

[Document Type] Specification

[Title of the Invention] COMBINED STEEL WALL

[Technical Field of the Invention]

[0001]

The present invention relates to a combined steel wall that is used for earth retaining works, coffering, shore protection, land reclamation, embankment, and the like.

Priority is claimed on Japanese Patent Application No. 2012-196899, filed on September 7, 2012, the content of which is incorporated herein by reference.

[Related Art]

[0002]

A combined steel wall is a wall structure which is build by the combination of a wall body, which is built by the connection of a plurality of steel sheet piles, and stiffening members, such as H-section steel beams or steel pipes and of which stiffness is improved. The combined steel wall can also be applied to a site, which requires the high height of a wall, or the like. Further, since the wall body is built by the fitting of adjacent steel sheet piles at a joint, it is possible to improve water cut-off performance as compared to a steel pipe sheet pile having a relatively large gap at a joint.

When a steel pipe is applied as a stiffening member in the combined steel wall, there are various merits on construction. When an H-section steel beam is used as a stiffening member, there is a problem in that flanges are likely to be deformed due to the ground resistance at the time of driving of the H-section steel beam into the ground. However, since a steel pipe does not include protruding portions like the flanges of the H-section steel beam, the deformation of the steel pipe hardly occurs at the time of embedment. Further, it is also possible to embed the steel pipe in the ground while

rotating the steel pipe.

Steel walls, which are disclosed in Patent Documents 1 to 3, are known as examples of a steel wall that is formed by the combination of steel pipes and steel sheet piles.

[0003]

In the steel wall disclosed in Patent Document 1, a machining jig for fitting a stiffening member is provided on at least one of the surface and back of a steel sheet pile and a stiffening member, such as an H-section steel beam or a steel pipe sheet pile, is installed through the machining jig. When a steel pipe sheet pile is applied as the stiffening member, a wall body is formed by fitting a joint of a steel pipe sheet pile to a machining jig mounted on a steel sheet pile for fitting the stiffening member. The transmission of a load to the steel pipe and the steel sheet pile is performed through the joint of the steel pipe sheet pile.

In the steel walls disclosed in Patent Documents 2 and 3, a wall body is formed by the connection of a plurality of steel sheet piles through joints, and steel pipes come into contact with the entire wall body or some of the steel sheet piles so that the longitudinal direction of the steel pipe corresponds to the longitudinal direction of the steel sheet pile. Since the wall body is formed by the combination of the steel pipes and the steel sheet piles, it is possible to provide a steel wall that has both high water cut-off performance and high stiffness.

[Prior Art Document]

[Patent Document]

[0004]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2005-299202

[Patent Document 2] PCT International Publication No. WO2011/142047

[Patent Document 3] PCT International Publication No. WO2011/142367

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0005]

In Patent Documents 1 to 3, a structure in which stiffening members, such as steel pipes, are arranged at a pitch is described as one embodiment. The structure in which the stiffening members are arranged at a pitch according to stiffness and proof stress required for a wall body can be achieved by the selection of a stiffening member, such as a steel pipe or an H-section steel beam, but there are the following problems in the setting of the pitch.

(a) When the pitch of the steel pipes is excessively large, the behavior of the wall body is unstable. For this reason, there is a possibility that predetermined performance cannot be exhibited.

(b) When the pitch of the steel pipes is excessively small, earth pressure cannot be appropriately shared and received by both the steel sheet piles and reinforcing members. For this reason, an uneconomical structure in which a load is concentrated on one of the steel sheet piles and the reinforcing members is formed.

[0006]

The stiffness and proof stress of the wall body in which the steel sheet piles are combined with the stiffening members also vary depending on the location, such as the installation positions of the stiffening members and the vicinity thereof, and the vicinity of the middle between adjacent stiffening members. However, if it is assumed that evaluation can be performed using stiffness obtained from the average of the stiffness and proof stress of the wall body, it is possible to reduce the weight of a

steel material to be used as the diameter of one steel pipe or the size of one H-section steel beam is increased and the pitch is increased.

However, since an effect of stiffening the steel sheet pile wall by the stiffening members is not uniform when the pitch of the stiffening members is increased, the deformation of the steel sheet pile wall in the vicinity of the middle between adjacent stiffening members is increased. For this reason, the deformation of the wall body becomes ununiform in the extending direction of the wall (a horizontal direction). Further, when the pitch of the stiffening members is further increased excessively, a stiffening effect does not act on the steel sheet pile positioned in the vicinity of the middle between the adjacent stiffening members. That is, a portion of the steel wall in the vicinity of the stiffening member behaves as a high-stiffness wall in which the steel sheet pile wall is combined with the stiffening member, but a portion of the steel wall in the vicinity of the middle between adjacent stiffening members behaves as a steel sheet pile wall that is provided alone or a wall that is similar to the steel sheet pile wall. In this case, it is not possible to average and treat the stiffness of the wall body, and, in the vicinity of the middle between adjacent stiffening members, the plastic deformation of the steel sheet pile wall occurs or excessive deformation of the steel sheet pile wall locally occurs in some cases. For this reason, a situation in which the stability of the wall body cannot be maintained is also considered.

[0007]

Meanwhile, when the pitch of the stiffening members is reduced, the earth pressure supported by the steel sheet pile wall is reduced. For this reason, only stiffening members resist the earth pressure. That is, although the stiffening members and the steel sheet piles are used while being combined with each other, the stiffness or proof stress of the steel sheet pile wall cannot be utilized. When the stiffening

members and the steel sheet piles are used while being combined with each other, it can be said that a structure resisting applied earth pressure utilizing the stiffness and proof stress of both the steel sheet pile wall and the stiffening member is a reasonable structure.

A pitch where an effect of stiffening the steel sheet pile wall by the stiffening members is appropriately obtained, a pitch where earth pressure can be resisted by both a stiffening member and a steel sheet pile wall, and the like are not mentioned in the above-mentioned invention.

[0008]

Accordingly, an object of the invention is to provide a combined steel wall capable of ensuring the safety and soundness of a wall body and having a reasonable structure that can utilize the stiffness and proof stress of both steel pipes and steel sheet piles.

[Means for Solving the Problem]

[0009]

The invention employs the following configuration to achieve the above-mentioned object.

