

DESCRIPTION

Title of Invention: STEEL SHEET PILE

Technical Field

[0001]

The present invention relates to a U-shaped steel sheet pile having a U-shaped sectional shape or a hat-shaped steel sheet pile having a hat-shaped sectional shape.

Background Art

[0002]

Since a U-shaped steel sheet pile and a hat-shaped steel sheet pile have sectional shapes that are asymmetric about a normal line of a steel sheet pile wall, there may be warp (see Fig. 18) and rotation (torsion) of the U-shaped steel sheet pile and the hat-shaped steel sheet pile when driven to the ground.

In particular, when a driving length of the steel sheet pile increases, this tendency becomes notable. As a result, ground resistance (penetration resistance) and contact resistance between a joint of the steel sheet pile and a joint of an adjacent steel sheet pile increase when the steel sheet pile is driven. This leads to problems such as difficulty of driving the steel sheet pile.

[0003]

In order to prevent these problems from occurring, the length by which the steel sheet pile can be driven and the

like are set in accordance with the sectional shape (size) of the steel sheet pile (see Non Patent Literature 1).

For example, in the case of hydraulic press-in construction method, a U-shaped II_W steel sheet pile can be driven by 10 m and a U-shaped VI_L steel sheet pile can be driven by 30 m.

[0004]

Meanwhile, in the case where, for example, an embankment is built on a thick soft ground layer, it may be required that a long steel sheet pile having a length of 30 m or more be driven in order to prevent subsidence from affecting reinforcing work for embankment or a surrounding structure.

In order to drive a long steel sheet pile, it is required that workability of the steel sheet pile be improved. A water jet construction method serves as a related-art technique that satisfies such a requirement. With the water jet construction method, the steel sheet pile is driven while the surrounding ground is softened by jetting water at high pressure (see Patent Literature 1).

Furthermore, as a technique that reduces frictional resistance on a steel sheet pile surface, there is a method with which a friction reducing material, which contains water-absorbing resin and alkaline water-soluble resin as its indispensable components, is applied or bonded to the

surface as described in Patent Literature 2.

Citation List

Non Patent Literature

[0005]

NPL 1: Japanese Association for Steel Pipe Piles,
"Koyaita: Sekkei Kara Seko Made" (Steel Sheet Pile: From
Design to Installation), pp 337-338, 2007.

Patent Literature

[0006]

PTL 1: Japanese Patent No. 4239566

PTL 2: Japanese Unexamined Patent Application
Publication No. 2008-303628

Summary of Invention

Technical Problem

[0007]

A related-art steel sheet pile may be required to have a larger sectional shape (size) than a sectional shape (size) with which required performance is sufficiently obtained from a viewpoint of a structural design, due to requirements in workability during driving of the steel sheet pile. This leads to a problem in that cost efficiency is degraded.

Furthermore, when the water jet construction method disclosed in Patent Literature 1 is used for improving the workability when driving the steel sheet pile, the following

problems may arise: that is, preparation time for installation at an installation site increases due to, for example, installation work of a jet nozzle through which high-pressure water passes and work for attaching a nozzle holder to the steel sheet pile; and the surrounding ground is disturbed by jetting the high-pressure water, resulting in reduction of soil bearing power and destabilizing the structure.

[0008]

Furthermore, according to Patent Literature 2, in order to reduce a drawing force (negative friction) acting on the steel sheet pile due to ground consolidation settlement in a soft ground layer, a friction reducing material is provided through the entire length of the surface of the steel sheet pile.

However, such a structure is not necessarily rational from the viewpoint of improving drivability by improving a straight advancing property of the steel sheet pile. In particular, in the case of a steel sheet pile with a long driving length, the area on which the friction reducing material is provided increases, thereby significantly increasing the cost. Here, the straight advancing property represents the degree of straightness with which the steel sheet pile penetrates into the ground without warp or rotation (torsion) of the steel sheet pile during the

driving of the steel sheet pile.

[0009]

The present invention is made in order to solve the above described problems. An object of the present invention is to improve the straight advancing property of the steel sheet pile during driving so as to obtain a steel sheet pile which can be prevented from, for example, being warped or falling during the driving and can be installed with a longer driving length than that of the related-art construction methods without adversely affecting a surrounding ground.

Solution to Problem

[0010]

The inventor studied causes of degradation of the straight advancing property occurring when the steel sheet pile is driven. Figs. 30A, 30B, and 31 are explanatory views explaining a state when the U-shaped steel sheet pile is driven.

One of a major causes of an increase in the penetration resistance during driving of the steel sheet pile is thought to be as follows: that is, as illustrated in Figs. 30A, 30B, and 31, soil 13 fills the inside of corners formed by a web and flanges at a lower end portion of a steel sheet pile 11, so that the inside of the lower end portion of the steel sheet pile is closed, and accordingly, frictional resistance

increases at that part.

[0011]

When the frictional resistance on an inner peripheral surface becomes greater than that on an outer peripheral surface in the steel sheet pile 11, a behavior occurs in which the steel sheet pile is warped toward the outside of the steel sheet pile where resistance is smaller. This degrades the straight advancing property. When driving the steel sheet piles, a preceding steel sheet pile is driven, and then a succeeding steel sheet pile is driven while being fitted to the preceding steel sheet pile with joints. Thus, when the preceding steel sheet pile is driven in a warped state, resistance in a joints fitting portion of the succeeding steel sheet pile increases. Thus, the installation becomes difficult.

[0012]

Since the major cause of degrading the straight advancing property of the steel sheet pile is closing of the inside the lower end portion of the steel sheet pile due to soil, the straight advancing property can be maintained by preventing this closing. As a method of preventing the closing of the inside of the lower end portion of the steel sheet pile, friction on a steel sheet pile surface at the lower end portion of the steel sheet pile is reduced. This can prevent the soil from filling the inside of the corners

on the inner peripheral surface of the steel sheet pile, and accordingly, the closing of the inside of the lower end portion can be suppressed. Thus, closing of the inside of the lower end portion of the steel sheet pile can be prevented. Furthermore, the frictional resistance is balanced between the inner peripheral surface and the outer peripheral surface of the steel sheet pile, and the straight advancing property of the steel sheet pile is improved. This can prevent warp, fall, and the like occurring during installation.

