Sept. 6, 1966 E. R. COLLE 3,270,511

METHOD OF FORMING PILES

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FIG. 1

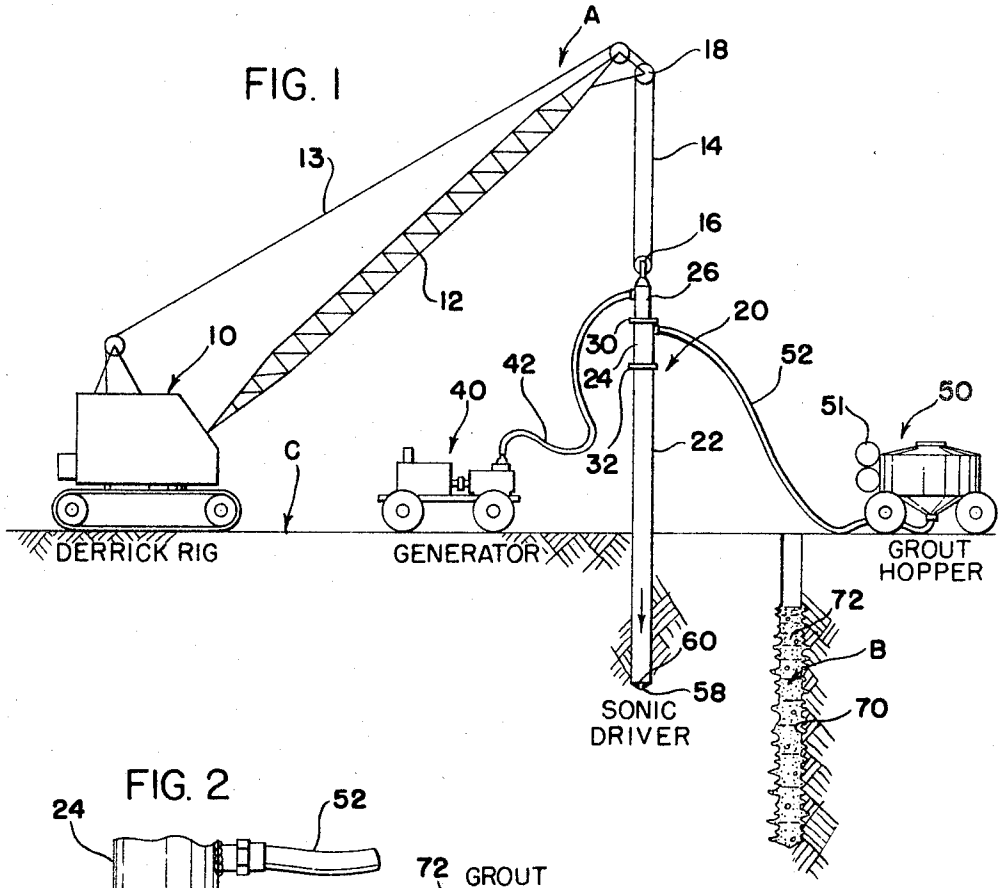
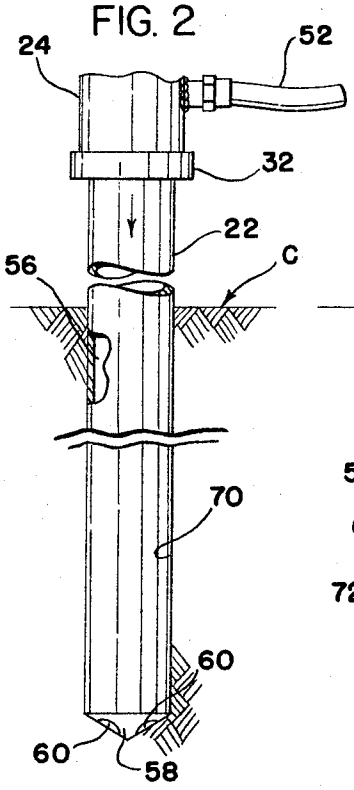


