

PIPE PILE STRUCTURE

FIELD OF INVENTION

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The present invention broadly relates to a pipe pile structure installable through soft soil below a seabed and to a method of building a pipe pile structure in soft soil.

10 BACKGROUND

Seawall systems gain importance as communities try to maximise the use of geographical resources. Seawall systems can be used for port development work or deep reclamation of land. In some cases, communities may want to make
15 improvements around existing navigation channels. Seawalls can also be used as wharves, providing recreational activities and a livelihood for residents of the communities. However, current approaches to building seawall systems are impractical or impossible in some geographic conditions, limiting the desired usage of available resources.

20 Examples of current approaches to seawall systems include cellular cofferdams and double wall sheetpile structures. A cellular cofferdam is a gravity structure that can be cantilevered to a limited height on firm foundation ground. Straight-web sheetpiles are fixed or jointed together in cellular form. The sheetpiles form a circular structure or cell which contains sandfill. The dead weight of the
25 sandfill inside the circular cell resists lateral loading. The cellular cofferdam must be founded on firm ground such as layers of sand and dense sand. The flat sheetpiles of a cellular cofferdam have minimum structural bending capacity and the depth of embedment below seabed is limited.

For a double wall sheetpile structure, two walls are connected together by
30 transverse sheetpile bulkheads or by tie rods and wallings to contain a granular fill between the walls. Lateral loading is partly resisted by the action of gravity on the soil contained by the two walls and partly by the passive soil resistance on the lower parts of the walls embedded below the foundation. A double wall sheetpile structure

can be built on a layer of clay and silt, with embedment into a firm stratum. However, the sheetpile section cannot be driven into very hard stratum or bedrock. The double wall sheetpile structure has better bending capacity action, but is not adequate in deep deposits of soft clay.

5 A common disadvantage with the current approaches is that such approaches require a firm seabed. These approaches cannot be used in deep soft clay or other soft subsoil, unless extensive soil improvement work or dredging and sand replacement is performed. A massive sand key would be necessary in order to provide support for the structure. However, in some situations, soil improvement
10 is impractical because sand is either scarce or dredging is prohibited as dredging obstructs an existing navigation channel, or creates instability to an existing seawall or nearby structure. Furthermore, anchoring on the dry side of the seawall may not be possible.

15 **SUMMARY**

One aspect of the invention provides a pipe pile structure installable through soft soil below a seabed, comprising: pipe piles interconnected to form walls of said pipe pile structure, and said pipe piles axially extending through said soft soil to be
20 embedded in a stratum located below said soft soil, wherein each pipe pile of said pipe piles is embedded in holes drilled into said stratum.

Said pipe pile structure may have a cross-sectional shape of a rectangle.

25 The rectangle cross-sectional shape of said pipe pile structure may be a square.

Said pipe pile structure may have a cross-sectional shape that includes multiple rectangles.

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Said pipe pile structure may have a capping beam located at a top of said pipe pile structure.

Said pipe piles of said pipe pile structure may be connected to said capping beam by a reinforced concrete plug.

Said pipe piles of said pipe pile structure may be steel pipes.

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Said pipe piles of said pipe pile structure may be interconnected by interlocks, each interlock comprising two cylinders that are mutually locked.

Each cylinder of said pipe pile structure may have an open slit parallel to a centre axis of said each cylinder, and said each cylinder extending through a corresponding open slit into an interior of the other cylinder, in order to achieve said mutual locking.

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Grouting may substantially fill a volume of space shared by interiors of said two cylinders of said pipe pile structure.

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Said stratum of said pipe pile structure may have Standard Penetration Test value (SPT) > 100.

A further aspect of the present invention provides a method of building a pipe pile structure in soft soil, comprising: embedding pipe piles through said soft soil into a stratum located below said soft soil; and interconnecting said pipe piles to form walls of said pipe pile structure, wherein said pipe piles are embedded into holes drilled into said stratum.

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The method may further comprise said pipe pile structure may have a cross-sectional shape of a rectangle.

The method may further comprise said rectangle may be a square.

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The method may further comprise said pipe pile structure may have a cross-sectional shape that includes multiple rectangles.

The method may further comprise placing a capping beam located at a top of said pipe pile structure.

The method may further comprise said pipe piles are connected to said capping beam by a reinforced concrete plug.

5 The method may further comprise said pipe piles are steel pipes.

The method may further comprise interconnecting said pipe piles by interlocks, each interlock comprising two cylinders that are mutually locked.

