

PILE AXIAL CAPACITY ENHANCER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/780,040 filed March 13, 2013, and is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention generally relates to the field of pile foundation systems, and, more particularly, to piles, either conventional driven piles or suction piles.

BACKGROUND

[0003] This section is intended to introduce various aspects of the art, which may be associated with exemplary embodiments of the present invention. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present invention. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

[0004] Offshore exploration and development of oil and gas fields continues to expand into deeper waters, reaching water depths of 1,000 to 3,000 meters and more. In addition, the size of floating exploration and production platform continues to increase. These developments require anchoring systems such as traditional driven piles, drag embedment anchors, plate anchors and suction piles or suction caissons. Furthermore, various subsea, umbilicals, risers and flowlines (SURF) structures require anchor systems at deep water sites worldwide, often in soft, under-consolidated clays.

[0005] Suction piles, also known as suction caissons, suction anchors, bucket foundations and skirt foundations, have found increased use offshore. Suction piles have the appearance of an inverted bucket with a sealed top and are installed by first establishing initial penetration into the seabed due to the weight of the pile. Then, subsequent penetration is achieved by the “suction” created by pumping water out from inside the pile. A submersible pump attached to the top of the pile applies suction pressure. When the required depth is reached, the pump can be disconnected and retrieved.

[0006] The geometry of suction piles differs from traditional piling in that suction piles are typically shorter in length and greater in diameter than traditional piling. For example, aspect ratios (pile length to pile diameter) of suction piles range between 0.5 and 8, compared

with aspect ratios of 30 to 60 for traditional piles. The diameter of a suction pile can range between 4 and 20 meters (12-66 feet), compared with 0.3 to 3 m (1-10 feet) for traditional piles.

[0007] Demand for increased pile loading capacity grows as the offshore floating platforms move to increasingly deeper waters, and the conventional solution has been to increase the capacity of piles by increasing either the pile diameter (D) or the embedded length (L) or both. Even for onshore applications the demand for increased pile loading capacity continues to grow. However, increasing the pile dimensions can have significant economic and technical challenges. For example, increasing the pile length may require deeper and more costly geotechnical investigations. There are also few fabricators qualified or capable of rolling large diameter piles over 6 meters or 20 feet. In addition, only the largest derrick barges can handle the longest and heavier piles (in particular, the suction piles), which means there is a reduced number of installation contractors. Furthermore, the larger diameter suction piles require increased wall thickness and structural reinforcement to avoid buckling, which results in very heavy and expensive construction and installation.

[0008] Thus, there is a need for improvement in this field.

SUMMARY OF THE INVENTION

[0009] The present invention provides a system and a method to increase the axial holding capacity of a pile by adding a capacity enhancer in the form of an external ring, cylindrical or otherwise, to the pile, often located at the lower end of the pile. Adding the capacity enhancer to the pile increases the axial holding capacity by increasing the surface area of the pile and maximizing the use of the higher soil strength by engaging the higher strength of the deepest soil layer. The axial holding capacity is increased without increasing the overall diameter of the pile or its length, and with a very nominal increase in total weight.

[0010] The foregoing has broadly outlined the features of one embodiment of the present disclosure in order that the detailed description that follows may be better understood. Additional features and embodiments will also be described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The foregoing and other advantages of the present invention may become apparent upon reviewing the following detailed description and drawings of non-limiting examples of embodiments in which:

[0012] FIG. 1 is an illustration of an embodiment of a capacity enhancer installed on a pile;

[0013] FIG. 2 is a graph of the increase in axial capacity provided by the capacity enhancer over that of a conventional pile;

[0014] FIG. 3 is a graph of the increase in axial capacity provided by the capacity enhancer with the increase in total pile weight due to the capacity enhancer;

[0015] FIG. 4 is a graphical illustration of how a capacity enhancer resolves limitations in penetration depth or pile diameter.

DETAILED DESCRIPTION

[0016] For the purpose of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications in the described embodiments, and any further applications of the principles of the invention as described herein are contemplated as would normally occur to one skilled in the art to which the invention relates. One embodiment of the invention is shown in great detail, although it will be apparent to those skilled in the relevant art that some features that are not relevant to the present invention may not be shown for the sake of clarity.