[0013]

The present invention is made based on the above-described findings and specifically includes the following structure.

[0014]

(1) A steel sheet pile according to the present invention is a steel sheet pile having a U-shaped or a hat-shaped section.

In the steel sheet pile, friction reducing treatment is applied at least on an inner peripheral surface side of a surface of the steel sheet pile by a length equal to or more than a sectional width of the steel sheet pile and equal to or less than a third of an entire length of the steel sheet pile from a position of the steel sheet pile that is a lower end of the steel sheet pile when the steel sheet pile is

driven into a ground.

[0015]

(2) Further, in the steel sheet pile described above in (1), the friction reducing treatment is applied only on the inner peripheral surface side of the surface of the steel sheet pile.

[0016]

(3) Further, in the steel sheet pile described above in (2), the friction reducing treatment is applied only to a corner on the inner peripheral surface side of the surface of the steel sheet pile.

Advantageous Effects of Invention

[0017]

According to the present invention, the friction reducing treatment is applied at least on the inner peripheral surface side of the surface of the steel sheet pile by a length equal to or more than the sectional width of the steel sheet pile and equal to or less than a third of an entire length of the steel sheet pile from the position of the steel sheet pile that is the lower end of the steel sheet pile when the steel sheet pile is driven into the ground. Thus, the straight advancing property of the steel sheet pile during the driving can be improved, and accordingly, warp, falling, and the like during the installation can be suppressed without adversely affecting

the surrounding soil. As a result, even when a plurality of steel sheet piles are longitudinally joined to one another by, for example, welding at an installation site and driven, the driving length can be increased compared to that of the related-art construction method by using the present invention.

Brief Description of Drawings

[0018]

[Fig. 1A] Fig. 1A is an explanatory view of a U-shaped steel sheet pile according to an embodiment of the present invention.

[Fig. 1B] Fig. 1B is an explanatory view of the U-shaped steel sheet pile according to the embodiment of the present invention.

[Fig. 2] Fig. 2 is an explanatory view of a form of friction reducing treatment applied to the U-shaped steel sheet pile according to the embodiment of the present invention (No. 1).

[Fig. 3] Fig. 3 is an explanatory view of another form of the friction reducing treatment applied to the U-shaped steel sheet pile according to the embodiment of the present invention (No. 2).

[Fig. 4] Fig. 4 is an explanatory view of another form of the friction reducing treatment applied to the U-shaped steel sheet pile according to the embodiment of the present

invention (No. 3).

[Fig. 5] Fig. 5 is an explanatory view of another form of the friction reducing treatment applied to the U-shaped steel sheet pile according to the embodiment of the present invention (No. 4).

[Fig. 6] Fig. 6 is an explanatory view of another form of the friction reducing treatment applied to the U-shaped steel sheet pile according to the embodiment of the present invention (No. 5).

[Fig. 7] Fig. 7 is an explanatory view of another form of the friction reducing treatment applied to the U-shaped steel sheet pile according to the embodiment of the present invention (No. 6).

[Fig. 8] Fig. 8 is an explanatory view of another form of the friction reducing treatment applied to the U-shaped steel sheet pile according to the embodiment of the present invention (No. 7).

[Fig. 9] Fig. 9 is an explanatory view of a hat-shaped steel sheet pile according to an embodiment of the present invention.

[Fig. 10] Fig. 10 is an explanatory view of a form of the friction reducing treatment applied to the hat-shaped steel sheet pile according to the embodiment of the present invention (No. 1).

[Fig. 11] Fig. 11 is an explanatory view of another

form of the friction reducing treatment applied to the hat-shaped steel sheet pile according to the embodiment of the present invention (No. 2).

[Fig. 12] Fig. 12 is an explanatory view of another form of the friction reducing treatment applied to the hat-shaped steel sheet pile according to the embodiment of the present invention (No. 3).

[Fig. 13] Fig. 13 is an explanatory view of another form of the friction reducing treatment applied to the hat-shaped steel sheet pile according to the embodiment of the present invention (No. 4).

[Fig. 14] Fig. 14 is an explanatory view of another form of the friction reducing treatment applied to the hat-shaped steel sheet pile according to the embodiment of the present invention (No. 5).

[Fig. 15] Fig. 15 is an explanatory view of another form of the friction reducing treatment applied to the hat-shaped steel sheet pile according to the embodiment of the present invention (No. 6).

[Fig. 16] Fig. 16 is an explanatory view of another form of the friction reducing treatment applied to the hat-shaped steel sheet pile according to the embodiment of the present invention (No. 7).

[Fig. 17A] Fig. 17A is an explanatory view of experimental conditions according to a first example of the

present invention explaining a form of the friction reducing treatment applied to the U-shaped steel sheet pile.

[Fig. 17B] Fig. 17B is an explanatory view of the experimental conditions according to the first example of the present invention explaining a form of the friction reducing treatment applied to the U-shaped steel sheet pile.

[Fig. 17C] Fig. 17C is an explanatory view of the experimental conditions according to the first example of the present invention explaining a form of the friction reducing treatment applied to the U-shaped steel sheet pile.

[Fig. 17D] Fig. 17D is an explanatory view of the experimental conditions according to the first example of the present invention explaining a form of the friction reducing treatment applied to the U-shaped steel sheet pile.

[Fig. 17E] Fig. 17E is an explanatory view of the experimental conditions according to the first example of the present invention explaining a form of the friction reducing treatment applied to the U-shaped steel sheet pile.

[Fig. 18] Fig. 18 is an explanatory view of an evaluation method for experimental results according the first example of the present invention.

[Fig. 19] Fig. 19 is a graph based on the experimental results according to the first example of the present invention (No. 1).

[Fig. 20] Fig. 20 is a graph based on the experimental

results according to the first example of the present invention (No. 2).

[Fig. 21] Fig. 21 is a graph based on the experimental results according to the first example of the present invention (No. 3).

[Fig. 22] Fig. 22 is a graph based on the experimental results according to the first example of the present invention (No. 4).

[Fig. 23] Fig. 23 is a graph based on the experimental results according to the first example of the present invention (No. 5).

