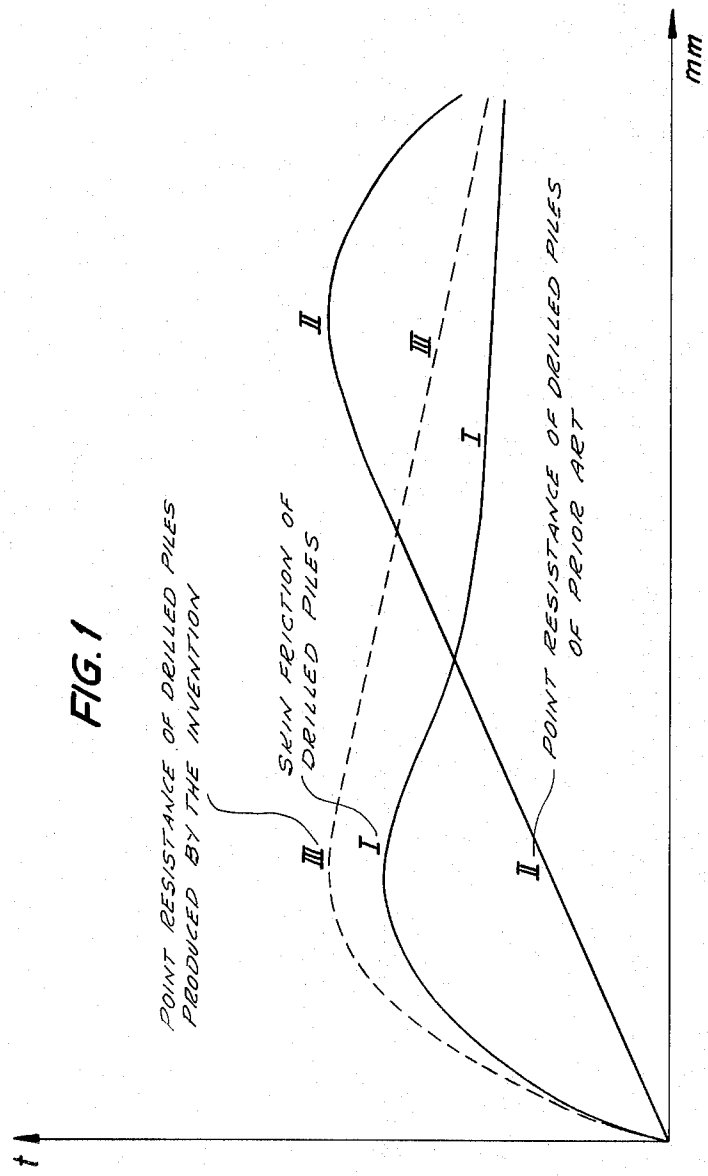
March 22, 1966 H. SIMONS 3,241,325

PILING CONSTRUCTION METHOD

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FIG. 1



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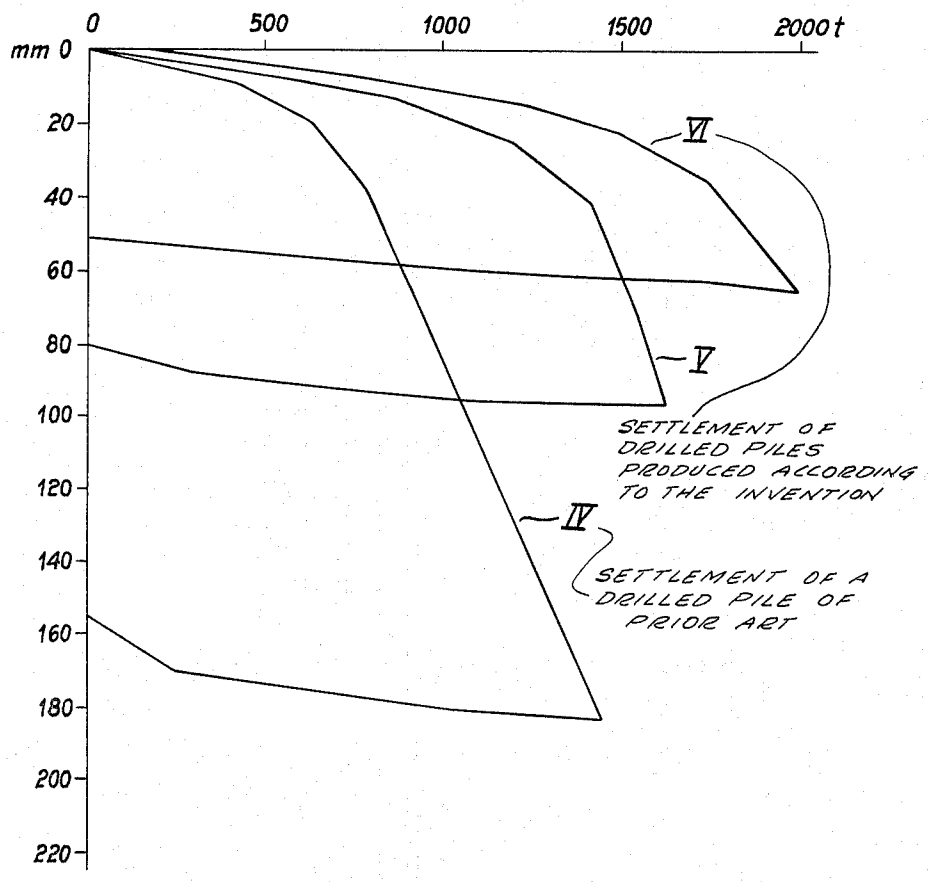
ATTORNEYS

