UNITED STATES PATENT

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METHOD OF GROUTING A PILE IN A HOLE INVOLVING THE OPTIMIZED FREQUENCY OF VIBRATION OF THE GROUTING MATERIAL

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Field of Search........ 61/53.52, 50, 36, 53, 53.5, 61/53.64, 53.60, 46, 35; 264/31, 32, 33

References Cited
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ABSTRACT
A pile is placed in an earth borehole which may or may not have a protective casing along at least a portion of its length. A predetermined amount of water is metered into the bottom of the hole in the annulus exterior to the pile and then dry sand is added to the water in the annulus. Alternatively, cement or other grouting materials are added to the hole around the pile. Various means are provided for vibrating either the pile or the external protective casing or the sand and water mixture itself or the other grouting material. To maximize the amplitude of vibration, the frequency of vibration is varied during the grouting process to match the ungrouted length of the pile, either by continuously varying the frequency of vibration or in steps along the length of the pile. The sand and water or other grouting mixture itself can be vibrated by one or more vibrating rods inserted into the mixture or by a multi-fingered sleeve which fits over the pile and into the annulus external to the pile. In some of the embodiments, the vibrated apparatus is removed while vibrating to successively compact the sand and water or other grouting mixture beginning at the bottom of the hole. When using a pipe pile, the bottom of the pipe pile can be plugged during the compaction of the sand and water or other grouting mixture and then removed if necessary. Dry sand is used as a ballast to prevent the pipe pile from floating when using a closed end.

10 Claims, 11 Drawing Figures
METHOD OF GROUTING A PILE IN A HOLE INVOLVING THE OPTIMIZED FREQUENCY OF VIBRATION OF THE GROUTING MATERIAL

RELATED APPLICATION.

This application relates to my U.S. Application Ser. No. 455,691, for "Method of Grouting a Pile in a Hole Involving the Optimized Vibration of the Grouting Material", filed on Mar. 28, 1974, and concurrently here-with.

BACKGROUND OF THE INVENTION.

This invention relates generally to the grouting of a pile in a hole, and particularly relates to the grouting of a pile in the ground while vibrating the grouting material.

It is well known in the art to secure a pile in a hole by placing the pile within the hole and then placing grouting material in the annulus exterior to the pile which then sets up to firmly anchor the pile within the ground. Such grouting materials have usually contained cement or other cement-type materials which harden upon setting. Furthermore, because cement expands while drying and also gives off heat, it has been proposed that, especially in the areas where permafrost is encountered, for example, in Alaska, that a mixture of sand and water could be used as the grouting material to eliminate the heat which would have been given off by the drying cement. When using a sand and water mixture, the water in the mixture becomes ice which then becomes an integral part of the permafrost.

In addition, while adding the sand to the water, or while using other grouting material, for example, cement, the grouting material is successively compacting along the length of the pile and thereby shortening the ungrouted length of the pile. This causes the frequency of vibration to be out of tune with respect to that portion of the pile being vibrated.

It is therefore the primary object of the present invention to provide a new and improved method of grouting a pile within a hole;

It is yet another object of the invention to provide new and improved methods for vibrating the grouting material used in grouting a pile within a hole by optimizing the frequency of vibration one or more times during the grouting process.

The objects of the invention are accomplished, in general, by a method of grouting a pile in a hole which involves the placement of the pile within the hole, the addition of grouting material to the hole and the vibration of the grouting material which causes the grouting material to be fluidized along the length of the pile within the hole. As a special feature of the invention, the grouting material is successively vibrated from the bottom of the hole to the top of the hole to provide a successive compaction of the grouting material along the length of the pile within the hole. The various methods embodied within the invention call for the pile to be vibrated or the protective casing to be vibrated or the use of additional means to be vibrated within the grouting material, or combination of same, and that the frequency of vibration be optimized one or more times during the grouting process.

These and other objects, features and advantages of the present invention will be more readily understood from a reading of the following detailed specification and drawing, in which:

FIG. 1 is an elevated view, partly in cross section, of an apparatus for carrying out the invention which causes the pile itself to be vibrated;

FIG. 2 is an elevated view, partly in cross section, of the apparatus according to FIG. 1, which also illustrates means for withdrawing the dry sand from the interior of the pile;

FIG. 3 illustrates, partly in cross section, the pile which has been grouted within a hole in the earth in accordance with the various methods according to the present invention;

FIG. 4A is an elevated view, partly in cross section, which illustrates an apparatus for vibrating and removing the protective casing according to the present invention;

FIG. 4B is a cross-sectional plan view taken along the sectional line 4-4 of FIG. 4A;