[Fig. 24A] Fig. 24A is an explanatory view of experimental conditions according to a second example of the present invention explaining a form of the friction reducing treatment applied to the hat-shaped steel sheet pile.

[Fig. 24B] Fig. 24B is an explanatory view of the experimental conditions according to the second example of the present invention explaining a form of the friction reducing treatment applied to the hat-shaped steel sheet pile.

[Fig. 24C] Fig. 24C is an explanatory view of experimental conditions according to the second example of the present invention explaining a form of the friction reducing treatment applied to the hat-shaped steel sheet pile.

[Fig. 24D] Fig. 24D is an explanatory view of experimental conditions according to the second example of the present invention explaining a form of the friction reducing treatment applied to the hat-shaped steel sheet pile.

[Fig. 24E] Fig. 24E is an explanatory view of experimental conditions according to the second example of the present invention explaining a form of the friction reducing treatment applied to the hat-shaped steel sheet pile.

[Fig. 25] Fig. 25 is a graph based on experimental results according to the second example of the present invention (No. 1).

[Fig. 26] Fig. 26 is a graph based on the experimental results according to the second example of the present invention (No. 2).

[Fig. 27] Fig. 27 is a graph based on the experimental results according to the second example of the present invention (No. 3).

[Fig. 28] Fig. 28 is a graph based on the experimental results according to the second example of the present invention (No. 4).

[Fig. 29] Fig. 29 is a graph based on the experimental results according to the second example of the present invention (No. 5).

[Fig. 30A] Fig. 30A is an explanatory view explaining a problem to be solved by the present invention (No. 1).

[Fig. 30B] Fig. 30B is an explanatory view explaining the problem to be solved by the present invention (No. 2).

[Fig. 31] Fig. 31 is an explanatory view explaining the problem to be solved by the present invention (No. 3).

[Fig. 32] Fig. 32 is a graph for evaluating the difference in the effect of reducing the friction affected by a steel sheet pile length.

Description of Embodiments

[0019]

In a U-shaped steel sheet pile 1 according to an embodiment of the present invention, friction reducing treatment is applied at least on an inner peripheral surface side of a steel sheet pile surface by a length equal to or more than a steel sheet pile sectional width and equal to a third of a steel sheet pile entire length from a position of the steel sheet pile that is a lower end of the steel sheet pile 1 when the steel sheet pile 1 is driven into the ground.

The U-shaped steel sheet pile 1 according to the present embodiment is described in detail below.

[0020]

As illustrated in Fig. 1A, the U-shaped steel sheet pile 1 has a substantially U-shaped section and includes a web portion 1a, flange portions 1b provided on both sides of

the web portion 1a, and joint portions 1c provided at ends of the flange portions 1b.

As illustrated in Fig. 1B, the steel sheet pile length and the steel sheet pile sectional width of the U-shaped steel sheet pile 1 are respectively indicated by L and B.

[0021]

The lower end portion of the U-shaped steel sheet pile 1 is provided with a friction reducing material 3 to which the friction reducing treatment is applied. The friction reducing treatment is applied in any of the following forms.

[0022] <Form of the Friction Reducing Treatment>

The friction reducing treatment may be in the form of, for example, applying a related-art friction reducing material such as a resinous material, asphalt, or paint, in the form of a method such as applying a chemical treatment to the surface of the steel sheet pile or adjusting chemical composition of the steel sheet pile, or in the form of attaching a plate-shaped member or the like capable of reducing friction to the steel sheet pile surface.

In the case of applying the friction reducing material, a coating film needs to be sufficiently hard so that the coating film is not removed by driving the steel sheet pile.

[0023] <A Range of Application of the Friction Reducing Treatment>

Preferably, the length of a range in which the friction

reducing treatment is applied (length S of a friction reducing treatment range) is a length equal to or more than a steel sheet pile sectional width B and equal to or less than a third of a steel sheet pile entire length L from the position of the steel sheet pile that is the lower end of the steel sheet pile when the steel sheet pile is driven into the ground. When a plurality of steel sheet piles are longitudinally joined to one another so as to be driven, the steel sheet pile entire length L is defined as the total length of the plurality of steel sheet piles.

The reason for this is that, as will be demonstrated in examples described later, even when the friction reducing treatment is applied by the length more than a third of the steel sheet pile entire length, a straight advancing property is not significantly improved while the cost is increased.

In contrast, when the length by which the friction reducing treatment is applied is less than the steel sheet pile sectional width B , an effect of ensuring the straight advancing property, which is an object of the present invention, cannot be sufficiently obtained.

[0024]

Furthermore, the friction reducing treatment is required to be applied at least on the inner peripheral surface side of the steel sheet pile surface. In the

present embodiment, as illustrated in Fig. 2, an example is described in which the friction reducing material 3 is applied to both the inner peripheral surface side and an outer peripheral surface side of the steel sheet pile 1. The application of the friction reducing material 3 may be application of the friction reducing material or the attachment of the friction reducing member described above as the form of the friction reducing treatment.

preparation time for installation at an installation site can be reduced by applying the friction reducing material 3 in advance at the factory or the like.

[0025]

According to the present embodiment, the friction reducing material 3 is applied at least on the inner peripheral surface side of the steel sheet pile surface by a length equal to or more than the steel sheet pile sectional width B and equal to a third of the steel sheet pile entire length L from the lower end position of the steel sheet pile 1. Thus, penetration resistance generated when the steel sheet pile 1 is driven can be reduced and the straight advancing property of the steel sheet pile can be improved. As a result, warp, fall, and the like of the steel sheet pile 1 during installation of the steel sheet pile can be suppressed.

Furthermore, unlike the case where a water jet

construction method is used, a long steel sheet pile can be installed without adversely affecting the surrounding ground.

These effects will be demonstrated in the examples described later.

[0026]

In the case where, for example, an embankment is built on a thick soft ground layer, a steel sheet pile having a length of 30 m or more may be driven in order to prevent subsidence from affecting reinforcing work for embankment or a surrounding structure. However, the length of the steel sheet pile that can be transported by a vehicle is usually about 15 m. Thus, a plurality of steel sheet piles are longitudinally joined to one another by welding or the like at an installation site.