FIG. 2



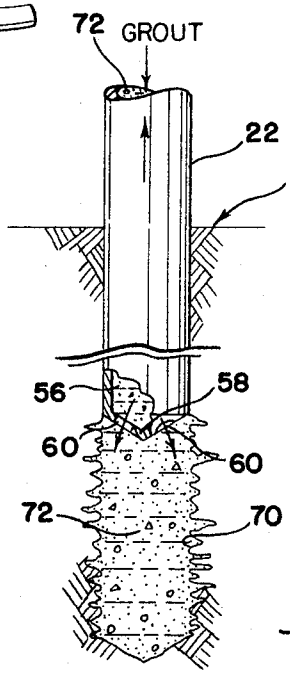


FIG. 3

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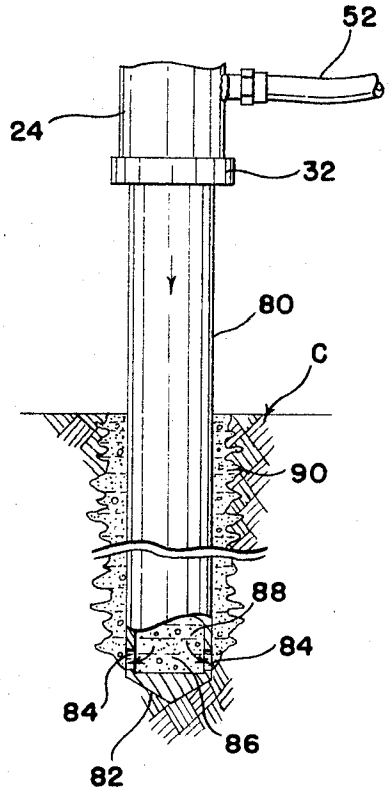

FIG. 4

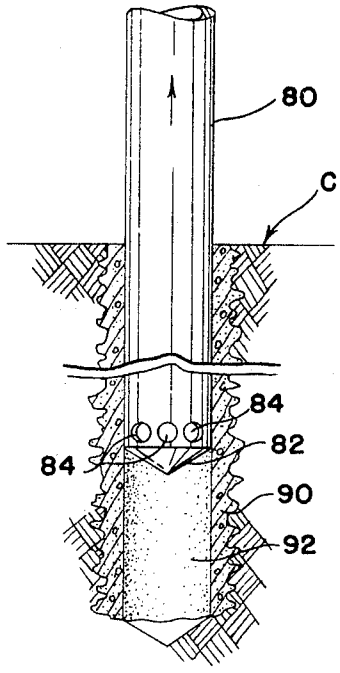

FIG. 5

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METHOD OF FORMING PILES

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4 Claims. (Cl. 61—53.52)

The present invention pertains to the art of concrete piles extending into the earth and more particularly to a method and apparatus for forming concrete piles in various types of soil.

In the construction of buildings, bridges, piers and other such structures, it is necessary to provide a plurality of piles within the earth for supporting such structures; and, a wide variety of methods have been employed for accomplishing this task. In accordance with one conventional method, each of the piles takes the form of a steel I-beam which is driven into the earth by a drop hammer. Such a method is quite noisy and can cause damage to adjacent buildings or other structures. Further, such a hammering method of driving piles into the earth requires a considerable amount of time and greatly increases the work involved in forming the foundation for the particular structure being fabricated. The relatively slow driving rate is caused by many factors, one of which is the inertia of the pile which tends to dissipate a large portion of the energy being exerted by the drop hammer. Further, the friction between the earth and the pile causes a frictional force which consumes the hammer energy and, thus, reduces the energy available for actually driving the pile. Consequently, there has been a substantial demand for a method of forming piles into the earth which method would not exhibit the obvious disadvantages of the impact hammering method.

