

DESCRIPTION

Title of Invention: HAT-SHAPED STEEL SHEET PILE

5 TECHNICAL FIELD

The present invention relates to a hat-shaped steel sheet pile (cold hat-shaped steel sheet pile), which is molded by cold working and is to be installed in the ground to constitute a wall.

10 BACKGROUND ART

A hat-shaped steel sheet pile formed by hot rolling is limited in size thereof such as the number of mold types and/or a steel-sheet-pile width owing to restrictions in, for example, factory equipment. As a result, the cross-sectional shape of the hat-shaped steel sheet pile is not necessarily optimal and rational with respect to structural performance required at each construction site. That is, the size of the hat-shaped steel sheet pile formed by the hot rolling is selected from existing sizes which are as close to the size for achieving required structural performance as possible.

Some hat-shaped steel sheet piles are formed by cold working (bending) (e.g., see Patent Literature 1). Such steel sheet piles have a relatively high degree of freedom in adjusting a size thereof. Consequently, a hat-shaped steel sheet pile having an almost optimal cross-sectional shape for the structural performance required for each of the construction sites can be provided.

CITATION LIST

25 PATENT LITERATURE

Patent Literature 1: JP H4-108619 U

SUMMARY OF INVENTION

In order to improve the cross-sectional performance and manufacturing efficiency of a hat-shaped steel sheet pile manufactured by cold working (bending), the plate thickness is reduced, and the cross-sectional shape is increased effectively. The steel sheet pile formed by the cold working (bending), however, has almost the same plate thickness at any part of a web, a flange, and an arm owing to a method of manufacturing the steel sheet pile. The fact causes a problem as described below when the plate thickness is reduced.

When a wall structure is formed by installing a hat-shaped steel sheet pile in

the ground, the bending moment generated by earth pressure and water pressure prominently acts on a wall body. When the bending moment acts on the wall body, the largest stress acts on the web and the arm, which are positioned at the outermost and innermost edges, in the hat-shaped steel sheet pile.

5 Compared to the web and the arm, a joint is provided at the tip portion of the arm. Early buckling thus hardly occurs since the arm has larger cross-sectional rigidity than the web. In contrast, the web has smaller cross-sectional rigidity. When the plate thickness is reduced, the web tends to be a weak point in the hat-shaped steel sheet pile formed by the cold working. In the cold working, the hat-shaped steel sheet
10 pile has substantially the same plate thickness at all parts. When compressive stress due to the bending moment acts on the web, buckling thus occurs early. As a result, the wall body has a risk of being collapsed (reduction in the deformation performance) at a load level (bending moment) smaller than an expected yield strength (yield moment) or all plastic moment.

15 It should be noted that, referring to Fig. 1 of Patent Literature 1, a bent portion bent in a U-shape or a V-shape is provided at the center of the web. The bent portion is formed as a center mark of a plate in a manufacturing process of a cold sheet pile. The bent portion is an extremely small depression, and has a size remarkably smaller than a protrusion in the invention described later. The intended action of the bent portion is
20 completely different from that of the protrusion of the invention.

The invention has been made to solve the above-described problem, and an object of the invention is to improve the cross-sectional performance of a hat-shaped steel sheet pile having a cross-sectional shape of thin wall by preventing early buckling of a web of the hat-shaped steel sheet pile and enhancing the deformation performance
25 to provide the hat-shaped steel sheet pile with excellent economy and manufacturing efficiency.

(1) A hat-shaped steel sheet pile according to the invention comprises: a web; a pair of flanges; a pair of arms; and a pair of joints. In the hat-shaped steel sheet pile, the pair of flanges is formed at both ends of the web, an arm constituting the pair of
30 arms is formed at an end of a flange constituting the pair of flanges, and a joint constituting the pair of joints is provided at a tip of the arm. The hat-shaped steel sheet pile is characterized by including a protrusion satisfying following expressions (1) and (2) over an entire length of the steel sheet pile in the web.

[Mathematical Expression 1]

$$V \geq B/16 \quad \dots (1)$$

$$1.5 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \leq 10 \quad \dots (2)$$

where V: protrusion height (mm); W: width (mm) between protrusion bases ($W < 5 \times V$); n: number of protrusions; H: steel-sheet-pile cross-section height (mm); B: steel-sheet-pile web width (mm); t: plate thickness (mm) of steel-sheet-pile-web; and ϵ_y : yield strain of steel sheet pile.