FIG. 5 is an elevated view, partly in cross section, which illustrates the use of a vibrating rod which is used to vibrate the grouting material in the annulus of the hole exterior to the pile;

FIG. 6A is an elevated pictorial view of an apparatus which utilizes a multi-fingered sleeve exterior to the pile which is vibrated and withdrawn from the hole during vibration according to the present invention;

FIG. 6B is a cross-sectional plan view taken along the sectional line 6-6 of FIG. 6A;

FIG. 7A is an elevated view, partly in cross section, of an apparatus for causing the pile to be successively vibrated along its length within the hole in accordance with the present invention;

FIG. 7B is a cross-sectional plan view taken along the sectional line 7-7 of FIG. 7A; and

FIG. 8 is a diagram illustrating the reinforcement of the vibrational wave in accordance with the present invention.

Referring now to the drawing in more detail, especially to FIG. 1, there is illustrated a hole 10 in the earth 11 which may be either a conventional earth formation, or may be comprised of permafrost in the more frigid zones of the earth, for example, in Alaska. A steel protective casing 12, which may or may not extend all the way from the earth's surface to the bottom of the hole, is used primarily to ensure the integrity of the hole. A steel pipe pile 13 is placed within the hole 10 and is sized such with respect to the hole that an annulus 14 exists between the pile 13 and the protective casing 12. At the earth's surface, a source of water 15 and a source of dry sand 16 are provided for placing water and sand into the annulus 14. A source 6 of grouting material, for example, cement, is connected through the valve 7 for placing such grouting material in the annulus. A variable frequency vibrator 17 is attached to the pile 13 which causes the pile 13 to vibrate along its length.

The variable frequency vibrator can be of conventional design.

A monitor 8 is attached by a conductor 9 to the vibrator element, or alternatively to the pile itself, to monitor the amplitude of vibration. The monitor 8 is conventional, for example, an oscilloscope, using conventional amplitude detecting techniques. It should be appreciated that the invention also contemplates the grouting operator adjusting the vibration frequency based upon either audible or visible indications of the maximizing of the vibration amplitude. One such successful optimizing of the frequency was accomplished...
by having the grouting operator feel the movement of the top of the pile while varying the frequency of vibration. Another successful operation was accomplished by observing the maximum agitation of the downhole water surface at the optimum frequency.

The bottom end of the pile 13 is closed with a plug 18 to keep the water and the sand and water or other grouting mixture from entering the bottom of the pile 13. The interior of the pile 13 is partially filled with a ballast material, for example, dry sand 19, for ballast purposes to keep the pile 13 from floating when water or other grouting materials are added to the annulus 14.

In practicing one method in accordance with the apparatus illustrated in FIG. 1, the pile 13 is placed in the hole and the dry sand 19 is added to the interior of the pile 13. Water 20 is then metered into the annulus from the water source 15 in a predetermined amount which is determined by the area of the annulus along the entire length of the hole and by the amount of water as is desired in the final sand and water mixture. By way of example, a recommended grouting mixture should have a water content of 8 to 15 percent by dry weight. The 15 percent water content has been found to be highly desirable in that the mixture is highly fluidized during at least a portion of the method according to the present invention.

After the water 20 is added to the annulus and is residing in the bottom of the hole, the dry sand is added to the annulus 14 from the sand source 16 and the variable frequency vibrator 17 is used to vibrate the pile 13 which in turn causes the sand and water mixture to be vibrated. If the grouting material 6 is to be used instead of sand and water, the valve 7 allows the alternative grouting material to be used.

Referring now to FIG. 2, there is illustrated the apparatus of FIG. 1 but also including means for withdrawing the sand 19 from the interior of the pile 13. A pipe 21 extends down into the sand at or near the bottom plug 18 and has attached at its upper end an apparatus for sucking the sand from the interior of the pile. The sand removal apparatus 22 in its simplest form can be a vacuum device.

Referring now to FIG. 3, the pile 13 is illustrated as being grouted in place by the compacted sand and water mixture 23 and which has had its bottom plug 18 (shown in FIG. 'S 1 and 2) removed. It should be appreciated that the bottom plug 18 can be a drillable material and merely drilled out, or can be a retrievable packer such as is used in oil wells and which is removed after the previous steps have been completed in accordance with the present invention. Although not illustrated, the compacted sand and water mixture 23 could be compacted concrete.