(1) According to an embodiment of the invention, there is provided a combined steel wall including: a wall body that includes a plurality of steel sheet piles connected to each other by joints and a plurality of recesses arranged at an interval in an extending direction; and a plurality of steel pipes that stand on a ground surface on a side, of which a horizontal position is low, of both sides of the wall body along a longitudinal direction of the steel sheet pile while a part of each steel pipe is received in the recess. At least a part of the wall body and the steel pipes in the longitudinal direction of the steel sheet pile are connected to each other, and a maximum interval L

(mm) as a center distance between first and second steel pipes which are adjacent to each other and between which a center distance is the maximum distance, a height H (mm) of the wall body, and a dimension D (mm) that is the sum of radii of the first and second steel pipes satisfy the following formula (A).

[Formula 1]

$$D \leq L \leq (1/2) \times H \quad \cdot \cdot \cdot (A)$$

(2) In the combined steel wall according to (1), the wall body and the steel pipes may be connected to each other by coming into contact with each other.

(3) In the combined steel wall according to (1), the wall body and the steel pipes may be connected to each other by connection members.

(4) In the combined steel wall according to (3), the connection members may connect at least upper portions of the steel sheet piles and the steel pipes.

(5) In the combined steel wall according to any one of (1) to (4), the maximum interval L (mm) may be set so that the maximum interval L (mm), the height H (mm) of the wall body, yield stress σ_y (N/mm²) of the steel sheet pile, a section modulus Z_s (mm³) of the steel sheet pile, and the maximum bending moment $M_{\max}$ (N·mm) applied to the wall body satisfy the following formula (B).

[Formula 2]

$$\frac{(3H-4L) \times (2L)^2}{H^3} \times \frac{M_{\max}}{Z_s} \leq \sigma_y \quad \cdot \cdot \cdot (B)$$

(6) In the combined steel wall according to any one of (1) to (5), the maximum interval L (mm) may be set so that the maximum interval L (mm), the height H (mm) of the wall body, the yield stress σ_y (N/mm²) of the steel sheet pile, the section modulus Z_s (mm³) of the steel sheet pile, and the maximum bending moment $M_{\max}$

(N·mm) applied to the wall body satisfy the following formula (C).

[Formula 3]

$$0.3 \times \sigma_y \leq \frac{(3H-4L) \times (2L)^2}{H^3} \times \frac{M_{max}}{Z_s} \quad \dots \quad (C)$$

(7) In the combined steel wall according to any one of (1) to (6), the respective recesses may be formed on the wall body at regular intervals when viewed in the longitudinal direction, and the steel pipes may be disposed in every other recess.

(8) In the combined steel wall according to any one of (1) to (6), the respective recesses may be formed on the wall body at regular intervals when viewed in the longitudinal direction, and the steel pipes may be disposed in every third or more recess.

[Effects of the Invention]

[0010]

According to the above-mentioned configuration, it is possible to reduce stress generated in the steel sheet pile in the vicinity of the middle between adjacent steel pipes, to exhibit an effect of the combination of the steel sheet piles and the steel pipes, and to ensure the safety and soundness of the wall body without yielding of the steel sheet pile in the extending direction of the wall body. Further, it is possible to utilize the stiffness and proof stress of both the steel pipe and the steel sheet pile. Accordingly, it is possible to form a more reasonable structure.

[Brief Description of the Drawings]

[0011]

FIG. 1A is a schematic plan view of an indoor model test device that is embodied for the examination of the pitch of steel pipes of a combined steel wall.

FIG. 1B is a schematic side cross-sectional view of the indoor model test

device shown in FIG. 1A.

FIG. 2 is a view showing the summaries of a first test, a second test, and a third test.

FIG. 3 is a graph showing the distribution of the strain of a steel pipe of each test in a vertical direction.

FIG. 4 is a graph showing the distribution of the strain of a steel sheet pile of each test in the vertical direction.

FIG. 5 is a view schematically illustrating a calculation method in which it is assumed that earth pressure is applied to the steel sheet pile between the deepest portion and the same height (L) as the pitch of steel pipes.

FIG. 6 is a graph illustrating the comparison between the distribution of the strain of the steel sheet pile of the first and second tests, in which the steel pipes come into contact with the steel sheet piles and are disposed on the front surface side, in the vertical direction and a calculated value that is calculated on the assumption that earth pressure is applied to the steel sheet pile between the deepest portion and the same height as the pitch of the steel pipes.

FIG. 7 is a view schematically illustrating a calculation method in which it is assumed that earth pressure is applied to the steel sheet pile between the deepest portion and a height (2L) that is twice as large as the pitch of the steel pipes.

FIG. 8 is a graph illustrating the comparison between the distribution of the strain of the steel sheet pile of the first, second, and third tests, in which the steel pipes are disposed on the front surface side in the vertical direction and a calculated value that is calculated on the assumption that earth pressure is applied to the steel sheet pile between the deepest portion and a height that is twice as large as the pitch of the steel pipes.

FIG. 9A is a schematic plan view showing an example of a combined steel wall according to a first embodiment of the invention, and shows a configuration in which one steel pipe is disposed per three hat-shaped steel sheet piles.

FIG. 9B is a schematic plan view showing an example of the combined steel wall according to the first embodiment of the invention, and shows a configuration in which one steel pipe is disposed per two hat-shaped steel sheet piles.

FIG. 9C is a schematic plan view showing an example of the combined steel wall according to the first embodiment of the invention, and shows a configuration in which steel pipes are disposed at sheet pile joints.

FIG. 10A is a schematic plan view showing a combined steel wall according to a second embodiment of the invention.

FIG. 10B is a schematic side view of the combined steel wall shown in FIG. 10A.

FIG. 11A is a schematic plan view showing a modification of the combined steel wall according to the second embodiment of the invention.

FIG. 11B is a schematic side view of the combined steel wall shown in FIG. 11A.

[Embodiments of the Invention]

[0012]

In order to solve the above-mentioned problems, the inventors have disposed steel pipes on a side (which may be referred to as a “front surface side” in this specification), of which a ground surface is low, of both sides of a wall body in a combined steel wall including steel pipes and steel sheet piles, performed an indoor model test on a structure in which the steel pipes are arranged at a pitch, and examined the range of a pitch in which an effect of stiffening steel sheet pile walls by the steel

pipes is appropriately obtained and the range of a pitch in which earth pressure can be resisted by both the steel pipes and the steel sheet pile walls.