March 22, 1966 H. SIMONS 3,241,325

PILING CONSTRUCTION METHOD

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FIG. 2



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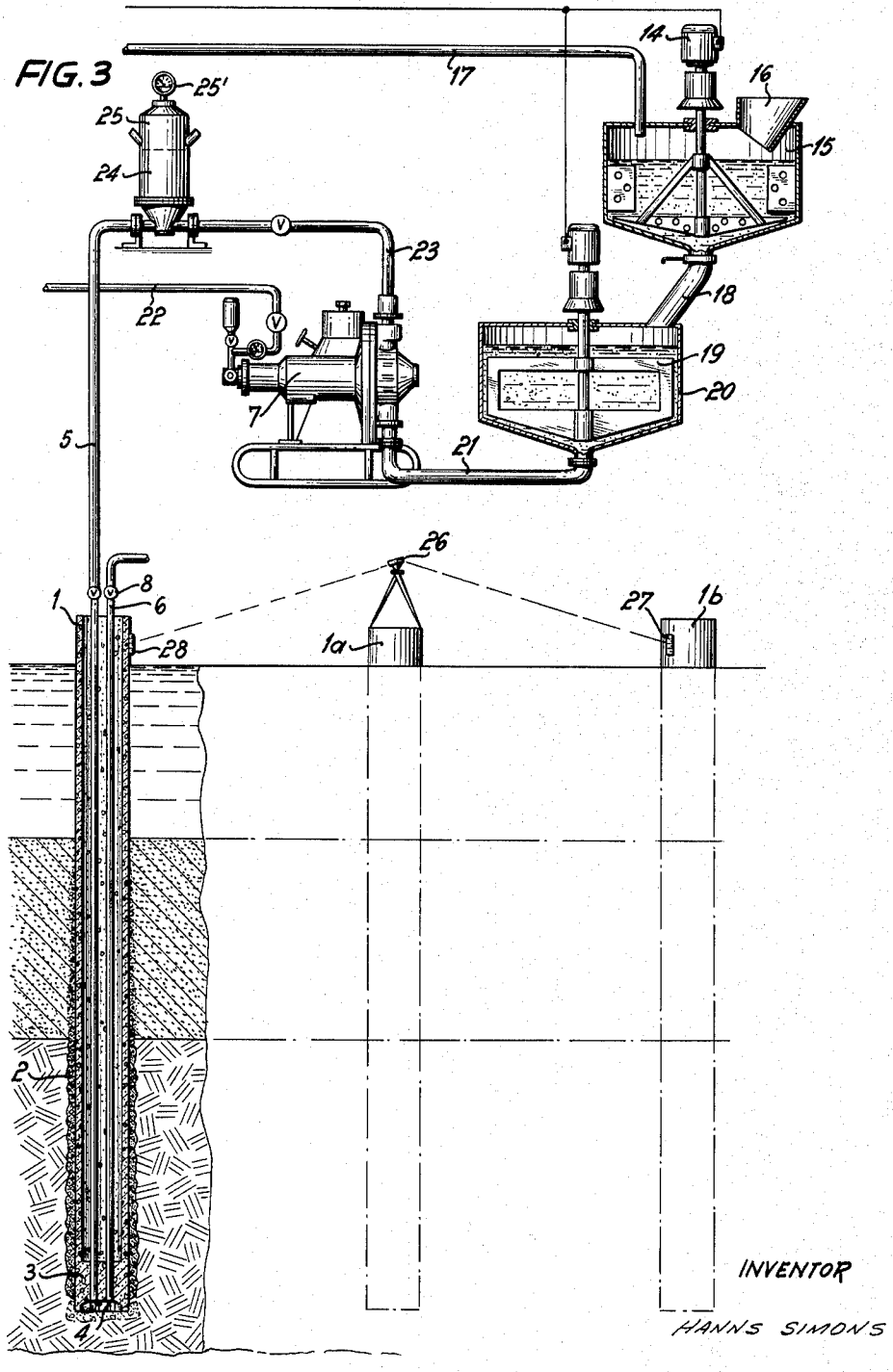
ATTORNEYS

