

STEEL SHEET PILE, METHOD FOR MANUFACTURING THE SAME, AND
STEEL SHEET PILE WALL

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a steel sheet pile and a method for manufacturing the steel sheet pile. The present invention particularly relates to a steel sheet pile that is used in civil engineering work, construction, or the like and excellent in water cut-off performance, a method for manufacturing the steel sheet pile, and a steel sheet pile wall using the steel sheet pile.

2. Description of the Related Art

Steel sheet piles are capable of being connected with each other by engaging joints provided to both ends thereof in the width direction for constructing a wall. The steel sheet piles are utilized for civil engineering work of harbors and rivers and for construction, for example. Various types of structures of the steel sheet piles have been developed. In terms of economy-of-scale advantages by hot rolling, steel sheet piles having claw-like joints as viewed in a cross sectional view, that is, so-called "Larssen U sections" or "Straight web sections" are widely used.

In the fields of civil engineering work and construction, structures tend to be large in recent years, and the depth of driving steel sheet piles into the ground increases accordingly. The steel sheet piles are therefore required to be excellent in both strength and water cut-off performance with respect to high water pressure. The water cut-off performance means that when a wall is constructed using steel sheet piles, water is not leaked from one side of the wall to the other side of the wall through joints. The demand for the water cut-off performance has been further increased especially in these days due to severe environmental issues.

To meet this demand, the research and development for improving the water cut-off performance of steel sheet piles have been performed conventionally and there have been disclosed many techniques (see Japanese Patent Application Laid-open No. 64-62511 and Japanese Patent Application Laid-open No. 1-207520, for example). Furthermore, Japanese Examined Utility Model Application No. 7-6179 (Japanese Utility Model Application Laid-open No. 3-128725) disclosed another technique for improving the water cut-off performance of the steel sheet piles described in the above-mentioned patent publications, i.e., technique for improving the water cut-off performance with respect to water pressures ranging from 1 to 5 kgf/cm². Specifically,

as illustrated in Fig. 5, a steel sheet pile 10 having a female/male joint with a recessed groove 4 formed on a fitting internal surface of the joint 9 in the axial longitudinal direction is disclosed, wherein the recessed groove 4 is filled with a water-swellable sealing material 6. Japanese Examined Utility Model Application No. 7-6179 reports that such a configuration provides an extremely improved water cut-off performance with respect to water pressures ranging from 2 to 3 kgf/cm², enhances the safety of operations, and enables construction of structures that have excellent durability.

The steel sheet pile 10 is manufactured by hot rolling, and then is set in a laid-down state after being hot-rolled to form a recessed groove 4 with a cutting tool or the like from above, which requires two manufacturing processes. Therefore, productivity may be lowered compared with the case of one process. Furthermore, there is a drawback that the manufacturing cost is increased. In addition, as illustrated in Fig. 5, since the recessed groove 4 is formed in a joint bottom portion having a usual thickness (about 6 to 10 mm), the depth of the recessed groove 4 cannot be increased in view of the strength of the joint. Hence, the recessed groove 4 having a small size of about 3 mm deep and 10 mm wide is formed. The recessed groove 4 is filled with a small amount of water-swellable sealing

material 6, and it is difficult for the joint to withstand a high water pressure of 5 kgf/cm² or more. Furthermore, the cross-sectional shape of the groove and the position of the groove on the bottom portion of the claw are limited due to the tip shape of the groove cutting tool or the type of a tool post. Furthermore, there exists the case in which the length of steel sheet piles is limited depending on the cutting tool. The groove is required to be filled with a water cut-off material before the steel sheet piles are driven into the ground.

SUMMARY OF THE INVENTION

The present invention has been made in view of the above circumstances, and an object of the present invention is to provide a steel sheet pile that is excellent in water cut-off performance, a method for manufacturing the same, and a steel sheet pile wall.

A steel sheet pile according to the present invention comprises claw-like Larssen-type joints formed on both ends thereof, wherein a recessed groove in which a water cut-off material is filled is formed on an inner side of a claw bottom portion of each of the joints by hot rolling.