Piles have been driven into various soils by providing a plurality of rotating weights at the upper end of the individual pile. The motion of these weights was so controlled that the resultant force components of the weights were in the vertical direction only. This was accomplished by providing weights which rotated in opposite directions so that the horizontal forces were balanced while the vertical forces were added. Such a system or method of driving a pile into the earth substantially reduced the noise and vibration problems concomitant with the drop hammer method; however, this method continued to require a substantial amount of time since the forces caused by the rotating weights had to overcome the inertia of the pile and the forces created by the friction between the pile and the earth into which it was driven.

To overcome the above-mentioned disadvantages, another method was developed wherein the weights were rotated at a relatively high velocity so that the frequency of the force impulses directed toward the pile were at the resonate frequency of the longitudinal length of the pile. In this manner, the pile was caused to expand and contract longitudinally at its resonate frequency resulting in a very efficient transfer of energy from the power source to the pile and an even more efficient use of such energy in driving the pile into the earth. In addition, because of the physical characteristics of the resonating pile, the transverse dimension of the pile would contract and expand, with the transverse contraction substantially corresponding to the instant that a downward force was being exerted onto the lower end of the pile. Accordingly, the frictional forces between the pile and the earth were substantially reduced while the pile was being driven downwardly and the pile would expand into frictional contact with the earth during the periods of rest in between the downward forces on the end of the pile so that the pile would not move upwardly within the cavity being formed by the downwardly moving pile.

The high frequency method as defined above, hereinafter referred to as sonic pile driving or the sonic driving method, requires substantially less time in driving a pile or casing in most soils than does the conventional hammering method. However, in order to convert the force created by the rapidly rotating weights into a resonating force in the pile or casing, a very stiff or rigid connection is required between the pile and the power unit comprising the weights and means for rotating the same. Such a stiff connection has proven to be impossible to provide with normal inexpensive clamping mechanisms, therefore, it has been economically necessary to weld the pile itself directly to the end of the sonic driving unit.

When the pile or casing was driven, the welded joint between the unit and the casing was cut by a conventional method such as by a metal cutting torch. Because of the necessity for providing this stiff joint or connection between the sonic driving unit and the casing, it has been found that the combined time of welding the casing onto the driving unit, driving the casing and, then, cutting the casing from the unit, was not substantially less than the time required to hammer the casing into the earth. In other words, when driving a plurality of separate casings, a drop hammer could often drive the casings in substantially the same time as a sonic pile driving apparatus including the time necessary for welding and cutting the casing from the driving unit.

The present invention pertains to a method of forming concrete piles in the earth which method overcomes the above-mentioned disadvantages and others, and which substantially reduces the time necessary for forming subsequent piles by a sonic pile driving apparatus.

In accordance with the present invention, there is provided a method of forming concrete piles in the earth comprising sonically driving a hollow grouting mandrel into the earth to define the location and depth of a pile cavity, forcing a fluid cement grout through the mandrel and into the pile cavity, and removing the mandrel, while simultaneously filling the cavity with the cement grout. The grout includes any hydraulic cement composition regardless of the size of the aggregates.

In accordance with another aspect of the present invention, a method as defined above further includes the step of forcing the grout into the cavity at a rate and pressure sufficient to apply a substantial lifting force onto the mandrel as it is being removed.

In accordance with still a further aspect of the present invention, there is provided a method of forming concrete piles in the earth comprising grouting the earth with a settable fluid hydraulic grout, at least after the grout has started setting, sonically driving a mandrel into the grouted earth to define the location and depth of a pile cavity, removing the mandrel from the cavity and filling the cavity with a hardenable cementitious material to form a concrete pile in the cavity.

In accordance with still a further aspect of the present invention, there is provided a method of forming concrete piles in the earth comprising sonically driving a hollow grouting mandrel into the earth to define the location and depth of a pile cavity, forcing a settable fluid hydraulic grout radially outward from the mandrel as it is being driven into the earth, at least after the grout has started setting, removing the mandrel to evacuate the pile cavity, and filling the evacuated cavity with a hardenable cement grout to form a concrete pile in the cavity.