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PILING CONSTRUCTION METHOD

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FIG. 3



INVENTOR

HANNS SIMONS

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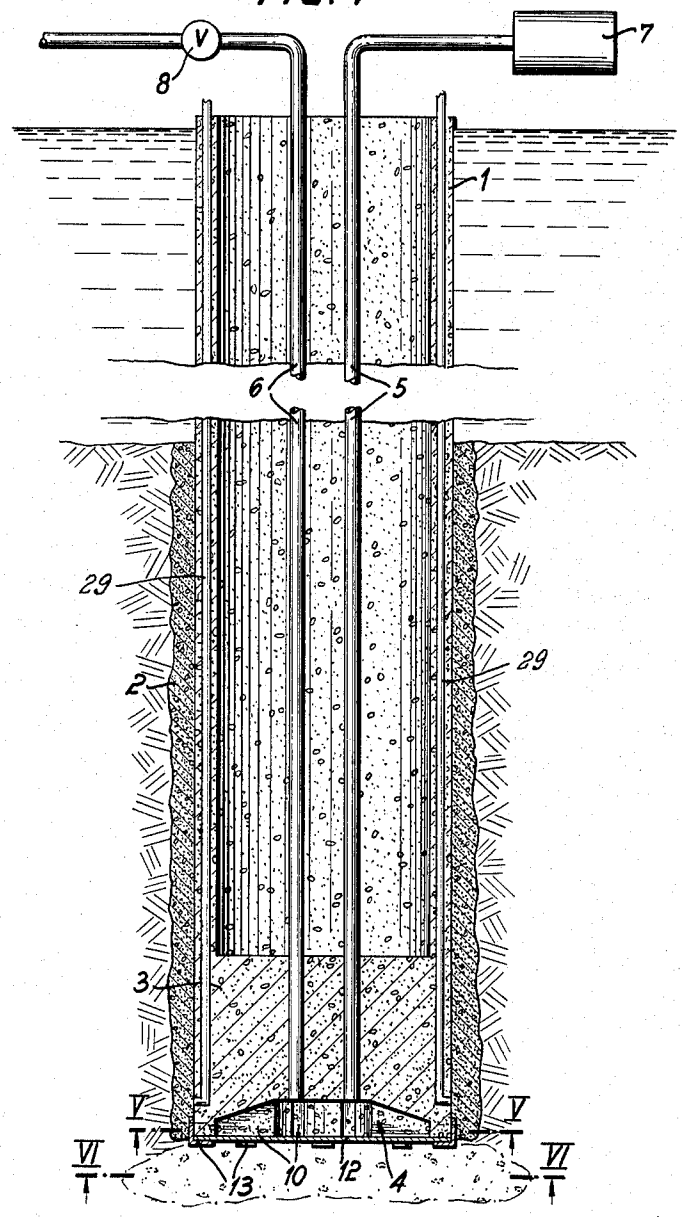
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PILING CONSTRUCTION METHOD

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FIG. 4



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PILING CONSTRUCTION METHOD

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FIG. 5

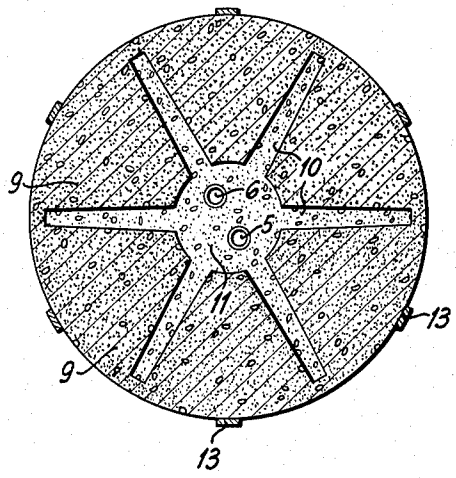
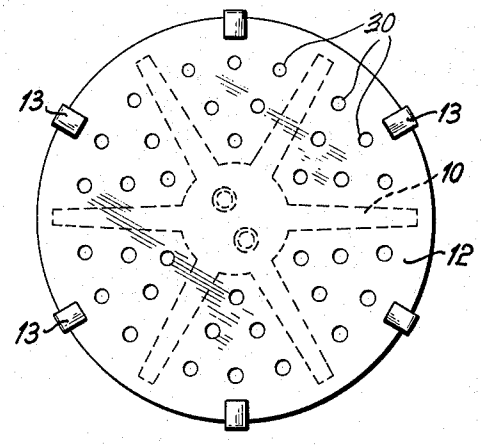


