

SPECIFICATION

COMBINED STEEL SHEET PILE, EARTH-RETAINING WALL FORMED BY COMBINED STEEL SHEET PILE, AND METHOD OF SELECTING COMBINED STEEL SHEET PILE

TECHNICAL FIELD

[0001]

The present invention relates to a combined steel sheet pile, an earth-retaining wall formed by the combined steel sheet pile, and a method of selecting the combined steel sheet pile. In particular, the combined steel sheet pile and the earth-retaining wall according to the present invention are used mainly for preventing the earth and the like from collapsing at the time of construction of harbor wharf facilities, reclamation and bank protection works, underground excavation works and the like.

BACKGROUND ART

[0002]

In the field of civil engineering and construction, steel sheet piles are generally used as a steel member of underground continuous walls, which are mainly used in an earth-retaining wall for preventing the earth and the like from collapsing, and a bank-protection wall at rivers. The shapes of the steel sheet piles include a U-shape, a Z-shape, a flat-web-shape and a hat-shape. At the time of the civil engineering and construction works, joints of adjacent steel sheet piles are interlocked with each other, and are installed into the ground, whereby the underground continuous walls (wall body) are integrally formed. In general, the strength of the wall body can be enhanced by increasing the cross-sectional size of each steel sheet pile to increase cross-sectional properties, or using a combined steel sheet pile in which an H-shaped steel or CT steel

is jointed to the steel sheet piles having the U-shape, the Z-shape, the flat web-shape, the hat-shape or the like by welding and the like.

[0003]

As related arts, Patent Documents 1 and 2, for example, disclose an underground continuous wall using a combined steel sheet pile. The arts disclosed in Patent Documents 1 and 2 employ a hat-shaped steel sheet pile including a web portion, a pair of flange portions provided continuously to respective ends of the web portion, a pair of arm portions each provided continuously to the end of each of the flange portions, and a joint portion formed at the end of each of the arms. Then, an H-shaped steel is combined with the hat-shaped steel sheet pile. The H-shaped steel has a central web portion, and a pair of flange portions (first flange portion and second flange portion) provided at the respect ends of the central web portion. More specifically, the hat-shaped steel sheet pile and the H-shaped steel are combined with each other such that the second flange portion of the H-shaped steel is fixed by welding on the outer surface of the web portion of the hat-shaped steel sheet pile. Note that, in the present invention, the inner side is defined as an arm portion side of the hat-shaped steel sheet pile (recessed side in its cross section), whereas the outer side is defined as a web portion side (protruding side in its cross section).

[0004]

In particular, the combined steel sheet pile has a high bending rigidity against the external bending force acting in the direction perpendicular to the longitudinal direction (installation direction). Therefore, conventionally, the combined steel sheet pile is usually used as a cut-off wall or self-standing earth-retaining wall.

RELATED ART DOCUMENTS

PATENT DOCUMENTS

[0005]

Patent Document 1: Japanese Unexamined Patent Application, First
Publication No. 2002-212943

Patent Document 2: PCT International Publication No. WO2008/029835

DISCLOSURE OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0006]

In general, a cut-off wall is required to have a bending rigidity only at the time of installation, and hence, in most cases, the cross-sectional shape of the cut-off wall is not determined based on the stress acting on a steel material after the installation. Therefore, it was not necessary for the cut-off wall formed by the combined steel sheet pile to employ a high-yield-point steel sheet pile and H-shaped steel.

[0007]

Further, as for a self-standing earth-retaining wall, the cross-sectional shape is determined in accordance with the amount of displacement of a head portion of the earth-retaining wall, and is not determined in accordance with the bending moment occurring due to an earth pressure or hydraulic pressure. Therefore, a high-yield-point steel sheet pile and H-shaped steel were not required for the self-standing earth-retaining wall formed by the combined steel sheet pile.

[0008]

Table 1 shows minimum yield points σ_{ys} , σ_{yh} of the hat-shaped steel sheet pile and the H-shaped steel, and a minimum yield point ratio σ_{yh}/σ_{ys} of the combination of the hat-shaped steel sheet pile and the H-shaped steel, in terms of a combined steel sheet pile formed by a hat-shaped steel sheet pile (SYW295) and an H-shaped steel (SM490A). Further, as for the H-shaped steel, the minimum yield point and the minimum yield point ratio are compared separately for flanges having a thickness of over 16 mm and a thickness of 16 mm or lower. The H-shaped steel and the hat-shaped steel sheet pile are formed by materials having almost the same strength as

each other. The minimum yield point of the H-shaped steel SM490A is in the range of 315 to 325 N/mm², and the minimum yield point of the hat-shaped steel sheet pile SYW295 is 295 N/mm². From Table 1, it can be seen that the yield point ratios σ_{yh}/σ_{ys} , which are obtained separately for each of the H-shaped steels having the flange with a thickness over 16 mm and the flange with a thickness of 16 mm or lower, is 1.102 in the case of the H-shaped steel having the flange thickness of 16 mm or lower, and is 1.068 in the case of the H-shaped steel having the flange thickness of over 16 mm. From these data, the yield point ratios σ_{yh}/σ_{ys} is about 1.1 at the most, regardless of the size of the flange thickness of the H-shaped steel.

[0009]

[Table 1]

	Flange thickness of H-shaped steel		Steel material standard (JIS standard)
	16 mm or lower	Over 16 mm	
Minimum yield point σ_{yh} (N/mm ²) of H-shaped steel	325	315	SM490A
Minimum yield point σ_{ys} (N/mm ²) of hat-shaped steel sheet pile	295	295	SYW295
Yield point ratio σ_{yh}/σ_{ys}	1.102	1.068	-

[0010]

However, in addition to the self-standing earth-retaining wall, the combined steel sheet pile is also used for an anchored earth-retaining wall, which is used in the large-sized harbor structure and the like. The anchored earth-retaining wall is formed by supporting the steel sheet pile combined with jointed steel sheet piles and H-shaped steels in the vicinity of the respect head portions thereof, for example, by a tie rod or other pulling member, and fixing them. However, as the steel sheet pile constituting the anchored earth-retaining wall, the hat-shaped steel sheet pile did not provide any special superiority over a Z-shaped steel sheet pile that has been subjected to a hot-rolling process.