10 The method may further comprise each cylinder having an open slit parallel to a centre axis of said each cylinder, and said each cylinder extending through a corresponding open slit into an interior of the other cylinder.

 The method may further comprise substantially filling a volume of space
15 shared by interiors of said two cylinders with grouting.

The method may further comprise said stratum has $SPT > 100$.

20 **BRIEF DESCRIPTION OF THE DRAWINGS**

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

25 FIG. 1 illustrates a pipe pile structure, according to an embodiment.

FIG. 2 illustrates a side view schematic of the pipe pile structure, according to an embodiment.

30 FIG. 3 illustrates a top-down view of the pipe pile structure, according to an embodiment.

FIG. 4(a) and FIG. 4(b) combined illustrates a schematic diagram of a cross-sectional
35 view of pipe pile structure, according to an embodiment.

FIG. 5 illustrates a P-P interlock, according to an embodiment.

FIG. 6 illustrates a side view of the pipe pile structure with a capping beam, according to an embodiment.

FIG. 7 illustrates a double box pipe pile structure, according to another embodiment.

FIG. 8 illustrates bending resistance of a pipe pile, according to an embodiment.

FIG. 9 illustrates induced bending moment distribution for pipe piles forming a box pipe pile structure, according to an embodiment.

FIG. 10 illustrates a method of building a pipe pile structure in soft soil, according to an embodiment.

DETAILED DESCRIPTION

Embodiments of the invention will be discussed hereinafter with reference to the figures. FIG. 1 illustrates a pipe pile structure, according to an embodiment. In FIG. 1, a pipe pile structure 102 is constructed using pipe piles 104 driven below the seabed 106. The pipe piles 104 are preferably fabricated in exact length for every individual pipe pile. Each pipe pile is preferably installed in two operations. A first pipe pile is pressed into the ground with accuracy by a push-in method using a hydraulic machine. A second pipe pile is driven in after drilling out the material below the hollow of the pipe pile. The pipe piles 104 are interconnected and substantially arranged according to a cross-sectional rectangle shape to form pipe pile structure 102. In some embodiments, the cross-sectional rectangle shape is a square. Each single pipe pile member of the pipe piles 104 has a cross-section substantially in the shape of a circle. To adjust the strength of pipe pile structure 102, the pipe piles' bending capacity can be adjusted by choosing the diameter and thickness of the pipe piles. When viewed from the top-down perspective, the cross-sectional square shape of pipe pile structure 102 forms the four side walls of the pipe pile structure 102, creating a "box pipe pile structure", also referred to herein as a "box pipe pile structural wall".

Pipe pile structure 102 has a cantilever height of about 11.5m above the seabed 106 in one embodiment, and a middle portion of pipe pile structure 102 axially extends through soft clay 108 to be embedded in strong foundation soil 110. Pipe pile structure 102 can be embedded, or inserted, into hard stratum with SPT > 100, including rock stratum, such as bedrock. Pipe pile structure 102 is preferably embedded deep enough into the strong foundation soil 110, such as hard stratum, to substantially ensure external stability. External stability is preferably ensured with the embedding of the pipe piles 104 in the strong foundation soil, despite a significant length of pipe pile structure 102 extending through soft clay 108. Geotechnical failure can substantially be eliminated. Sandfill 112 is contained as dead weight within the walls of pipe pile structure 102, increasing the lateral resistance of pipe pile structure 102. Pipe pile structure 102 is formed with landside 114 located at one side of pipe pile structure 102. Reclamation is carried out of the landside 114, and landside 114 exerts lateral pressure against pipe pile structure 102.

FIG. 2 illustrates a side view schematic of the pipe pile structure 102 (FIG. 1), according to an embodiment. In FIG. 2, pipe pile structure 102 is capped with a capping beam 202. Pipe piles 104 of pipe pile structure 102 are rigidly connected by capping beam 202, which provides stiffness at the top of pipe pile structure 102 to preferably ensure that the pipe piles 102 are rigidly connected. Interlocks 204 provide additional structural tensile strength to resist outward expansion of pipe pile structure 102. Interlocks 204 are flexible tensile connectors to pipe piles 104 and provide additional tensile support to the sandfill 112, and also accommodate the outward expansion of pipe piles 104. Likewise, pipe piles 104 preferably are of sufficient flexural capacity to support sandfill 112 without the contribution of the structural tensile capacity of the interlock 204. Pipe piles 104 extend through seabed 106 into the soft clay 108, and are embedded in strong foundation soil 110. A drilling machine may be used to drill holes into the strong foundation soil 110 to allow the embedding of pipe piles 104 into the strong foundation soil 110 for anchoring. Pipe pile structure 102 is placed between a landside 114 and a seaside 206. The pipe pile structure 102 contains the reclamation on the landside 114 and functions as a high cantilever structure at the seaside 206. The gravity weight of sandfill 112 is contained by pipe pile structure 102. Pipe piles' 104 diameter and thickness are chosen to have a sufficient bending capacity to resist the reclamation lateral pressure from landside 114 in combination with the gravity weight of sandfill 112 within the box pipe pile structure 102. Interlocks preferably are installed