(2) A hat-shaped steel sheet pile according to the invention comprises: a web; a pair of flanges; a pair of arms; and a pair of joints. In the hat-shaped steel sheet pile, the pair of flanges is formed at both ends of the web, an arm constituting the pair of arms is formed at an end of a flange constituting the pair of flanges, and a joint constituting the pair of joints is provided at a tip of the arm. The hat-shaped steel sheet pile is characterized by including a protrusion satisfying following expressions (1) and (3) over an entire length of the steel sheet pile in the web.

[Mathematical Expression 2]

$$V \geq B/16 \quad \dots (1)$$

$$2 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \leq 10 \quad \dots (3)$$

where V: protrusion height (mm); W: width (mm) between protrusion bases ($W < 5 \times V$); n: number of protrusions; H: steel-sheet-pile cross-section height (mm); B: steel-sheet-pile web width (mm); t: plate thickness (mm) of steel-sheet-pile-web; and ϵ_y : yield strain of steel sheet pile.

(3) A hat-shaped steel sheet pile according to the invention comprises: a web; a pair of flanges; a pair of arms; and a pair of joints. In the hat-shaped steel sheet pile, the pair of flanges is formed at both ends of the web, an arm constituting the pair of

arms is formed at an end of a flange constituting the pair of flanges, and a joint constituting the pair of joints is provided at a tip of the arm. The hat-shaped steel sheet pile is characterized by including a protrusion satisfying following expressions (1) and (4) over an entire length of the steel sheet pile in the web.

5 [Mathematical Expression 3]

$$V \geq B/16 \quad \cdot \cdot \cdot \cdot (1)$$

$$2 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \leq 4 \quad \cdot \cdot \cdot \cdot (4)$$

where V: protrusion height (mm); W: width (mm) between protrusion bases ($W < 5 \times V$); n: number of protrusions; H: steel-sheet-pile cross-section height (mm); B: steel-sheet-pile web width (mm); t: plate thickness (mm) of steel-sheet-pile-web; and ϵ_y : yield strain of steel sheet pile.

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In the hat-shaped steel sheet pile of the invention, the optimal cross-sectional performance (deformation performance) of a steel sheet pile can be obtained by providing a predetermined protrusion in a web. As a result, the hat-shaped steel sheet pile having excellent economy and manufacturing efficiency and a small plate thickness can be achieved.

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BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is an explanatory view illustrating the shape of a hat-shaped steel sheet pile according to an embodiment of the invention.

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Fig. 2 is an explanatory view illustrating a process of deriving an expression that defines the shape of the hat-shaped steel sheet pile according to the embodiment of the invention and illustrating the shape of the hat-shaped steel sheet pile being a subject.

Fig. 3 is an explanatory diagram illustrating the process of deriving the expression that defines the shape of the hat-shaped steel sheet pile according to the embodiment of the invention, and is a graph indicating influence of existence or non-existence of a protrusion on deformation performance.

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Fig. 4 is an explanatory diagram illustrating the process of deriving the

expression that defines the shape of the hat-shaped steel sheet pile according to the embodiment of the invention, and is a graph of an analysis result used for determining the range of an effective protrusion height.

Fig. 5 is a cross-sectional diagram of a square-type steel pipe used for illustrating the process of deriving the expression that defines the shape of the hat-shaped steel sheet pile according to the embodiment of the invention.

Fig. 6 is an explanatory diagram illustrating the process of deriving the expression that defines the shape of the hat-shaped steel sheet pile according to the embodiment of the invention, and is a graph of an analysis result for seeing the influence of the shape of the hat-shaped steel sheet pile.

Fig. 7 is an explanatory diagram illustrating the process of deriving the expression that defines the shape of the hat-shaped steel sheet pile according to the embodiment of the invention, and is a graph of an analysis result for seeing the influence of the ratio of a web width B to a cross-sectional height H.

Fig. 8 is an explanatory diagram illustrating the process of deriving the expression that defines the shape of the hat-shaped steel sheet pile according to the embodiment of the invention, and is a graph of an analysis result for seeing the effect of the shape of the protrusion.