Referring now to FIG. 4A, there is illustrated an alternative embodiment of the present invention wherein the protective casing 12 is vibrated instead of, or in addition to, the vibration of the pile 13. A conventional mast assembly 30 having drawworks 31 and a crown block assembly 32 is used to allow the casing 12 to be withdrawn from the hole. The casing 12 is illustrated as having slots or openings through which arms 33 of a traveling assembly 34 are provided which enable the casing 12 to be withdrawn. The traveling assembly 34 includes a top plate 35 having a center opening 36 and a bottom plate 37 having the arms 33 as integral parts thereof. The top plate 35 also has four wheels 38, two of which are illustrated, for traveling along the frame 39 of the mast assembly 30. The drawworks 31 has a line 40 which passes over the crown block 32 and is connected by means of a traveling block 41 to an anchor assembly 42 mounted on the top plate 35. A variable frequency vibrator 43 is attached to a vertical frame member 44 which connects the top plate 35 to the lower plate 37. A second vertical plate member 45 also connects the segmented bottom plate 37 to the top plate 35. In the preferred embodiment, the vertical plate members are welded to the top plate 35 and are bolted to the bottom plate 37 by bolts 46, 47, 48 and 49.

An assembly 50 having a first pipe-like structure 51 which is attached to the upper portion of the mast assembly 30 has a lower bell structure 52 having an outside diameter which substantially matches the outside diameter of the pile 13. The assembly 50 also has a cylindrical, reduced diameter portion 53 which substantially mates with the internal diameter of the pile 13 and extends down inside the pile for a distance, for example, 5 feet, to provide stability to the pile 13 as the protective casing 12 is being vibrated and removed from the hole.

In assembling the apparatus according to FIG. 4A, it should be appreciated that the bottom plate 37 is segmented for ease in placing the arms 33 within the slots in the protective casing 12. After the arms 33 are inserted within the slots in the protective casing 12, the bolts 46, 47, 48 and 49 are used to secure the segmented bottom plate 37 to the vertical plate members 44 and 45.

In the operation of the apparatus according to FIG. 4A, it should be appreciated that there may not necessarily be a need for the ballast sand 19 when the assembly 50 is used to hold the pile 13 in place but can be used as needed. As with the other embodiments, the grouting material 6 is added, or alternatively, the water is added to the annulus between the pile and the protective casing 12 and sand is added to the water to form a sand and water mixture. The protective casing 12 is vibrated by means of the vibrator 43, using the optimized frequency, and the drawworks 31 is then activated to cause the protective casing 12 to be withdrawn. By using such a procedure, the sand and water or other grouting mixture is fluidized and begins to compact in the areas beneath the vibrating protective casing 12. Thus, the grouting mixture is successively vibrated along the length of the pile 13, varying the frequency as desired, and is successively compacted as the casing 12 is withdrawn from the bottom of the hole to the earth's surface.

Referring now to FIG. 5, there is illustrated an alternative embodiment of the present invention wherein a vibrating rod 60 from a variable frequency vibrator 61 which extends to the bottom of the annulus is used to successively vibrate the grouting mixture, for example, cement or sand and water, from the bottom of the hole to the earth's surface. The rod 60 is withdrawn from the hole while vibrating to successively compact the grouting mixture along the length of the pile, the frequency of vibration being changed as desired.

Referring now to FIG. 6A, an alternative embodiment of the present invention is illustrated in pictorial fashion and has a conventional mast assembly 70 having a conventional drawworks 71. A traveling assembly 72 has an upper plate 73 and a lower plate 74 which are
joined together by a pair of vertical plate members 75 and 76. The upper plate member 73 has four wheels at its corners, only two of which are illustrated and are designated by the reference numerals 77 and 78. In a similar manner, the bottom plate 74 has four wheels at its corners, only two of which are illustrated and are designated by the reference numerals 79 and 80. The wheels which are attached to the upper and lower plates are aligned to travel along tracks (not shown) in the vertical members of the mast 70. A hoist line 81 runs from the drawworks 71 over the crown block 82 and is connected to an anchor assembly 83 on the upper plate 73 by means of a traveling block 84.

A multi-fingered sleeve 90, a portion of which is shown in cross section along the section lines 6-6 in FIG. 6B, and having a variable frequency vibrator 94 attached thereto, fits over the pile 13 and has a plurality of fingers 91 which are sized so as to fit into the annulus exterior to the pile 13. In order to hold the pile 13 in place during the vibration of the sleeve 90 and its withdrawal, a pair of rods 92 and 93 are connected between the horizontal frame members of the mast 70 and pass through the openings between the fingers 91 and rest on top of the pile 13 to prevent any upward movement of the pile 13. Although not illustrated, ballast sand 19 can also be added to the interior of the pile 13 as needed.