[0027]

In the example of the above description, the friction reducing material 3 is applied to the entire periphery of the surface of the U-shaped steel sheet pile 1 (see Fig. 2). However, it is sufficient that the friction reducing material 3 be applied at least on the inner peripheral surface side of the surface of the U-shaped steel sheet pile 1. Thus, the friction reducing material 3 may be applied only to the inner peripheral surface side of the U-shaped steel sheet pile 1 as illustrated in Fig. 3.

In this case, cost can be reduced due to reduction of

the amount or the like of the friction reducing material 3 and, at the same time, the effect of reducing the penetration resistance similar to that obtained with the structure of Fig. 2 can be obtained.

[0028]

Furthermore, from the viewpoint of preventing the warp and falling during installation, frictional resistance on the inner peripheral surface and the outer peripheral surface of the steel sheet pile are balanced more in the case where the friction reducing material 3 is applied only to the inner peripheral surface side of a certain region of the surface of the steel sheet pile from the lower end of the steel sheet pile than in the case where the friction reducing material 3 is applied to an entire periphery of a certain region of the surface of the steel sheet pile from the lower end of the steel sheet pile. When the frictional resistance is balanced as described above, the straight advancing property of the steel sheet pile is further improved, and accordingly, the effect of suppressing the warp during the installation can be expected. This is demonstrated in the examples to be described later.

[0029]

In the case where the friction reducing material 3 is applied only to the inner peripheral surface side of the steel sheet pile 1, it is not required to apply the friction

reducing material 3 to the entirety of the inner peripheral surface. Preferred forms of the application of the friction reducing material 3 only to the inner peripheral surface of the steel sheet pile 1 are described in detail below.

[0030]

Fig. 4 is a variant of the steel sheet pile 1 of Fig. 3 in which the application of the friction reducing material 3 to inner peripheral surfaces of the joint portions 1c is omitted. The reason for this is that contribution of the frictional resistance to an effect of constraining soil is thought to be small at the inner peripheral surfaces of the joint portions 1c.

[0031]

In an example illustrated in Fig. 5, the friction reducing material 3 is applied only to corners 1d on the inner peripheral surface side of the U-shaped steel sheet pile 1. Here, the web portion 1a and the flange portions 1b form obtuse angles at the corners 1d. The portion to which the friction reducing material 3 is applied in a corner 1d may be determined from the viewpoints of an effect of improvement and cost efficiency. Ranges of the application are preferably, for example, from a fifth to a third of the entire length of the web portion 1a in the web portion 1a and from a third to two thirds of the entire length of the flange portions 1b in the flange portions 1b.

Since contribution of the frictional resistance to the effect of constraining soil is thought to be large at the corners 1d, effects of suppressing the warp and reducing the penetration resistance during driving are high when the friction reducing material 3 is applied to those portions.

That is, with the example of Fig. 5, cost can be further reduced since the amount of the friction reducing material 3 to be applied can be further reduced compared to the case of Fig. 4, and, at the same time, the effects of suppressing the warp and reducing the penetration resistance during the driving of the steel sheet pile similar to those obtained with the structure of Fig. 2 or Fig. 3 can be obtained.

[0032]

In an example illustrated in Fig. 6, the friction reducing material 3 is also applied to a central portion of the inner peripheral surface side of the web portion 1a of the U-shaped steel sheet pile 1 in addition to the corners 1d illustrated in Fig. 5.

Since the frictional resistance at the central portion of the inner peripheral surface side of the web portion 1a is also thought to contribute to the effect of constraining soil, the application of the friction reducing material 3 to those portions is effective for suppressing the warp and reducing the penetration resistance during installation of

the steel sheet pile.

[0033]

In an example illustrated in Fig. 7, the friction reducing material 3 is applied only to an inner peripheral surface of the web portion 1a of the U-shaped steel sheet pile 1. By applying the friction reducing material 3 to the inner peripheral surface of the web portion 1a of the U-shaped steel sheet pile 1, friction is reduced on one side (web portion 1a side) of each of the corners 1d, and accordingly, an effect of preventing soil from being constrained at the corners 1d can be expected.

[0034]

In an example illustrated in Fig. 8, the friction reducing material 3 is applied only to inner peripheral surfaces of the flange portions 1b of the U-shaped steel sheet pile 1. As is the case with the example illustrated in Fig. 7, the effect of preventing soil from being constrained at the corners 1d can be expected also in this case.

[0035]

Although the examples of the U-shaped steel sheet pile 1 have been described above as the target steel sheet pile of the present invention, the present invention is similarly targeted also for a hat-shaped steel sheet pile 5.

As illustrated in Fig. 9, the sectional shape of the

hat-shaped steel sheet pile 5 includes a web portion 5a, flange portions 5b provided on both sides of the web portion 5a, arm portions 5c extending from the flange portions 5b in the width direction so as to be bent relative to the flange portions 5b, and joint portions 5d provided at ends of the arm portions 5c.

[0036]

Forms of the friction reducing treatment for the case of the hat-shaped steel sheet pile 5 are described below.

Referring to Fig. 10, the friction reducing material 3 is applied to an entire periphery of a surface of the hat-shaped steel sheet pile 5.

Referring to Fig. 11, the friction reducing material 3 is applied entirely on the inner peripheral surface side of the surface of the hat-shaped steel sheet pile 5.

Referring to Fig. 12, the application of the friction reducing material 3 to the arm portions 5c of the inner peripheral surface of the surface of the hat-shaped steel sheet pile 5 is omitted. The reason for this is that contribution of the frictional resistance to the effect of constraining soil is thought to be small at the arm portions 5c.

[0037]

Referring to Fig. 13, the friction reducing treatment is applied only to corners 5e of the inner peripheral

surface of the hat-shaped steel sheet pile 5 as is the case with the U-shaped steel sheet pile 1 (see Fig. 5). With the example of Fig. 13, as is the case with the U-shaped steel sheet pile 1 of Fig. 5, the amount of the friction reducing material 3 to be applied can be reduced, and, at the same time, the effects of suppressing the warp and reducing the penetration resistance during the installation similar to those obtained with the structure of Fig. 10 or Fig. 11 can be obtained.