[0011]

Table 2 shows comparison results of section modulus and steel material weight in the case where a necessary section modulus per 1 m of quay wall is about 4000 cm^3 . In the example of the combined steel sheet pile in Table 2, a 10H hat-shaped steel sheet pile is combined with an H-shaped steel having a length from a bottom surface of the lower flange to a top surface of the upper flange of 700 mm, a flange width of 200 mm, a web thickness at the center of 9 mm, and a flange thickness of 12 mm. Further, as a comparative example, a Z-shaped steel sheet pile that has been subjected to the hot-rolling process is given. From Table 2, it can be seen that the combined steel sheet pile exhibits almost the same necessary section modulus ($= 4000 \text{ cm}^3$) as the Z-shaped steel sheet pile, and the steel weights thereof are almost equal. However, the combined steel sheet pile requires fixing the hat-shaped steel sheet pile with the H-shaped steel by welding and the like, resulting in the large working cost. Therefore, the combined steel sheet pile does not provide any special superiority over the Z-shaped steel sheet pile.

[0012]

[Table 2]

Cross section of steel sheet pile	Characteristic of cross section per 1 m of wall	
	Section modulus	Steel material weight
Combined steel sheet pile	4061 cm^3	193 kg
Z-shaped sheet pile	4000 cm^3	191 kg

[0013]

In view of the problems described above, the present invention has been made. An object of the present invention is to provide a combined steel sheet pile capable of achieving weight reduction while maintaining necessary section modulus, and providing special superiority against a conventional Z-shaped steel sheet pile, by significantly improving the flexural strength of a combined steel sheet pile formed by a hat-shaped steel sheet pile and an H-shaped steel (especially in the case where the present invention is applied to a anchored earth-retaining wall and the like), and to provide an earth-retaining wall formed by connecting the combined steel sheet piles.

MEANS FOR SOLVING THE PROBLEMS

[0014]

To solve the problem above, the present invention uses the following measures.

(1) A first aspect of the present invention is a combined steel sheet pile having a hat-shaped steel sheet pile and an H-shaped steel. The hat-shaped steel sheet pile has a web portion; a pair of flange portions provided at both ends of the web portion; a pair of arm portions each provided at respective ends of the pair of flange portions; and, a pair of joint portions each formed at respective ends of the pair of arm portions. The H-shaped steel sheet pile has a central web portion; a first flange portion provided at one end of the central web portion; and, a second flange portion provided at the other end of the central web portion. The second flange portion is fixed on an outside of the web portion of the hat-shaped steel sheet pile, and, a minimum yield point ratio σ_{yh}/σ_{ys} between a minimum yield point σ_{yh} of the H-shaped steel and a minimum yield point σ_{ys} of the hat-shaped steel sheet pile is 1.105 or more.

[0015]

(2) In the combined steel sheet pile according to (1) above, the minimum yield point ratio σ_{yh}/σ_{ys} may be in the range of 1.109 to 1.559.

[0016]

(3) A second aspect of the present invention is an earth-retaining wall employing two or more combined steel sheet piles according to (1) or (2) above. In the earth-retaining wall, the adjacent joint portions of the combined steel sheet piles are connected with each other.

[0017]

(4) A third aspect of the present invention is a method of selecting combination of a combined steel sheet pile having a hat-shaped steel sheet pile and an H-shaped steel. In the selection method, the combination is selected such that a minimum yield point

ratio σ_{yh}/σ_{ys} between a minimum yield point σ_{yh} of the H-shaped steel and a minimum yield point σ_{ys} of the hat-shaped steel sheet pile is 1.105 or more.

EFFECTS OF THE INVENTION

[0018]

According to the configurations described in (1) and (4) above, it is possible to enhance the flexural strength of the combined steel sheet pile, by setting the ratio σ_{yh}/σ_{ys} to 1.105 or more, where σ_{yh} is the minimum yield point of the H-shaped steel in the combination steel sheet pile and σ_{ys} is the minimum yield point of the hat-shaped steel sheet pile.

According to the configuration described in (2) above, it is possible to further reliably and firmly enhance the flexural strength of the combined steel sheet pile 1.

According to the configuration described in (3) above, it is possible to obtain the earth-retaining wall formed by the combined steel sheet pile having further enhanced flexural strength.

As described above, according to the present invention, it is possible to provide special superiority against a conventional Z-shaped steel sheet pile, by further reducing the weight at the time of satisfying the necessary section modulus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

FIG. 1 is a front view of a combined steel sheet pile according to an embodiment of the present invention.

FIG. 2 is a perspective view of the same combined steel sheet pile.

FIG. 3 is a side view of the same combined steel sheet pile.

FIG. 4 is a front view of an underground continuous wall body configured by connecting plural combined steel sheet piles according to an embodiment of the present invention.

FIG. 5 is a perspective view of the same underground continuous wall body.

FIG. 6 is a diagram illustrating values of y/H of 194 types of combined steel sheet piles.