It is preferable that the steel sheet pile is a U-shaped steel sheet pile that is formed of a web and flanges, formed in a U shape as viewed in a cross sectional view,

and formed with the Larssen-type joints on distal ends of the flanges, an inclination angle (θ) of the flanges with respect to a normal line of a web surface ranges from 4° to 10° , and an orthogonal-direction joint space allowance (dy) formed on the inner side of the claw bottom portion in connecting the joints with each other is 7.0 mm or less and a claw rotation angle (α) defined by engaging surfaces of the claws adjacent to each other is 30° or more. In this case, it is preferable that an opening width formed as a space between the distal end of the claw and the corresponding flange in connecting the joints with each other is 14.4 mm or less. Also, it is preferable that an upper limit value (W_{max}) of the opening width formed as a space between the distal end of the claw and the corresponding flange in connecting the joints with each other is determined by calculating the following expression (1) based on a relationship with the inclination angle (θ):

$$W_{max} \text{ (mm)} = -\theta/12 + 15.2.$$

A method for manufacturing a steel sheet pile according to the present invention comprises forming the recessed groove in the steel sheet pile with a rolling mill.

A steel sheet pile wall according to the present invention comprises the steel sheet pile, wherein a water cut-off material is charged into the recessed grooves after

the steel sheet pile is driven into ground. A water-swellable rubber material may be attached to inside of the recessed grooves before the steel sheet pile is driven into ground. Furthermore, out of the joints connected to each other, a water cut-off material may be charged into a recessed groove of one of the joints and a water-swellable rubber material may be attached to inside of a recessed groove of the other joint.

In the present invention, since the joint having a large space in the inside of the claw bottom portion is formed only by hot rolling, it is possible to manufacture steel sheet piles having the recessed grooves capable of being filled with a large amount of water cut-off material efficiently at low cost compared with conventional steel sheet piles having the recessed grooves. Thus, it is possible to continuously fill the water cut-off material all over the joint without discontinuity, and therefore, the leakage of water from the joint can be prevented even under a high-water-pressure environment when a wall is formed using the steel sheet piles. Furthermore, the water cut-off material can be filled or charged into the inside of the joint both before and after being engaged. In addition, because only hot rolling is used, it is possible to form a groove having a shape favorable for fixing the water cut-off material at a position favorable for

improving the water cut-off performance, and it is also possible to manufacture elongated products.

Furthermore, according to the present invention, the recessed groove formed in the inside surface of the joint of one of the steel sheet piles is filled with the water cut-off material, and the water cut-off material, which is swelled when the steel sheet pile is driven into the ground, adheres to the outside surface of the joint of the other steel sheet pile engaged. The leakage of the water cut-off material from the recessed groove is also prevented. The water cut-off performance of the joint is thus further improved compared with that of the conventional one.

As described above, according to the present invention, it is possible to manufacture the steel sheet pile having the recessed grooves capable of being filled with a large amount of water cut-off material efficiently at low cost compared with the conventional steel sheet pile having the recessed grooves. Accordingly, even under a high-water-pressure environment or at a waste disposal site, it is possible to ensure the water cut-off performance. The steel sheet pile can be filled with the water cut-off material both before and after the steel sheet pile is driven into the ground.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an entire cross sectional view of a steel sheet pile according to an embodiment of the present invention;

Fig. 2 is a cross sectional view illustrating the joint portion of the steel sheet pile;

Fig. 3 is a schematic view illustrating the layout of rolling mills for manufacturing the steel sheet pile;

Fig. 4 is a cross sectional view explaining the caliber of a roll used in each rolling mill illustrated in Fig. 3;

Fig. 5 is a cross sectional view illustrating a conventional steel sheet pile having a recessed groove formed in the inside surface of the joint thereof;

Fig. 6 is a view illustrating joints engaged with each other such that the volumetric capacity of the space between the joint portions is maximum;

Figs. 7A and 7B are cross sectional views illustrating other types of joint portions of steel sheet piles according to embodiments of the present invention, Fig. 7A illustrating one of the joints in the case where the opening width of the recessed groove is smaller than the maximum width in the inside of the groove and Fig. 7B illustrating the other joint in the case where only one side of a groove wall protrudes;

Figs. 8A and 8B are cross sectional views illustrating

still other types of joint portions of steel sheet piles according to embodiments of the present invention, Fig. 8A illustrating one of the joints in the case where the center position of the recessed groove is deviated from the center of the claw bottom portion in the width direction toward the claw and Fig. 8B illustrating the other joint in the case where the opening of the recessed groove is positioned at the center of the claw bottom portion in the width direction;

Fig. 9 is a table listing experimental results of a relationship between the shape of the groove and the filling factor of a water cut-off material;