The primary object of the present invention is the provision of a method of forming concrete piles in the earth including a sonic driving step which method rapidly produces the piles and allows rapid movement from one pile to another for successive forming thereof.

Another object of the present invention is the provision of a method of forming concrete piles in the earth which

method includes a sonic driving step without requiring a substantial amount of time between successive piles being formed.

Another object of the present invention is the provision of a method of forming concrete piles in the earth which method includes a sonic driving step and enables the formation of a concrete pile in relatively loose soil without the use of a casing remaining in the soil.

Still another object of the present invention is the provision of a method for forming a concrete pile in the earth which method includes a sonic driving step without requiring a time consuming clamping or welding operation between forming of successive piles.

Yet another object of the present invention is the provision of a method of forming a concrete pile in the earth which method includes a sonic driving step and a step of grouting soil around the pile so that a self-sustaining cavity can be produced in various soils characterized as being loose and unstable.

Yet another object of the present invention is the provision of a method for forming concrete piles in the earth comprising driving a hollow grouting mandrel into the earth and forcing a cementitious grout, which ultimately forms the pile, through the end of the mandrel into the cavity so that the tube can be removed at the same time the cavity is being filled by the grout.

These and other objects and advantages will become apparent from the following description used to illustrate the preferred embodiments of the present invention as read in connection with the accompanying drawings in which:

FIGURE 1 is a side elevational view showing, somewhat schematically, an apparatus for performing the preferred embodiment of the present invention;

FIGURE 2 is a fragmentary, somewhat schematic, side elevational view of an apparatus illustrating an operating characteristic of the preferred embodiment of the invention;

FIGURE 3 is a fragmentary, somewhat schematic side elevational view of an apparatus showing another operating characteristic of the preferred embodiment of the present invention;

FIGURES 4 and 5 are fragmentary, somewhat schematic, side view of an apparatus showing operating characteristics of a modification of the preferred embodiment of the present invention.

Referring now to the drawings, wherein the showings are for the purpose of illustrating preferred embodiments of the present invention only and not for the purpose of limiting same, FIGURE 1 shows an apparatus A for forming a plurality of concrete piles B in the earth C. Primarily, the present invention is directed toward the method of utilizing the apparatus A and various modifications may be made in this apparatus without departing from the intended spirit and scope of the present invention. In accordance with the illustrated embodiment of the apparatus A, the apparatus comprises a conventional derrick 10 having an upwardly and outwardly extending crane 12 with a control cable 13 for operating cable 14 entrained around blocks 16, 18. The lower block 16 is connected onto the pile forming apparatus 20 so that operation of the cable 13 will move apparatus 20 vertically as desired.

The pile forming apparatus 20 comprises a lower, tube-like, mandrel 22, an intermediate adapter and grout reservoir 24 and an upper sonic driving unit 26 with these members being rigidly affixed by appropriate flanges 30, 32. As is common knowledge, the sonic driving unit 26 usually comprises a plurality of rotating weights which are so co-ordinated in movement that the components of force in the horizontal direction are balanced while the components of force in the vertical direction are added.

By rotating these weights, not shown, at a sufficient speed to create vertical force impulses having a frequency substantially corresponding to the natural frequency of the mandrel 22, considering the other elements rigidly attached to the mandrel, the mandrel 22 is forced into the earth by the creation of sonic waves within the mandrel which waves drive the mandrel downwardly. Numerous mechanisms could be used for driving the rotating weights; however, in accordance with the illustrated apparatus, there is provided a motor driven generator 40 connected by an electrical cable 42 to an internal electric motor, not shown, within the driving unit 26 which electrical motor drives the weights. It shall be appreciated that other arrangements for sonically driving the mandrel 22 into the earth could be devised without departing from the intended scope of the present invention. In accordance with the invention, a grout tank 50 provided with a pumping compressor 51 is connected onto a grout hose 52 for directing a grout, to be explained hereinafter in more detail, into the adapter 24 positioned between the mandrel 22 and the sonic driving unit 26. Of course, the grout from tank 50 could feed a positive displacement pump for positively forcing the grout through hose 52.