[0038]

Referring to Fig. 14, as is the case with the U-shaped steel sheet pile 1 of Fig. 6, the friction reducing material 3 is also applied to a central portion of an inner peripheral surface of the web portion 5a of the hat-shaped steel sheet pile 5 in addition to the corners 5e.

In an example illustrated in Fig. 15, as is the case with the U-shaped steel sheet pile 1 of Fig. 7, the friction reducing material 3 is only applied to the inner peripheral surface of the web portion 5a of the hat-shaped steel sheet pile 5. Also in this case, as is the case with the U-shaped steel sheet pile 1, friction is reduced on one side (web portion 5a side) of each of the corners 5e, and accordingly, the effect of preventing soil being constrained at the corners 5e can be expected.

In an example illustrated in Fig. 16, as is the case

with the U-shaped steel sheet pile 1 of Fig. 8, the friction reducing material 3 is applied only to inner peripheral surfaces of the flange portions 5b. As is the case with the example illustrated in Fig. 15, the effect of preventing soil from being constrained at the corners 5e can be expected also in this case.

First Example

[0039]

In order to verify the effects of the present invention, an experiment with models (1/10 scale models) of the U-shaped steel sheet pile 1 was performed. The results are described below.

The experiment was performed by simulating actual installation. A homogeneous sand ground having a depth of 1.5 m (corresponding to a full-scale depth of 15 m) was created in a soil box. Steel sheet pile models to which the friction reducing treatment was applied under different conditions were penetrated into the sand ground by their entire lengths using hydraulic pressure. The ratio of penetration resistance and the warp of each of the steel sheet pile models of the different conditions during the driving were used as evaluation items, and the experiment results were obtained.

In the experiment, a pattern of the application of the friction reducing material and the length of the range of

the application of the friction reducing material 3 (length S of the friction reducing treatment range) from the lower end of each of the steel sheet pile were varied.

In the experiment, the driving length was the steel sheet pile entire length.

[0040]

Patterns of the application of the friction reducing material are described with reference to Figs. 17A to 17E. Dimensions in Figs. 17A to 17E represent full-scale values. The plate thickness is 20 mm in full scale.

The patterns of the application of the friction reducing material are the following five patterns: that is, a pattern N in which the friction reducing material 3 is not applied (see Fig. 17A); a pattern A in which the friction reducing material 3 is applied to the entire surface by the length S of the friction reducing treatment range from the lower end of the U-shaped steel sheet pile 1 (see Fig. 17B); a pattern B in which the friction reducing material 3 is applied only to the inner peripheral surface side of the surface by the length S of the friction reducing treatment range from the lower end of the U-shaped steel sheet pile 1 (see Fig. 17C); a pattern C in which the friction reducing material 3 is applied only to the corners 1d on the inner peripheral surface side of the surface by the length S of the friction reducing treatment range from the lower end of

the U-shaped steel sheet pile 1 (see Fig. 17D); and a pattern D in which the friction reducing material 3 is applied only to the web portion 1a on the inner peripheral surface side of the surface by the length S of the friction reducing treatment range from the lower end of the U-shaped steel sheet pile 1 (see Fig. 17E).

[0041]

The length S of the friction reducing treatment range is one of the following seven values: 0 m (the friction reducing material 3 is not applied); 0.2 m ($= 1/3 \times B$, where B is the steel sheet pile sectional width); 0.6 m ($= B$); 1.2 m ($= 0.1 \times L$, where L is the steel sheet pile length); 4 m ($= 1/3 \times L$); 6 m ($= 1/2 \times L$); and 12 m ($= L$, that is, the friction reducing material 3 is applied through the steel sheet pile entire length).

[0042]

Next, the evaluation items, that is, the ratio of penetration resistance and the warp of the steel sheet pile during the driving are described.

The ratio of penetration resistance during the driving is the ratio of a maximum penetration resistance force in cases where the friction reducing material 3 is applied to a reference ($= 1.0$) which is a maximum penetration resistance force in a case where the friction reducing material 3 is not applied (U-shaped-N-0 (first comparative example)). As

the value of the ratio of penetration resistance of a case reduces, the penetration resistance of the case reduces and the case is preferred.

As illustrated in Fig. 18, the warp (rad) of the steel sheet pile is Δ/L when displacement between a head of the steel sheet pile and the lower end of the steel sheet pile in the horizontal direction is the amount of warp Δ . As the value of Δ reduces, the warp of the steel sheet pile reduces and the case is preferred.

The conditions and results of the above-described experiment are summarized in Table 1.

[0043]

[Table 1]

Case name	Experimental conditions				Experimental results	
	Steel sheet pile width B(m)	Steel sheet pile length L(m)	Pattern of friction reducing material	Length S of friction reducing treatment range (m)	Ratio of penetration resistance during installation	Warp of steel sheet pile (rad)
U-shaped-N-0 (first comparative example)	0.6	12	Pattern N	0	1.00	0.120
U-shaped-A-02 (second comparative example)	0.6	12	Pattern A	0.2	0.97	0.115
U-shaped-A-06 (first example of present invention)	0.6	12	Pattern A	0.6	0.79	0.081
U-shaped-A-12 (second example of present invention)	0.6	12	Pattern A	1.2	0.56	0.051
U-shaped-A-40 (third example of present invention)	0.6	12	Pattern A	4	0.32	0.031
U-shaped-A-60 (third comparative example)	0.6	12	Pattern A	6	0.30	0.029
U-shaped-A-120 (fourth comparative example)	0.6	12	Pattern A	12	0.26	0.030
U-shaped-B-12 (fourth example of present invention)	0.6	12	Pattern B	1.2	0.60	0.047
U-shaped-C-12 (fifth example of present invention)	0.6	12	Pattern C	1.2	0.64	0.057
U-shaped-D-12 (sixth example of present invention)	0.6	12	Pattern D	1.2	0.82	0.084

[0044]

It is noted that, in Table 1, the steel sheet pile

sectional width B , the steel sheet pile length L , and the length S of the friction reducing treatment range represent calculated full-scale values (multiplying the sizes of the actual steel sheet pile models by ten).

Various graphs are drawn in accordance with the experimental results (evaluation items) listed in Table 1 and evaluation is made in accordance with these graphs. Results of the evaluation are described as follows.