[0013]

This indoor model test is as follows:

FIGS. 1A and 1B are schematic views of an indoor model test device. FIG. 1A is a schematic plan view of the indoor model test device, and FIG. 1B is a schematic cross-sectional view taken along line I-I of FIG. 1A. The indoor model test device has a structure in which lower ends of acrylic specimens K are fixed to the ground by an adhesive in the middle in a rigid earth tank G having a width of 1957 mm, a height of 1000 mm, and a depth of 940 mm. The acrylic specimen K forms a wall body by the combination of a wavy sheet pile K1 that is formed by the simulation of a steel sheet pile and a pipe K2 (having an outer diameter of 140 mm and a thickness of 3 mm) that is formed by the simulation of a steel pipe. Further, when the installation of a coping (connection member), which connects the sheet pile to the pipe, at an upper portion is simulated, a connection plate K3 is attached as shown in FIG. 1B. Meanwhile, the connection plate K3 is not shown in the schematic view of FIG. 1A for simplification.

[0014]

In the indoor model test, quartz sand No. 5 (dry sand) is installed on both sides of the specimens K by an air-pluviation method. Further, quartz sand No. 5, which is present on a wall body-front surface side on which the pipes K2 are installed (the right side in FIGS. 1A and 1B), is dug out to the deepest portion from this state, and the behavior of the wall body (the acrylic specimen K) is checked. Here, the ground, which is present on the side where quartz sand No. 5 is installed, is denoted by GH and the ground, which is present on the side where quartz sand No. 5 is dug out to

the deepest portion, is denoted by GL.

[0015]

For the examination of the contact state between the sheet pile K1 and the pipe K2 and the influence of the presence/absence of the connection plate K3, a first test, a second test, and a third test are performed while conditions are changed as summarized in FIG. 2.

Meanwhile, even in the third test where the sheet pile K1 and the pipe K2 do not come into contact with each other, a part of the pipe K2 enters a recess of the sheet pile wall so that the position of the outer peripheral surface of the pipe K2 corresponds to the middle of the sheet pile wall. That is, even in any test, a part of the pipe K2 enters a recess of the sheet pile wall.

In the test, a strain gauge is attached to the outer peripheral surface of the pipe K2, which is disposed at the middle portion, opposite to the side where the sheet pile wall is installed, and a strain gauge is attached to a web middle portion of the sheet pile K1 that is interposed between adjacent two pipes K2 and is most distant from both pipes K2. The strain gauges measure strain that is generated after digging.

Further, a tool for measuring displacement is mounted on an upper portion of the pipe K2, which is disposed at the middle portion, and measures the displacement of the upper portion at a position that is distant from a lower end (the ground GL) by a distance of 1050 mm.

[0016]

In regard to each test, the distribution of vertical strain, which is generated in the pipe K2, in the depth direction is shown in FIG. 3 and the distribution of vertical strain, which is generated in the sheet pile K1 at a middle position between adjacent pipes K2, in the depth direction is shown in FIG. 4.

In the graph shown in FIG. 3, a compression side is defined as a positive side in regard to strain generated in the pipe K2.

Further, in the graph shown in FIG. 4, a tension side is defined as a positive side in regard to strain generated in the sheet pile K1.

Meanwhile, strain, which is calculated when it is assumed that the total earth pressure is applied to each of the sheet pile K1 and the pipe K2 as a cantilever of which a lower end is fixed, is also shown in the graph. In regard to earth pressure for the calculation of strain at this time, the same tests as the above-described tests are performed using only separate sheet piles K1 and earth pressure is calculated from the results of the tests.

Furthermore, the following Table 1 shows displacement measured at a position distant from the lower end of the pipe K2, which is disposed in the middle, by a distance of 1050 mm.

[0017]

[Table 1]

	FIRST TEST	SECOND TEST	THIRD TEST
Displacement measured at a position distant from the lower end of the pipe K2, which is disposed in the middle, by a distance of 1050 mm	4.5 mm	4.6 mm	4.0 mm

[0018]

As shown in FIG. 3, values of strain, which is generated in the vertical direction in a deep portion of the pipe K2, obtained in the first and second tests are slightly smaller than a value thereof that is obtained when total earth pressure is applied to the pipe K2, and a value thereof obtained in the third test is smaller than the values thereof obtained in the first and second tests. Further, as shown in Table 1, the

displacement of the pipe in the third test is smaller than those in the first and second tests.

The amount of strain, which is shown in FIG. 4 and generated in the sheet pile K1, varies depending on the contact condition between the sheet pile K1 and the pipe K2 and the presence/absence of the connection plate K3. However, in all tests, maximum strain is generated at the deepest portion and the strain is smaller than strain that is calculated on the assumption that total earth pressure is applied to only the sheet pile K1. That is, since it is possible to reduce strain, which is generated in the sheet pile K1, even in the vicinity of the middle between pipes K2 that are adjacent to each other in the extending direction of the wall body, it can be said that an effect of the combination of the sheet pile K1 and the pipe K2 can be exhibited. Further, the value of the strain of the sheet pile K1 in the third test is larger than the values thereof in the first and second tests. That is, since the sheet pile K1 shares a load, it can be said that the share of the load allocated to the pipe K2 tends to be reduced.

[0019]

The range of a pitch in which an effect of stiffening the steel sheet pile walls by the steel pipes is appropriately obtained and the range of a pitch in which earth pressure can be resisted by both the steel pipes and the steel sheet pile walls are calculated on the basis of these test results.

[0020]

First of all, a pitch in which an effect of stiffening the steel sheet pile walls by the steel pipes is obtained in the extending direction of the wall body will be examined.

When the steel pipe (the pipe K2) and the steel sheet pile (the wavy sheet pile K1) are installed so as to come into contact with each other (the first and second tests), strain is not substantially generated even at the upper portion of the steel sheet pile

between the adjacent steel pipes but strain is generated at a position substantially between the deepest portion and the same height (360 mm) as the pitch of the steel pipes (FIG. 4). The reason for this is considered that deformation is restricted by the steel pipes (the pipes K2) installed on both sides of the steel sheet pile (the wavy sheet pile K1) but the restriction of deformation performed by the steel pipes is not sufficient in the steel sheet pile in the vicinity of the middle between the steel pipes of which deep portions are adjacent to each other and the behavior of the steel sheet pile and the steel pipes is locally similar to the behavior of a steel sheet pile wall provided alone.