Fig. 10 is a cross sectional view illustrating joints of conventional U-shaped steel sheet piles provided with recessed grooves for being filled with a water cut-off material;

Fig. 11 is a cross sectional view illustrating the joints for explaining a problem related to the water cut-off performance of the U-shaped steel sheet piles;

Fig. 12 is a cross sectional view illustrating the joints for explaining another problem of the conventional U-shaped steel sheet piles other than the problem in Fig. 11;

Fig. 13 is a chart illustrating the profile of a relationship between a joint opening width and an

orthogonal-direction joint space allowance with the inclination angle of a flange as a parameter;

Fig. 14 is a cross sectional view explaining the definition of a claw rotational angle in the joints;

Fig. 15 is a chart illustrating the profile of a relationship between the joint opening width and the claw rotation angle with the inclination angle of a flange as a parameter;

Fig. 16 is a chart illustrating the profile of a relationship between the inclination angle of the flange and the allowable range of the joint opening width; and

Fig. 17 is a chart illustrating the profile of the effects of the inclination angle of the flange on a roll cutting amount required for restoring a roll caliber.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention are explained hereinafter in conjunction with circumferences under which the invention has been made.

First, the inventors have determined that shapes of the claw of a joint and a space into which the claw is inserted are basically the same as conventional shapes so that joints can be engaged with each other in a manner equivalent to conventional joints. The space has been determined to have a size sufficient to engage the joints

with each other intensively at the center of the claw bottom portion or the position deviated from the center of the claw bottom portion toward the claw, so that a steel sheet pile can be manufactured only by hot rolling. Furthermore, a recessed groove formed in the inside surface of the claw bottom portion has been determined to have a size of 10 mm or more as viewed in a cross sectional view, so that a water cut-off material can be filled into the groove both before and after the joints are engaged with each other.

As a result, a steel sheet pile 10 having Larssen-type joints has been developed as illustrated in Fig. 1. That is, the steel sheet pile 10 according to the present embodiment includes, as viewed in a cross sectional view, a horizontal web 1, flanges 2 formed on both ends of the web 1 in the width direction thereof in such a manner that the flanges 2 are inclined to face each other, and claw-like Larssen-type joints formed on the distal ends of the flanges 2. In addition, the steel sheet pile 10 has recessed grooves 4 for being filled with a large amount of water cut-off material 6, each recessed groove 4 being formed in the inside surface of a claw bottom portion 3 of the corresponding Larssen-type joint by hot rolling. The claw bottom portion 3 is, as illustrated in Fig. 2, a portion that forms the root of a claw 5 and the flange 2.

The important point of the steel sheet pile 10 according to the present embodiment is to increase the thickness of the claw bottom portion 3 before the recessed groove 4 is formed in a rolling process. It becomes thus possible to easily form the recessed groove 4 having the size such that the recessed groove 4 can be filled with a larger amount of water cut-off material 6 than in the conventional groove. The recessed groove 4 having the size such that the recessed groove 4 can be filled with a large amount of water cut-off material 6 means that the diameter of the water cut-off material 6 illustrated by the circle in Fig. 2 is 10 mm or more. This is because, according to examinations performed by the inventors, the recessed groove 4 having the size of less than 10 mm cannot be filled easily with an amount of the water cut-off material 6 sufficient for preventing the leakage of water under a water pressure of 5 kgf/cm² or more.

Furthermore, it is preferable that the bottom thickness of the recessed groove 4 be larger than the wall thickness of the flange 2. This is because, if the bottom thickness of the recessed groove 4 is thin, the strength of the thin bottom portion is lowered, thus giving rise to a drawback with respect to the durability of the steel sheet pile 10. This is also because, if the bottom thickness of the recessed groove 4 is sufficiently increased, it is

possible to use this steel sheet pile 10 even when the recessed groove 4 is not required to be filled with the water cut-off material 6.

Furthermore, as illustrated in Fig. 7A, it is preferable that the opening width 21 of the recessed groove 4 be, as viewed in a cross sectional view, smaller than a maximum width 22 in the inside of the groove. Since the opening width 21 is narrowed, even when there exist small clearances between the water cut-off material 6 and a groove wall in the inside of the groove, the water cut-off material 6 is prevented from coming off from the recessed groove 4 due to vibrations generated when the steel sheet pile 10 is driven into the ground. In this case, as illustrated in Fig. 7B, only one side of the opening may protrude.