Fig. 9 is an explanatory view illustrating another aspect of the shape of the hat-shaped steel sheet pile according to the embodiment (part 1).

Fig. 10 is an explanatory view illustrating another aspect of the shape of the hat-shaped steel sheet pile according to the embodiment (part 2).

Fig. 11 is an explanatory view illustrating another aspect of the shape of the hat-shaped steel sheet pile according to the embodiment (part 3).

DESCRIPTION OF EMBODIMENTS

[First Embodiment]

A hat-shaped steel sheet pile 1 according to an embodiment of the invention is a cold hat-shaped steel sheet pile manufactured by cold working (bending). As illustrated in Fig. 1, the hat-shaped steel sheet pile 1 includes a web 3, a pair of flanges 5, a pair of arms 7, a pair of joints 9, and a protrusion 11.

The pair of flanges 5 is formed at both ends of the web 3. Specifically, the flange 5 is provided at each end of the web 3 in a width direction x of the hat-shaped steel sheet pile 1.

The arm 7 is formed at an end of a flange 5 constituting the pair of flanges 5. Specifically, the arm 7 is provided at the outer end of the flange 5 in the width direction

x. The inner end of the flange 5 in the width direction x is continuous with an end of the web 3 in the width direction x.

The joint 9 is provided at the tip of an arm 7 constituting the pair of arms 7. Specifically, the joint 9 is provided at the outer end of the arm 7 in the width direction x.

The inner end of the arm 7 in the width direction x is continuous with an end of the flange 5 in the width direction x. It should be noted that one joint 9 and the other joint 9, which constitute the pair of arms 7, may be asymmetric with each other in cross section in the width direction x and a height direction y.

The hat-shaped steel sheet pile 1 has the protrusion 11 in the web 3 over the entire length of the steel sheet pile. Specifically, the protrusion 11 is provided in the web 3. The protrusion 11 protrudes in the height direction y of the hat-shaped steel sheet pile 1. In the embodiment, the protrusion 11 protrudes toward the side (inside) where the flange 5 is disposed in the height direction y.

The protrusion 11 extends over the entire length of the hat-shaped steel sheet pile 1 in the web 3. The length of the protrusion 11 in a length direction z is the same as that of the hat-shaped steel sheet pile 1 in the length direction z. It should be noted that the length direction z is orthogonal to the width direction x and the height direction y.

The protrusion 11 satisfies the following expressions (1) and (2).

[Mathematical Expression 4]

$$V \geq B/16 \quad \dots (1)$$

$$1.5 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} - 0.25 \right)^2 \right)} \leq 10 \quad \dots (2)$$

where V: protrusion height (mm); W: width (mm) between protrusion bases ($W < 5 \times V$); n: number of protrusions; H: steel-sheet-pile cross-section height (mm); B: steel-sheet-pile web width (mm); t: plate thickness (mm) of steel-sheet-pile-web; and ϵ_y : yield strain of steel sheet pile.

It should be noted that V (height of the protrusion 11) corresponds to the length (height) of the protrusion 11 in the height direction y. The protrusion base corresponds to an outer end of the protrusion 11 in the width direction x in cross section in the width

direction x and the height direction y. W (width between the protrusion bases) is equal to the length (width) of the protrusion 11 in the width direction x. H (steel-sheet-pile cross-section height) corresponds to the height of the hat-shaped steel sheet pile 1 in the height direction y. That is, H is equal to the maximum length from the web 3 to the flange 7 in the height direction y. B (steel-sheet-pile web width) corresponds to the length (width) of the web 3 in the width direction x. Then, t (plate thickness of the steel-sheet-pile-web) corresponds to the height (thickness) of the web 3 in the height direction.

The expression (1) defines the height of the protrusion 11 necessary for achieving the effects of the invention. The expression (2) defines deformation performance of a cross section of a steel sheet pile. A hat-shaped steel sheet pile having a value, which is defined by the expression (2), of less than 1.0 collapses by elastic buckling before reaching the yield moment. How the expressions (1) and (2) have been derived will now be described.

First, the deformation performances of a hat-shaped steel sheet pile 13 without the protrusion 11 illustrated in Fig. 2(a) and the hat-shaped steel sheet pile 1, illustrated in Fig. 2(b), including the protrusion 11 provided in the web 3 were analytically considered. $\varepsilon_y = 0.0016$.