Then, strain is calculated on the assumption that earth pressure is applied to a wall body formed of a steel sheet pile between the deepest portion and the position of the same height as the pitch L of the steel pipes as shown in FIG. 5. The distribution (calculated values) of the calculated strain in the depth direction is shown in FIG. 6. Meanwhile, test values of the first and second tests shown in FIG. 4 are also shown in FIG. 6 together with the distribution of the calculated strain in the depth direction.

[0021]

Since calculated values substantially correspond to the test values (the first and second tests) as shown in FIG. 6, it is possible to express the vertical behavior of the steel sheet pile (wavy sheet pile K1) at a middle position between adjacent steel pipes by calculating strain on the assumption that earth pressure is applied to a wall body formed of a steel sheet pile between the deepest portion and the position of the same height as the pitch L of the steel pipes (the pipes K2) when the steel pipes are disposed on the wall body-front surface side so that the steel pipes come into contact with the steel sheet piles in a longitudinal direction. Accordingly, when the pitch L of the steel pipes is equal to the height of the wall in this structure, stress generated in the steel sheet pile (wavy sheet pile K1) at a middle position between adjacent steel pipes

has substantially the same behavior as that in a case in which only a steel sheet pile is applied. For this reason, an effect of stiffening the steel sheet pile by the steel pipe is not partially obtained. In other words, if the pitch L of the steel pipes is equal to or smaller than the height H of the wall (if " $L \leq H$ " is satisfied), stress generated in the steel sheet pile is reduced even at a portion distant from the steel pipe and an effect of the combination of the steel pipes and the steel sheet piles can be exhibited. That is, an effect of the combination of the steel sheet piles and the steel pipes can be exhibited even in a structure in which the steel pipes are arranged at a pitch and stiffness required for a wall body is obtained using steel pipes having a large diameter.

[0022]

Further, since a part of the steel pipe enters a wavy recess of the steel sheet pile wall when the steel pipe and the steel sheet pile are installed so as to be distant from each other and are connected to each other at upper portions thereof (the third test), an effect of restricting deformation is exhibited to some extent at the time of the deformation of the steel sheet pile wall but the restriction of the steel sheet pile performed by the steel pipe is reduced as compared to the first and second tests in which the steel pipe and the steel sheet pile come into direct contact with each other. Accordingly, it is considered that the range in a depth direction in which the behavior of the steel sheet pile and the steel pipe is similar to the behavior of a steel sheet pile wall provided alone tends to increase as compared to the first and second tests in external appearance. Vertical strain is calculated on the assumption that the application range of earth pressure at this time is a range in which earth pressure is applied to the steel sheet pile between the deepest portion and the position of a height ($2L$) that is twice as large as the pitch L of the steel pipes as shown in FIG. 7. The distribution of the calculated strain in the depth direction (calculated value) is shown in

FIG. 8. The results of the first to third tests shown in FIG. 4 are also shown in FIG. 8 together with the distribution of the calculated strain in the depth direction. When the application range of earth pressure from the deepest portion is set to $2L$ or more, as shown in FIG. 8, vertical strain generated in the deep portion of the steel sheet pile at a position, which is most distant from the steel pipe, is smaller than a calculated value even in the case of the third test in which vertical strain is largest.

[0023]

From the above description, in the combined steel wall in which the steel pipes are combined with the steel sheet piles and which has a structure in which steel pipes are disposed on the side (the front surface side), of which a ground surface is low, of both sides of the wall body, if " $2L \leq H$ " is satisfied in a structure in which the steel pipe enters a recess of the steel sheet pile wall and the steel pipe and the steel sheet pile come into contact with each other or are connected to each other by a connection member at any position in a vertical direction or come into contact with each other and are connected to each other by the connection member, strain generated in the steel sheet pile in the vicinity of the middle between adjacent steel pipes can be reduced as compared to a case in which only the steel sheet piles are provided.

That is, if the pitch L of the steel pipes satisfies the following expression, stress generated in the steel sheet pile in the vicinity of the middle between adjacent steel pipes is reduced and an effect of the combination of the steel pipes and the steel sheet piles is obtained. That is, since an effect of stiffening the steel sheet pile walls by the steel pipes can be exhibited in the extending direction of the wall body, an effect of the combination of the steel sheet piles and the steel pipes can be exhibited even in a structure in which the steel pipes are arranged at a pitch and stiffness required for a wall body is obtained using steel pipes having a large diameter.

[Formula 4]

$$D \leq L \leq (1/2) \times H \quad \cdots (1)$$

Further, if the pitch L of the steel pipes is larger than the diameter of the steel pipe, the steel pipes can be disposed substantially parallel to the steel sheet pile wall. Accordingly, the lower limit of L is a dimension D that is the sum of the radii of two adjacent steel pipes. If the steel pipes can be disposed substantially parallel to the steel sheet pile wall, the width of a combined wall body including the steel pipes and the steel sheet piles can be reduced. That is, if the pitch L of the steel pipes satisfies the above-mentioned expression (1), the width of the combined wall body can be reduced.

[0024]

Next, examination is additionally performed from the viewpoint that the wall body also ensures the safety and soundness of the steel sheet pile in the extending direction of the wall body when the steel pipe, which is a main member, is set so as to ensure safety and soundness. Since an effect of stiffening the steel sheet pile wall by the steel pipes is smallest in the vicinity of the middle between adjacent steel pipes, a large amount of stress is generated at that portion. When the steel pipes are disposed on the side (the front surface side), of which a ground surface is low, of both sides of the wall body, the pitch of the steel pipe is denoted by L, and “ $D \leq L \leq (1/2)H$ ” is satisfied as described above, the stress of the steel sheet pile in the vicinity of the middle between adjacent steel pipes is equal to or smaller than stress that is calculated on the assumption that earth pressure is applied to the steel sheet pile, which is provided alone, between the deepest portion and the position of a height (2L) that is twice as large as the pitch L of the steel pipes as shown in FIG. 7. That is, the

following expression (2) is satisfied. Here, when a triangular distributed load of which the load at the deepest portion is denoted by p is applied to the wall body as shown in (a) in FIG. 7, the maximum bending moment at that time is denoted by $M_{\max}$, the maximum bending moment, which is calculated using a model of (b) in FIG. 7 and is applied to the steel sheet pile in the vicinity of the middle between adjacent steel pipes, is denoted by $M_{\max}$, and the maximum stress is denoted by $\sigma_{\max}$.