In addition, as illustrated in Fig. 8A, it is preferable that the center line (indicated by symbol B) of the recessed groove 4 be deviated from the center (indicated by symbol A) of the claw bottom portion in the width direction toward the side of the claw 5. Spaces occupied by swelled water cut-off material 23 are indicated by hatched lines. Compared with the case in which the center line of the recessed groove 4 illustrated in Fig. 8B is positioned at the center of the claw bottom portion in the width direction, a large amount of water cut-off

material enters into the engaged claw portion. Hence, even when an amount of swelled water cut-off material that occupies the spaces between the joint portions is the same as that in the case of the joints illustrated in Fig. 8B, a water cut-off effect is improved, or even when an amount of swelled water cut-off material that occupies the spaces between the joint portions is smaller than that in the case of the joints illustrated in Fig. 8B, the water cut-off effect is equivalently exhibited.

The type of the water cut-off material 6 with which the recessed groove 4 is filled is not limited. Any material capable of being swelled several times by being brought into contact with water may be used, and any material obtained by blending a super-absorbent polymer substance into resin or rubber that is conventionally used may adequately be used. For example, materials obtained by blending high polymer substances such as starch-based polymer, cellulosic polymer, polyacrylate polymer, or polyvinyl alcohol polymer into crude rubber, chloroprene rubber, or the like may be used. Fig. 8A illustrates only a joint portion of a steel sheet pile wall 14 in which the joints of steel sheet piles are connected (engaged) with each other. The water cut-off material 6 may be, after the joints are connected with each other as illustrated in Fig. 8A and the steel sheet piles 10 are driven into the ground,

charged into the recessed grooves 4 to form the steel sheet pile wall 14. Alternatively, before the steel sheet piles 10 are driven into the ground, a water-swellaable rubber material may be attached to the recessed grooves 4 as the water cut-off material 6, and the steel sheet piles 10 may be driven into the ground thereafter to form the steel sheet pile wall 14. As a matter of course, the following procedures may be adopted: out of the joints connected with each other, the recessed groove 4 of one of the joints is filled with the water cut-off material 6 after the steel sheet piles 10 are driven into the ground, and the rubber material is attached to the recessed groove 4 of the other joint before the steel sheet piles 10 are driven.

In the same manner as the method for generally manufacturing steel sheet piles, a roll 7 having a caliber may be used for hot-rolling the steel sheet piles. For example, as illustrated in Fig. 3, a steel material 11 is passed through a roughing mill, an intermediate rolling mill, and a finishing mill in the direction indicated by the arrows to perform rolling (Symbols K.1, K.2 ... in Fig. 3 indicate the types of calibers illustrated in Fig. 4). In each rolling mill, a pair of rolls 7 arranged in the vertical direction has a caliber 8 having the corresponding one of the shapes illustrated in Fig. 4 to form the recessed groove 4 in the joint. The important points of

rolling processes are as follows: the steel sheet is rolled so that a part for the claw bottom portion 3 has a large thickness in the roughing mill, the part for the recessed groove 4 is formed in a V shape in an intermediate rolling process thereafter, and is then formed in a U shape in the finishing mill. At the same time, a claw 5 is bent by being pressed. This is because, if the thickness of the part for the claw bottom portion 3 is thin, the steel sheet pile according to the embodiment of the present invention cannot be manufactured. If the part of the claw bottom portion 3 is formed in a U shape in one process, the recessed groove 4 having a proper shape cannot be formed only by rolling. The cross sectional shape and the position of the groove can be easily modified by changing the roll caliber.

The steel sheet pile 10 according to the present embodiment was manufactured using a 300-mm-thick, 400-mm-wide, 5,000-mm-long steel material 11 of the steel grade of SY295 as a raw material only by hot rolling. The rolling mills and the rolls used in manufacturing the above-mentioned steel sheet pile 10 were the same as those illustrated in Fig. 3 and Fig. 4. Furthermore, the rolling processes were performed under the conditions that the web temperature of the raw material when being rolled ranged from 1,050 to 1,250°C for the roughing mill, from 900 to

1,050°C for the intermediate rolling mill, and from 700 to 850°C for the finishing mill while the size of the recessed groove to be formed in the Larssen-type joints were changed. As a result, the products of the steel sheet piles 10 were able to be manufactured without any problem. Each product had a web thickness of 16.1 mm, an effective width of 400 mm, a flange thickness of 9.0 mm, and an effective height of 185 mm.