EMBODIMENTS OF THE INVENTION

[0020]

To solve the problems described above, the present inventors paid attention to the fact that the flexural strength of a combined steel sheet pile is governed by a material type of an H-shaped steel, rather than by a material type of a hat-shaped steel sheet pile. The combined steel sheet pile is formed by fixing the H-shaped steel with the hat-shape steel sheet pile by welding and the like. Therefore, the material types of the H-shaped steel and the hat-shaped steel sheet pile can be selected independently of each other. More specifically, based on the properties of the materials of the H-shaped steel and the hat-shaped steel sheet pile, it is possible to optionally select the combination of a minimum yield point σ_{yh} of the H-shaped steel and a minimum yield point σ_{ys} of the hat-shaped steel sheet pile, and a ratio thereof σ_{yh}/σ_{ys} . Then, the present inventors found that it is possible to obtain the larger flexural strength, by setting the minimum yield point σ_{yh} of the H-shaped steel higher than the minimum yield point σ_{ys} of the hat-shaped steel sheet pile. Further, the present inventors found that a ratio y/H does not reach 0.5, and it is preferable that the ratio of y/H be about 0.475 at most as described later, where H is a length from a bottom surface of an arm portion of the hat-shaped steel sheet pile to an upper surface of a first flange of the H-shaped steel, and y is a length from the bottom surface of the arm portion to a neutral axis of the combined steel sheet pile. The present inventors investigated a value of the ratio y/H concerning 194 types of the combined steel sheet piles formed by generally used 10H hat-shaped steel sheet piles (width: 900 mm, height: 230 mm, cross-sectional area: 110 cm²/piece, and moment inertia: 9430 cm⁴/piece) or 25H hat-shaped steel sheet piles (width: 900 mm, height: 300 mm, cross-sectional area: 144.4 cm²/piece, and

moment inertia: $22000 \text{ cm}^4/\text{piece}$), and H-shaped steels having a height in the range of 400 mm to 1000 mm. From the H-shaped steels used for the combination described above, specific H-shaped steels having a flange thickness of more than 30 mm, which is used for a pillar, are excluded. For the steel sheet piles and the H-shaped steel, values of a so-called plate thickness-width ratio (t/d) are set for the purpose of achieving a predetermined cross-sectional performance. Therefore, the values of the y/H of the combined steel sheet piles are distributed in a certain range. As illustrated in FIG. 6, the lower limit of the value of y/H of the combined steel sheet piles in the range described above is about 0.37, and the upper limit thereof is about 0.48. At the time of actual designing, it is possible to select further economical combined steel sheet piles through other combined steel sheet piles, in the case of the combined steel sheet pile in the vicinity of the upper limit. For example, the section modulus is $5050 \text{ cm}^3/\text{m}$ and the steel material weight is $266 \text{ kg}/\text{cm}^2$ in the case of the combined steel sheet pile having the y/H value of 0.48 and formed by the 10H-type steel sheet pile and the H-shaped steel having a height of 450 mm, a flange width of 250 mm and a flange thickness of 28 mm. However, this can be replaced with a combined steel sheet pile having a more economical cross section with a section modulus of $5186 \text{ cm}^3/\text{m}$ and a steel material weight of $253 \text{ kg}/\text{m}$, and formed by the 10H-type steel sheet pile and the H-shaped steel having a height of 500 mm, a flange width of 250 mm and a flange thickness of 25 mm. In this case, the value of the y/H of the combined steel sheet pile is 0.467. However, from the viewpoint of productivity and availability of the H-shaped steel, it is desirable to secure more varied combinations. The present inventors determined that it is desirable that the upper limit of the y/H be set to be 0.475, which is close to the upper limit obtained by the investigation results described above. This is because that, by employing this setting, the value of the y/H can be set close to the upper limit, whereby it is possible to sufficiently achieve the performances that the combined steel sheet pile originally has. Further, the y/H value of the combined steel sheet pile is 0.475 or lower. Therefore, a ratio of a length ($H - y$) from the neutral axis

of the combined steel sheet pile to the upper surface of the first flange of the H-shaped steel relative to y is larger than 1, and $(H - y)/y$ is 1.105 or more. Therefore, the flexural strength is determined depending on an edge stress of the H-shaped steel.

[0021]

At the time of selecting the cross section of the combination of the H-shaped steel and the hat-shaped steel sheet pile, the shape of the cross section should be selected such that a ratio $(H - y)/y$ of the length $(H - y)$ from the neutral axis of the combined steel sheet pile to the upper surface of the first flange of the H-shaped steel relative to y is equal to or more than the σ_{yh}/σ_{ys} from viewpoint of preventing the stress at the end portion of the cross section from reaching the yield point. At this time, if the $(H - y)/y$ is set to a range extremely larger than the above-described σ_{yh}/σ_{ys} , a steel material has an unnecessarily high strength. However, by selecting the range such that the $(H - y)/y$ is almost equal to the σ_{yh}/σ_{ys} , it is possible to suppress the stress occurring at the peripheral edge of the hat-shaped steel sheet pile to the minimum yield point or lower of the hat-shaped steel sheet pile with the minimum steel material strength, even when the bending moment that yields the peripheral edge of the H-shaped steel acts. Therefore, it is possible to achieve the effective configuration of the cross section of the combined steel sheet pile.

[0022]

By paying attention to the point that the combination of σ_{yh} and σ_{ys} should be selected so as to generally satisfy $(H - y)/y = \sigma_{yh}/\sigma_{ys}$ while satisfying the relationship of $(H - y)/y \geq \sigma_{yh}/\sigma_{ys}$, the present inventors found that it is possible to obtain a design guideline of the combined steel sheet pile based only on the material property, by replacing the limitation of $(H - y)/y \geq 1.105$ concerning the shape of the cross section with the limitation of $\sigma_{yh}/\sigma_{ys} \geq 1.105$, which is a limitation concerning the material property of σ_{yh}/σ_{ys} . With this design guideline, it is possible to provide the combined steel sheet pile having extremely reduced steel material weight in terms of the same bending moment, by setting the yield point ratio σ_{yh}/σ_{ys} to 1.105 or more.

[0023]

Below, as a preferred embodiment according to the present invention, a combined steel sheet pile 1 applied to an earth-retaining wall and the like will be described in detail.

[0024]

FIG. 1 is a front view illustrating the combined steel sheet pile 1 according to one embodiment of the present invention; FIG. 2 is a perspective view thereof; and FIG. 3 is a side view thereof.

[0025]

The combined steel sheet pile 1 has a hat-shaped steel sheet pile 10 and an H-shaped steel 20.