above interlock line 208. The interlock line 208 is defined as the depth at which the interlocks will not be damaged during the hydraulic press-in method. The interlock line is normally set at 2m above a Giken line i.e. the limit of the push-in capability of the hydraulic press-in machine. The installation of the interlock within the soil is preferably accomplished with precise positioning of the pipe pile and a 25mm tolerance of the P-P interlock.

The strength of the box pipe pile structure in the example embodiment is derived from 1) the high bending capacity pipe piles; 2) the contained dead weight within the interlocked box pipe pile structure; 3) the embedment into the strong foundation; and 4) the capping beam that connected the pipe piles as rigid joints. A strong box pipe pile structure or multiple box pipe pile structure can be created that can be cantilevered to a height of 20 m or more in a deep soft clay deposit. Costly and extensive removal of soft clay and replacement with sand is no longer necessary. Such removal may be impossible to carry out in a navigation channel, for example. A massive sand key is no longer necessary, allowing port development work or deep reclamation that was not previously possible or practical. Where soil improvement works cannot be performed, or where anchoring on the dry side of the seawall system is prohibited, the pipe pile structure may still be cantilevered to a height of 20 m or more in deep soft clay deposits. Deep reclamation is thus advantageously possible.

FIG. 3 illustrates a top-down view of the pipe pile structure 102 (FIG. 1), according to an embodiment. In FIG. 3, pipe piles 104 are substantially arranged to form the pipe pile structure 102 with a cross-sectional shape of a square, which is a box pipe pile structure, also can be described as a "single" box pipe pile structure. In some embodiments, pipe piles 104 are substantially arranged to form the pipe pile structure 102 with a cross-sectional shape that includes a square. Since the cross-sectional shape of pipe pile structure 102 is substantially uniform throughout the structure, the top-down view in FIG. 3 of pipe pile structure 102 also depicts a square shape. Pipe pile structure 102 contains sandfill 112. Interlocks 204 between each of pipe piles 104 allow for resisting outward expansion of pipe pile structure 102. The single box pipe pile structure should be of sufficient size in dead weight, but preferably is not so large as to exceed the tensile capacity of the interlocks 204. Although pipe pile structure 102 has a cross-sectional shape that resembles the shape of a square, pipe pile structure 102 is not limited to a cross-sectional shape that resembles the shape of a square. The cross-

sectional shape of pipe pile structure 102 may resemble other shapes as well, such as a circle or rectangle.

FIG. 4(a) and FIG. 4(b) illustrate a schematic diagram of a cross-sectional view of pipe pile structure 102 (FIG. 1), according to an embodiment. As depicted in FIG. 4(b), a pipe pile 402 is spaced approximately 247.8 mm apart from an interconnected pipe pile 404. Pipe pile 404 is interconnected to a pipe pile 406 and similarly spaced approximately 247.8 mm apart from pipe pile 406. An interlock 408 connects pipe pile 402 with pipe pile 404. An interlock 410 connects pipe pile 404 with pipe pile 406. The remainder of the pipe piles in pipe pile structure 102 are also generally spaced apart with an approximate distance of 247.8 mm, with interlock connections installed between the pipe piles as appropriate.

A side wall 412 of pipe pile structure 102 measures approximately 130 cm from the centre of a pipe pile labelled "C1" to the centre of another pipe pile labelled "C2", and the other side walls have approximately the same measurement. The pipe piles labelled "C1" and "C2" each have three interlocks connecting to three different pipe piles. As depicted in the example of FIG. 4(a), the width of each wall of the pipe pile structure 102 is approximately the same, with ten pipe piles forming each wall. The dimensions depicted in FIG. 4(a) and FIG. 4 (b) correspond to one embodiment, and other embodiments may utilise different dimensions. For example, in another embodiment, pipe pile structure 102 may have a lesser number of pipe piles interconnected to form each wall of pipe pile structure 102, or pipe pile structure 102 may have a greater number of pipe piles interconnected to form each wall of pipe pile structure 102. The pipe piles may also have different diameters and/or thicknesses.