Subsequently, the filling property of the space between the joints was examined. As a method for examining the property, the recessed groove 4 of each steel sheet pile 10 obtained was filled with the water cut-off material 6, the joints were engaged with each other, the water cut-off material 6 was impregnated with water, and an amount of the water cut-off material 6 that occupied the space between the joints was evaluated thereafter. The joints were engaged with each other in a state that the volumetric capacity of a space 13 formed in the joint portions was maximized as illustrated in Fig. 6.

In the present examples, the steel sheet piles 10 having grooves with a diameter of 10 mm (Example 1) and 12 mm (Example 2) were used. The material to be compared was a conventional material in which a recessed groove of 10 mm in width and 3 mm in depth was formed (comparative example).

The water cut-off materials 6 of a rate of swelling of 300% and 500% were used. Results are listed in Fig. 9.

In each of the steel sheet piles according to Examples 1 and 2, a filling factor of 75% or higher was obtained, whereas the filling factor remained low in the conventional steel sheet pile. It should be noted that when the steel sheet pile is actually driven into the ground, earth and sand enter into the space between the joints depending on the condition that the joints are engaged with each other. This method, therefore, does not necessarily require a filling factor of 100% to prevent the leakage of water. However, it is preferable that the filling factor be at least 50% or higher. When the filling factor is 75% or higher, the leakage of water is prevented without fail.

Actually, in the steel sheet piles each having the groove with a diameter of 12 mm, the grooves were filled with the water cut-off material 6 having a rate of swelling of 300%, and the steel sheet piles were driven into the ground thereafter to form a waterproof wall. After the waterproof wall was formed, even after a lapse of 6 months from the time the water cut-off material was completely swelled, the favorable condition has been maintained with no leakage of water observed.

In the case of filling the groove with a diameter of 12 mm with the water cut-off material with a diameter of 12

mm, the water cut-off material may come off if adhesives are not used. However, in the steel sheet pile illustrated in Fig. 7A whose groove having an opening width of 10 mm was filled with the water cut-off material, the water cut-off material did not come off even when no adhesives were used, and thus reburying was not required. In addition, in the example in which the groove diameter was 12 mm and, as illustrated in Fig. 8A, the center line of the recessed groove was deviated from the center of the claw bottom portion in the width direction toward the claw by 3 mm, the space at the position effective for preventing the leakage of water was filled with the water cut-off material. Hence, the filling factor of the water cut-off material for ensuring the prevention of the leakage of water when being filled after the steel sheet piles were driven into the ground was lowered from 75% to 70%.

Next, a configuration example of the steel sheet pile 10 according to the present embodiment is explained in detail.

The steel sheet pile 10 according to the present embodiment includes, as illustrated in Fig. 10, the claw-like Larssen-type joint (hereinafter, simply referred to as the "joint 12") formed on the distal end of the flange 2 as viewed in a cross-sectional view. In the steel sheet pile, the recessed groove 4 for being filled with the water cut-

off material 6 is formed on the inside surface side of the claw bottom portion 3 of the joint 12 by hot rolling, thus improving the water cut-off performance compared with the conventional steel sheet pile. With this configuration, the water cut-off material 6 placed in the recessed groove 4 is swelled by being brought into contact with water and occupies the spaces formed by joints 12 engaged with each other. Hence, it is expected that the water cut-off performance will be further improved compared with the conventional steel sheet pile. Fig. 10 illustrates only the joint portion of the steel sheet pile wall 14 formed by connecting (engaging) the joints 12 with each other.

In an impervious wall used in sea area landfill sites or the like for waste materials, large-sized U-shaped steel sheet piles such as 4W-type, 5L-type, or 6L-type steel sheet piles are typically used (see "Steel Sheet Pile Standard Product Specifications" issued by Japanese Association for Steel Pipe Piles in December 2000). As illustrated in Fig. 1, a 4W-type steel sheet pile is, for example, a steel sheet pile 10 having an effective width w_1 of 600 mm, an effective height h_1 of 210 mm, and a thickness t_1 of 18.0 mm. Similarly, a 5L-type steel sheet pile is, for example, a steel sheet pile 10 having an effective width w_1 of 500 mm, an effective height h_1 of 200 mm, and a thickness t_1 of 24.3 mm. A 6L-type steel sheet

pile is, for example, a steel sheet pile 10 having an effective width w_1 of 500 mm, an effective height h_1 of 225 mm, and a thickness t_1 of 27.6 mm. These large-sized U-shaped steel sheet piles have sufficiently large claw space allowances (also referred to as "joint space allowances") in the space formed by the joints engaged with each other so that claws are not disengaged, and resistance while the steel sheet piles are driven into the ground is kept small for forming an earth retaining wall or the like in a civil engineering work, for example. Furthermore, in order to pile up a plurality of steel sheet piles efficiently, "inclination of the flange" of the joint 12 with respect to the normal line N (see Fig. 10) of the web surface is typically increased up to 16 to 18°.