[0026]

The hat-shaped steel sheet pile 10 has a web portion 11, a pair of flange portions 12, a pair of arm portions 13 and a pair of joint portions 14. The pair of flange portions 12 connect with and extend obliquely from respective ends of the web portion 11. Further, the pair of arm portions 13 connect with and extend from leading ends of the flange portions 12 so as to be parallel to the web portion 11. The pair of joint portions 14 are formed at leading ends of the respective arm portions 13. As for the pair of joint portions 14, cross sectional shapes of one joint 14 and the other joint portion 14 are point-symmetrically formed with each other. Each of the joint portions 14 has a shape that can interlock with a joint portion 14 of the adjacent combined steel sheet pile 1, and interlocking strength of both of the joint portions 14 are increased in order not to be detached from each other especially during interlocking.

[0027]

Further, the hat-shaped steel sheet pile 10 employed in the present invention is formed by a hot-rolling process, and the joint portion 14 thereof is formed in a complicated shape, and has increased strength.

[0028]

The H-shaped steel 20 is produced by a rolling process. The H-shaped steel 20 has a central web portion 21, and a pair of flange portions 22a (first flange portion) and 22b (second lower flange portion) provided at respective ends of the central web portion 21. The flange portion 22b (second flange portion) of the H-shaped steel 20 is fixed to an outer surface of the web portion 11 of the hat-shaped steel sheet pile 10. The flange portion 22b (second flange portion) of the H-shaped steel 20 may be fixed to the web portion 11 of the hat-shaped steel sheet pile 10, for example, by means of welding, adhesion, bolt, rivet, screw, nail or the like. Note that, in the following description, an example will be given in which a welding portion 27 is fixed to the second flange portion 22b through welding. The welding portion 27 may be either welded intermittently at given intervals or welded continuously, toward the longitudinal direction (installation direction) of the H-shaped steel 20 as illustrated in FIG. 3. By welding as described above, it is possible to easily and firmly fix the hat-shaped steel sheet pile 10 and the H-shaped steel 20.

[0029]

In the combined steel sheet pile 1 described above, it is desirable that the second flange portion 22b of the H-shaped steel 20 be brought into surface contact with the outer surface of the web portion 11 of the hat-shaped steel sheet pile 10, at the time of forming a structure in which the hat-shaped steel sheet pile 10 is fixed integrally to the H-shaped steel 20. This is because, by bringing the second flange portion 22b into surface contact with the outer surface of the web portion 11 of the hat-shaped steel sheet pile 10, when the combined steel sheet pile 1 receives an external force such as hydraulic pressure, the hat-shaped steel sheet pile 10 and the H-shaped steel 20 can function as an integral structure to resist the external force. Further, it is possible to stabilize the H-shaped steel 20 at the time of welding the hat-shaped steel sheet pile 10 and the H-shaped steel 20, whereby it is possible to easily proceed the welding operation.

[0030]

FIG. 4 and FIG. 5 illustrate an example of an underground continuous wall body 5 configured by jointing the combined steel sheet piles 1 having the configuration as described above with each other. The underground continuous wall body 5 is formed as one wall body by jointing the combined steel sheet piles 1 with each other by way of the joints 14. Further, the underground continuous wall body 5 is configured by sequentially arranging the same combined steel sheet piles 1.

[0031]

Next, a detailed configuration of the combined steel sheet pile 1 according to this embodiment will be further described. In the combined steel sheet pile 1 according to this embodiment, when the minimum yield point of the H-shaped steel 20 is denoted by σ_{yh} and the minimum yield point of the hat-shaped steel sheet pile 10 is denoted by σ_{ys} , the ratio thereof σ_{yh}/σ_{ys} is set so as to be 1.105 or more.

[0032]

In the case where the σ_{yh}/σ_{ys} is less than 1.105, the flexural strength of the combined steel sheet pile cannot be sufficiently improved. Therefore, in order to obtain a desired section modulus, it is necessary to increase the cross sectional area of the steel material, resulting in increase in the total weight of the steel material. Accordingly, in the case where the σ_{yh}/σ_{ys} is less than 1.105, the combined sheet pile, which requires the welding working cost to integrate them becomes disadvantage as compared with the conventional Z-shaped steel sheet pile. In this respect, according to the combined steel sheet pile 1 of the present invention, the material of the hat-shaped steel sheet pile 10 and the material of the H-shaped steel 20 are selected such that the σ_{yh}/σ_{ys} is 1.105 or more as described above. Therefore, the flexural strength of the combined steel sheet pile can be further increased, whereby it is possible to provide the superiority especially at the time of employing the combined steel sheet pile for the anchored earth-retaining wall.

[0033]

It should be noted that the upper limit of the σ_{yh}/σ_{ys} is not specified, and may be set to about 1.6, which is the upper limit of the ratio of the minimum yield points of the hat-shaped steel sheet pile and the H-shaped steel under the current standard. Incidentally, even if the standard for the steel material does not exist, it may be possible to employ a combination whose σ_{yh}/σ_{ys} is 1.6 or over because the H-shaped steel having the high yield point can be produced.

[0034]

In particular, in the present invention, the ratio σ_{yh}/σ_{ys} between the minimum yield point σ_{yh} of the H-shaped steel and the minimum yield point σ_{ys} of the steel sheet pile may be adjusted so as to be in the range of 1.109 to 1.559, as described later. This makes it possible to further reliably and firmly achieve the increase in the flexural strength of the combined steel sheet pile 1.