Referring now to FIGURES 2 and 3, the apparatus A as so far described is shown as it is to be used to practice a method of forming the concrete pile B. Mandrel 22 is provided with an internal passage 56 leading to a piercing end 58 which end is provided with a plurality of generally circumferentially arranged, downwardly oriented grout orifices 60. These orifices can be closed during the driving operation by plugs or one-way valves so that the grout can be forced from mandrel 22 but earth can not enter the mandrel. By proper operation of the derrick 10 and sonic driving unit 26, the mandrel 22 is driven downwardly into the earth C to create a pile cavity 70 having a transverse cross section and a depth determined by the cross section of the mandrel 22 and the depth to which the mandrel is forced by the sonic driving unit 26. After the mandrel has been driven to the desired depth, the compressor 51 of grout tank 50 is energized to force grout through hose 52 into passage 56 of mandrel 22 which grout is under a hydraulic pressure determined primarily by the operating characteristics of the compressor 51. When the grout, referred to as numeral 72, is pumped through the passage 56, it exits below the piercing end 58 through orifices 60 into the cavity 70 previously formed by mandrel 22. Proper actuation of derrick 10 causes the mandrel 22 to move upwardly from the cavity 70 at a controlled velocity and the grout 72 fills the cavity which is evacuated by the mandrel. The grout is under high pressure; therefore, the grout will be forced transversely outwardly to an extent determined by the make-up of the surrounding soil. After the level of the grout in cavity 70 is proper for the desired concrete pile, the grout flow through the mandrel is discontinued and the mandrel is removed from the cavity 70 so that the grout can solidify.

In accordance with the present invention, the grout 72 is a hardenable, cementitious material, such as concrete, so that after withdrawal of the mandrel, the grout hardens to form a concrete pile B. A plurality of suitable cementitious grouts are available for use with the present invention.

The upward movement of mandrel 22 can be assisted by operation of the sonic driving unit with an upward biasing force being applied onto the mandrel by the derrick 10. Also, it is appreciated that the grout 72 can be provided with sufficient hydraulic pressure to assist in raising the mandrel 22 from the cavity 70. The assisting force caused by the grout 72 is determined primarily by the relative areas between the external dimension of mandrel 22 and the internal dimension of passage 56. It is also appreciated, that the grout 72 can be placed into the cavity 70 without substantially hydraulic pressure so that the grout causes very little removing force to be exerted onto the mandrel 22.

As so far explained, the present invention contemplates a method of forming a concrete pile B into the earth C which method includes sonically driving the hollow grout mandrel 22 into the earth to define the location and depth of the pile cavity 70, forcing a fluid cementitious grout 72 through passage 56 into the cavity 70 and re-

moving the mandrel while simultaneously filling the cavity **70** with the grout.

In some situations, it is desirable to pour the grout **72** into the cavity **70** after the mandrel **22** has been completely removed from the cavity. In the past, this has been done by driving a cylindrical metal casing into the earth C so that the soil surrounding the cavity **70** would not collapse into the cavity and, thereafter, pouring the casing full of a hardenable grout. Such an operation required the added expense of providing a metal casing which ultimately formed a permanent part of the pile. In accordance with another aspect of the present invention, there is provided a method for forming a concrete pile cavity to be filled by a hardenable grout which cavity is self-sustaining without being provided with a metal casing.