FIG. 6



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United States Patent Office

3,241,325

Patented Mar. 22, 1966

3,241,325

PILING CONSTRUCTION METHOD

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Filed Mar. 12, 1962, Ser. No. 179,156
Claims priority, application Germany, Mar. 11, 1961, B 61,539
9 Claims. (Cl. 61—53.6)

This invention relates in general to a new and useful method of installing piles of piers which carry at their bottom or foot a mortar or cement injection chamber having inlet and outlet passages in communication therewith for delivering mortar under pressure and including means in the chamber for directing the mortar radially outwardly to permit a uniform formation of a mortar fot therebeneath, and to a method of effecting such formation.

To produce a drilled pile a hole must be drilled into the ground and the hole must be prevented from collapse during the drilling and excavation. This may be accomplished, for example, by insertion of steel tubes, by water pressure or by the insertion of a thixotropic liquid. After the hole is formed, the pile can then be cast in situ with concrete, or a pre-cast or pre-finished pile can be inserted into the hole. When foundations are built in deep water or for those cases in which, for the purpose of absorbing bending movements, prestressed concrete pilings are necessary, then the insertion of a pre-cast pile is preferred as compared to cast in situ piles.

In accordance with present known practices, cast in situ piles support almost exclusively by their skin friction with the surrounding soil. The ultimate point or toe resistance is not achieved, because the soil under the point or toe of the pile which has been loosened by the drilling operation is usually not able to absorb higher pressure loads until after extensive settling has taken place.

To finish pre-cast piles it is usual procedure to inject a jacket of cement mortar between the piling and the surrounding soil after it is positioned in the hole. This so called lateral injection can be made by extending thin pipes downward between the inserted pile and the steel tube of the bore for the pile, and by introducing mortar into these pipes while simultaneously withdrawing the steel tube, so that the space between the inserted precast pile and the surrounding soil will be filled with mortar or concrete when the tube is being withdrawn. It is also possible to incorporate said thin pipes in the precast pile itself. The reason for the provision of the extra surrounding jacket is for the purpose of producing a friction connection between the finished pile and the surrounding soil after the steel tube which formed the hole is removed. A disadvantage in the prior art constructions is that even with the additional surrounding jacket, pre-cast piles will carry large loads almost only by their skin friction. Thus, if it is desired to permit the piling to support its ultimate load it will be necessary to mobilize not only the skin friction but also full point resistance, which, however in almost all instances will produce a non-permissible amount of settlement of the structure to be built on the piles. In addition, during the settlement of a pile the skin friction will be reduced from its maximum value to a considerable lower value so that even with the maximum settlement the piling is not able to carry the maximum load to which it would be capable when utilizing the method covered by the invention.

Attempts have been made to introduce cement mortar below the bottom or foot of the piling for the purpose of stabilizing the soil below the pile. However, great difficulty has been encountered in evenly distributing the mortar or cement below the piling and the results have been generally ineffective. In addition, various difficulties have been encountered in providing means for effecting the injection of mortar below the piling and in those instances where injection has been possible, the mortar has not formed in a satisfactory manner.

In accordance with the present invention there is provided a method for producing a pile which includes a chamber formed at the point or bottom thereof. The piling includes means for distributing mortar down to the chamber under pressure and radially outwardly in the chamber at the bottom or base of the piling. The arrangement further includes a return conduit for regulating the back pressure and for controlling the flow of mortar thereto to insure proper constituency thereof by circulation until the high water content mortar which is initially produced when injection starts is purged. The chamber includes radially extending passages in order to insure an even distribution of mortar under the complete base surface of the piling. The chamber is covered by means of a bottom plate which will be moved downwardly under the force of the injection pressure at which the mortar is supplied. Especially in gravel or in other soils which can be stabilized by cement mortar, it is advantageous to perforate the bottom plate between the passages. After the plate has been forced off the bottom of the pile, the mortar can penetrate through these holes and can form a mortar body also under the plate, or it can penetrate into the soil which will be stabilized by this enrichment with mortar.

In accordance with a preferred method of carrying out the invention the piling is advantageously formed with the chamber at its bottom and conduits are extended to the chamber for the injection of the mortar. Before the mortar shauld be injected below the point of the pile (point injection), however, a connection must be formed between the piling and the ground for precast piles, e.g. by forming a concrete jacket around the piling by lateral injection. After the jacket has set, mortar is pumped down to the chamber under a pressure great enough to permit the formation of a large foot of mortar beneath the piling which extends out in a manner of a widened elephant's foot. During the formation of this foot of mortar the ground beneath the piling is advantageously subjected to loading and unloading such as by cyclically binding up and relieving the mortar injection pressure in order to provide the most desirable formation at the bottom of the pile.