[0035]

Next, with reference to FIG. 1, sizes of the combined steel sheet pile 1 according to this embodiment will be described. As illustrated in FIG. 1, H represents a length from the bottom surface of the arm portion 13 of the hat-shaped steel sheet pile 10 to the upper surface of the first flange portion 22a of the H-shaped steel. Further, y represents a length from the bottom surface of the arm portion 13 to the neutral axis of the combined steel sheet pile 1. At this time, a ratio of a length (H - y) from the neutral axis of the combined steel sheet pile 1 to the upper surface of the first flange portion 22a of the H-shaped steel relative to y is expressed by (H - y)/y. It may be possible to select the shape of the cross section such that the ratio (H - y)/y is larger than the σ_{yh}/σ_{ys} . By determining the shapes of the hat-shaped steel sheet pile 10 and the H-shaped steel 20 such that the ratio (H - y)/y is larger than the σ_{yh}/σ_{ys} , it is possible to suppress the stress occurring at the peripheral edge of the hat-shaped steel sheet pile 10 to the minimum yield point σ_{ys} of the steel sheet pile or lower, when the bending moment causing the stress of the peripheral edge of the first flange portion 22a of the H-shaped steel 20 corresponding to the minimum yield point σ_{yh} of the H-shaped steel

20 acts on the combined steel sheet pile 1. This makes it possible to further increase the flexural strength of the combined steel sheet pile 1. As a result, it is possible to further reduce the weight while satisfying the necessary section modulus, whereby it is possible to provide the special superiority against the conventional Z-shaped steel sheet pile.

[0036]

Next, combination of the combined steel sheet pile 1 according to this embodiment of the present invention will be described in detail. Below, description will be made of combination in which the ratio σ_{yh}/σ_{ys} between the minimum yield point σ_{yh} of the H-shaped steel and the minimum yield point σ_{ys} of the hat-shaped steel sheet pile is 1.105 or more.

[0037]

Table 3 shows a combination example of the combined steel sheet pile 1 with the hat-shaped steel sheet pile 10 and the H-shaped steel 20.

[0038]

[Table 3]

	Steel standard of H-shaped steel 20		
	Q345B	SM490YA	SM570
Minimum yield point σ_{yh} (N/mm ²) of H-shaped steel 20	345	355	460
Minimum yield point σ_{ys} (N/mm ²) of hat-shaped steel sheet pile 10	295	295	295
Minimum yield point ratio σ_{yh}/σ_{ys}	1.169	1.203	1.559

[0039]

In the combination example in Table 3, SYW295 of JIS A 5523 is employed for the hat-shaped steel sheet pile 10. The SYW295 has a minimum yield point of 295 N/mm². Further, in the combination example in Table 3, Q345B of the Chinese Standard GB/T1591, SM490YA of JIS G 3106 and SM570 of JIS G 3106 are employed for the H-shaped steel 20. In the table, the minimum yield points σ_{yh} and σ_{ys} of the H-shaped steel 20 and the hat-shaped steel sheet pile 10 are shown. From Table 1, it

can be seen that: the σ_{yh}/σ_{ys} is 1.169 in the case where Q345B is used as the standard for the H-shaped steel 20; the σ_{yh}/σ_{ys} is 1.203 in the case where SM490YA is used as the standard for the H-shaped steel 20; and, the σ_{yh}/σ_{ys} is 1.559 in the case where SM570 is used as the standard for the H-shaped steel 20.

[0040]

Further, in Table 4, another combination example of the combined steel sheet pile 1 with the hat-shaped steel sheet pile 10 and the H-shaped steel 20 are shown.

[0041]

[Table 4]

	Steel standard of H-shaped steel 20	
	SM490YA	SM570
Minimum yield point σ_{yh} (N/mm ²) of H-shaped steel 20	355	460
Minimum yield point σ_{ys} (N/mm ²) of hat-shaped steel sheet pile 10	320	320
Minimum yield point ratio σ_{yh}/σ_{ys}	1.109	1.438

[0042]

In Table 4, S320GP of the European standard EN10248 is used as the standard for the hat-shaped steel sheet pile 10. The S320GP has a minimum yield point of 320 N/mm². Further, SM490YA and SM570 are employed for the H-shaped steel 20 as examples. In Table 4, the minimum yield points σ_{yh} and σ_{ys} of the H-shaped steel 20 and the hat-shaped steel sheet pile 10 are shown. From Table 4, it can be seen that: the σ_{yh}/σ_{ys} is 1.109 in the case where SM490YA is used as the standard for the H-shaped steel 20; and, the σ_{yh}/σ_{ys} is 1.438 in the case where SM570 is used as the standard for the H-shaped steel 20.

[0043]

As described above, by employing the hat-shaped steel sheet pile 10 and the H-shaped steel 20 with the standards shown in Tables 3 and 4, it is possible to obtain the σ_{yh}/σ_{ys} in the range of about 1.109 to 1.559, and to increase the flexural strength of the combined steel sheet pile 1. However, there are various standards for steel

materials other than the standards described above, and hence it may be possible to optionally combine the hat-shaped steel sheet pile 10 and the H-shaped steel 20 within the range that the minimum yield point ratio σ_{yh}/σ_{ys} of the combined steel sheet pile 1 is 1.105 or more.

[0044]

Below, description will be made of a cross-sectional shape selected such that the ratio $(H - y)/y$ of the length $(H - y)$ from the neutral axis of the combined steel sheet pile to the upper surface of the first flange portion 22a of the H-shaped steel relative to y is larger than the σ_{yh}/σ_{ys} .

Based on the dimensions of the hat-shaped steel sheet pile 10 and the H-shaped steel 20 illustrated in FIG. 1, it is possible to obtain the length y from the bottom surface of the arm portion 13 to the neutral axis of the combined steel sheet pile 1 from the Expression (1) below.

$$y = \{(As \cdot hs/2) + (2 \cdot Ah \cdot hs + Ah \cdot h_h)/2\} / (As + Ah) \quad \dots \text{Expression (1)}$$

[0045]

Where

hs : height of the hat-shaped steel sheet pile 10 (see FIG. 1)

h_h : height of the H-shaped steel 20 (see FIG. 1)

As : cross-sectional area per sheet of the hat-shaped steel sheet pile 10

Ah : cross-sectional area per piece of the H-shaped steel 20.