In accordance with this aspect of the present invention, as is shown in FIGURES 4 and 5, the adapter **24** is connected by flange **32** onto a downwardly extending mandrel **80** having a lowermost piercing end **82**. Facing radially outward from the side of mandrel **80** and adjacent the piercing end thereof, there are provided a plurality of grout orifices **84** leading to a central passage **86** in the mandrel **80**. As explained in conjunction with FIGURES 2 and 3, the mandrel **80** is sonically driven by driving unit **26** into earth C at the desired location and to the desired depth to form the ultimate pile cavity. As distinguished from the operation of mandrel **22**, the mandrel **80** is supplied with a settable grout **88** from hose **52** during the driving of mandrel **80** into the earth. Accordingly, the settable grout is forced radially outward from the mandrel **80** to reinforce the soil directly adjacent the downwardly moving mandrel **80**. Such reinforced soil is designated as **90** which forms a self-sustaining cavity for receiving a hardenable grout for forming the actual concrete pile. After the mandrel **80** has reached its lowermost position, and the settable grout has commenced to set, the mandrel **80** is removed forming a reinforced soil casing **90** with a central pile cavity **92** as is best shown in FIGURE 5.

The term "settable" grout indicates any of a number of grouting materials which can be used for reinforcing relatively loose soil and they are stated, without limitations, as follows: Portland cement, silicate floc, dispersed clay, chrome-lignin-solution, and sodium silicate and sodium bicarbonate solution. It is appreciated that other soil reinforcing grouts could be used as the "settable" grout contemplated in the aspect of the present invention disclosed in FIGURES 4 and 5.

After the cavity **92** is produced, the pile is formed by pouring hardenable material, such as concrete, into the cavity to the desired height to form the pile. It is appreciated, in some instances, especially when the pile is to be relatively short, that the earth C may be reinforced by extending various tubes or pipes into the earth adjacent the location of the pile and pumping the settable grout directly into the soil to the planned depth of the pile. Thereafter, a mandrel of desired shape can be driven into the reinforced earth C to the desired depth to form a cavity for receiving the hardenable grout to be used for the pile.

In accordance with the aspect of the invention illustrated in FIGURES 4 and 5, the present invention includes a method of forming piles in the earth comprising sonically

driving a hollow grout mandrel **80** into the earth C to define the location and depth of a pile cavity **92**, forcing a settable grout radially outward from the mandrel through orifices **84** as the mandrel is being driven into the earth, at least after the grout has started setting, removing the mandrel **80** to evacuate the pile cavity **92**, and filling the evacuated cavity **92** with a hardenable cementitious material to form a pile in the cavity **92**.

Piles constructed in accordance with the present invention actually extend outwardly into the surrounding soil; therefore, the piles have superior load carrying capacity as compared to a pile with an outer casing which form a smooth, low friction, engaging surface between the casing and the soil.

The present invention has been described in connection with certain structural embodiments; however, it is appreciated that the invention is not limited by these embodiments and various changes may be made without departing from the intended spirit and scope of the present invention as defined by the appended claims.

Having thus described my invention, I claim:

1. A method of forming a concrete pile in the earth comprising sonically driving a hollow grouting mandrel into the earth to define the location and depth of a pile cavity, forcing a settable fluid hydraulic grout through said mandrel and radially outward from said mandrel as it is being driven into the earth, allowing the grout to commence setting, removing the mandrel to evacuate said cavity, and filling the evacuated cavity with a hardenable cement grout.

2. A method of forming a concrete pile in the earth comprising sonically driving a hollow grouting mandrel into the earth to define the location and depth of a pile cavity, forcing a settable fluid hydraulic grout through said mandrel and radially outward from said mandrel as it is being driven into the earth, allowing the grout to commence setting, and removing the mandrel while simultaneously filling the cavity with a hardenable cement grout.

3. A method as defined in claim **2** including the step of applying a sufficient hydraulic pressure on said cement grout to assist in removing said mandrel.

4. A method as defined in claim **2** including the step of removing said mandrel at a sufficient velocity that substantially no hydraulic force is exerted by the cement grout on the mandrel in the removing direction.

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