[Formula 5]

$$\sigma_{\max} = \frac{M_{\max}}{Z_s} \leq \frac{(3H-4L)(2L)^2}{H^3} \cdot \frac{M_{\max}}{Z_s} \dots (2)$$

$M_{\max}$: maximum bending moment generated in steel sheet pile in the vicinity of middle between adjacent steel pipes

Z_s : section modulus of steel sheet pile per 1 m in extending direction

L : pitch of steel pipes

p : maximum value of triangular distributed load

H : height of wall

$M_{\max}$: maximum bending moment generated in wall body ($=pH^2/6$)

[0025]

If the left side of Expression (2) is equal to or smaller than the yield stress σ_y of the steel sheet pile, the maximum stress generated in the steel sheet pile in the vicinity of the middle between adjacent steel pipes is equal to or smaller than the yield stress σ_y when steel pipes are disposed on the side (the front surface side), of which a ground surface is low, of both sides of the wall body and the pitch of the steel pipe is denoted by L . That is, if Expression (3) is satisfied, it is possible to ensure safety and soundness in the extending direction of the wall body without yielding the steel sheet pile in the extending direction of the wall body.

[0026]

[Formula 6]

$$\frac{(3H-4L)(2L)^2}{H^3} \cdot \frac{M_{\max}}{Z_s} \leq \sigma_y \quad \dots (3)$$

σ_y : yield stress of steel sheet pile

[0027]

From the above description, in the “combined steel wall” in which the steel pipes are combined with the steel sheet piles and which has a structure in which steel pipes are disposed on the side (the front surface side), of which a ground surface is low, of both sides of the wall body, if Expression (1) and Expression (3) are satisfied with respect to the pitch L of the steel pipes in a structure in which the steel pipe enters a recess of the steel sheet pile wall and the steel pipe and the steel sheet pile come into contact with each other or are connected to each other by a connection member at any position in a vertical direction or come into contact with each other and are connected to each other by the connection member, it is possible to reduce stress generated in the steel sheet pile in the vicinity of the middle between adjacent steel pipes, to exhibit an effect of the combination of the steel sheet piles and the steel pipes, and to ensure the safety and soundness of the wall body without yielding of the steel sheet pile in the extending direction of the wall body.

In addition, an embodiment that can utilize the stiffness and proof stress of both the steel pipes and the steel sheet piles (the pitch of the steel pipes) is additionally examined to form the “combined steel wall”, which includes the steel pipes and the steel sheet piles, with a more reasonable structure.

As described above, in this indoor model test, values of strain, which is

generated in the deep portion of the steel pipe, obtained in the first and second tests are slightly smaller than a value thereof that is obtained when total earth pressure is applied to the steel pipe, and a value thereof obtained in the third test is smaller than the values thereof obtained in the first and second tests. Further, the displacement of an upper portion of the steel pipe in the third test is also smaller than those in the first and second tests. In contrast, the strain of the deep portion of the steel sheet pile in the third test has a larger value. That is, the load of the steel pipe can be reduced as the share of a load allocated to the steel sheet pile is increased. That is, if the pitch of the steel pipes is increased and the steel sheet pile can also share an appropriate load without losing structural stability, it is possible to form an efficient structure that can reduce a load supported by the steel pipe and can resist an applied load by using the stiffness and proof stress of both the steel pipe and the steel sheet pile.

[0028]

Since a large amount of stress tends to be generated in the deep portion of the steel sheet pile of the combined wall body of the invention at a middle position between adjacent steel pipes as described above, applicants have found that the value of the large amount of stress can be expressed by Expression (2).

According to Expression (2), bending moment, which is applied to a deep portion at a middle position between adjacent steel pipes, is equal to or smaller than a value obtained by multiplying bending moment, which is applied when a steel sheet pile is provided alone, by a reduction coefficient $(3H-4L)(2L)^2/H^3$.

Since the share of a load allocated to the steel sheet pile is increased when the pitch of the steel pipes is increased and the value of the reduction coefficient $(3H-4L)(2L)^2/H^3$ is excessively increased, there is a possibility that the steel sheet pile may yield due to the stress generated in the steel sheet pile. An expression that limits the

range of the pitch of the steel pipes in consideration of this fact is the above-mentioned Expression (3).

[0029]

Meanwhile, when the value of the reduction coefficient is excessively reduced by the reduction of the pitch of the steel pipes, stress generated in the steel sheet pile is reduced and the share of a load allocated to the steel sheet pile is reduced. In this case, it is possible to increase the value of the reduction coefficient by adjusting the pitch of the steel pipes. Accordingly, if the pitch of the steel pipes can be increased so as to be equal to or larger than a certain level, it is possible to form an efficient structure that can reduce a load supported by the steel pipe and can resist an applied load by using the stiffness and proof stress of both the steel pipe and the steel sheet pile. However, there is also a case in which it is difficult to increase the pitch of the steel pipes due to a limitation on a construction method, a shape condition such as the width of the sheet pile, a structural condition such as the height of the wall, or the like. In this case, it is possible to form a reasonable structure by reducing the weight of a steel material through the reduction of the size of the model of the steel sheet pile, that is, the reduction of the section modulus of the steel sheet pile. For example, when the height of the wall changes in the extending direction, there is a case in which it is necessary to reduce the pitch of the steel pipes to ensure high proof stress and stiffness at a portion of the wall, which has a large height, with steel pipes by applying steel pipes having the same diameter from the viewpoint of construction. In this case, a load supported by the steel sheet pile is reduced. An effect of reducing the share of a load allocated to the steel pipes by the steel sheet piles cannot be particularly expected under such a condition. However, if the model of a steel sheet pile corresponding to the magnitude of a load, which can be shared by the steel sheet pile, can be selected,

the performance of a member to be used can be effectively utilized.