The distributing chamber is advantageously closed by a bottom plate which has the same surface as that of the pile. The chamber formation is such that even with a small increase in the mortar injection pressure a distribution of the mortar over at least the entire bottom surface will take place. By providing the connecting line for circulating the mortar down to the chamber and a return line having an adjustable valving, it is possible to regulate the

injection pressure of the mortar in a manner which will insure a proper formation below the piling. The process is advantageously carried out by flushing the distribution chamber with cement mortar for a sufficient period until a mortar of a settable constituency flows out beneath the piling after the return line valve is closed. Pumping is then continued until a desired pre-loading of the ground beneath the entire toe of the pile has been obtained. When using the inventive method, the piling will be retained, during the point injection, in the ground by the action of the skin friction. Then the point beneath the toe of the pile will be pretensioned or prestressed by the injection between toe and ground, until the desired point resistance will be obtained. Such pretensioning or prestressing of the ground beneath the toe of the pile will permit, contrary to prior methods of making drilled piles, the utilization of a desired point resistance without any settlement or with very small settlements only.

By the inventive construction and method it is possible to form below the pile a cement or concrete body which is capable of transferring the point load from the pile point to the underlying soil which has been prestressed by the injection. By closing the bottom distribution chamber with a plate it is insured that there is no danger of clogging of the distribution channels for the supply and circulation of the cement mortar by the soil underneatth of the pile. A discharge or circulation line makes it possible to continuously rinse the chamber until it has received a mortar of a desirable constituency. It is very important that a water cement factor is reached in the chamber to insure that the mortar will set, that is, a water cement factor of a magnitude of about 0.4 to 0.42 is maintained. This also insures that the cement mortar does not give off excess water during the setting thereof which would flow upwardly and form an undesirable water pocket between the cement plug and the toe of the pile. The presence of such a water pocket would be highly undesirable because then the load bearing capacity of the piling would not be materially increased as intended and, in addition, no significant reduction of the settlement would be possible.

It should be appreciated that the improved process, in cases where a pre-cast or pre-formed pile is employed, is to initially inject a jacket around the piling after the supporting tube is lifted. A bottom mortar injection is carried out after the hardening of the jacket around the piling.

Accordingly, it is an object of this invention to provide an improved piling construction.

A further object of the invention is to provide an improved method of inserting drilled pilings.

A further object of the invention is to provide an improved process for the forming of a foot beneath a piling by circulating mortar to a distributing chamber formed at the bottom of a piling and regulating the back pressure to insure a flushing of the chamber with the mortar until a mortar of a desired constituency is in the chamber, thereafter closing off the circulating line and forcing the mortar under pressure to cause a foot of mortar to form at the bottom of the piling.

A further object of the invention is to provide process for producing a piling having a bottom chamber formed thereon with means for distributing mortar beneath the entire base surface and uniformly therearound, and including inlet and discharge lines for delivering mortar to the chamber and for permitting the return flow outwardly therefrom.

A further object of the invention is to provide a process for producing a piling which includes a chamber formed at the bottom thereof and covered by a bottom plate which is removable under pressure with means for distributing motar uniformly under and outwardly around the bottom surface of the piling and including inlet and discharge lines for delivering and returning mortar from said chamber.

A further object of the invention is to provide a process for producing pre-cast piling having a chamber formed at the bottom thereof comprising excavating a hole by inserting a steel casing to support the soil around the hole, placing a piling in the hole, thereafter removing the casing and injecting a concrete between the piling and the soil, directing a concrete or mortar to the chamber at the bottom of the piling after the concrete of the lateral injection has set and permitting the circlulation of the concrete until a desired constituency of concrete is obtained at the bottom thereof, closing the return line for the concrete and injecting concrete under pressure until a foot is formed extending downwardly and outwardly from the bottom of said piling, whereby the soil is pretensioned up to its later point load.

A further object of the invention is to provide a piling construction which is simple in design, rugged in construction and economical to manufacture.

The various features of novelty which charatcerize the invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which there are illustrated and described preferred embodiments of the invention.

In the drawings:

FIG. 1 is a graph indicating various curves of known pile constructions and those produced with the method according to the invention indicating the supporting capacity in relation to the settlement;

FIG. 2 is a graph indicating the characteristics of the prior art pile constructions and methods in relationship to the pile constructed and installed in the manner of the present invention;

FIG. 3 is a somewhat schematic indication of a pile construction and equipment for carrying out the process in accordance with the present invention;

FIG. 4 is an enlarged transverse section indicating a piling constructed in accordance with the invention;

FIG. 5 is a section taken on the line V—V of FIG. 4; and

FIG. 6 is a section taken on the line VI—VI of FIG. 4.