When the recessed groove 4 is formed in such a large-sized U-shaped steel sheet pile, the following two problems arise. One of them is that, as can be clearly understood from Fig. 11 illustrating the cross section of a steel sheet pile, a joint space allowance in the direction orthogonal to the so-called "construction extension direction" (horizontal direction on the paper on which Fig. 11 is drawn) in which the joints 12 are connected (hereinafter, referred to as an "orthogonal-direction joint space allowance" represented by a symbol d_y) is large. Consequently, even when the water cut-off material 6 with

which the recessed groove 4 is filled when the steel sheet piles are driven into the ground is swelled up to its expansion limit Δy , the space is not entirely filled with the water cut-off material, thus lowering the water cut-off performance. The other problem is that, as illustrated in Fig. 12, a joint space allowance along the a "construction extension direction" (hereinafter, referred to as "extension-direction joint space allowance" represented by a symbol dx) is also large and hence, the water cut-off material 6 flows out from the recessed groove 4, thus lowering the water cut-off performance.

To solve the above-mentioned two problems in conventional U-shaped steel sheet piles; that is, "the orthogonal-direction joint space allowance dy is large and hence, even when the water cut-off material with which the recessed groove is filled is swelled when the steel sheet piles are driven into the ground, the space between the inner surface of the joint in which the recessed groove of one of the steel sheet piles is formed and the outer surface of the joint of the other steel sheet pile is not entirely filled with the water cut-off material. Furthermore, the extension-direction joint space allowance dx is also large and hence, the water cut-off material flows out from the recessed groove, thus lowering the water cut-off performance ", the inventors have found it

necessary to optimize the shape of the joint. The inventors carried out various examinations on the shape as described below to achieve means for solving the problems.

First, the inventors set, in engaging the joints of the two steel sheet piles with each other, a space between the distal end of each claw and the flange within a range such that the claws are not separated, and the width of the space was defined as a joint opening width W (see Fig. 12). The joint opening width W (hereinafter, referred to as the "opening width W ") is obtained by adding the thickness t of the corresponding claw and the extension-direction joint space allowance dx . Furthermore, the inventors examined, when the thickness t of the claw is constant and the extension-direction joint space allowance dx was variously changed, a relationship established between the opening width W ($= t + dx$) and the orthogonal-direction joint space allowance dy by using the inclination of the flange with respect to the normal line N of the web surface of the steel sheet pile 10 illustrated in Fig. 10 (hereinafter, referred to as an "inclination angle" represented by a symbol θ) as a parameter.

As a result, relationships illustrated in Fig. 13 were obtained. When the inclination angle θ is increased, the orthogonal-direction joint space allowance dy is increased.

The increasing rate of the orthogonal-direction joint space allowance dy is also increased along with an increase in the opening width W . Experience has shown that a swelled water cut-off material exhibits the water cut-off performance in a range of $dy \leq 7.0$ mm. Hence, in the case where the inclination angle θ is large; that is, 18° , the opening width W is equal to or less than 13.5 mm. On the other hand, in the case where the inclination angle θ is small; that is, 2° , the range of the opening width W allowable for exhibiting the water cut-off performance is equal to or less than 15.0 mm.

In the engagement of the joints, as illustrated in Fig. 14, it is necessary to consider a claw rotation angle (symbol: α) defined by the inclination angle formed by engaging surfaces of the claws adjacent to each other. This is because the claw rotation angle represents difficulty in driving the steel sheet piles into the ground while engaging the joints 12 with each other; that is, an indicator representing the resistance of the steel sheet piles upon driving the steel sheet piles into the ground. Accordingly, the inventors also examined a relationship established between the claw rotation angle α and the opening width W ($t + dx$) by using the inclination angle θ as a parameter.