[0030]

Generally, in a civil engineering structure, members forming a structure are set so as to have safety margins to some extent in consideration of a variation between an applied load and the strength of a material. For example, in many design guides, such as road bridge specifications and the manual thereof (March, 2012, Japan Road Association), allowable stress obtained by multiplying yield strength by a safety factor of $1/1.7$ (≈ 0.6) is set in the case of a steel material so that a variation between an applied load and the strength of a material is considered.

[0031]

Even in this structure, from the viewpoint of a safety in regards to a variation between an applied load and the strength of a material, it is considered appropriate for a load to be applied to a steel sheet pile in a range that has a margin to some extent. Accordingly, it is considered appropriate for stress, which is equal to or larger than about a half of a value considering the safety factor, to be generated in the steel sheet pile, that is, it is considered appropriate for the range of stress, which is generated in the steel sheet pile, to be in the range of about 0.3 to 0.6 times of yield stress.

Meanwhile, since there are some kinds of models as steel sheet piles that are generally used at present, it is possible to selectively use the models according to required stiffness and proof stress. If the stress of the steel sheet pile of the left side of Expression (3) is smaller than 0.3 times of yield stress, a possibility that a smaller model of the steel sheet pile can be applied becomes high. Accordingly, it is considered that there is room for the rationalization of the structure. From the above description, the following Expression (4) is set from the viewpoint of generating appropriate stress in the steel sheet pile.

[0032]

[Formula 7]

$$0.3 \sigma_y \leq \frac{(3H-4L)(2L)^2}{H^3} \cdot \frac{M_{\max}}{Z_s} \dots (4)$$

[0033]

When setting is performed so that Expression (4) is satisfied, it is possible to reduce the share of a load allocated to the steel pipe by sharing a load at the pitch of the steel pipes by the steel sheet piles. Alternatively, when the share of a load allocated to the steel sheet pile is small, it is possible to select an appropriate model of the steel sheet pile. Accordingly, it is possible to form a reasonable structure by utilizing the performance of a steel material.

From the above description, in the “combined steel wall” in which the steel pipes are combined with the steel sheet piles and which has a structure in which steel pipes are disposed on the side (the front surface side), of which a ground surface is low, of both sides of the wall body, if Expression (4) is satisfied with respect to the pitch L of the steel pipes in a structure in which the steel pipe enters a recess of the steel sheet pile wall and the steel pipe and the steel sheet pile come into contact with each other or are connected to each other at any position in a vertical direction or come into contact with each other and are connected to each other by a connection member, it is possible to utilize the stiffness and proof stress of the steel pipe and the steel sheet pile. Accordingly, it is possible to form a further reasonable structure.

[0034]

The invention made on the basis of the above-mentioned new knowledge will be described in detail below with reference to the drawings.

FIGS. 9A to 9C show an example of a combined steel wall 3 according to a first embodiment of the invention.

As shown in FIGS. 9A to 9C, the combined steel wall 3 according to this embodiment has a structure in which a wall body 4 including hat-shaped steel sheet piles 1 is combined with steel pipes 2 disposed along the longitudinal direction of the hat-shaped steel sheet pile 1.

For example, the steel wall 3 is embedded in the horizontal ground and the ground is then dug up on one side of the steel wall 3, so that the steel wall 3 stands between a ground surface of which the horizontal position is high and a ground surface of which the horizontal position is low.

[0035]

The hat-shaped steel sheet pile includes a web 1a, a pair of flanges 1b that obliquely extend from both side edges of the web 1a so that a distance between the flanges increases, a pair of arms 1c that extend from ends of the left and right flanges 1b to the left and right side so as to be parallel to the web 1a, and joints 1d that are formed at the ends of the arms 1c.

Further, the wall body 4 has a structure in which adjacent hat-shaped steel sheet piles 1 are connected to each other by the joint 1d (the connection member).

That is, the wall body 4 is formed so that a plurality of recesses are formed at an interval in the extending direction of the wall body (horizontal direction). The recess, which is mentioned here, means (A) a space that is formed by the web 1a of the hat-shaped steel sheet pile 1 and the pair of flanges 1b or (B) a space that is formed by the arms 1c and 1c of the adjacent hat-shaped steel sheet piles 1 and 1 and the flanges 1b and 1b.

[0036]

The steel pipes 2 stand on the ground on the side, of which a horizontal position is low, of both sides of the wall body 4 along the longitudinal direction of the hat-shaped steel sheet pile 1 while a part of each steel pipe 2 is received in the recess of the wall body 4.

[0037]

Here, the steel pipe 2 comes into direct contact with the flanges 1b of the hat-shaped steel sheet pile 1 in the vertical direction without the connection members or the like interposed therebetween. When the steel pipe 2 is adapted to come into direct contact with the flanges 1b of the hat-shaped steel sheet pile 1 as described above, a load, such as earth pressure or water pressure, applied to the hat-shaped steel sheet pile 1 can be transmitted as a horizontal force by the contact between the steel members. Further, since it is also not necessary to dispose a connection member on the outer peripheral surface of the steel pipe, protrusions are not formed on the outer peripheral surface of the steel pipe. Accordingly, the steel pipe can rotatively penetrate.

[0038]

For example, a configuration in which one steel pipe 2 is disposed per three hat-shaped steel sheet piles 1 as shown in FIG. 9A, that is, a configuration in which the steel pipes are disposed in every other recess of the wall body 4, or a configuration in which one steel pipe 2 is disposed per two hat-shaped steel sheet piles 1 as shown in FIG. 9B, that is, a configuration in which the steel pipes are disposed in every other recess of the wall body 4 may be provided in regard to the disposition of the steel pipes 2.

Furthermore, the steel pipes 2 may be disposed so as to face the joints 1d of the hat-shaped steel sheet piles 1 as shown in FIG. 9C.

[0039]

The diameter and the thickness of the steel pipe 2, the pitch of the steel pipes 2, and the like may be set according to the need in consideration of stiffness required for the steel wall 3. When a dimension that is the sum of the radii of two adjacent steel pipes 2 is denoted by D , the pitch of the steel pipes 2 is denoted by L , and the height of the steel wall 3 is denoted by H , the pitch of the steel pipes may be set so that “ $D \leq L \leq (1/2)H$ ” is satisfied.