Referring to the drawings in particular, in FIG. 1 the various surface friction and bottom pressure characteristics of the prior art pile constructions are shown. The supporting capacity of a pile is indicated on the ordinate in tons, while the settlement of the pile is indicated on the abscissa in millimeters. Curve I indicates the carrying capacity which is achieved from the skin friction action as a function of settlement while curve II indicates the point resistance of the pile in an ordinary drilled pre-cast pile construction method. As indicated in the figure, the maximum carrying capacities occur at different settlements, because for the purpose of obtaining the maximum point resistance, larger settlement paths must be traversed than in the case of skin friction. As indicated, except in those cases where exceedingly large settlements are acceptable, only skin friction can be exploited for the bearing capacity of such piles. Attempts at exploiting the increasing of the point resistance have resulted in almost all instances in non-permissible settlement of the structure to be built on the piles. In addition, the skin friction is already reduced in the event of greater settlements from its maximum value to a considerable lower value, so that the addition of surface friction and point resistance did not yield satisfactory total carrying capacity despite an abnormally large settlement.

When the inventive point injection is carried out, the soil below the pile is prestressed or pretensioned in a direction from the pile proper downwardly. A graph indicated by curve II assumes the form of curve III. This means that the maximum point resistance is ob-

tained nearly at the same settlement as the maximum surface friction (curve I).

In FIG. 2 there is indicated a settlement of the prior art pile construction and method without point injection and of two identical piles with point injection. A test pile of .35 meter diameter of usual prior art construction and having an 8 meter high lateral injection supported at permissible setting of 15 mm. and 550 tons is indicated on curve IV. In curve V a pile of identical nature which has been imparted with point injection in accordance with this invention carries by contrast at a settlement of 15 mm. 925 tons. A second pile with a 20 meter high lateral injection is indicated in graph VI which also has been imparted with a point injection carried out in accordance with this invention, and it carries at 15 mm. a load of 1250 tons. This pile could be loaded to a capacity of 2002 tons, which is an unusually high test load.

Referring in particular to FIGS. 3 and 4, the invention embodied therein includes a pile generally designated **1** which is hollowed at its upper portion and is inserted into a drill hole in the usual manner. The pile is connected to the surrounding soil at least in the lower region of the drill hole by means of a lateral injection forming the surrounding concrete jacket **2**. This surface injection consists of mortar. This lateral injection can be introduced through pipes between the pile and the steel casing, or through pipes incorporated in the wall of the pile, while extracting the said steel casing. FIG. 4 shows such pipes number **29**. For cast-in-situ piles such mortar injection is not necessary as such piles will automatically join the surrounding soil by means of the concrete of which they are made. As indicated in the drawings, the pile projects above a water surface. The lower end of the pile includes a solid foot or bottom **3** which is formed for example of concrete.

In accordance with the invention, at the bottom face of the foot **3** there is formed an injection chamber generally designated **4**. As indicated in FIG. 5, the injection chamber **4** is formed by a plurality of distributing passages **10** (FIG. 5), communicating at their radially inner end with the central circular chamber **11**, both chamber **11** and passages **10** being covered by a bottom plate **12**. The plate **12** is secured by means of flanges **13** to the bottom of the pile **1** which will be torn off upon the application of an increased mortar injection pressure.

An inlet conduit or pipe **5** received mortar under pressure from an injection pump **7** located above the water line. The conduit **5** extends downwardly through the hollow portion of the pile **1** and through the solid bottom portion **3** to the interior of the chamber **4**. A discharge conduit **6** extends upwardly from the highest portion of the chamber **4** and is provided with a shut-off valve **8** for closing and opening this line as desired. By means of the injection pump **7** cement mortar may be circulated through the conduit **5** into the chamber **4** and back through conduit **6**. The pressure in the conduit **5** and the chamber **4** is controlled by pressure gauges and suitable automatic means located above the water line.

As previously mentioned, the chamber **4** includes the radially extending passages **10** so that it is in a star-shaped configuration. The section taken along the lines V—V indicated in FIG. 4 shows a flat bottom portion **9** on which plate **12** rests. This bottom portion closes the holes **30** provided in the plate as long as the plate has not yet been forced off by the pressure of the mortar. The holes are arranged between the distributing passages, so that the distribution chamber and the distributing passages cannot be clogged when the pile is inserted. It should be appreciated that the star configuration indicated in FIG. 5 is only one form of the injection chamber in accordance with the invention. Other configurations, for example, such as a spiral configuration, would be advantageous. If a spiral configuration is used, then the inlet pipe **5** is connected to the beginning of the spiral and the outlet pipe **6** is connected to the end of the spiral. Such an arrangement, of course, insures a continuous flow through the spiral and a distribution of material throughout the complete base surface of the chamber **4**.