FIG. 5 illustrates a P-P interlock, according to an embodiment. Interlocks 204 (FIG. 2) allow pipe piles 104 to be interconnected, forming walls of pipe pile structure 102 (FIG. 1). In FIG. 5, an interlock such as interlock 408 is depicted in greater detail. Interlock 408 can be a P-P interlock as depicted in FIG. 5. Interlock 408 is located between tubular steel pipes of pipe pile 402 and pipe pile 404. The distance allowed for the interlock between the tubular steel pipes is approximately 247.8 mm. The thickness 502 of each circular part of the interlock 408 is approximately 15 mm. Grouting 504 fills the gaps in the centre of the interlock. A fillet weld 506 attaches each circular part to the respective tubular steel pipe. The interlocks 204 preferably should have the tensile strength and flexibility, in combination with the bending capacity of the pipe pile structure 102, to contain the dead weight of sandfill 112, and to prevent the outward expansion of

pipe pile structure 102. Interlocks 204 are preferably located between interconnected pipe piles within the soft clay and subsoil of SPT $N < 20$.

The pipe piles 104 are interconnected by interlocks, each interlock comprising two cylinders that are mutually locked, each cylinder 508, 510 having an open slit 512, 514 parallel to a centre axis 516, 518 of each cylinder, and each cylinder extending through a corresponding open slit 514, 512 into an interior 520, 522 of the other cylinder, of the two cylinders, in order to achieve the mutual locking. The centre axes 516, 518 are substantially parallel. The length of each of the cylinders 508, 510 along the respective centre axis 516, 518 of the cylinder may be chosen as appropriate to adjust the strength of the interlock. Each open slit 512, 514 of each cylinder 508, 510 measures approximately 35 mm along the circumference of the cylinder in one embodiment. The grouting substantially fills a volume of space shared by interiors of the two cylinders. The filling of grout in the three gaps of the interlock advantageously eliminates the tolerance of the P-P interlock and ensures tightness. There is preferably very limited structural contribution from the grouting of the P-P interlock. The three gaps of the P-P interlock may be drilled and soil flushed out, before grouting. Grout jacket are then inserted into the three gaps to fill up the voids. Out of three gaps, one successful filling with grout jacket will substantially ensure tightness of the P-P interlock.

FIG. 6 illustrates a side view of pipe pile structure 102 (FIG. 1) with a capping beam, according to an embodiment. As depicted in FIG. 6, a rigid capping beam 202 (FIG. 2) is placed at, or on top of, pipe pile structure 102. The depicted capping beam 202 is approximately 2m deep and 1.75m wide. The dimensions of capping beam 202 can be custom manufactured as necessary to accommodate the shape and dimensions of pipe pile structure 102. A concrete plug is preferably located between the pipe piles 104 and capping beam 202. The pipe piles 104 are preferably rigidly connected to the capping beam 202 by the concrete plug. The concrete plug is preferably strongly reinforced. The rigid capping beam 202 provides stiffness at the top of pipe pile structure 102 to ensure that all the pipe piles 104 are rigidly connected. The rigid joints created at the top of pipe pile structure 102 restrains the capping beam 202, maintaining the inclination of pipe pile structure 102 in a vertical direction despite lateral movement due to reclaimed soil. Such lateral movement, due to lateral pressure from reclaimed land, is depicted in FIG. 6.

FIG. 7 illustrates a double box pipe pile structure 700, according to another embodiment. As depicted, the double box pipe pile structure 700, with a cantilever

height of about 22 m, can be installed in about 31.5 m of a soft clay deposit 702, and embedded into a strong foundation soil 704. The double box pipe pile structure 700 axially extends down into the seabed and below. The double box pipe pile structure 700 can be embedded into hard stratum with SPT > 100, including rock stratum, such as bedrock. Holes may be drilled into the hard stratum for installation of the pipe piles.

A contained dead weight in the double box pipe pile structure 700 can include reclaimed sand 706. As depicted in the example cross-sectional view of FIG. 7, a left side box 708 is approximately 12.58 m and a right side box 710 is approximately 11.14 m. Due to the reinforced configuration of the double box pipe pile structure 700, the double box pipe pile design can withstand stronger structural stress than the "single" box pipe pile structure. In some embodiments, still additional box pipe piles may be added for stronger structures. If the structural stress of a single box pipe pile structure is exceeded, multiple box pipe pile structures can be built to handle the excessive structural stress. The cross-section of a multiple box pipe pile structure will include multiple rectangles. In some embodiments, the cross-section of a multiple box pipe pile structure will include multiple squares. Interlocks preferably are installed above interlock line 712.