Fig. 3 is a graph of the analysis result. The vertical axis indicates (acting load/yield load). The horizontal axis indicates deformation performance. In Fig. 3, the deformation performance in the case where yielding occurs at the time when the acting load is equal to the yield load is expressed as 1.0.

According to Fig. 3, the hat-shaped steel sheet pile 13 without the protrusion 11 in Fig. 2(a) has a deformation performance of 0.79 (less than 1.0 and elastic buckling). In contrast, in the case of Fig. 2(b) in which the protrusion 11 having a height of 27 mm is provided at the center of the web, the deformation performance is 1.67. It is found that the hat-shaped steel sheet pile 1 provided with the protrusion 11 has an improved deformation performance and a maximum load exceeding a yield load level. The incremental rate of the deformation performance in the case can be expressed as “ $0.79/1.67 - 1 (= 1.11)$ ”.

As described above, it was found that the protrusion 11 provided in the web 3 can increase the deformation performance. An effective height of the protrusion 11 was then considered. Specifically, the increment of the deformation performance when (protrusion height V)/(web width B) is changed from 0.02 to 0.135 was investigated.

Fig. 4 illustrates the consideration result. The horizontal axis indicates (protrusion height V)/(web width B). The vertical axis indicates the incremental rate

of deformation performance. A larger value of (protrusion height V)/(web width B) tends to lead to a larger incremental rate of the deformation performance. When (protrusion height V)/(web width B) is less than 1/16, however, the incremental rate of the deformation performance is minute (0.3 or less). The deformation performance is thus not sufficiently improved. Consequently, the required height of the protrusion 11 is defined by the expression (1) in the invention.

$$V \geq B/16 \cdots (1)$$

Consideration was then performed based on the analysis result in order to derive the relational expression between the cross-sectional shape of the steel sheet pile and the shape of the protrusion 11, and the deformation performance of the hat-shaped steel sheet pile 1.

The hat-shaped steel sheet pile 1, which is a subject of the invention, has a shape close to a shape formed by bending both ends of a linear plate element in cross section in the width direction x and the height direction y. That is, the web 3, which is a weak part, corresponds to a central linear portion, and the flanges 5 correspond to bent portions of both ends of the plate element. Examples of a structure having the shape similar to that of the hat-shaped steel sheet pile 1 thus include a square-type steel pipe having a square cross section as illustrated in Fig. 5. That is, when one side of the square-type steel pipe is focused on, the square is formed by bending both ends of the linear plate element at 90°. The square-type steel pipe is analogous with the hat-shaped steel sheet pile in that the square-type steel pipe is formed by bending both ends of the linear plate element.

Then the following evaluating expression (5) for deformation performance μ of a square-shaped steel pipe (width B, height B, plate thickness t, yield strain ε_y , and equilateral shape) was referred. The evaluating expression (5) is indicated as known knowledge in, for example, a document "Hitoshi Kuwamura (2002) Performance and Design of Steel Structures, Kyodo-shuppan". The deformation performance evaluating expression in the case of a cross-sectional shape of the hat-shaped steel sheet pile (in view of the protrusion 11) was tried to be derived based on the expression.

[Mathematical Expression 5]

$$\mu = \frac{5}{\left(\left(\frac{B \times \sqrt{\epsilon_y}}{t} \right)^2 - 0.25 \right)}$$

... Expression (5)

It should be noted that the hat-shaped steel sheet pile 1 and the square-shaped steel pipe differ in a bending angle of the plate-shaped element at the end of the web 3. The square-type steel pipe is bent at a bending angle of 90°, whereas the hat-shaped steel sheet pile 1 is bent at a bending angle smaller than 90°. The square-type steel pipe is basically square, and thus the cross-sectional width and the cross-sectional height are equivalent. In contrast, it is necessary to assume the case where the length (B) of the web 3 is different from the height (H) of the steel sheet pile in the hat-shaped steel sheet pile 1.

Then, in order to see the influence of such a difference in shape, Fig. 6 illustrates the relationship between a generalized width-thickness ratio β ($= B/t \times \epsilon_y^{0.5}$) and the deformation performance μ when analyzed under the following conditions in the hat-shaped steel sheet pile not provided with the protrusion 11 in the web 3.