As a result, relationships illustrated in Fig. 15 were obtained. Experience has shown that when U-shaped steel sheet piles are used, the U-shaped steel sheet piles having a claw rotation angle α of 30° or larger can be driven into ground without problems. When the claw rotation angle α is smaller than 30° , the inner space of the claws is narrow and hence, it is difficult to drive the steel sheet piles into the ground. According to Fig. 15, in a joint having a claw such that the inclination angle θ is as large as 18° , an opening width W of 13.7 mm or more is appropriate for driving the steel sheet piles into the ground. Accordingly, as described above, the opening width W , which is appropriate for exhibiting the water cut-off performance obtained based on the condition such that $dy \leq 7.0$ mm, is 13.5 mm or more and hence, there exists no range of the opening width W that satisfies both the condition such that $dy \leq 7.0$ mm and the condition such that the claw rotation angle $\alpha \geq 30^\circ$ for driving the steel sheet piles into the ground.

On the other hand, when the inclination angle θ is as small as 2° , an opening width W of 13.0 mm or more obtained from Fig. 15 is appropriate for driving the steel sheet piles into the ground. Therefore, considering the above-mentioned appropriate opening width W of 15.2 mm or less

obtained based on the condition such that $dy \leq 7.0 \text{ mm}$ (result in Fig. 13), there exists the range of the opening width W that satisfies both the appropriate value of the opening width W for exhibiting the water cut-off performance and the appropriate value of the opening width W obtained based on the condition such that the claw rotation angle $\alpha \geq 30^\circ$ for driving the steel sheet piles into the ground.

Consequently, the inventors considered that the joints having the opening width W simultaneously satisfying these two kinds of appropriate values would improve the water cut-off performance compared with the conventional joints. Appropriate limiting opening widths were specified independently from Fig. 13 and Fig. 15, and the difference between these opening widths (that is, the region of the opening width W simultaneously satisfying the above-mentioned two kinds of appropriate values) was organized by the inclination angle θ . As a result, the relationship illustrated in Fig. 16 was obtained. According to Fig. 16, it became apparent that, with an inclination angle of 14° or less, the water cut-of performance was improved compared with the conventional joints. However, in practical use for steel sheet piles driven into the ground, it became apparent that a little larger permissible difference of the

opening width W was preferable and the permissible difference was 1 mm or more for effective construction, that is, the inclination angle θ of the flange was preferably equal to or less than 10° .

In the present embodiment, the lower limit of the inclination angle θ is 4° . This is because the smaller the inclination angle θ , the larger the permissible difference of the opening width W becomes. However, in manufacturing a U-shaped steel sheet pile having a joint whose inclination angle is that small by rolling, there gave rise to a drawback that the cost for controlling the caliber of a rolling roll was increased compared with the conventional steel sheet piles. This is because, in order to restore the caliber of the rolling roll abraded in use, it is necessary to machine the roll with the use of a cutting tool, and there exists a tendency that a cutting amount is increased along with a decrease in the inclination angle θ . The actual condition of cutting the roll was examined and the relationship illustrated in Fig. 17 was obtained. According to Fig. 17, it became apparent that the inclination angle θ that increased the cutting amount (basic unit) extremely was less than 4° , and an increase in the cost remained moderate by avoiding this range.

Based on the discussion above, it is possible to

determine, as illustrated in Fig. 13, the upper limit value $W_{\max}$ of the opening width W by calculating the following expression (1) depending on the relationship with the inclination angle θ . That is, in Fig. 13, when the inclination angle θ is 10° , in order to set the orthogonal-direction joint space allowance dy to 7 mm or less, the opening width W must be equal to or less than 14.4 mm. Furthermore, when the inclination angle θ is 4° , in order to set the orthogonal-direction joint space allowance dy to 7 mm or less, the opening width W must be equal to or less than 14.9 mm. When the upper limit value $W_{\max}$ of the opening width is proportionate to the inclination angle θ under the condition that the inclination angle θ ranges from 4° to 10° , as the expression that satisfies the above-mentioned two conditions, the maximum opening width $W_{\max}$ with respect to the inclination angle θ can be expressed by the following expression (1).

$$W_{\max} \text{ (mm)} = -\theta/12 + 15.2 \quad (1)$$

Furthermore, under the condition that the inclination angle θ of the flange ranges from 4° to 10° and the orthogonal-direction joint space allowance dy is equal to or less than 7 mm, it is preferable that the opening width W be equal to or less than 14.4 mm. With this range, it is possible to obtain still higher water cut-off performance.

In addition, according to the present embodiment, when the joints of the same size are compared with each other, the smaller the inclination angle θ , the larger the width of the claw bottom becomes, and the degree of freedom in setting the size or the position of the recessed groove is increased.