[0046]

Further, the y/H can be obtained through calculation based on the Expression (2) below.

$$y/H = \{hs/H + (Ah/As)/(1 + (Ah/As))\} / 2 \quad \dots \text{Expression (2)}$$

[0047]

Further, the ratio $(H - y)/H$ of the length $(H - y)$ from the neutral axis of the combined steel sheet pile 1 to the upper surface of the first flange 22a of the H-shaped steel 20 relative to H can be expressed by $(1 - (y/H))$. The ratio of the length y from

the neutral axis of the combined steel sheet pile 1 to the bottom surface of the arm portion 13 of the hat-shaped steel sheet pile 10 relative to H can be expressed by y/H . Then, the Expression (3) below expresses that the ratio of the expressions above $(1 - (y/H))/(y/H)$ is equal to or larger than the ratio of the minimum yield points σ_{yh}/σ_{ys} .

$$(1 - (y/H))/(y/H) \geq \sigma_{yh}/\sigma_{ys} \quad \dots \text{Expression (3)}$$

[0048]

The Expression (3) indicates that the ratio of the length from the neutral axis to the upper surface of the first flange 22a of the H-shaped steel 20 relative to the length from the neutral axis to the bottom surface of the arm portion 13 of the hat-shaped steel sheet pile 10 is greater than or equal to the ratio of the minimum yield points σ_{yh}/σ_{ys} .

[0049]

Then, the Expression (4) below can be obtained by substituting the value from the Expression (2) into the Expression (3) and developing it.

$$(2 - ((hs/H) + (Ah/As)/(1 + (Ah/As)))/((hs/H) + (Ah/As)/(1 + (Ah/As))) \geq \sigma_{yh}/\sigma_{ys} \quad \dots \text{Expression (4)}$$

[0050]

Then, by making calculation for Ah/As with $\sigma_{yh}/\sigma_{ys} = \beta$, the following Expression (5) can be derived.

$$Ah/As \leq (2 - (1 + \beta) \cdot (hs/H)) / (\beta + (1 + \beta) \cdot (hs/H) - 1) \quad \dots \text{Expression (5)}$$

[0051]

More specifically, it is possible to obtain the ratio Ah/As of the cross-sectional area Ah of the H-shaped steel 20 employed in the combined steel sheet pile 1 relative to the cross-sectional area As of the hat-shaped steel sheet pile 10 on the basis of parameters defined in the Expression (5).

[0052]

More specifically, by assuming the heights of the hat-shaped steel sheet pile 10 and the H-shaped steel 20 in the combined steel sheet pile 1, and further assuming the yield points of the hat-shaped steel sheet pile 10 and the H-shaped steel 20, it is possible

to obtain the ratio (h_s/H) of the height (h_s) of the hat-shaped steel sheet pile 10 and the height (H) of the combined steel sheet pile 1, and the ratio $\beta (= \sigma_{yh}/\sigma_{ys})$ between the yield points of the H-shaped steel 20 and the hat-shaped steel sheet pile 10. Therefore, it is possible to set the reasonable cross-sectional shape on the basis of the combination of the cross section (A_h/A_s) of the hat-shaped steel sheet pile 10 and the H-shaped steel 20 that satisfies the Expression (5).

[0053]

More specifically, by selecting the combination of the hat-shaped steel sheet pile 10 and the H-shaped steel 20 so as to satisfy the Expression (5), it is possible to select the respective cross-sectional shapes such that the ratio $(H - y)/y$ of the length from the neutral axis of the combined steel sheet pile 1 to the upper surface of the first flange 22a of the H-shaped steel 20 is larger than the ratio $\beta (= \sigma_{yh}/\sigma_{ys})$ between the yield points of the H-shaped steel 20 and the hat-shaped steel sheet pile 10. Consequently, even if the bending moment causing the stress corresponding to the minimum yield point σ_{yh} of the H-shaped steel 20 at the peripheral edge of the first flange portion 22a of the H-shaped steel 20 actually acts on the wall body formed by the combined steel sheet pile 1, it is possible to suppress the stress occurring at the peripheral edge of the hat-shaped steel sheet pile 10 to the minimum yield point of the hat-shaped steel sheet pile 10 itself or lower, whereby it is possible to form the effective cross-sectional shape of the combined steel sheet pile 1 for increasing the flexural strength.

[0054]

Next, an approach method for selecting a cross-sectional shape of the combined steel sheet pile 1 will be described. Table 5 shows data on cross section of the hat-shaped steel sheet pile 10 used for explaining the approach method. Table 6 shows data on cross section of the H-shaped steel 20.

[0055]

[Table 5]

Type	Width	Height h_s	Cross-sectional area A_s	Moment inertia I_s	Steel material weight
10H	900 mm/sheet	230 mm	110 cm ² /sheet	9430 cm ⁴ /sheet	86.4 kg/sheet/m

[0056]

[Table 6]

Combina tion number	Height h_h (mm)	Flange width (mm)	Web thickness (mm)	Flange thickness (mm)	Cross-secti onal area A_h (cm ² /piece)	Moment inertia I_h (cm ⁴ / piece)	Steel material weight (kg/m)
1	700	200	9	12	112	83100	87.6
2	700	200	9	16	127	100000	99.6
3	700	200	9	19	138	113000	109
4	700	250	12	19	177	142000	139
5	700	300	13	24	235	197000	182
6	700	300	14	25	244	206000	191
7	700	300	14	28	261	224000	205

[0057]

As the hat-shaped steel sheet pile 10, a 10H hat-shaped steel sheet pile 10 shown in Table 5 is used. The 10H hat-shaped steel sheet pile 10 has a width, height, cross-sectional area A_s , moment inertia I_s , and steel material weight as shown in Table 5. Further, seven types of the H-shaped steels 20 having different cross-sectional areas A_h are prepared. The H-shaped steels 20 have a size, cross-sectional area A_h , moment inertia I_h and steel material weight as shown in Table 6.