Ratio (H/B) of the web width B to the cross-sectional height H of the hat-shaped steel sheet pile 1: 0.71, 1.00, and 1.57.

Plate thickness: 6 to 18 mm

Referring to Fig. 6, it is found that the analytical value of the deformation performance μ of the hat-shaped steel sheet pile 1 tends to be a bit below the deformation performance evaluating expression for the square-shaped steel pipe in the expression (5). When the numerator value 5 on the right side in the expression (5) is modified based on the analysis result, the following expression (6) is obtained as an evaluating expression for the deformation performance μ of the hat-shaped steel sheet pile 1.

[Mathematical Expression 6]

$$\mu = \frac{4.1}{\left(\left(\frac{B \times \sqrt{\epsilon_y}}{t} \right)^2 - 0.25 \right)} \quad .$$

... Expression (6)

In addition, even with the same generalized width-thickness ratio β , the smaller H/B leads to the larger deformation performance. It was found that the ratio of the web width B to the cross-sectional height H has influence in the case of the hat-shaped steel sheet pile 1. Then, the generalized width-thickness ratio β indicated by the horizontal axis in Fig. 6 was multiplied by $(H/B)^{0.1}$ to correct the web width. Fig. 7 illustrates the relationship between the corrected width-thickness ratio $\beta_2 (= B/t \times \epsilon_y^{0.5} \times (H/B)^{0.1})$ and the deformation performance μ . The following deformation performance evaluating expression (7) using the corrected width-thickness ratio β_2 was in good agreement with the analysis result.

[Mathematical Expression 7]

$$\mu = \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t} \right)^2 - 0.25 \right)}$$

... Expression (7)

The influence of the shape of the protrusion 11 provided in the web 3 of the hat-shaped steel sheet pile 1 was then evaluated.

The protrusion 11 provided in the web 3 increases the cross-sectional rigidity of the web 3, thereby improving the deformation performance of the hat-shaped steel sheet pile 1. The effect can be expressed by apparently increasing the plate thickness t in the deformation performance evaluating expression (7). Then, when the effect of increase in the web plate thickness by providing the protrusion 11 is defined as Δt , the deformation performance evaluating expression is expressed by the expression (8).

[Mathematical Expression 8]

$$\mu = \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \Delta t} \right)^2 - 0.25 \right)} \quad \dots \text{Expression (8)}$$

Here, possible factors contributing to Δt include the protrusion height V , the width W between the protrusion bases, the number n of the protrusions, and the steel-sheet-pile web width (corrected by multiplying the web width B by $(H/B)^{0.1}$). As a result of comparison with the analysis result in view of these facts, it was found that

[Mathematical Expression 9]

$$\Delta t = \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}} \quad \dots \dots (9)$$

In addition, a deformation performance evaluating expression (10) in view of the protrusion 11 provided in the web 3 is derived when the expression (9) is substituted for the expression (8).

[Mathematical Expression 10]

$$\mu = \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \quad \dots \dots (10)$$

Fig. 8 illustrates the comparison between the deformation performance evaluating expression (10) and the analysis result.

It should be noted that other cases were considered in addition to the case where one protrusion 11 is provided at the center of the web. The other cases include a case where the protrusion 11 is provided at two locations as illustrated in Fig. 9 and a case where the protrusion 11 is provided at three locations as illustrated in Fig. 10.

The upper and lower limit values of the deformation performance μ defined by the expression (10) were then considered.

Wall body structures using the hat-shaped steel sheet pile 1 are roughly divided into a temporary wall and a permanent wall (permanent structure). Generally,

a steel sheet pile is designed assuming behaviors within an elastic range (equal to or less than the yield load level) in the temporary wall (referred to as elastic design). In contrast, the permanent wall (permanent structure) may be designed assuming a big earthquake owing to a long in-service period. In the case, the design is performed assuming behaviors in a plastic region after the yield load is reached (referred to as plastic design).

The upper and lower limit values of the deformation performance μ in the case of usage in the temporary wall (application to the elastic design) were then considered in the embodiment.