FIG. 8 illustrates bending resistance of a pipe pile, according to an embodiment. In FIG. 8, bending resistance in two directions of a pipe pile 802 is illustrated. Pipe pile 802 has a circular cross-section. In other words, the cross-section at any point along the length of pipe pile 802 has the shape of a circle. Pipe pile 802 can be, for example, a single pipe pile member of pipe piles 104 (FIG. 1). Each pipe pile has a bending resistance in two directions, the directions being along both axes that are orthogonal to the length axis of the pipe pile. In comparison, sheetpile wall only resists bending in one direction.

FIG. 9 illustrates induced bending moment distribution for pipe piles forming a box pipe pile structure, according to an embodiment. Pipe piles forming a box pipe pile structure, such as pipe pile structure 102, advantageously distribute the bending moment more efficiently than a double row sheetpile wall. In the example box pipe pile structure, the maximum bending moment is 2360 kNm/m for the box pipe pile structure. For comparison purposes, using a comparative double row sheetpile wall, the maximum bending moment of the double row sheetpile wall can reach up to 5580 kNm/m.

FIG. 10 illustrates a method of building a pipe pile structure in soft soil, comprising embedding pipe piles through said soft soil into a stratum located below

said soft soil and interconnecting said pipe piles to form walls of said pipe pile structure, wherein said pipe piles are embedded into holes drilled into said stratum.

5 It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A pipe pile structure installable through soft soil below a seabed, comprising:
pipe piles interconnected to form walls of said pipe pile structure, and
5 said pipe piles axially extending through said soft soil to be embedded in a stratum located below said soft soil,
wherein each pipe pile of said pipe piles is embedded in holes drilled into said stratum.
- 10 2. The pipe pile structure of claim 1, wherein said pipe pile structure has a cross-sectional shape of a rectangle.
3. The pipe pile structure of claim 2, wherein said rectangle is a square.
- 15 4. The pipe pile structure of claim 1, wherein said pipe pile structure has a cross-sectional shape that includes multiple rectangles.
5. The pipe pile structure of any one of the preceding claims, further comprising a capping beam located at a top of said pipe pile structure.
- 20 6. The pipe pile structure of claim 5, wherein said pipe piles are connected to said capping beam by a reinforced concrete plug.
7. The pipe pile structure of any one of the preceding claims, wherein said pipe
25 piles are steel pipes.
8. The pipe pile structure of any one of the preceding claims, wherein said pipe piles are interconnected by interlocks, each interlock comprising two cylinders that are mutually locked.
- 30 9. The pipe pile structure of claim 8, wherein each cylinder has an open slit parallel to a centre axis of said each cylinder, and said each cylinder extending through a corresponding open slit into an interior of the other cylinder, in order to achieve said mutual locking.

10. The pipe pile structure of any one of claims 8 to 9, wherein grouting substantially fills a volume of space shared by interiors of said two cylinders.

5 11. The pipe pile structure of any one of the preceding claims, wherein said stratum has SPT > 100.

12. A method of building a pipe pile structure in soft soil, comprising:
embedding pipe piles through said soft soil into a stratum located below said soft
10 soil; and
interconnecting said pipe piles to form walls of said pipe pile structure,
wherein said pipe piles are embedded into holes drilled into said stratum.

13. The method of claim 12, wherein said pipe pile structure has a cross-
15 sectional shape of a rectangle.

14. The method of claim 13, wherein said rectangle is a square.

15. The method of claim 12, wherein said pipe pile structure has a cross-
20 sectional shape that includes multiple rectangles.

16. The method of any one of claims 12 to 15, further comprising placing a capping beam located at a top of said pipe pile structure.

25 17. The method of claim 16, wherein said pipe piles are connected to said capping beam by a reinforced concrete plug.

18. The method of claim any one of claims 13 to 17, wherein said pipe piles are
30 steel pipes.

19. The method of any one of claims 13 to 18, further comprising interconnecting said pipe piles by interlocks, each interlock comprising two cylinders that are mutually locked.

20. The method of claim 19, further comprising each cylinder having an open slit parallel to a centre axis of said each cylinder, and said each cylinder extending through a corresponding open slit into an interior of the other cylinder.

5 21. The method of claims 19 or 20, further comprising substantially filling a volume of space shared by interiors of said two cylinders with grouting.

22. The method of any one of claims 13 to 21, wherein said stratum has SPT > 100.