[0058]

Table 7 shows a list of the combined steel sheet piles 1 obtained by combining the hat-shaped steel sheet pile 10 shown in Table 5 with the various types of the H-shaped steels 20 shown in Table 6.

[0059]

[Table 7]

Combina tion number	Ah/As	hs/H	y/H	$(1-(y/H))/(y/H)$	Z (cm ³)	w (kg/piece)	σ_s (N/mm ²)	
1	1.01	0.247	0.375	1.667	3660	174	213	
2	1.15	0.247	0.391	1.558	4190	186	228	Comparison on minimum guaranteed yield point of steel sheet pile
3	1.25	0.247	0.402	1.488	4590	195	239	
4	1.61	0.247	0.432	1.315	5650	225	270	
5	2.10	0.247	0.462	1.165	7360	268	305	> 295
6	2.21	0.247	0.468	1.137	7670	277	313	> 295
7	2.37	0.247	0.475	1.105	8213	291	321	> 295

[0060]

The combination numbers in Table 7 correspond to the combination numbers of the H-shaped steel 20 in Table 5. For example, as for the combination number 1 in Table 7, the combined steel sheet pile 1 is configured by combining the H-shaped steel 20 corresponding to the combination number 1 in Table 6 with the hat-shaped steel sheet pile 10 shown in Table 5. Incidentally, for each combination number, Table 7 shows a ratio Ah/As of the cross-sectional area Ah of the H-shaped steel 20 relative to the cross-sectional area As of the hat-shaped steel sheet pile 10; a ratio hs/H of the height hs of the hat-shaped steel sheet pile 10 to the height H of the combined steel sheet pile 1; a ratio y/H of the length y from the bottom surface of the arm portion 13 to the neutral axis of the combined steel sheet pile 1 relative to the height H of the combined steel sheet pile 1; and a $(1 - (y/H))/(y/H)$. Further, Table 7 also shows: a section modulus Z (cm³) per a piece of combined sheet pile determined depending on the edge stress of the H-shaped steel 20 of the combined steel sheet pile 1; the steel material weight w (kg/piece) per a piece of the combined steel sheet pile 1; and, the stress σ_s (N/mm²) occurring at the outer edge of the steel sheet pile 10 in the case where

a stress corresponding to the minimum yield point of the H-shaped steel acts on the outer edge (outer edge of the first flange 22a) of the H-shaped steel 20.

[0061]

Within the elastic limit, the occurring stress is generally proportional to the distance from the neutral axis. Therefore, the stress σ_s occurring at the outer edge of the steel sheet pile 10 can be obtained by using the following expression on the basis of the stress σ_h occurring at the outer edge of the first flange 22a of the H-shaped steel, and the ratio $(1 - (y/H))/(y/H)$ of the distance of the neutral axis. Note that it is assumed that this expression can be applied even if the stress σ_s occurring at the outer edge of the steel sheet pile 10 falls beyond the yield point.

[0062]

It should be noted that, since it is assumed that the minimum yield point σ_{yh} of the H-shaped steel acts, the stress σ_h occurring at the outer edge of the flange 22a of the H-shaped steel is $\sigma_h = \sigma_{yh}$.

$$\sigma_h : \sigma_s = (H - y) : y = (1 - (y/H)) : (y/H)$$

$$\sigma_s = \sigma_h / ((1 - (y/H))/(y/H))$$

[0063]

Further, Table 8 shows the minimum yield points of the H-shaped steel 20 and the hat-shaped steel sheet pile 10, which are combined in Table 7, and the minimum yield point ratios. The minimum yield points are 355 (N/mm²) for the H-shaped steel 20, and 295 (N/mm²) for the hat-shaped steel sheet pile 10. Further, the yield point ratio σ_{yh}/σ_{ys} is 1.20.

[0064]

[Table 8]

Minimum yield point σ_{yh} (N/mm ²) of H-shaped steel 20	355
Minimum yield point σ_{ys} (N/mm ²) of hat-shaped steel sheet pile 10	295
Minimum yield point ratio σ_{yh}/σ_{ys}	1.20

[0065]

[Table 9]

hs/H	$\sigma_{yh}/\sigma_{ys} (= \beta)$	Maximum Ah/As
0.247	1.20	1.96

[0066]

Further, Table 9 shows the ratio Ah/As of the cross-sectional area Ah of the H-shaped steel 20 relative to the cross-sectional area As of the hat-shaped steel sheet pile 10, which is obtained through the Expression (5). Table 9 shows that, from Table 8, the hs/H is 0.247 and the yield point ratio σ_{yh}/σ_{ys} is 1.20, whereby the area ratio Ah/As is 1.96.

[0067]

At the time of actually selecting the cross-sectional shape of the combined steel sheet pile 1, it is possible to select the cross section such that the ratio $(1-(y/H))/(y/H)$ is more than or equal to the ratio σ_{yh}/σ_{ys} of the minimum yield points, by selecting the cross section of the combination so as to have Ah/As of 1.96 or lower from the Expression (5) and Table 9. Therefore, by setting the cross-sectional shape with the combination numbers 1 to 4 in Table 7, it is possible to suppress all the stresses σ_s occurring at the outer edge of the steel sheet pile 10 to the minimum yield stress (295 N/mm²) or lower of the hat-shaped steel sheet pile 10, even in the case where the stress corresponding to the minimum yield point of the H-shaped steel acts on the outer edge of the H-shaped steel 20. In fact, as shown in Table 7, the calculated stresses σ_s occurring at the outer edge of the steel sheet pile 10 are 213 N/mm² for the combination number 1, 228 N/mm² for the combination number 2, 239 N/mm² for the combination number 3, and 270 N/mm² for the combination number 4, and are suppressed to the minimum yield point (295 N/mm²) or lower of the hat-shaped steel sheet pile 10. Therefore, it can be seen that it is possible to obtain the further effective cross-sectional shape of the combined steel sheet pile 1 in terms of increasing the flexural strength.