In the elastic design, assumed acting force is equal to or less than the yield load, and thus the performance of the steel sheet pile to the deformation performance $\mu = 1.0$ (at the time where the yield load is reached) is required to be guaranteed, for example, in the relationship between the acting load/yield load and the deformation performance illustrated in Fig. 3.

The acting load, however, may be increased by, for example, variations in the quality and shape of the steel sheet pile and errors (e.g., inclination, rotation, and deviation) in construction, and a structure has a risk of collapsing immediately after the yield load is exceeded. In view of these facts, the deformation performance μ of 1.5 of the steel sheet pile should be secured even in the elastic design.

In contrast, even when large plastic deformation occurs, the load bearing capacity of the steel sheet pile can be held with the deformation performance increased by increasing the rigidity of the steel sheet pile. In this case, however, the wall structure may collapse owing to another factor such as active collapsing of the ground. In general, the steel sheet pile is deformed at a rotation angle of approximately $1/50$ at the time of yielding. When the steel sheet pile has a deformation performance of 10, the rotation angle is $1/50 \times 10 = 1/5$. The deformation at a rotation angle of $1/5$ or more may cause the active collapsing of the ground. The deformation performance μ is thus preferably 10 or less from the viewpoint of avoiding the active collapsing of the ground. The hat-shaped steel sheet pile 1 preferably has the deformation performance μ of 1.5 $\leq \mu \leq 10$ when assuming the elastic design.

From the above, the protrusion 11 was determined to be provided in the web 3 such that the expression (2) (and the expression (1)) is satisfied.

[Mathematical Expression 11]

$$1.5 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \leq 10 \quad \dots (2)$$

As described above, the hat-shaped steel sheet pile of the embodiment has excellent deformation performance owing to the protrusion 11, which satisfies the expressions (1) and (2), provided in the web 3. As a result, even when the yield load is exceeded in usage in the temporary wall, the hat-shaped steel sheet pile does not collapse, and does not cause the active collapsing of the ground.

[Second Embodiment]

In the above-described first embodiment, the case where the hat-shaped steel sheet pile 1 is applied as a temporary wall is described, whereas, in the embodiment, a value of the deformation performance μ in the case where the hat-shaped steel sheet pile 1 is applied (applied to the plastic design) as a permanent wall (permanent structure) was considered.

In the plastic design, a level of deformation performance required for a steel sheet pile varies depending on structures and environments. The performance for withstanding the all plastic moment load of the steel sheet pile is, however, essential. In general, a deformation performance μ of 2 or more leads to the all plastic moment load. When assuming the plastic design, the protrusion 11 is thus required to be provided in the web 3 such that the hat-shaped steel sheet pile 1 has a deformation performance μ of $2.0 \leq \mu \leq 10$ and the expression (3) (and the expression (1)) is satisfied.

[Mathematical Expression 12]

$$2 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \leq 10 \quad \dots (3)$$

As described above, the hat-shaped steel sheet pile of the embodiment has excellent deformation performance owing to the protrusion 11, which satisfies the expressions (1) and (3), provided in the web 3. As a result, even when the yield load is exceeded in usage in the permanent wall (permanent structure), the hat-shaped steel sheet pile does not collapse, and does not cause the active collapsing of the ground.

[Third Embodiment]

The embodiment relates to a steel sheet pile suitable for application to a road structure and a harbor structure.

Plastic design is adopted for a regular structure of the road and harbor structures. In general, a deformation performance $\mu = 4$ is set as the upper limit of performance requirements.

When applied to the road structure or the harbor structure, the protrusion 11 is thus required to be provided in the web 3 such that the hat-shaped steel sheet pile 1 has a deformation performance μ of $2.0 \leq \mu \leq 4.0$ and the expression (4) (and the expression (1)) is satisfied.

[Mathematical Expression 13]

$$2 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} - 0.25 \right)^2 \right)} \leq 4 \quad \dots (4)$$

As described above, the hat-shaped steel sheet pile of the embodiment has excellent deformation performance owing to the protrusion 11, which satisfies the expressions (1) and (4), provided in the web 3. As a result, even when the yield load is exceeded in usage in the road structure or the harbor structure, the hat-shaped steel sheet pile does not collapse, and satisfies the upper value of the deformation performance required for the road structure or the harbor structure.

