

IMPROVED STEEL PIPE PILES AND PIPE PILE STRUCTURES

BACKGROUND OF THE INVENTION

The present invention relates to an improvement in pipe piles - and especially, steel pipe piles - which are adapted to be driven into the earth for use as a structural element in a foundation or in a wall. More particularly, the present invention relates to metal pipe piles, for use in a foundation or wall, which are subject to corrosion by the elements.

When in contact with water and at the same time in the presence of air with oxygen, steel is subject to a natural corrosion process. Material abrasion from corrosion depends, on the one hand, on local (e.g. hydrological) conditions and, on the other hand, on the vertical position of the steel with respect to the water line. When pipe piles are driven into an ocean bed, for example to support a pier or ocean platform, or to form a seaside retaining wall, different vertical zones of the pipe piles are subject to different rates of corrosion or "rusting".

Fig. 1 shows a retaining wall 10, formed of a row of steel pipe piles for example, which holds back the earth 12 on the edge of the sea 14. Preferably, an earth anchor 16 provides horizontal support for the pipe piles against lateral forces exerted by the earth side 12. With such an anchor in place, the pipe piles are subject to a bending moment with a distribution, along their length, as shown by the graph 18.

The vertical levels of the retaining wall are divided into zones, depending on the expected rates of corrosion of the steel. These zones, which are defined by the expected water

levels due to the tides and storms are called, successively from upper to lower, the "splash zone" 20 (from the mean high water level to the top of the wall); the "intertidal zone" 22 (between the mean low water and the mean high water levels); the "low water zone" 24 (from the lowest water level to the mean low water level); the "permanent immersion zone" 26 (from the ocean floor to the lowest water level); and the "buried zone" 28 (below the ocean floor). As shown by the graph 30 the pipe piles have different expected rates of corrosion in each of these zones.

Depending upon the vertical zone, and therefore the degree of corrosion intensity, the outer surface of the pipe piles corrodes away at a prescribed rate, thus decreasing the wall thickness of a pipe pile. Referred to in time units, one speaks of the "rusting speed" (rusting rate in mm/year). Investigations of steel sheet piling with differing service lives indicate that the rusting speed decreases in time resulting from the formation of a cover layer, unless this cover layer is constantly eroded away by mechanical or chemical action. Accordingly, when rating the decrease in thickness or rusting speed, the design period or "service life", respectively, of the sheet pile member must also be stated.

In many applications, steel piling durability concerns are minimal simply because steel piling is usually over-designed, due to the use of a relatively high safety factor with steel as compared to concrete. This inherent factor obviously takes the natural and inevitable aspect of corrosion into account. However, in salt water applications (or, in some cases involving polluted waters or polluted soils), it is recommended that the engineer design a foundation or retaining wall using the

"sacrificial steel" method, and also consider if a protective coating would be advantageous or necessary in the particular environment.

As shown by the graph 30, the highest corrosion rates are usually found in the (sea water) splash zone or in the low water zone. However, as shown by the graph 18, the highest stresses are usually in the permanent immersion zone 26. See "Recommendations of the Committee for Waterfront Structures Harbors and Waterways", 7th Edition, EAU 1996 Section 8.1.8.3, Fig. R 35-1, page 293.

When designing a pipe pile or sheet pile structure in or near the water, the area of most concern is the low water zone because it is closest to the area of highest stress. For salt water applications, therefore, it is recommended that the exposed steel surfaces be coated (and/or be subjected to "cathodic protection") down to 1.5 meters to 2.5 meters below the mean low water so that the critical low water zone is protected.

According to "Recommendations of the Committee for Waterfront Structures Harbors and Waterways", EAU 2004 Section 8.1.8.4, page 320, such coatings can delay the start of corrosion by more than 20 years.

The European Pre-standard, promulgated as "Eurocode 3: Design of Steel Structures - Part 5: Piling" (BS ENV 1993-5: 1997 and BS ENV 1993-5: 2007) provides tables for the expected loss of thickness due to corrosion for steel pipe piles and steel sheet piles in fresh water and in sea water for temperate climates. For example, in sea water and in the zones of high corrosion

rate, it is expected that 7.5 mm of steel will be lost from the steel surface over a period of 100 years.

As noted above, this amount of loss can be delayed by up to 20 years by coating the steel surface with paint or epoxy, particularly in the regions that are most vulnerable to corrosion. The application of such a protective coating also allows the design engineer to specify a thinner wall thickness for the pipe or sheet piling than would otherwise be required, resulting in a cost saving in the total amount of steel.

The use of a protective coating has a number of disadvantages, however:

- (1) The coating is relatively expensive to purchase and apply in such large quantities;
- (2) The coating is often damaged during transport, leaving uncoated scratches or the like which are especially vulnerable to corrosion;
- (3) The coating, which is toxic to plant and fish life, can bleed or rub off in the water.