[0017] The undrained shear strength of a soil often times increases linearly with depth. In these circumstances, thus the axial capacity of a pile increases with the square of the depth. The present disclosure addresses increasing the axial holding capacity of a pile by adding a capacity enhancer in the form of an external ring, cylindrical or otherwise, to the pile, often at the lower end of the pile. Adding the capacity enhancer, which can also be referred to as a Pile Axial Capacity Enhancer (PACE), to the pile increases the axial holding capacity by increasing the surface area of the pile and maximizing the use of the higher soil strength by

engaging the higher strength of the deepest soil layer. The axial holding capacity is increased without increasing the overall diameter of the pile or its length, and with a very nominal increase in total weight.

[0018] Thus, the axial holding capacity is increased, but more costly geotechnical investigations which could have been required for a longer length pile may be avoided. In addition, the pile may continue to be of a size that can be easily fabricated and installed. The present disclosure may be applied to piles either onshore or offshore, above or below the water table. The present disclosure may be used to increase the axial capacity of a pile, either bearing, or compression capacity, and/or pull-out, tension, anchoring or upward capacity. The capacity enhancer may be any cross-section, such as, for example, circular, triangular, square, octagonal or any polygon shape. Furthermore, the shape or cross-section of the capacity enhancer does not have to match shape or cross-section of the pile. The capacity enhancer may be made of any suitable material, including but not limited to metal, steel, concrete, etc. The pile with the capacity enhancer may be installed by any available method, such as with gravity or dead weight either by itself or with additional ballast, driving, vibrations, suction, or any combination of these or other methods.

[0019] Figure 1 illustrates an embodiment in which a pile 100 is embedded below the seafloor 102, by conventional measures such as suction or driving the pile, as described previously. The pile 100 has a length L and comprises a capacity enhancer 104 that is connected to the bottom of the pile. As shown in Fig. 1, the capacity enhancer 104 has a length L_{ce} and an outer diameter D_{ce} . The diameter D_{ce} of the capacity enhancer 104 is greater than the diameter D of the pile 100. The ratio of the length L_{ce} to the D_{ce} of the capacity enhancer can range between 0.2 to 1, with dimensions outside of this range possible. In the embodiment of Fig. 1, the capacity enhancer 104 is connected concentrically with pile 100, in other embodiments, the capacity enhancer could be connected non-concentrically with the pile.

[0020] As seen in Fig. 1, the capacity enhancer is located in the deeper regions of the soil, which usually has the highest shear strength, providing increased pile surface area of in a local soil region of highest shear strength. This will significantly increase the axial holding capacity of the pile. The capacity enhancer may be attached to the end or other location of the pile by any suitable means known in the art, such as, for example, by welding. The capacity enhancer may also be constructed of any suitable material used in the industry.

[0021] Figure 2 illustrates graphically the increase in axial capacity provided by the capacity enhancer over that of a conventional pile. Figure 2 is a graphical presentation of axial capacity calculations 200 made for a base pile anchor of 18 feet diameter and 100 feet length with a capacity enhancer of four different diameters and various lengths ranging from 2 feet to 20 feet. The x-axis 202 of the graph provides the length in feet of the capacity enhancer; the y-axis 204 provides the increase in capacity over that of the same size conventional base pile. Line 206 provides the calculated capacity increases for the addition of a capacity enhancer with a diameter of 24 feet. Line 208 provides the calculated capacity increases for the addition of a capacity enhancer with a diameter of 26 feet. Line 210 provides the calculated capacity increases for the addition of a capacity enhancer with a diameter of 28 feet. Line 212 provides the calculated capacity increases for the addition of a capacity enhancer with a diameter of 30 feet. As can be seen, a capacity enhancer of 26 feet diameter and 12 feet in length provides a 40% higher axial capacity compared to that of a base pile of the same size (diameter and length) without a capacity enhancer. The ratio of the length of the base pile to the length of the capacity enhancer may be between 5 to 20. The ratio of the diameter of the capacity enhancer to the diameter of the pile may be between 1.2 to 2.

[0022] Figure 3 illustrates graphically the increase in axial capacity provided by the capacity enhancer with the increase in total pile weight due to the capacity enhancer. The x-axis 302 of the graph provides the percent increase in pile weight due to the capacity enhancer; the y-axis 304 provides the increase in capacity over that of the base pile. As can be seen from line 306, a capacity enhancer can achieve 40% and 80% axial capacity increase for only a 15% and 31% increase in total pile weight.

