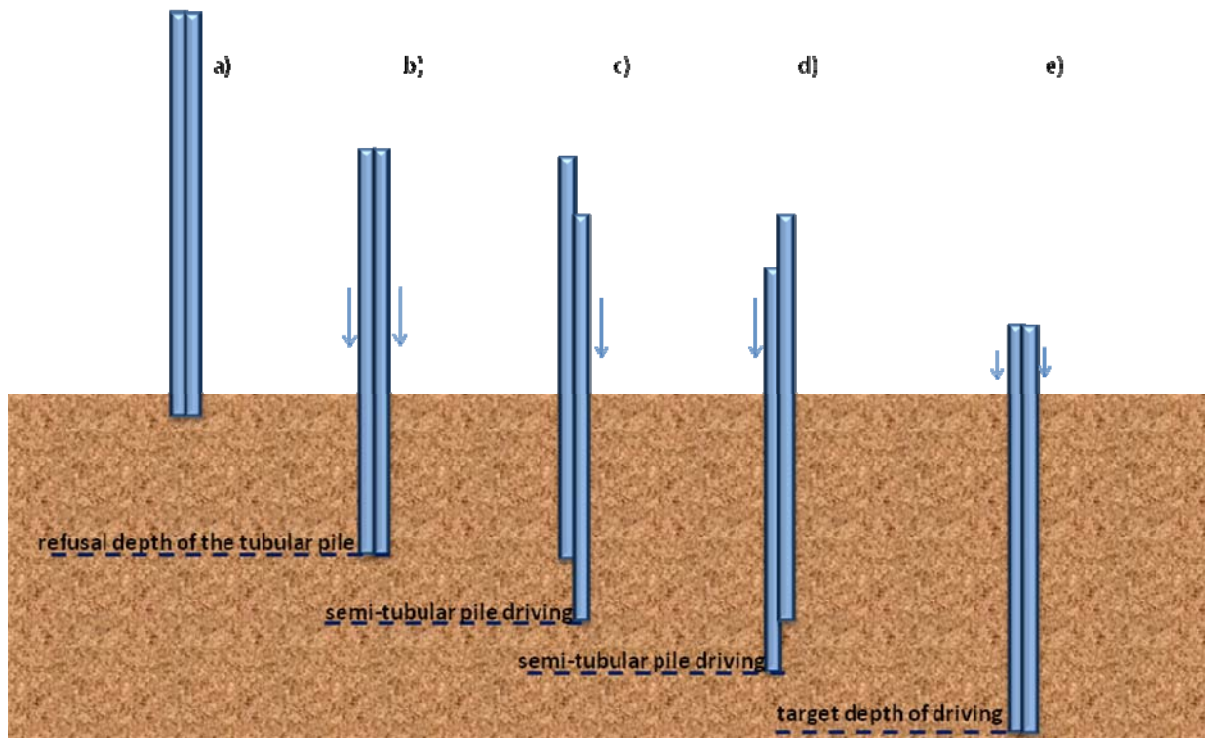


Fig. 4 Tubular pile installation procedure applying multistep driving of semi-tubes via interlocks.

tubular pile. Because of such design driving force may be applied either on ring cross-section of the tubular pile as a whole or alternately by stepping on semi-ring cross-sections of each semi-tube (in the last case no soil plug is initiated owing to driving of open cross-section of semi-tubular pile).

The installation scheme (Fig. 4) includes several steps. Step 1 (Fig. 4a) provides driving of both semi-tubes “1” simultaneously as one solid tube (until it is possible due to soil resistance). Step 2 (Fig. 4b) provides driving of one of the semi-tubes (for example, the left one); step 3 (Fig. 4c) includes driving of another semi-tube (the right one).

Next possible steps repeat steps 2 and 3 until reaching the target depth. So due to semi-tubes penetration at each step, tubular open end pile is driven without forming of soil plug. After achieving the target depth both semi-tubular parts of the open end pile may be rigidly clamped (welded) in the interlocks above ground level to provide their joint action and designed bearing capacity (Fig. 4e). Considered solution also simplifies the pile removal

procedure; if necessary withdrawing of each semi-tube may be done separately-alternatively and by stepping.

To avoid possible problems with fixing of the driving elements in proper position for both considered in this section solutions (i.e. both for “tube with core” and “semi-tubes”) and to prevent negative influence of deviations or deformations on accuracy and safety of installation process we recommend to apply rigid templates (including one located at the sea bottom level).

Main advantages of the two considered approaches aimed to prevent soil plug formation are:

- possibility to achieve large target depth when other methods are not sufficient because of soil plug effect;
- possibility to apply driving machine of less capacity to reach finally the same target depth as in case of using machine of greater capacity in traditional piles installation methods;
- possibility to avoid such auxiliary methods as augering, water jetting, etc.;
- energy/fuel saving because of use of less

powerful equipment;

- positive ecological effect due to use of less powerful equipment, avoiding drilling, jetting, etc.

3. Anchorage System Improvement for Sheet Piled Quay Walls

In marine and port engineering sheet-pile walls with anchorage are widely used. Proposed improved anchor device provides decreasing of the material consumption (keeping the same structure's bearing capacity as at the known facilities) due to anchor plates, which are made in a "comb" type (Fig. 5).

On the other side, proposed construction may provide increasing of the bearing capacity both of the anchorage and of the structure in whole (keeping the same material consumption for the anchorage as at the traditional solutions with one large anchor plate).

So these advantages improve operational parameters of the retaining wall and lead to cheaper design solution of the quay wall [4]. Comparatively small height of plates (within 1 m) allows putting them lower, than it is possible for one

traditional plate of larger height. All plates of the "comb" take anchor force simultaneously.