The US Army Corps of Engineers' "Design of Sheet Pile Walls Engineer Manual" (Section 2-2) is unambiguous in its general preference of steel over concrete for in the construction of retaining walls:

"The designer must consider the possibility of material deterioration and its effect on the structural integrity of the system. Most permanent structures are constructed of steel or concrete. Concrete is capable of providing a long service life under normal circumstances but has relatively

high initial costs when compared to steel sheet piling. They are more difficult to install than steel piling. Long-term field observations indicate that steel sheet piling provides a long service life when properly designed."

There is accordingly a need for pipe piling which avoids the disadvantages of surface coating in regions susceptible to increased corrosion (the low water and splash zones, for example) while increasing the expected service life of piling when used in corrosive environments (such as in polluted water or sea water).

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a pipe pile, for use in a foundation or retaining wall, which has increased service life without the need for a surface coating.

It is a further object of the present invention to provide a pipe pile, for use in a foundation or wall, which has a reduced amount of steel as compared to a conventional pipe pile with an equal service life.

These objects, as well as further objects which will become apparent from the discussion that follows, are achieved, in accordance with the present invention, by providing a pipe pile which comprises a substantially cylindrical, and preferably steel, pipe body extending longitudinally between two opposite ends, the pipe body being formed of a plurality of pipe sections, interlocked or welded together end to end, arranged on a common central longitudinal axis between the two ends. All of the pipe sections have substantially the same outside diameter; however, two or more pipe sections have differing inside

diameters, and thus a differing wall thickness, between the two ends of the pipe pile.

This structure allows a design engineer to specify the material wall thickness of the pipe piles approximately in accordance with the expected rate of corrosion over the service life of the project, with certain ones of the pipe sections of the pipe piles having a greater wall thickness than other pipe sections.

For a full understanding of the present invention, reference should now be made to the following detailed description of the preferred embodiments of the invention as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a representational diagram of a pipe pile retaining wall with accompanying graphs showing the approximate rate of corrosion and a typical bending moment distribution along the length of the pipe piles.

Fig. 2 is an illustration of a row of pipe piles of the type to which the present invention relates.

Fig. 3 is a plan view showing two pipe piles linked together by male and female connecting elements, welded to the exterior pipe pile surfaces.

Fig. 4 is a detailed plan view of the male and female connecting elements shown in Fig. 3.

Fig. 5 is a detailed plan view showing another embodiment of male and female connecting elements that may be used to connect pipe piles.

Fig. 6 is a plan view of two pipe piles linked by two Z-shaped sheet piles.

Fig. 7 is a plan view of two pipe piles linked by a U-shaped sheet pile.

Fig. 8 is a cross-sectional view of a retaining wall (not to scale) of the type to which the present invention relates.

Fig. 9 is a cross-sectional view of a pier (not to scale) of the type to which the present invention relates.

Fig. 10a is a cross-sectional view (not to scale) showing a single pipe pile comprised of three sections, welded together end-to-end along a common longitudinal axis, with each section having the same outer diameter but a differing internal diameter.

Fig. 10b is a lateral cross-sectional view (not to scale) of each pipe pile section of Fig. 10a.

Fig. 11 is a cross-sectional, detailed view (not to scale) of the abutting ends of two pipe piles of differing wall thickness, welded together along their seam.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention will now be described with reference to Figs. 1-11 of the drawings.

Identical elements in the various figures are designated with the same reference numerals.

Fig. 1 shows a retaining wall 10 formed of steel pile piles which retains and separates the earth 12, on one side, from the sea 14 on the other. As explained in the Background of the Invention section above, the pipe piles in this wall are subjected to continuous stress and to the continuous effects of corrosion due to the action of air and water.

The pipe piles of the retaining wall are driven into the earth below the sea bed with their longitudinal axes arranged substantially in parallel and along a common, substantially horizontal, line. Fig. 2 shows such a series of pipe piles 32, arranged along a horizontal line 33 and connected together by intermediate connecting elements 34, which are affixed to the external, curved surfaces of the piles by welding.

Fig. 3 illustrates how two such pipe piles 32 are joined by such connecting elements 34, the details of which are presented in Fig. 4. Prior to ramming, a "male" connecting element 36 is welded to one side of each pipe 32 and a "female" connecting element 38 is welded to the opposite side, over the entire length (or nearly the entire length) of the pipe. The pipes are then driven into the earth, one at a time, with the male connecting element 36, welded to one pipe, inserted in and interlocked with the female connecting element 38 that is welded to the next, adjacent pipe.