In accordance with a possible method of the invention, the pile, as indicated in FIG. 3, is inserted into hole which is maintained by means of a steel jacket or similar means. The surrounding steel jacket is then removed and the surface or jacket of mortar or concrete is formed around the pile **1** and permitted to harden, as indicated in FIG. 2. Thereafter the injection pump **7** is operated and mortar is delivered to the chamber **4**. Valve **8** is maintained opened and the mortar is circulated to ensure that the mortar which remains in the chamber **4** is of an acceptable water cement ratio. For example, a ratio of 0.4 is allowed to flow through the inlet pipe **5** and into the injection chamber **4**, while the valve **8** is opened. During this procedure the cement and water sinks, due to its great heaviness, to the bottom of the cut-outs **10** and against the plate **12** and in doing so the water in the injection chamber which becomes mixed with the mortar is directed toward the apex of the chamber **11** and then through the outlet pipe **6** back to the surface. This initial mortar flow contains a great deal of water which is located at the chamber **4**. The outlet valve is kept open until the cement mortar, which exits from the outlet pipe, is of the same consistency, that is with the same water cement factor, and in a settable condition as the cement mortar which is being supplied by the injection pump **7**. When this point is reached, the valve **8** is closed, thus insuring that no non-settable cement or water pockets are formed below the piling which would produce undesired settlement.

Thereupon the pressure of the motor in the conduit **5** and the chamber **4** is increased by means of the injection pump **7**. As the pressure increases the flanges **13** tear off and the steel plate **12** is pressed downwardly over its entire bottom cross section so that the injection pressure is distributed over the entire bottom surface. The plate which has become separated from the pile **1** and the injection mortar form a mortar body which resembles somewhat the form of an elephant's foot which widens outwardly toward the base. Only by means of the distribution of the injection pressure on the entire bottom surface of the pile is a sufficiently large preloading force obtained by the multiplication of injection pressure on this whole surface.

It is advantageous during the injection to cause the mortar to remain liquid for as long a period of time as possible. This is accomplished by periodically opening and closing the valve **8** on the outlet pipe **6** so that the soil below the pile has sufficient time to give off its pore-water and to settle. In addition, in this manner the soil below the pile **1** is loaded and unloaded in an intermittent stroke-like manner. This causes a further stabilization and at the same time the desired prestressing of the soil under the point of the pile as the mortar body is formed.

In FIG. 3 there is indicated an entire apparatus for carrying out the preferred method. A mixing means **15** which is driven by an electric motor **14**, is supplied with cement at **16** and through a line **17** the required amount of water is supplied. The mixture is led through a conduit **18** to a tank or intermediate chamber **20**, having an agitator **19**. From the intermediate chamber **20** a connecting line **21** leads to the cement injection pump **7**. This pump **7** will most advantageously be operated by compressed air from a line **22**. It discharges the injection mortar through a line **23**. A pressure device or air vessel **24** having an air space **25** and a pressure gauge or manometer **25'** is connected in the pressure line **23** and discharges through the inlet line **5** which leads to the chamber **4**.

In some instances the steel plate 12 is advantageously provided with holes or openings 30 (FIG. 6) between the channels 10 of the star-shaped injection chamber which are closed by means of the concrete bottom 9 of the pile during the insertion of the pile. As soon as the plate is pressed downwardly by the pressure of injection applied by the pump 7, the mortar penetrates through the holes into the soil below the bottom plate 12. If the soil particles have sufficiently large grain size, an enrichment of mortar in the soil below the pile is obtained, and the soil will not only be prestressed but also stabilized.

Each injection under pressure constitutes a test loading of the pile. For example, if the pile is under an injection load of 800 tons between the point of the pile and the soil beneath it, and the pile does not lift to any extent, then the skin friction will also amount to about 800 tons. The work load of 800 tons is therefore carried or supported by at least doublefold security. This simple testing method cannot be accomplished in any other kind of pile construction method. The lifting of each pile caused by the bottom injection can, as diagrammatically indicated in FIG. 3, be measured, for example, by means of theodolite 26 arranged on an adjacent pile 1*a*. The zero marking 27 of theodolite is arranged on another pile 1*b*. At the pile 1 there is arranged a marking 28. The theodolite 26, prior to starting the injection procedure, is adjusted at pile 1 to the zero marking of the scale 27. Thereafter, in a direction toward the pile 1 it is rocked and, at the position of the contact the marking 28, is fixed. After termination of the injection procedure the theodolite 26 is now adjusted to the new position of the marking 28 and is again rocked back to the pile 1*b*, where the sight line, after the pile 1 has lifted itself, will engage in a higher position on the scale 27. In this manner the extent about which the pile 1 has lifted itself can be calculated.