It should be noted that the width W between the bases of the protrusion 11 is preferably smaller than five times the height V of the protrusion 11 ($W < 5 \times V$). The reason for setting of $W < 5 \times V$ is as follows.

In the invention, the expression (1) defines $V \geq B/16$. When $W = 5 \times V$ (maximum width exceeded) is substituted into the expression (1), $W \geq B \times 5/16$ is obtained. This means that the width W between the bases of the protrusion 11

occupies approximately 1/3 or more of the web width B. When such a protrusion 11 is disposed at the center of the web 3, the lengths of web parallel portions on both sides of the protrusion 11 in the width direction x are smaller than the width W between the bases. There is concern that earth and water pressures acting on the web 3 are not transmitted to the entire web 3 in a balanced manner. In addition, when a strut or a waling is provided along a steel-sheet-pile wall direction, a load may fail to be sufficiently transmitted. Consequently, in order to avoid this situation, setting of $W < 5 \times V$ is preferably performed.

In the above-described embodiment, the protrusion 11 has a V-shape as illustrated in Figs. 1, 8, and 9. The shape of the protrusion 11 in the invention is, however, not limited to the shape. For example, as illustrated in Fig. 11, the protrusion 11 may have an arc-shaped roundness. That is, the protrusion 11 may have an arc-shape in cross section in the width direction x and the height direction y. The protrusion 11 may also have a trapezoidal shape.

When a plurality of protrusions 11 is provided, the heights V of the protrusions 11 are not required to be the same. The heights V of the plurality of protrusions 11 may be different.

In the above description, the protruding direction (overhanging direction) of the protrusion 11 is described in an example of the protrusion 11 that protrudes (overhangs) to the inner surface side of the web 3, that is, the side where the flange 5 is disposed in the height direction y. In the invention, the protruding direction of the protrusion 11 is, however, not limited to the direction. The protrusion 11 may protrude to the outer surface side of the web 3, that is, the side where the flange 5 is not disposed in the height direction y.

It should be noted that the invention is on the assumption that the protrusion 11 is provided in the web 3. In addition to this configuration, the protrusion 11 may be provided in the arm 7. The protrusion 11 may be provided at a corner portion, which is an inflection portion between the web 3 and the flange 5. The protrusion 11 may be provided at a corner portion, which is an inflection portion between the arm 7 and the flange 5.

When the cross-sectional height H of the steel sheet pile is larger than the web width B, the protrusion 11 may be provided in the flange 5. In the case, the protrusion 11 may be attached to the vicinity of the center of the flange 5. The protrusion 11 may be provided in the vicinity of the base of the flange 5. The protrusion 11 may be attached to the vicinity of the base of the arm 7.

[Example]

The following table illustrates the specific hat-shaped steel sheet piles 1 in the first to third embodiments and the hat-shaped steel sheet pile (in a comparative example) without the protrusion 11.

[Table 1]

	Cross-sectional height H (mm)	Web width B (mm)	Plate thickness t (mm)	Yield strain ϵ_y	Protrusion height V (mm)	Protrusion width W (mm)	V/B	Number of protrusion n	Deformation performance μ	Remarks
Comparative Example	350	350	6	0.0016	0	0	0.000	0	0.79	(Without protruding portion)
First Present Inventive Example	350	350	6	0.0016	22	60	0.063	1	1.53	Satisfy first embodiment
Second Present Inventive Example	350	350	6	0.0016	35	70	0.100	1	2.46	Satisfy first to third embodiments
Third Present Inventive Example	350	350	6	0.0016	45	85	0.129	1	3.82	Satisfy first to third embodiments
Fourth Present Inventive Example	350	350	6	0.0016	60	120	0.171	1	9.81	Satisfy first and second embodiments
Fifth Present Inventive Example	350	350	9	0.0016	22	25	0.063	1	2.39	Satisfy second and third embodiments
Sixth Present Inventive Example	350	350	9	0.0016	35	70	0.100	1	4.60	Satisfy first and second embodiments
Seventh Present Inventive Example	350	350	9	0.0016	50	100	0.143	1	9.48	Satisfy first and second embodiments
Eighth Present Inventive Example	450	500	9	0.0016	35	70	0.070	1	1.63	Satisfy first embodiment
Ninth Present Inventive Example	450	500	9	0.0016	45	90	0.090	1	2.20	Satisfy first to third embodiments
Tenth Present Inventive Example	450	500	9	0.0016	45	90	0.090	2	4.43	Satisfy first and second embodiments
Eleventh Present Inventive Example	450	500	9	0.0016	45	90	0.090	3	8.22	Satisfy first and second embodiments
Twelfth Present Inventive Example	250	300	6	0.0016	20	20	0.067	1	1.52	Satisfy first embodiment
Thirteenth Present Inventive Example	250	300	6	0.0016	30	60	0.100	1	3.32	Satisfy first to third embodiments
Fourteenth Present Inventive Example	250	300	6	0.0016	25	50	0.083	2	4.83	Satisfy first and second embodiments
Fifteenth Present Inventive Example	250	300	6	0.0016	25	50	0.083	3	8.66	Satisfy first and second embodiments