Fig. 19 is a graph for evaluating the difference in accordance with values of the length S of the friction reducing treatment range. In this graph, the horizontal axis represents the length S (m) of the friction reducing treatment range and the vertical axis represents the warp (rad) of the steel sheet pile.

Referring to Fig. 19, the experimental results of the pattern N (first comparative example) and the pattern A (second to fourth comparative examples and first to third examples of the present invention) of the application of the friction reducing material out of the experimental results listed in Table 1 are plotted.

[0045]

As illustrated in Fig. 19, as the length S of the friction reducing treatment range increases, the warp of the steel sheet pile generally reduces. However, when the length S of the friction reducing treatment range exceeds 4

$m (= 1/3 \times L)$, the degree of the reduction of the warp of the steel sheet pile becomes small. Thus, when considering the cost of applying the friction reducing material 3, setting the length S of the friction reducing treatment range to be $1/3 \times L$ or less is a preferable condition as has been described above in the embodiment.

[0046]

Furthermore, according to Fig. 19, with the second comparative example having a length S of the friction reducing treatment range of $0.2 \text{ m} (= 1/3 \times B)$, the effect of reducing the warp of the steel sheet pile compared to the warp of the first comparative example without the friction reducing treatment is small. In contrast, the effect of reducing the warp of the steel sheet pile is significant with the first example of the present invention having a $0.6 \text{ m} (= B)$ length S of the friction reducing treatment range. From these, it has been confirmed that setting the length S of the friction reducing treatment range to B (steel sheet pile sectional width) or more is preferred.

[0047]

Fig. 20 is a graph for comparing the warp of the steel sheet pile observed with the patterns of the application of the friction reducing material. In this graph, the pattern N in which the friction reducing material 3 is not applied and the cases (pattern A to pattern D) where the friction

reducing material 3 is applied are compared. Furthermore, in order to evaluate only the effects of the patterns of the application of the friction reducing material, the experimental results of the example (second example of the present invention) having a 0.12 m length S of the friction reducing treatment range that is the same as those of the pattern B to pattern D are used as the experimental results of the pattern A.

The vertical axis of Fig. 20 represents the warp (rad) of the steel sheet pile.

[0048]

As illustrated in Fig. 20, compared to the pattern N in which the friction reducing material 3 is not applied, the warp of the steel sheet pile reduces with the patterns A to D in which the friction reducing material 3 is applied. The magnitude of the effect (effect of reducing the warp of the steel sheet pile) is in the following order from the greatest: the pattern B, the pattern A, the pattern C, and the pattern D. That is, the pattern B is most effective.

The reason why the effect of suppressing the warp of the steel sheet pile is higher with the pattern B than with the pattern A is thought to be as follows: that is, frictional resistance on the inner peripheral surface and the outer peripheral surface of the steel sheet pile are balanced, and accordingly, the straight advancing property

of the steel sheet pile is increased, thereby suppressing the warp during the installation. That is, in a state in which the friction reducing material 3 is not applied, frictional resistance is smaller in the outer peripheral surface than in the inner peripheral surface of the steel sheet pile. Thus, applying the friction reducing material 3 only to the inner peripheral surface is thought to balance the frictional resistance between the inner peripheral surface and the outer peripheral surface of the steel sheet pile.

[0049]

Fig. 21 is a graph for comparing the ratio of penetration resistance observed with the patterns of the application of the friction reducing material. In this graph, as is the case with Fig. 20, the pattern N in which the friction reducing material 3 is not applied and the cases (pattern A to pattern D) where the friction reducing material 3 is applied are compared. The experimental results of the second example of the present invention are used as the experimental results of the pattern A.

As illustrated in Fig. 21, compared to the pattern N in which the friction reducing material 3 is not applied, the ratio of penetration resistance reduces with the patterns A to D in which the friction reducing material 3 is applied. The magnitude of the effect (effect of reducing the ratio of

penetration resistance) is in the following order from the greatest: the pattern A, the pattern B, the pattern C, and the pattern D.

[0050]

Fig. 22 is a graph illustrating the relationship between the peripheral length of the application of the friction reducing material 3 and the warp of the steel sheet pile in the cases where the friction reducing material 3 is applied (pattern A to pattern D).

Referring to Fig. 22, the pattern A and the pattern D are plotted at positions above a line P_1 that passes through positions where the pattern B and the pattern C are plotted. This means that the effect of suppressing the warp of the steel sheet pile in relation to the peripheral length of the application of the friction reducing material 3 is smaller with the pattern A and the pattern D than with the pattern B and the pattern C.

Accordingly, from the viewpoint of suppressing the warp of the steel sheet pile, as the patterns of the application of the friction reducing material, the shapes of the pattern B and the pattern C are preferred.

[0051]

Fig. 23 is a graph illustrating the relationship between the peripheral length of the application of the friction reducing material 3 and the ratio of penetration

resistance in the cases where the friction reducing material 3 is applied (pattern A to pattern D). With the pattern A, the pattern B, and the pattern C, as the peripheral length of the application of the friction reducing material 3 increases, the ratio of penetration resistance substantially linearly (see line P_2 of Fig. 23) reduces. However, the position where the pattern D is plotted is located above the line P_2 connecting the pattern A, the pattern B, and the pattern C to one another. This means that the effect of reducing the ratio of penetration resistance in relation to the peripheral length of the application of the friction reducing material 3 is smaller with the pattern D than with the other patterns. Accordingly, from the viewpoint of reducing the ratio of penetration resistance, as the patterns of the application of the friction reducing material, the shapes of the pattern A, the pattern B, and the pattern C are preferred.

Second Example

[0052]

Regarding the hat-shaped steel sheet pile 5, in order to verify the effects of the present invention, an experiment with models similar to that of the first example was performed. The results are described below.

Parameters in the experiment were the patterns of the application of the friction reducing material and the length

S of the friction reducing treatment range.

In the experiment, the driving length was the steel sheet pile entire length.

[0053]

Patterns of the application of the friction reducing material are illustrated in Figs. 24A to 24E. Dimensions in Figs. 24A to 24E represent full-scale values. The plate thickness is 20 mm in full scale.