[0040]

Further, it is preferable that the steel sheet piles and the steel pipes be connected to each other in the longitudinal direction at upper portions thereof. If the steel sheet piles and the steel pipes are connected to each other at upper portions thereof, it is easy to connect the steel sheet piles to the steel pipes after embedding the steel sheet piles and the steel pipes and it is possible to transmit a horizontal force through at least the upper portions of the steel sheet piles and the steel pipes even if the steel sheet piles are separated from the steel pipes during the embedment of the steel sheet piles and the steel pipes in the structure in which the steel pipes come into contact with the steel sheet piles. Furthermore, if the upper portions of the steel sheet piles and the steel pipes are joined to each other by welding joining or concrete, it is also possible to suppress shear distortion in a vertical direction and to improve the stiffness and proof stress of the wall body.

[0041]

For example, if the pitch of the steel pipes is 1800 mm when the height H of the steel wall 3 is 5000 mm, a load caused by earth pressure forms triangular distribution, a load P at the deepest portion is $27 \text{ kN} \cdot \text{m}^2$, and the yield stress σ_y of the steel sheet pile is 295 N/mm^2 , Expression (1) is satisfied and Expression (3) is also satisfied since the left side of Expression (3) is 101 N/mm^2 . Accordingly, it is

possible to reduce stress generated in the steel sheet pile in the vicinity of the middle between adjacent steel pipes, to exhibit an effect of the combination of the steel sheet piles and the steel pipes, and to ensure the safety and soundness of the wall body without yielding the steel sheet pile in the extending direction of the wall body. Further, since Expression (4) is also satisfied, it is possible to utilize the stiffness and proof stress of both the steel pipe and the steel sheet pile. Accordingly, it is possible to form a further reasonable structure.

When the steel pipes are embedded at the pitch of the steel pipes and are to be constructed through hydraulic press-fitting or rotary press-fitting by taking reaction forces applied from the plurality of embedded steel pipes, the size of a holding device for a reaction force is increased and a distance between the steel pipe taking a reaction force and a steel pipe to be embedded is increased. For this reason, construction becomes unstable. However, since the embedded steel sheet piles are held and reaction forces applied from the embedded steel sheet piles are taken in this case, stable embedment can be achieved even though the steel pipes are arranged at a pitch.

[0042]

FIGS. 10A and 10B show an example of a combined steel wall according to a second embodiment of the invention.

As shown in FIGS. 10A and 10B, in a steel wall 3 of this embodiment, steel sheet piles 1 and steel pipes 2 are installed so that a part of each steel pipe 2 enters a recess of a wall body 4 while the steel sheet piles 1 and the steel pipes 2 are separated from each other in a longitudinal direction, and the steel sheet piles 1 and the steel pipes 2 are connected to each other at upper portions, and more specifically, top portions thereof by welding using steel plates J as connection members. Since the steel sheet piles 1 and the steel pipes 2 are installed so that a part of each steel pipe 2

enters the recess of the wall body 4, an effect of stiffening the wall body 4 by the steel pipes 2 is obtained and the thickness of the steel wall 3 can be made smaller than the sum of the thickness of the steel sheet pile (a distance between a web 1a and an arm 1c) and the diameter of the steel pipe. Accordingly, it is possible to build the combined steel wall 3 while reducing a construction space and the thickness of the wall body 4.

Even in this case, when setting is performed so that Expression (1) and Expression (3) are satisfied, it is possible to reduce stress generated in the steel sheet pile in the vicinity of the middle between adjacent steel pipes, to exhibit an effect of the combination of the steel sheet piles and the steel pipes, and to ensure the safety and soundness of the wall body without yielding the steel sheet pile in the extending direction of the wall body. Further, if Expression (4) is also satisfied, it is possible to utilize the stiffness and proof stress of both the steel pipe and the steel sheet pile. Accordingly, it is possible to form a further reasonable structure.

[0043]

In this case, since the steel sheet piles and the steel pipes are installed so as to be separated from each other, noise and vibration on construction are suppressed and the deformation of the steel sheet pile and the steel pipe caused by the contact therebetween during construction does not occur. Furthermore, since the steel sheet piles do not come into contact with the steel pipes, a vibration method such as a vibrating hammer method also can be employed. Moreover, since the steel sheet piles and the steel pipes are installed so as to be separated from each other without the installation of fitting tools, joints, or the like, a rotary press-fitting method of embedding steel pipes by rotating the steel pipes and the like also can be applied.

Further, at least a part of the steel pipes and the steel sheet piles in a

longitudinal direction may come into contact with each other or may be connected to each other by using connection members so that a horizontal force can be transmitted. Concrete that is installed over both the steel sheet pile and the steel pipe, welding joining between the steel sheet pile and steel pipe, a steel plate or a reinforcing bar on which bolts or drill screws are mounted, or the combination thereof can be used as the connection member. Furthermore, if the steel sheet pile and the steel pipe are joined to each other by welding joining or concrete and shear variation in the vertical direction between the steel sheet pile and the steel pipe is suppressed, it is also possible to improve the stiffness and proof stress of the wall body. Accordingly, it is possible to improve safety by the reduction of the displacement of the wall body and to select a more economical combination of the steel pipe and the steel sheet pile. Meanwhile, since shear distortion in the vertical direction is largest at upper portions of the steel pipe and the steel sheet pile, it is preferable that the steel pipe and the steel sheet pile be connected to each other so that distortion is suppressed and a shear force can be transmitted at the upper portions. Meanwhile, when the steel pipe and the steel sheet pile are to be connected to each other, it is preferable that the steel pipe and the steel sheet pile be connected to each other at two or more points or on the surface in a cross-section. Specifically, connection members may be installed at two or more position on one steel pipe in a cross-section as shown in FIG. 10A, or steel pipes and steel sheet piles may be joined to each other by concrete C that is installed at upper portions of the steel pipe and the steel sheet pile so as to connect the steel pipes to the steel sheet piles as in a modification shown in FIGS. 11A and 11B.