REFERENCE SIGNS LIST

	1	Hat-shaped steel sheet pile
	3	Web
	5	Flange
	7	Arm
5	9	Joint
	11	Protrusion
	13	Hat-shaped steel sheet pile (without protrusion)

CLAIMS

1. A hat-shaped steel sheet pile comprising:

a web;

a pair of flanges;

a pair of arms; and

a pair of joints,

the pair of flanges being formed at both ends of the web, an arm constituting the pair of arms being formed at an end of a flange constituting the pair of flanges, and a joint constituting the pair of joints being provided at a tip of the arm,

wherein the hat-shaped steel sheet pile includes a protrusion satisfying following expressions (1) and (2) over an entire length of the steel sheet pile in the web, [Mathematical Expression 1]

$$V \geq B/16 \quad \cdot \cdot \cdot \cdot (1)$$

$$1.5 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \leq 10 \quad \cdot \cdot \cdot \cdot (2)$$

where V: protrusion height (mm); W: width (mm) between protrusion bases ($W < 5 \times V$); n: number of protrusions; H: steel-sheet-pile cross-section height (mm); B: steel-sheet-pile web width (mm); t: plate thickness (mm) of steel-sheet-pile-web; and ϵ_y : yield strain of steel sheet pile.

2. A hat-shaped steel sheet pile comprising:

a web;

a pair of flanges;

a pair of arms; and

a pair of joints,

the pair of flanges being formed at both ends of the web, an arm constituting the pair of arms being formed at an end of a flange constituting the pair of flanges, and a joint constituting the pair of joints being provided at a tip of the arm,

wherein the hat-shaped steel sheet pile includes a protrusion satisfying

following expressions (1) and (3) over an entire length of the steel sheet pile in the web,
[Mathematical Expression 2]

$$V \geq B/16 \quad \dots (1)$$

$$2 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \leq 10 \quad \dots (3)$$

where V: protrusion height (mm); W: width (mm) between protrusion bases ($W < 5 \times V$); n: number of protrusions; H: steel-sheet-pile cross-section height (mm); B: steel-sheet-pile web width (mm); t: plate thickness (mm) of steel-sheet-pile-web; and ϵ_y : yield strain of steel sheet pile.

3. A hat-shaped steel sheet pile comprising:

a web;

a pair of flanges;

a pair of arms; and

a pair of joints,

the pair of flanges being formed at both ends of the web, an arm constituting the pair of arms being formed at an end of a flange constituting the pair of flanges, and a joint constituting the pair of joints being provided at a tip of the arm,

wherein the hat-shaped steel sheet pile includes a protrusion satisfying following expressions (1) and (4) over an entire length of the steel sheet pile in the web,
[Mathematical Expression 3]

$$V \geq B/16 \quad \dots (1)$$

$$2 \leq \frac{4.1}{\left(\left(\frac{B \times (H/B)^{0.1} \times \sqrt{\epsilon_y}}{t + \frac{W \times V^{0.85} \times n}{B \times (H/B)^{0.1}}} \right)^2 - 0.25 \right)} \leq 4 \quad \dots (4)$$

where V : protrusion height (mm); W : width (mm) between protrusion bases ($W < 5 \times V$); n : number of protrusions; H : steel-sheet-pile cross-section height (mm); B : steel-sheet-pile web width (mm); t : plate thickness (mm) of steel-sheet-pile-web; and ε_y : yield strain of steel sheet pile.