[0068]

However, the ratios A_h/A_s of the combination numbers 5 to 7 are 2.10, 2.21, and 2.37, respectively, exceeding 1.96, which is calculated from the Expression (5). Further, the stresses σ_s occurring at the outer edge of the steel sheet pile 10 are 305 N/mm² for the combination number 5, 313 N/mm² for the combination number 6 and 321 N/mm² for the combination number 7, all of which exceed the minimum yield point (295 N/mm²) of the hat-shaped steel sheet pile 10. Therefore, although the yield point of the H-shaped steel 10 increases as compared with the yield point of the hat-shaped steel sheet pile 20, it is not possible to enjoy its advantage. Consequently, it is necessary to lower the section modulus in order to suppress the stresses to the minimum yield point (295 N/mm²) or lower of the hat-shaped steel sheet pile 10. In the above-described embodiment, the approach method for selecting the cross-sectional shape of the combined steel sheet pile 1 has been described by giving an example of the 10H-type hat-shaped steel sheet pile shown in Table 5. However, other hat-shaped steel sheet pile may be employed for the steel sheet pile used in the combined steel sheet pile 1. For example, it is possible to employ a 25H-type hat-shaped steel sheet pile having a width of 900 mm, height of 300 mm, cross-sectional area of 144.4 cm²/piece, and moment inertia of 22000 cm⁴/piece.

[0069]

Table 10 shows the steel-weight-reduction effect of the conventional example and the example of the present invention in the case where the necessary yielding bending moment is 1450 kN·m/piece.

[0070]

[Table 10]

	Minimum Yield point of steel material (N/mm ²)		Applied steel sheet pile and H-shaped steel		Section modulus Z (cm ³ /piece)	Yield moment (kN·m/piece)	Steel material weight (kg/piece)
	Steel sheet pile	H shaped steel	Steel sheet pile	H shaped steel			
Conventional Example	295	315	10H	700×200×9×19	4590	1450	195
Example of present invention	295	355	10H	700×200×9×16	4190	1490	186

[0071]

In the conventional example, the minimum yield point of the hat-shaped steel sheet pile 10 is 295 N/mm², and the minimum yield point of the H-shaped steel 20 is 315 N/mm². In order to satisfy the necessary yielding bending moment of 1450 kN·m/piece, it is necessary for the conventional example to have the weight of the steel material of 195 kg/piece, whereas it is possible for the example of the present invention to achieve the above-described requirement only by the weight of the steel material of 186 kg/piece. Therefore, the example of the present invention can achieve the weight reduction by about 5% as compared with the conventional example.

[0072]

Table 11 shows the steel-weight-reduction effect of the conventional example and the example of the present invention in the case where the necessary yielding bending moment is 1490 kN·m/piece. In order to satisfy the necessary yielding bending moment of 1490 kN·m/piece, it is necessary for the conventional example to have the weight of the steel material of 225 kg/piece, whereas it is possible for the example of the present invention to achieve the above-described requirement only by the weight of the steel material of 186 kg/piece. Therefore, the example of the present

invention can achieve the weight reduction by about 17% as compared with the conventional example.

[0073]

[Table 11]

	Minimum Yield point of steel material (N/mm ²)		Applied steel sheet pile and H-shaped steel		Section modulus Z (cm ³ /piece)	Yield moment (kN·m/piece)	Steel material weight (kg/piece)
	Steel sheet pile	H shaped steel	Steel sheet pile	H shaped steel			
Conventional Example	295	315	10H	700×250×12×19	5650	1780	225
Example of present invention	295	355	10H	700×200×9×16	4190	1490	186

INDUSTRIAL APPLICABILITY

[0074]

According to the present invention, it is possible to significantly improve the flexural strength of a combined steel sheet pile formed by combining a hat-shaped steel sheet pile and an H-shaped steel, and to achieve weight reduction of the combined steel sheet pile, whereby the industrial applicability is great.

EXPLANATION OF REFERENCE NUMERALS

[0075]

- 10 Hat-shaped steel sheet pile
- 11 Web portion
- 12 Flange portion
- 13 Arm portion
- 14 Joint portion
- 20 H-shaped steel

- 21 Central web portion
- 22a First flange portion
- 22b Second flange portion
- 27 Welding portion

CLAIMS

1. A combined steel sheet pile having a hat-shaped steel sheet pile and an H-shaped steel, wherein
the hat-shaped steel sheet pile comprises:
 - a web portion;
 - a pair of flange portions provided at both ends of the web portion;
 - a pair of arm portions each provided at respective ends of the pair of flange portions; and
 - a pair of joint portions each formed at respective ends of the pair of arm portions, the hat-shaped steel sheet pile being a 10H hat-shaped steel sheet pile,the H-shaped steel sheet pile comprises:
 - a central web portion;
 - a first flange portion provided at one end of the central web portion;and
 - a second flange portion provided at the other end of the central web portion,the second flange portion is fixed on an outside of the web portion of the hat-shaped steel sheet pile, and
 - a minimum yield point ratio σ_{yh}/σ_{ys} of a minimum yield point σ_{yh} of the H-shaped steel and a minimum yield point σ_{ys} of the hat-shaped steel sheet pile is in the range of 1.109 to 1.559.
2. An earth-retaining wall employing two or more combined steel sheet piles according to claim 1, wherein

the joint portions of the adjacent combined steel sheet piles are connected with each other.

3. A method of selecting combination of a combined steel sheet pile having a hat-shaped steel sheet pile and an H-shaped steel, wherein the hat-shaped steel sheet pile is a 10H hat-shaped steel pile, and

the combination is selected such that a minimum yield point ratio σ_{yh}/σ_{ys} of a minimum yield point σ_{yh} of the H-shaped steel and a minimum yield point σ_{ys} of the hat-shaped steel sheet pile is in the range of 1.109 to 1.559.