The patterns of the application of the friction reducing material are similar to those for the U-shaped steel sheet pile 1 of the first example and are the following five patterns as illustrated in Figs. 24A to 24E: that is, a pattern N in which the friction reducing material 3 is not applied (see Fig. 24A); a pattern A in which the friction reducing material 3 is applied to the entire surface by the length S of the friction reducing treatment range from the lower end of the hat-shaped steel sheet pile 5 (see Fig. 24B); a pattern B in which the friction reducing material 3 is applied only to the inner peripheral surface side of the surface by the length S of the friction reducing treatment range from the lower end of the surface of the hat-shaped steel sheet pile 5 (see Fig. 24C); a pattern C in which the friction reducing material 3 is applied only to the corners 5e on the inner peripheral surface side of the surface by the length S of the friction reducing treatment

range from the lower end of the hat-shaped steel sheet pile 5 (see Fig. 24D); and a pattern D in which the friction reducing material 3 is applied only to the web portion 5a on the inner peripheral surface side of the surface by the length S of the friction reducing treatment range from the lower end of the hat-shaped steel sheet pile 5 (see Fig. 24E).

[0054]

The length S of the friction reducing treatment range is one of the following five values: 0 m (the friction reducing material 3 is not applied); 0.9 m (= B, where B is the steel sheet pile sectional width); 2.4 m (= $0.2 \times L$, where L is the steel sheet pile length); 4 m (= $1/3 \times L$); and 6 m (= $1/2 \times L$).

[0055]

Since evaluation items (the ratio of the penetration resistance during the driving and the warp of the steel sheet pile) are similar to those of the first example, description thereof is omitted.

The conditions and results of the experiment are summarized in Table 2.

[0056] [Table 2]

Case name	Experimental conditions				Experimental results	
	Steel sheet pile width B(m)	Steel sheet pile length L(m)	Pattern of application of friction reducing material	Length S of friction reducing treatment range (m)	Ratio of penetration resistance during installation	Warp of steel sheet pile (rad)
Hat-N-0 (fifth comparative example)	0.9	12	Pattern N	0	1.00	0.060
Hat-A-09 (seventh example of present invention)	0.9	12	Pattern A	0.9	0.75	0.046
Hat-A-24 (eighth example of present invention)	0.9	12	Pattern A	2.4	0.60	0.038
Hat-A-40 (ninth example of present invention)	0.9	12	Pattern A	4	0.53	0.031
Hat-A-60 (sixth comparative example)	0.9	12	Pattern A	6	0.51	0.030
Hat-B-40 (tenth example of present invention)	0.9	12	Pattern B	4	0.59	0.029
Hat-C-40 (eleventh example of present invention)	0.9	12	Pattern C	4	0.63	0.039
Hat-D-40 (twelfth example of present invention)	0.9	12	Pattern D	4	0.90	0.056

[0057]

Graphs corresponding to the graphs of the first example are drawn in accordance with values listed in Table 2 and evaluation is made in accordance with these graphs. Results of the evaluation are described as follows.

[0058]

Fig. 25 corresponds to Fig. 19 of the first example and

illustrates the relationship between the length S of the friction reducing treatment range and the warp of the steel sheet pile.

As is the case with the first example, as the length S of the friction reducing treatment range increases, the ratio of penetration resistance generally tends to reduce. However, as illustrated in Fig. 25, when the length S of the friction reducing treatment range exceeds 4 m ($= 1/3 \times L$), the degree of the reduction of the warp of the steel sheet pile becomes small. Thus, when considering the cost of applying the friction reducing material 3, setting the length S of the friction reducing treatment range to be 4 m ($= 1/3 \times L$) or less is a preferable condition.

[0059]

Fig. 26 corresponds to Fig. 20 of the first example and illustrates the relationship between the warp of the steel sheet pile observed with the patterns of the application of the friction reducing material. In this graph, the pattern N in which the friction reducing material 3 is not applied and cases (pattern A to pattern D) where the friction reducing material 3 is applied are compared. The experimental results of the ninth example of the present invention are used as the experimental results of the pattern A.

As illustrated in Fig. 26, compared to the pattern N in

which the friction reducing material 3 is not applied, the warp of the steel sheet pile reduces in cases where the friction reducing material 3 is applied (patterns A to D). The magnitude of the effect (effect of reducing the warp of the steel sheet pile) is in the following order from the greatest: the pattern B, the pattern A, the pattern C, and the pattern D. That is, the pattern B is most effective for suppressing the warp of the steel sheet pile. Accordingly, also for the hat-shaped steel sheet pile 5, as is the case with the U-shaped steel sheet pile, the application of the friction reducing material 3 in the pattern B is most preferred from the viewpoint of the straight advancing property.

[0060]

Fig. 27 corresponds to Fig. 21 of the first example and illustrates the ratio of penetration resistance observed with the patterns of the application of the friction reducing material.

As illustrated in Fig. 27, compared to the pattern N in which the friction reducing material 3 is not applied, the ratio of penetration resistance reduces with the cases in which the friction reducing material 3 is applied (pattern A to pattern D). The magnitude of the effect (effect of reducing the ratio of penetration resistance) is in the following order from the greatest: the pattern A, the

pattern B, the pattern C, and the pattern D.

[0061]

Fig. 28 corresponds to Fig. 22 of the first example and illustrates the relationship between the peripheral length of the application of the friction reducing material 3 and the warp of the steel sheet pile in the cases where the friction reducing material 3 is applied (pattern A to pattern D).

Referring to Fig. 28, the pattern A and the pattern D are plotted at positions above a line P_3 that passes through positions where the pattern B and the pattern C are plotted. This means that the effect of reducing the warp of the steel sheet pile in relation to the peripheral length of the application of the friction reducing material 3 is smaller with the pattern A and the pattern D than with the pattern B and the pattern C.

Accordingly, from the viewpoint of suppressing the warp of the steel sheet pile, as the patterns of the application of the friction reducing material, the shapes of the pattern B and the pattern C are preferred as is the case with the first example.

[0062]

Fig. 29 corresponds to Fig. 23 of the first example and illustrates the relationship between the peripheral length of the application of the friction reducing material 3 and

the ratio of penetration resistance in the cases where the friction reducing material 3 is applied (pattern A to pattern D).