[0044]

The positions of lower ends of the steel sheet pile 1 and the steel pipe 2 may be separately set as shown in FIG. 10B. After embedded lengths required for the

stability of the wall body are ensured by the steel pipes 2, the steel sheet piles 1 may ensure the required embedded lengths, such as embedded lengths that facilitate the prevention of boiling, heaving, and circular arc slip. Further, even in regard to the positions of the upper portions, the position of the upper portion of the steel pipe may be lower than the position of the upper portion of the steel sheet pile. Accordingly, when the steel sheet piles are held and the hydraulic press-fitting or rotary press-fitting of the steel pipes is performed, holding positions may be set so as not to reach steel pipes having already been embedded.

[0045]

Meanwhile, the invention is not limited to the above-mentioned embodiments, and may have various modifications without departing from the scope of the invention.

For example, an every-third-configuration in which one steel pipe 2 is disposed per three hat-shaped steel sheet piles 1 and an every-second-configuration in which one steel pipe 2 is disposed per two hat-shaped steel sheet piles 1 have been described in the above-mentioned embodiments, but an every-fourth or more-structure in which one steel pipe 2 is disposed per four or more hat-shaped steel sheet piles 1 may be applied.

Further, cases in which the hat-shaped steel sheet piles 1 having the same width are combined with the steel pipes 2 having the same diameter and the pitch L of the steel pipes 2 is set to be constant have been described in the above-mentioned embodiments, but the widths of the hat-shaped steel sheet piles 1 and the diameters of the steel pipes 2 can be arbitrarily set and the pitch L of adjacent steel pipes 2 also can be arbitrarily set. For example, when an interval between steel pipes 2 adjacent to each other is arbitrarily set, a center distance (the maximum interval) between first and second steel pipes, which are adjacent to each other and between which a center

distance is the maximum distance, may be set to L . Furthermore, when steel pipes 2 having different diameters are used, a dimension, which is the sum of the radii of the adjacent first and second steel pipes, may be set to D . Moreover, the steel sheet pile is not limited to the hat-shaped steel sheet pile, and the combination using a U-shaped steel sheet pile and a Z-shaped steel sheet pile may be used as the steel sheet pile.

Further, whether the steel sheet pile 1 and the steel pipe 2 are connected to each other at the upper portions thereof by a connection member or are joined to each other at the upper portions thereof by concrete C can be arbitrarily set.

Furthermore, whether or not Expression (2) and Expression (3) are satisfied can be arbitrarily set.

[Industrial Applicability]

[0046]

According to the invention, it is possible to provide a combined steel wall having a reasonable structure that can ensure the safety and soundness of the wall body and utilize the stiffness and proof stress of both a steel pipe and a steel sheet pile.

[Brief Description of the Reference Symbols]

[0047]

1: HAT-SHAPED STEEL SHEET PILE (STEEL SHEET PILE)

2: STEEL PIPE

3: STEEL WALL

4: WALL BODY

M_{smax} : MAXIMUM BENDING MOMENT GENERATED IN STEEL SHEET PILE IN THE VICINITY OF MIDDLE BETWEEN ADJACENT STEEL PIPES

Z_s : SECTION MODULUS OF STEEL SHEET PILE PER 1 M IN

EXTENDING DIRECTION

L: PITCH OF STEEL PIPES

p: MAXIMUM VALUE OF TRIANGULAR DISTRIBUTED LOAD

H: HEIGHT OF WALL

M_{max}: MAXIMUM BENDING MOMENT GENERATED IN WALL BODY

($=pH^2/6$)

[Document Type] CLAIMS

[Claim 1]

A combined steel wall comprising:

a wall body that includes a plurality of steel sheet piles connected to each other by joints and a plurality of recesses arranged at an interval in an extending direction; and

a plurality of steel pipes that stand on a ground surface on a side, of which a horizontal position is low, of both sides of the wall body along a longitudinal direction of the steel sheet pile while a part of each steel pipe is received in the recess,

wherein at least a part of the wall body and the steel pipes in the longitudinal direction of the steel sheet pile are connected to each other, and

a maximum interval L (mm) as a center distance between first and second steel pipes which are adjacent to each other and between which a center distance is the maximum distance, a height H (mm) of the wall body, and a dimension D (mm) that is the sum of radii of the first and second steel pipes satisfy the following formula (1).

[Formula 1]

$$D \leq L \leq (1/2) \times H \quad \cdots (1)$$

[Claim 2]

The combined steel wall according to claim 1,

wherein the wall body and the steel pipes are connected to each other by coming into contact with each other.

[Claim 3]

The combined steel wall according to claim 1,

wherein the wall body and the steel pipes are connected to each other by connection members.

[Claim 4]

The combined steel wall according to claim 3,
wherein the connection members connect at least upper portions of the steel sheet piles and the steel pipes.

[Claim 5]

The combined steel wall according to any one of claims 1 to 4,
wherein the maximum interval L (mm) is set so that the maximum interval L (mm), the height H (mm) of the wall body, yield stress σ_y (N/mm²) of the steel sheet pile, a section modulus Z_s (mm³) of the steel sheet pile, and the maximum bending moment M_{max} (N·mm) applied to the wall body satisfy the following formula (2).

[Formula 2]

$$\frac{(3H-4L) \times (2L)^2}{H^3} \times \frac{M_{max}}{Z_s} \leq \sigma_y \quad \cdot \cdot \cdot (2)$$

[Claim 6]

The combined steel wall according to any one of claims 1 to 5,
wherein the maximum interval L (mm) is set so that the maximum interval L (mm), the height H (mm) of the wall body, the yield stress σ_y (N/mm²) of the steel sheet pile, the section modulus Z_s (mm³) of the steel sheet pile, and the maximum bending moment M_{max} (N·mm) applied to the wall body satisfy the following formula (3).

[Formula 3]

$$0.3 \times \sigma_y \leq \frac{(3H-4L) \times (2L)^2}{H^3} \times \frac{M_{max}}{Z_s} \quad \cdot \cdot \cdot (3)$$

[Claim 7]

The combined steel wall according to any one of claims 1 to 6,

wherein the respective recesses are formed on the wall body at regular intervals when viewed in the longitudinal direction, and
the steel pipes are disposed in every other recess.

[Claim 8]

The combined steel wall according to any one of claims 1 to 6,
wherein the respective recesses are formed on the wall body at regular intervals when viewed in the longitudinal direction, and
the steel pipes are disposed in every third or more recess.