Number of plates in such "comb" device depends on required bearing capacity of the anchor system and on lifting capacity of applied installation equipment. We would recommend to consider 3-5 plates in one "comb" device.

Quay wall incorporates sheet piling, soil backfilling behind the wall and the anchor tie-rods with anchor bearers located in the filling behind of sliding wedge of soil backfilling. Anchor bearers are made of "comb" type as several anchor plates fixed along the rigid core. The distance between adjacent anchor plates is such that the closer to the front wall plate does not cross the boundaries of the bulge wedge in front of more distant from the front wall plate (bulge wedge is usually built at an angle of $45^\circ + \varphi/2$ to the vertical, where φ —angle of internal friction of the soil).

Required bearing capacity of this anchor device may be designed by varying number of plates in the "comb", plates' height, depth of their location, angle of plates' inclination from the vertical.

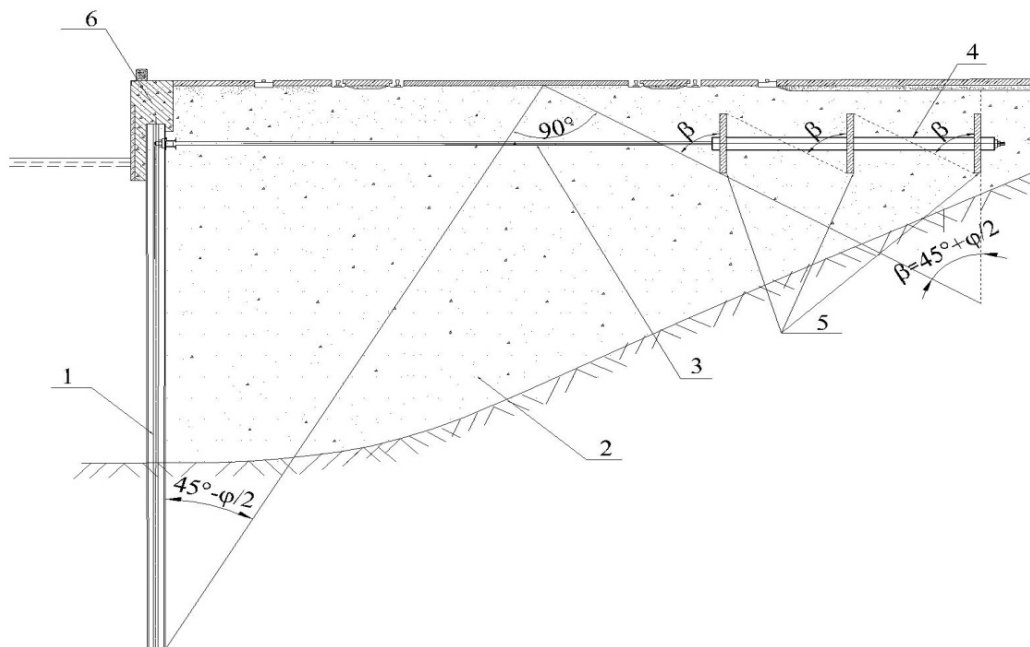


Fig. 5 Sheet-pile quay wall with anchor bearer of new "comb" type.

1—sheet piling; 2—soil backfilling; 3—tie-rod; 4—rigid core; 5—anchor plates; 6—concrete bulkhead.

This type of structure demands a construction sequence of the sheet pile wall-backfilling—anchoring; active pressure of the backfilling may be applied upon the front sheet piling only after reliable anchoring of the structure (obviously this is the same condition as for traditional anchorage system).

Fulfilled in Odessa National Maritime University (Ukraine) both numerical modeling and laboratory model tests of new anchor device and their comparison with traditional anchor plate demonstrated the following main results [5]:

- “comb” type anchor device provides significant increment (up to 30%) of bearing capacity with the same material consumption as in traditional solutions;
- inclination of the plates in the “comb” increases their bearing capacity (in particular inclination 10° – 30° from the vertical leads to proportional increasing 10-30% of the bearing capacity);
- obvious technological advantages of the “comb” type anchor device facilitate anchor bearer installation (it is not necessary to provide deep trench for traditional high anchor plate installation or to drive piled anchor wall) and its maintenance (in cases of inspection or repair).

4. Conclusions

Worked out innovative solutions for long piles installation may be in use in number of cases when it is necessary to provide deeper target depth of driving, to apply cheaper pile driving equipment of decreased power, to save installation costs and to improve environmental situation on construction site.

Numerical modeling of the proposed driving approaches in different soil conditions for steel tubular pile of 820 mm diameter demonstrated increasing of the refusal depth approximately by two times for shoe/shaft driving method, by three times for core/shaft method and by four times for semi-tubes approach. Correspondingly, final axial bearing capacity of the completed pile was achieved approximately by three times more than maximal

applied driving force for shoe/shaft driving method described in Section 2.1, by six times more for core/shaft method and by four times for semi-tubes approach (two last methods are considered in the Section 2.2).

Proposed solutions may be applied to various soil foundation conditions (sandy, clayey, etc.) permitting use of traditional pile driving technologies (hammering, vibrating or pressing). Final choice of the driving method may depend on selected goal: either to save power of the machine or to increase driving depth, or to provide higher bearing capacity of the pile.

New approach to anchor system design and construction by use of “comb” type device allows to simplify anchor installation process, to save time and to avoid large volume of dredging works when erecting port quay walls. Numerical and physical modeling of the structure behavior confirmed increasing of anchoring capacity from 40% to 60% (partially by “comb” effect and partially due to plates’ inclination).

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