Due to the inventive process, non-uniform settlement of the piles within a pile group can be compensated to a large extent. Non-uniform settlement caused by varying soil conditions below the piles of a structure can otherwise cause large damage to the structure supported by these piles. In the injection method of this invention injection mortar is pressed under the piles for a sufficiently long period to obtain the same final injection pressure at all piles of a pile group. The mortar consumption of the individual piles varies in this procedure considerably. Non-uniform settlements are almost entirely compensated in this manner.

According to experience obtained in the building of a large bridge, it has been further ascertained that soft soil formations below the foundation can be completely displaced by the bottom injection method, so that below the piles instead of an undesirable soft layer, there will be formed a mortar bed. This mortar bed or layer gives an excellent pile carrying characteristic and uniform settlement within a pile group or foundation is assured.

While specific embodiments of the invention have been shown and described in detail to illustrate the application of the inventive principles, it will be understood that the invention may be embodied otherwise without departing from such principles.

What is claimed is:

1. A process for increasing the carrying capacity of piling using a pile having a mortar distributing chamber at the bottom thereof covered by a bottom plate having a cross-sectional surface similar to that of the bottom of said pile, said pile including inlet and outlet conduits connected to the bottom distributing chamber, comprising directing mortar through the inlet conduit while the outlet conduit is open until the mortar constituency through the outlet conduit is of an acceptable value, closing the outlet conduit, and applying pressure on the mortar in the inlet conduit to build up the pressure acting on the mortar in said distributing chamber and to force the plate off the bottom of said pile.

2. A process according to claim 1, including intermittently releasing and applying pressure to the distributing chamber.

3. A process according to claim 1, wherein after the pile is inserted into the ground, mortar is introduced into the distributing chamber through the inlet conduit and the distribution chamber and discharged through the discharge conduit together with any ground water which has entered the distributing chamber until the consistency of the mortar leaving the discharge conduit is the same consistency as the mortar introduced through the inlet conduit.

4. A process according to claim 1, wherein a pre-cast pile is employed, and including the step of boring a hole in the ground soil and inserting the pre-formed pile into the hole, injecting mortar around the outside of the pile for the purpose of embedding the pile in the surrounding soil, and permitting the mortar to become hardened before introducing mortar into said distributing chamber.

5. A process for increasing the carrying capacity of piling by injection of cement mortar below the bottom surface of a pile, wherein means are provided for location in an excavated ground hole adjacent the bottom surface of said pile to define a hollow mortar distributing chamber which is closed downwardly by means of a bottom plate having at least the same cross-sectional surface as that of the pile and which is separable from the bottom of the pile upon the application of a predetermined pressure thereto, the said means including inlet and outlet conduits connected to said mortar distributing chamber, comprising flushing the chamber by circulating mortar downwardly to said chamber through said inlet conduit and back upwardly to said discharge conduit for a period of time until a settable cement mortar is discharged from said discharge conduit and any ground water which has entered into said chamber removed, thereafter blocking off said discharge conduit and continuing to increase the pressure acting on the mortar in the supply conduit and said distributing chamber until the desired prestressing of the soil with mortar at the bottom of the pile has been obtained.

6. A process for increasing the carrying capacity of a pile, using a pile having a mortar distributing chamber formed at the bottom thereof covered by a bottom plate having an exterior surface complementary to that of the pile, and inlet and outlet conduits connected to said mortar distributing chamber, comprising forming a receiving bore in the ground, inserting the pile in the bore, injecting mortar around the exterior of said piling to form an exterior jacket, permitting the exterior jacket to harden to join the pile to the surrounding soil, directing mortar under pressure through said inlet conduits while said outlet conduit is open until the constituency of the mortar as evidenced by the mortar exiting from said outlet conduit is of a satisfactory character, intermittently stopping the circulation of the mortar to permit ground water to accumulate in the chamber and repeating the circulation to remove the water, thereafter closing the discharge conduit and building up the pressure exerted on the mortar in said inlet conduit and thereby in the mortar distributing chamber, and periodically decreasing and increasing the pressure on the mortar.

7. A process according to claim 6, wherein during injection the pressure of the mortar and thus the pretensioning or prestressing force is measured between the paint of the pile and the underlying soil so that as long as the pile is not lifted by the injection there is evidenced a total skin friction at an amount corresponding to the point pressure force applied.

8. A process according to claim 6, wherein a plurality of piles are erected and wherein cement mortar is injected to each pile of each plurality for a period lasting until the same end injection pressure has been obtained in all the piles of said plurality.

9. A process according to claim 6, wherein the bottom plate is perforated to provide holes for the discharge of mortar therethrough, after the plate has been forced off the foot of the pile downwardly by the pressure of the mortar so that the holes have been opened.

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