[0023] Figure 4 illustrates how a capacity enhancer resolves limitations in penetration depth or pile diameter. The graph 400 provides an indication of resisting force on the x axis 402 and depth below the mudline 401 on the y-axis 404, with increasing depth in the direction of the arrow 403. Line 406 is the shaft resistance to penetration of the pile depending upon the depth and line 408 is the end bearing resistance against which the pile can be pulled down into the seabed using the suction pump. As can be seen on the graph 400, the end bearing resistance exceeds the shaft friction until a certain depth is achieved, which is indicated at line 410. When this depth is achieved, the pile cannot be penetrated any further into the seabed because the shaft friction resistance exceeds the end bearing resistance, which

results in soil plug pull out. In other words, at this point, it is easier for the soil plug to be sucked up inside the pile than for the pile to continue sinking into the seabed.

[0024] Still referring to Fig. 4, pile 412 indicates that, to achieve a given axial capacity, suction pile 412 with a diameter D would need to be too long and would not be able to penetrate far enough into the seabed. In order to achieve the given axial capacity, the diameter of the pile could be increased to diameter D' and have an acceptable length, as shown for pile 414, however the diameter D' of pile 414 presents problems and increased costs in design, fabrication and installation. Through the use of a capacity enhancer, pile 416 meets the given axial capacity, has an overall acceptable length, and is designed with an acceptable diameter D.

[0025] It should be noted that the figures are merely examples of several embodiments of the present invention and no limitations on the scope of the present invention are intended thereby. Further, the figures are generally not drawn to scale, but are drafted for purposes of convenience and clarity in illustrating various aspects of certain embodiments of the invention.

[0026] It should be understood that the preceding is merely a detailed description of specific embodiments of this invention and that numerous changes, modifications, and alternatives to the disclosed embodiments can be made in accordance with the disclosure here without departing from the scope of the invention. The preceding description, therefore, is not meant to limit the scope of the invention. Rather, the scope of the invention is to be determined only by the appended claims and their equivalents. It is also contemplated that structures and features embodied in the present examples can be altered, rearranged, substituted, deleted, duplicated, combined, or added to each other. The articles "the", "a" and "an" are not necessarily limited to mean only one, but rather are inclusive and open ended so as to include, optionally, multiple such element.

CLAIMS

What is claimed is:

1. An apparatus for a foundation comprising:
a first elongated member with a first length and a first cross-section; and
a second elongated member with a second length and a second cross-section,
wherein the second elongated member is connected near an end of the first elongated member, and wherein the second cross-section is greater than the first cross-section and the second length is less than the first length.
2. The apparatus of claim 1, wherein the second elongated member is attached concentrically with the first elongated member.
3. The apparatus of claim 1 or 2, wherein the second elongated member is connected near the end of the first elongated member that will be located in the deepest portion of the soil.
4. The apparatus of any of claims 1-3, wherein the first elongated member is a cylinder and the first cross-section has a first diameter, and wherein the second elongated member is a cylinder and the second cross-section has a second diameter.
5. The apparatus of any of claims 1-4, wherein the ratio of the length of the first member to the first diameter is between 0.5 to 8.
6. The apparatus of any of claims 1-5, wherein the ratio of the length of the second member to the second diameter is between 0.2 to 1.
7. The apparatus of any of claims 1-6, wherein the ratio of the length of the first member to the length of the second member is between 5 to 20.
8. The apparatus of any of claims 1-7, wherein the ratio of the diameter of the second member to the diameter of the first member is between 1.2 to 2.
9. The apparatus of any of claims 1-3 and 5-8, wherein the second elongated member is a polygon.
10. A method of improving the axial capacity of a pile comprising:
providing a pile with a first length and a first cross-section;
attaching a capacity enhancer with a second length and a second cross-section,

wherein the capacity enhancer is connected near an end of the pile, and wherein the second cross-section is greater than the first cross-section and the second length is less than the first length.

11. The method of claim 10, wherein the capacity enhancer is attached concentrically with the pile.

12. The method of claim 10 or 11, wherein the capacity enhancer is connected near the end of the pile that will be located in the deepest portion of a soil.

13. The method of any of claims 10-12, wherein the pile is a cylinder and the first cross-section has a first diameter, and wherein the capacity enhancer is a cylinder and the second cross-section has a second diameter.

14. The method of any of claims 10-13, wherein the ratio of the length of the pile to the first diameter is between 0.5 to 8.

15. The method of any of claims 10-14, wherein the ratio of the length of the capacity enhancer to the second diameter is between 0.2 to 1.

16. The method of any of claims 10-15, wherein the ratio of the length of the pile to the length of the capacity enhancer is between 5 to 20.

17. The method of any of claims 10-16, wherein the ratio of the diameter of the capacity enhancer to the diameter of the pile is between 1.2 to 2.

18. The method of any of claims 10-12 and 14-17, wherein the capacity enhancer is a polygon.