Although not illustrated, it should be appreciated that the hole shown in FIG. 6A can have a protective well casing 12 if desired.

In the operation of the apparatus of FIG. 6A, the grouting material is added to the annulus as with the previous embodiments. The vibrator 94 which is attached to the sleeve 90 is used to vibrate the sleeve 90 and its fingers 91 and the drawworks 71 is activated to cause the sleeve 90 to be withdrawn from the hole since the sleeve 90 is attached to the bottom plate 74 and moves as it moves. Thus, the grouting mixture is successively vibrated and compacted along the length of the pile 13 as the sleeve 90 is removed from the hole, the frequency of vibration being changed as desired.

Referring now to FIG.'S 7A and 7B, there is illustrated an alternative embodiment of the present invention wherein a clamp member 100 is used to hold the pipe pile 13 in place while a variable frequency vibrator 104 is used to traverse the interior of the pile 13. The vibrator 104 is connected to a pipe 101 which can be lifted from the hole or lowered into the hole inside the pile 13 by any conventional means, for example, the mast and drawworks illustrated in FIG. 4A.

The assembly 100 is segmented (best shown in FIG. 7B which is a view taken along the section line 7-7 of FIG. 7A) and is bolted together by bolt 102 to fit around the pile 13 in a secure manner. The assembly 100 has a hinge 103 which allows the segmented assembly to be swung into place around the pile 13 and then bolted together.

In the operation of the apparatus of FIG. 7A, the grouting material is added to the annulus of the hole. The vibrator 104 is vibrated, preferably beginning at the bottom of the interior of the pile 13, and is then run along the length of the pile 13 to successively compact the sand and water or other grouting mixture beginning at the bottom of the hole, the frequency of vibration being changed as desired as the successive compaction occurs.

Although not illustrated, a protective casing 12 can be used along any portion of the hole as desired.

Referring now to FIG. 8, there is diagrammatically illustrated a pile 120 in place within an earth borehole 121 which is partially grouted by the compacted sand 122 at the bottom of the hole. In addition to the compacted material 122, there is free-standing water 123. As the pile 120 is vibrated at any given frequency, the waveform, for example, the waveform diagrammatically illustrated and identified by the numeral 124, is clamped or nulled out at the point 125 which coincides with the point of compaction along the pile 120. Because of the compaction at the point 125, the pile 120 is substantially unable to vibrate at that point. Depending upon the frequency of vibration, the waveform 124 may or may not be tuned to the ungrouted length of the pile, i.e., the length of the pile 120 between the point 125 and the uppermost end of the pile 126. In the particular waveform 124 which is illustrated, being the worst case situation, the waveform 124 reaches a null point coinciding with the top end of the pile 126 and thus would have a very low amplitude and be quite inefficient. By varying the frequency of vibration, and thus producing the waveform as illustrated by the wave 127, the waveform is nonetheless clamped at the point 125 but is seen to have a maximum amplitude at the point 126. Thus, the amplitude of vibration is maximized. Although not illustrated, a point of compaction also occurs with other grouting materials and produces analogous results.

As previously explained with regard to the embodiments illustrated in FIG.'S 1-7, the invention contemplates that the optimized frequency is readily ascertainable by various observations, for example, by watching for a maximum agitation of the surface of the standing water 123 when using sand and water, by monitoring the amplitude of vibration of the pile 120, by listening for a maximum amplitude of vibration or by various other ways to indicate that the vibration has been tuned to the ungrouted length of the pile 120.

In understanding the process according to the present invention, it should be appreciated that the piling has a natural frequency of vibration which depends on its free length above the point where the packed grouting material constrains the vibration. As the level of the packed grouting material rises in the hole, the free piling length decreases and its natural frequency increases, much as the pitch of a violin string rises as the violinist's fingers shorten the vibrating string's length. If a vibrating force is applied to the piling at the natural frequency, then the input vibrations reinforce the pile's vibration and the maximum vibration amplitude is attained. If the applied vibrating force is not at a reinforcement frequency, an interference will be produced and the piling will not vibrate as much. Thus, as the piling's free length changes, the vibrator's frequency should be changed to obtain the maximum vibration of the piling during the entire process. The maximum vibration transfers the greatest energy to the grouting mixture giving the most effective packing. It is not necessary, however, that the vibrator have the exact same frequency as the natural vibration frequency of the piling. If the vibrator applies force impulses at some frequency so that the vibrator's impulses will reinforce the vibration of the pile, the vibration amplitude will be increased and the desired results are achieved.
In practicing the invention, it is contemplated that the vibrator may be continuously varied as the compaction occurs along the length of the pile, or the frequency may be varied one or more times at steps as compaction occurs along the pile as determined by the operator. If desired, the entire process may be automated such that the frequency can be varied in response to the detection of the vibration amplitude without resorting to human control of the apparatus.