Fig. 5 shows another type of connecting element 40 that may be used between adjacent pipes 32 to connect the pipes closely together. This connecting element, which is similar to the

connecting elements described in detail in the U.S. Patent No. 7,168,214, comprises a short male element 42 with an interlocking head strip 44 and a female element formed by a claw 46.

Figs. 6 and 7 each show two pipe piles 32, also arranged side by side and longitudinally in parallel, which are separated by sheet piles instead of connectors only. In Fig. 6 the adjacent pipe piles are connected together by two Z-shaped sheet piles 50 and 52; in Fig. 7 the pipe piles are connected by an intervening U-shaped sheet pile 54.

Fig. 8 is a cross-sectional side view of a pipe pile 32, one of many in a seaside retaining wall 60. The wall supports the earth 62, on one side, from eroding and falling into to the sea 64, on the other. The pipes of the wall, represented by pipe 32, pass through the sandy earth 66 beneath the sea floor and are preferably of sufficient length to reach the bedrock 68 below.

Although the average level of the sea varies with the tides within a certain range, indicated by the double arrow 70, and waves splash against the wall within a certain average range, indicated by the double arrow 72, the wall of pipes is constructed considerably higher so as to protect against storms and other contingencies. To achieve the total length of pipe required, the pipes are transported to the construction site in convenient (e.g. 20 foot) lengths and welded end-to-end when they are installed. Depending on the total length of the pipe piles required, and upon the preferences of the contractor, the pipe sections can either be rammed, section by section, and welded together during the ramming process, or they can be welded first, end to end, and rammed as a single lengthy unit.

The useful life of a pipe pile and sheet pile wall depends entirely upon the rate of corrosion of the material (e.g., steel) caused by the elements, particularly the exposure to water and/or air. The water - particularly salt water, brackish water or polluted water - causes a steel pile wall to corrode at an accelerated rate, particularly in the regions 70 and 72. Outside of these regions, where the sheet pile wall is either continuously immersed in the water or in the ground, or where the pipe pile wall meets primarily air, except on rainy days, the corrosion is somewhat, or even substantially, less.

To increase the life of pipe pile walls, it is known to cover at least a portion of the pipe surfaces with a coat of paint or epoxy, for example in the region 74 which is most vulnerable to corrosion. The application of such a protective coating allows the construction engineer to specify thinner-walled pipes for the sheet pile wall than would otherwise be required, resulting in a considerable cost saving in the total amount of material (e.g., steel).

Fig. 9 is a diagram, similar to Fig. 8, which shows the use of steel pipe piles 32 to support an ocean pier 76. Like Fig. 8, this diagram shows an intertidal zone 70 and a splash zone 72. As compared to the pipes of the retaining wall of Fig. 8, the steel pipe piles 32 are subjected to a substantially less bending moment. However, they are subjected to corrosion, especially in the splash zone, intertidal zone, low water zone and permanent immersion zone, as explained above in connection with Fig. 1.

According to the present invention, as illustrated in Figs. 10a and 10b, the pipe piles 32 of Figs. 8 and 9 are of differing

wall thickness at different places along their length, so as to take into consideration the differing rates of corrosion during their useful life. Fig. 10a shows a length of pipe 32 in three sections: a lower section 86 (intended to remain continuously beneath the water level); a middle section 88 (intended for location in the tide zone and splash zone of the wall) and an upper section 90 (intended to remain continuously in the open air). As indicated in Fig. 10b, the pipe in section 88, which corrodes at a much faster rate, has a considerably thicker wall than the pipe in sections 86 and 90. The pipe section 86, which must withstand a greater bending stress, has a somewhat greater wall thickness than the pipe section 90.

However, all three sections of pipe have the same external (outside) diameter.

The seams 92 and 94 between the sections of pipe are welded together with the sections abutting end-to-end.

Fig. 11 shows in detail the welded seam between the pipe sections 86 and 88. As may be seen, the ends of the pipe sections are chamfered at an angle of about 30 to 35°, leaving a "land" of at least 1/16 inches to make abutting contact with the adjacent section. The weld material 96 fills the space afforded by the chamfer.

When designing port or a pier, the civil engineer should specify the chamfer for each pipe section, for example 35° with a 1/16 inch land. The engineer should also specify the following parameters:

1. The number, the lengths and the wall thicknesses of all the pipes; more specifically, all the pipe sections that make up the pipes to be used in a project.
2. The outer diameter of all the pipes. Different pipes in the project may have different outer diameters, but all the pipe sections making up an individual pipe must have the same outer diameter.
3. The inner and outer tolerance of the outer diameter; for example, an OD of 36 inches from minus 0 to plus 1/4 inch.
4. The tolerance of the out of roundness of the pipes; for example, equal to or less than 1%.
5. The type and grade of material; for example, the steel base grade ASTM A572, Grade 50.
6. The type of pipe: for example, spiral wound and welded for thinner pipe having a wall thickness of less than 1 inch, or rolled and longitudinally welded for thicker pipe.