With the pattern A, the pattern B, and the pattern C, in accordance with the peripheral length of the application of the friction reducing material 3, the ratio of penetration resistance substantially linearly (see line P_4 of Fig. 29) reduces. However, the position where the pattern D is plotted is located above the line P_4 connecting the pattern A, the pattern B, and the pattern C to one another. This means that the effect of reducing the ratio of penetration resistance in relation to the peripheral length of the application of the friction reducing material 3 is smaller with the pattern D than with the other patterns. Accordingly, from the viewpoint of reducing the ratio of penetration resistance, as the patterns of the application of the friction reducing material, the shapes of the pattern A, the pattern B, and the pattern C are preferred.

Third Example

[0063]

Regarding the effects of the present invention, in order to verify the effects due to changes in the steel sheet pile length, an experiment with models (1/20 scale models) of the U-shaped steel sheet pile 1 was performed. The results are described below.

The experiment was performed by simulating actual installation. A homogeneous sand ground having a depth of 2.0 m (corresponding to a full-scale depth of 40 m) was created in a soil box. Steel sheet pile models having lengths L corresponding to full-scale lengths of 12 m, 24 m, and 36 m were penetrated into the sand ground by their entire lengths using hydraulic pressure. The ratio of penetration resistance and the warp of each of the steel sheet pile models of the different conditions during the driving were used as evaluation items, and the experiment results were obtained.

The experiment was performed for the models of the steel sheet piles having the varied lengths with or without the friction reducing treatment applied thereto.

In the experiment, the driving length was the steel sheet pile entire length.

[0064]

For all cases where the friction reducing material is applied, the pattern of the application of the friction reducing material is the pattern A (see Fig. 17B, values are represented in full scale). The length S of the friction reducing treatment range is $0.1 \times L$ (where L is the steel sheet pile length).

[0065]

Next, the evaluation items, that is, the ratio of

penetration resistance and the warp of the steel sheet pile during the driving are described.

The ratio of penetration resistance during the driving is the ratio of a maximum penetration resistance force in cases where the friction reducing material 3 is applied to a reference (= 1.0) which is a maximum penetration resistance force in cases where the friction reducing material 3 is not applied (U-shaped 12-N-0 (seventh comparative example), U-shaped 24-N-0 (eighth comparative example), and U-shaped 36-N-0 (ninth comparative example)). As the value of the ratio of penetration resistance of a case reduces, the effect of reducing the penetration resistance of the case increases and the case is preferred.

As illustrated in Fig. 18, the warp (rad) of the steel sheet pile is Δ/L when displacement between the head of the steel sheet pile and the lower end of the steel sheet pile in the horizontal direction is the amount of warp Δ . As the value of Δ reduces, the warp of the steel sheet pile reduces and the case is preferred.

It is noted that, the U-shaped 36-N-0 (ninth comparative example) was failed to be penetrated due to deformation of the steel sheet pile at a depth (corresponding to a full-scale depth) of 28 m during installation, and accordingly, measurement of the final warp of the steel sheet pile failed.

The conditions and results of the above-described experiment are summarized in Table 3.

[0066]

[Table 3]

Case name	Experimental conditions				Experimental results	
	Steel sheet pile width B(m)	Steel sheet pile length L(m)	Pattern of friction reducing material	Length S of friction reducing treatment range (m)	Ratio of penetration resistance during installation	Warp of steel sheet pile (rad)
U-shaped 12-N-0 (seventh comparative example)	0.6	12	Pattern N	0	1.00	0.114
U-shaped 12-A-12 (thirteenth example of present invention)	0.6	12	Pattern A	1.2	0.61	0.042
U-shaped 24-N-0 (eighth comparative example)	0.6	24	Pattern N	0	1.00	0.161
U-shaped 24-A-24 (fourteenth example of present invention)	0.6	24	Pattern A	2.4	0.52	0.048
U-shaped 36-N-0 (ninth comparative example)	0.6	36	Pattern N	0	1.00	-
U-shaped 36-A-36 (fifteenth example of present invention)	0.6	36	Pattern A	3.6	0.45	0.052

[0067]

It is noted that, in Table 3, the steel sheet pile sectional width B, the steel sheet pile length L, and the length S of the friction reducing treatment range represent calculated full-scale values (multiplying the sizes of the

actual steel sheet pile models by twenty).

Fig. 32 is a graph for evaluating the difference in the effect of reducing the friction affected by the steel sheet pile length. In this graph, the horizontal axis represents the steel sheet pile length L (m) and the vertical axis represents the ratio of penetration resistance.

[0068]

As illustrated in Fig. 32, as the steel sheet pile length L increases, the ratio of penetration resistance reduces. Thus, as the steel sheet pile length increases, the effect produced by the friction reducing material tends to increase. Accordingly, it has been confirmed that application of the present invention is preferred.

[0069]

As has been described, it has been demonstrated that, with the steel sheet pile according to the present invention, the straight advancing property of the steel sheet pile can be improved and the warp, the falling, and the like during the installation can be suppressed.

Reference Signs List

[0070]

- 1 U-shaped steel sheet pile
 - 1a web portion
 - 1b flange portion
 - 1c joint portion

1d corner

3 friction reducing material

5 hat-shaped steel sheet pile

5a web portion

5b flange portion

5c arm portion

5d joint portion

5e corner

11 steel sheet pile (related-art example)

13 soil

CLAIMS

[Claim 1]

A steel sheet pile having a U-shaped or a hat-shaped section,

wherein friction reducing treatment is applied at least on an inner peripheral surface side of a surface of the steel sheet pile by a length equal to or more than a sectional width of the steel sheet pile and equal to or less than a third of an entire length of the steel sheet pile from a position of the steel sheet pile that is a lower end of the steel sheet pile when the steel sheet pile is driven into a ground.

[Claim 2]

The steel sheet pile according to Claim 1,

wherein the friction reducing treatment is applied only on the inner peripheral surface side of the surface of the steel sheet pile.

[Claim 3]

The steel sheet pile according to Claim 2,

wherein the friction reducing treatment is applied only to a corner on the inner peripheral surface side of the surface of the steel sheet pile.