The above-mentioned U-shaped steel sheet pile having a shape equivalent to that of a 4W-type steel sheet pile (as illustrated in Fig. 1, a steel sheet pile having an effective width w_1 of 600 mm, an effective height h_1 of 210 mm, and a thickness t of 18.0 mm, for example) and an inclination angle θ of 10° was manufactured. A conventional 4W-type U-shaped steel sheet pile (with no groove in the claw bottom portion) has a flange whose inclination angle is 18° . The reference value of the opening width W was set to 14.0 mm based on the condition that the opening width W was equal to or less than 14.4 mm, which satisfied $dy \leq 7.0$ mm, and equal to or more than 13.3 mm, which satisfied $\theta \geq 30^\circ$. When the steel sheet piles were manufactured with the reference value of the opening width W being 14.0 mm, the steel sheet piles whose opening width W ranged from 13.3 to 14.7 mm depending on a variation in operation were obtained. The steel sheet piles having the opening width W ranging from 13.3 to 14.4

mm were used as they were. The steel sheet piles having the opening width W exceeding 14.4 mm were corrected by cold processing so that the opening width W became around 14.0 mm, and used as products.

When these products were driven into the ground under the sea, the products were driven into the ground with efficiency equivalent to that of the case of conventional 4W-type U-shaped steel sheet piles. In addition, the grooves formed in the claw bottom portions were filled with the water cut-off materials, and the water cut-off performance of the products was examined. That is, the steel sheet piles were driven into the ground in a box shape to form a weir on the sea surface, and seawater was poured into the weir. A change in water level was then measured to obtain the coefficient of permeability, and the water cut-off performance was evaluated. In this experiment, the smaller the coefficient of permeability, the more excellent the water cut-off performance was. In this embodiment, the coefficient of permeability was 2 to 3×10^{-7} cm/sec, and this value satisfies the reference value of 1×10^{-6} cm/sec described in "Industrial Waste Final Disposal Site Before-use Inspection Manual" issued by Japan Waste Management & 3R Research Foundation in January 2001. Hence, the products have been confirmed to exhibit

excellent water cut-off performance.

What is claimed is:

1. A steel sheet pile comprising:

claw-like Larssen-type joints formed on both ends thereof, wherein

a recessed groove in which a water cut-off material is filled is formed on an inner side of a claw bottom portion of each of the joints by hot rolling.

2. The steel sheet pile according to claim 1, wherein

the steel sheet pile is a U-shaped steel sheet pile that is formed of a web and flanges, formed in a U shape as viewed in a cross sectional view, and formed with the Larssen-type joints on distal ends of the flanges,

an inclination angle (θ) of the flanges with respect to a normal line of a web surface ranges from 4° to 10° , and

an orthogonal-direction joint space allowance (dy) formed on the inner side of the claw bottom portion in connecting the joints with each other is 7.0 mm or less and a claw rotation angle (α) defined by engaging surfaces of the claws adjacent to each other is 30° or more.

3. The steel sheet pile according to claim 2, wherein an opening width formed as a space between the distal end of

the claw and the corresponding flange in connecting the joints with each other is 14.4 mm or less.

4. The steel sheet pile according to claim 2, wherein an upper limit value (W_{max}) of the opening width formed as a space between the distal end of the claw and the corresponding flange in connecting the joints with each other is determined by calculating the following expression (1) based on a relationship with the inclination angle (θ):

$$W_{max} \text{ (mm)} = -\theta/12 + 15.2 \quad (1).$$

5. A method for manufacturing a steel sheet pile, the method comprising:

forming the recessed groove in the steel sheet pile according to any one of claims 1 to 4 with a rolling mill.

6. A steel sheet pile wall comprising:

the steel sheet pile according to any one of claims 1 to 4, wherein

a water cut-off material is charged into the recessed grooves after the steel sheet pile is driven into ground.

7. A steel sheet pile wall comprising:

the steel sheet pile according to any one of claims 1

to 4, wherein

a water-swellable rubber material is attached to inside of the recessed grooves before the steel sheet pile is driven into ground.

8. A steel sheet pile wall comprising:

the steel sheet pile according to any one of claims 1 to 4, wherein

out of the joints connected to each other, a water cut-off material is charged into a recessed groove of one of the joints and a water-swellable rubber material is attached to inside of a recessed groove of the other joint.