The invention has the advantage of supplanting the need for coating the pipes in regions susceptible to increased corrosion (the tidal zone and splash zone, for example), while at the same time allowing for reduced pipe thickness in the regions which are less susceptible to corrosion (the region beneath the earth for example).

There has thus been shown and described an improved steel pipe pile, and pipe pile structures incorporating a plurality of this type of pipe pile, which fulfill all the objects and advantages

sought therefor. Many changes, modifications, variations and other uses and applications of the subject invention will, however, become apparent to those skilled in the art after considering this specification and the accompanying drawings which disclose the preferred embodiments thereof. All such changes, modifications, variations and other uses and applications which do not depart from the spirit and scope of the invention are deemed to be covered by the invention, which is to be limited only by the claims which follow.

C L A I M S

What is claimed is:

1. A pipe pile adapted to be driven into the earth for use as a structural element in a foundation or in a wall, said pipe pile comprising a substantially cylindrical pipe body extending longitudinally between two opposite ends, said pipe body being formed of a plurality of pipe sections, interlocked or welded together end to end, arranged along a common central longitudinal axis between said two ends, wherein all of said pipe sections have substantially the same outside diameter and at least two of said pipe sections have a differing inside diameter, and thereby a differing material thickness, between said two ends.
2. The pipe pile according to claim 1, wherein said pipe pile is made of a steel which corrodes when exposed to water and air.
3. A support structure formed of a plurality of pipe piles according to claim 1, said pipe piles being driven into the earth, side by side, with their longitudinal axes arranged substantially in parallel.
4. The support structure according to claim 3, wherein the material thickness of the pipe piles varies approximately in accordance with the expected rate of corrosion, with a pipe pile having a greater material thickness in one or more of its pipe sections than in others.

5. The support structure according to claim 3, disposed in a body of water, said pipe piles extending downward through the water into the earth below.

6. The support structure according to claim 5, further comprising a platform supported by the pipe piles.

7. The support structure according to claim 5, wherein the body of water is an ocean and the water is sea water.

8. The support structure according to claim 7, wherein the material thickness of the pipe piles is greater in a splash zone of the support structure than in a permanent immersion zone thereof.

9. The support structure according to claim 7, wherein the material thickness of the pipe piles is greater in a low water zone of the support structure than in a permanent immersion zone thereof.

10. The support structure according to claim 7, wherein the material thickness of the pipe piles is greater in an intertidal zone of the support structure than in a permanent immersion zone thereof.

11. The support structure according to claim 7, wherein the material thickness of the pipe piles is greater in a permanent immersion zone of the support structure than in a zone of the support structure below the water.

12. A retaining wall formed of a plurality of pipe piles according to claim 1, said pipe pile sections being driven into

the earth with their longitudinal axes arranged substantially in parallel and along a common, substantially horizontal, line.

13. The retaining wall according to claim 12, wherein the material thickness of the pipe piles varies approximately in accordance with the expected rate of corrosion, with a pipe pile having a greater material thickness in one or more of its pipe sections than in others.

14. The retaining wall according to claim 12, wherein the material thickness of the pipe piles varies approximately in accordance with the expected applied lateral stress, with at least one pipe pile having a greater material thickness in one or more of its pipe sections than in others.

15. The retaining wall according to claim 12, disposed along a coast of a body of water, with earth retained on one side of the wall against air and water on an opposite side.

16. The retaining wall according to claim 15, wherein the body of water is an ocean and the water is sea water.

17. The retaining wall according to claim 16, wherein the material thickness of the pipe piles is greater in a splash zone of the wall than in a permanent immersion zone of the wall.

18. The retaining wall according to claim 16, wherein the material thickness of the pipe piles is greater in a low water zone of the wall than in a permanent immersion zone of the wall.

19. The retaining wall according to claim 16, wherein the material thickness of the pipe piles is greater in an intertidal zone of the wall than in a permanent immersion zone of the wall.

20. The retaining wall according to claim 16, wherein the material thickness of the pipe piles is greater in a permanent immersion zone of the wall than in a zone of the wall below the water.

21. The retaining wall according to claim 12, further comprising pipe pile connecting elements, welded to opposite sides of a plurality of said pipe piles.

22. The retaining wall according to claim 21, wherein said connecting elements are interlocked between adjacent pipe piles.

23. The retaining wall according to claim 21, further comprising at least one sheet pile disposed between two adjacent pipe piles, said sheet pile being interlocked with connecting elements welded to said adjacent pipe piles.

24. The retaining wall according to claim 23, wherein said sheet pile is has a U-shaped cross-section.

25. The retaining wall according to claim 23, wherein said sheet pile is has a Z-shaped cross-section.