Thus it should be appreciated that there have been described herein the preferred embodiments of the present invention wherein various methods are described relating to the grouting of a pile within a hole in the earth. Although the preferred embodiments contemplate the use of either sand and water or cement, it is contemplated that various grouting materials or minerals can be used. Furthermore, it should be appreciated that even though the preferred embodiments contemplate that the grouting mixture be vibrated commencing with the addition of the grouting material to the annulus, those skilled in the art will recognize that a given amount of material can be added to the annulus before commencing the vibration step. Likewise, after the vibration has ceased, dry sand can be added to the very top of the annulus surrounding the pile. It should also be appreciated that although the preferred embodiments illustrate the use of a pipe pile, the methods of the present invention can also be utilized with solid piles to grout them in place within a hole in the earth. Likewise, those skilled in the art will recognize that, on occasion, the annulus may be filled with grouting material prior to the commencement of vibration.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of grouting a pile in a hole, comprising: placing a pile of a given external diameter in a hole having a diameter larger than said external diameter; adding a wet grouting material to said hole within the annulus external to said pile; vibrating said grouting material; and varying the frequency of said vibration to reinforce the amplitude of said vibration.

2. A method of grouting a pile in a hole, comprising: placing a pile of a given external diameter in a hole having a diameter larger than said external diameter; adding a wet grouting material to said hole within the annulus external to said pile; vibrating said grouting material at a frequency optimized to reinforce the amplitude of said vibration; and ceasing to vibrate said grouting material while said material is still fluidized.

3. A method of grouting a pile in a hole, comprising: placing a pile of a given external diameter in a hole having a diameter larger than said external diameter; adding a wet grouting material to said hole within the annulus external to said pile; vibrating said pile while said grouting material is being added to said hole at a frequency optimized to reinforce the amplitude of said vibration; and ceasing to vibrate said pile short of adding grouting material in such an amount that said grouting material would no longer be fluidized.

4. A method of grouting a pile in a hole, comprising: placing a pile of a given external diameter in a hole having a diameter larger than said external diameter; adding a wet grouting material to said hole within the annulus external to said pile; vibrating at least one rod in said grouting material at a frequency optimized to reinforce the amplitude of said vibration; and withdrawing said at least one rod from said grouting material during said vibration.

5. A method of grouting a pile in a hole, comprising: placing a pile of a given external diameter in a hole having a diameter larger than said external diameter; adding a wet grouting material to said hole within the annulus external to said pile; vibrating a multi-fingered sleeve in said grouting material at a frequency optimized to reinforce the amplitude of said vibration, said sleeve fingers being located in the annulus of said hole external to said pile; and withdrawing said sleeve from said hole while continuing the vibration.

6. A method of grouting a pile in a hole, comprising: placing a pile of a given external diameter in a hole having a diameter larger than said external diameter; adding a wet grouting material to said hole within the annulus external to said pile; vibrating said protective casing at a frequency optimized to reinforce the amplitude of said vibration; and withdrawing said casing during said vibration.

7. A method of grouting a pile in a hole, comprising: placing a pile of a given external diameter in a hole having a diameter larger than said external diameter and having a protective casing; adding a wet grouting material to said hole within the annulus external to said pile; vibrating said protective casing at a frequency optimized to reinforce the amplitude of said vibration; and removing said ballast material from the interior of said pipe pile.

8. A method of grouting a pipe pile having a closed bottom end in a hole, comprising: placing a closed bottom end pipe pile of a given external diameter in a hole having a diameter larger than said external diameter; adding a ballast material to the interior of said pipe pile; adding a wet grouting material to said hole exterior to said pipe pile; vibrating said grouting material at a frequency optimized to reinforce the amplitude of said vibration; and removing said ballast material from the interior of said pipe pile.

9. The method according to claim 8, including the additional step of removing said bottom end of said pipe pile.

10. A method of grouting a pile in a hole, comprising: placing a pile of a given external diameter in said hole having a diameter larger than said external diameter; adding a wet grouting material to said hole within the annulus external to said pile; and successively inducing vibration of said grouting material along the length of said pile at a frequency optimized to reinforce the amplitude of said vibration.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,898,848
DATED : August 12, 1975
INVENTOR(S) : Reece E. Wyant

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Heading:
Add --Assignee: Dresser Industries, Inc., Dallas, Tex.--

Signed and Sealed this fourth Day of November 1975

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks