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(54) METHOD OF FORMING A PILE IN THE EARTH

(71) I, WATARU NAKANISHI, a Japanese citizen of 4-10-3, Tsurukawa, Machida-shi, Tokyo, Japan, do hereby declare the invention for which I pray that a patent may be granted to me, and the method by which it is to be performed to be particularly described in and by the following statement:-

This invention relates to a method of and apparatus for forming a pile in the earth, for example as a fundamental construction body in a cut-off wall, formation of an underground successive wall, or stable construction of a basic foundation.

Recently there have been proposed a number of methods for forming a pile in the earth by jetting a consolidation liquid agent through a nozzle at the front end of an injecting shaft member. The prior art has enabled the formation of an underground pile of at most, 400-500 m/m diameter even if a jetting pressure of 200 kg/cm² is used, because the attenuation of jetting pressure in the earth is extremely large as compared with the same in the air.

Since there is a limitation on the production of a jetting pressure, research has been carried out to attempt to reduce the attenuation and diffusion of the jetting pressure, for example by improving the finish of nozzle shape, but, at most, this method enables the expansion of a pile in diameter by 5-10% or so. Therefore, research has also been carried out to enclose the periphery of a stream jetted through a nozzle so as to form an atmosphere of air in the earth so as to decrease the pressure attenuation. This method has the disadvantages that much air has to be consumed to envelop the jetting stream and that an airlift phenomenon arises, thereby sending out the jetted consolidation liquid agent together with the air toward the ground surface.

This invention seeks to provide a method wherein an air jet is enveloped with a jet of the consolidation liquid agent, so that the perfect mixture of the air with the consolidation liquid agent is obtained, the airlift phenomenon is restricted, and the pulverization thrust is maintained, whereby the limitation of operation and effect in the conventional methods is broken. It is thus possible to form the underground pile with a large diameter reaching to 2000 m/m.

According to this invention, we provide a method of forming a pile in the earth comprising telescoped pipes providing a plurality of stream passages and a jet nozzle connected with each stream passage in the peripheral wall of the lower portion of said injecting shaft member and rotatively lifting and lowering said injecting shaft member simultaneously with jetting air from a central opening of said nozzle and consolidation liquid agent from an opening under high pressure so that the jet of air is surrounded by a jet or jets of said consolidation liquid agent.

Furthermore, we provide an injecting shaft member for forming a pile in the earth, comprising a telescoped hollow pipe and a rod, at the lower end of which injecting shaft member a head crown is provided so as to close that opening end of said injecting shaft member, a jointing pipe divided into a chamber for consolidation liquid agent connected to said hollow pipe and an air chamber connected to the interior of said rod, a central opening connected to said air chamber in the side wall of said jointing pipe, and a single annular opening or a plurality of small openings arranged around said central opening and connected to said liquid consolidation agent chamber.

Hereinafter the invention will be described by way of example with reference to experimental results.

As a test for pulverizing solid by liquid, one can employ pulverization of the earth and soil

by means of a high pressure jet means to destroy the earth and soil using the dynamic energy of a water jet. The excavation mechanism is complicated and the excavation effect depends greatly on the physical and dynamic quality of the earth. The main factors affecting excavation by water force are the dynamic pressure action of the jet, the impacting power of the waterdrops, the water wedge effect, the jet pulsing load and the cavitation phenomenon.

These factors do not function independently and the overall pulverization effect is generated as a result of all these effects and their interactions. Of these factors, those affected by using air additionally as a jetting fluid are the jet operating pressure and the cavitation phenomenon. Namely, the greater the jet operating power, the easier is the pulverization of the earth and the use of air makes the pressure attenuation small. The high operating pressure reaches areas far from the nozzle, whereby the earth may be pulverized to areas at a greater distance from the nozzle than without the air.

According to the method of this invention, pressure distribution is shown in Figure 1. Figure 1 illustrates the experimental results obtained for stream pressure distribution under conditions such that the diameter of the nozzle used is 2 m/m and the output pressure is 200 kg/cm². Reference numeral I depicts a water jet in water, II a water jet in air, III a water jet enveloped with air in water and IV an air jet enveloped with water in water. For the three conditions of the jet in water, Figure 1 shows that an air jet enclosed with water exhibits the least pressure attenuation. In other words, the jet pressure is decreasing spontaneously after jetting, but the air enclosed with water reaches a limit if the water pressure is reduced gradually, and the liquid is not capable of keeping its homogeneity so that it becomes a mixture of gas and liquid and the gas appears as bubbles in a dynamic liquid, thus causing a cavitation phenomenon that generates cavities. The cavities burst when the gas reaches the high pressure portion so as to generate pressure waves. The shock pressure generated at this time is very high and gives a great effect so as to pulverize the earth.

The magnitude of the shock pressure was determined by the following equation resulting from experiments subject to the environmental pressure of 200 kg/cm²:

$$P' = K \times P_0 \times \left(\frac{r_0}{r}\right)^3 \text{ kg/cm}^2$$

where, K : experimental constant 0.163,
 P_0 : peripheral pressure 200 kg/cm²
 P' : pressure when an air bubble bursts,
 r_0 : size of an initial air bubble, and
 r : size of a bubble when it bursts.

Here, r_0/r is 1/0.3 or so and from the above equation, the following result may be obtained:

$$P' = 0.163 \times 200 \times \left(\frac{1}{0.3}\right)^3 = 1200 \text{ kg/cm}^2$$

Therefore, there may be obtained a great impact strength.

These two tests show that the pressure attenuation of a water jet becomes extremely small by jetting both a water jet and air. In addition, the mixture of air and water can increase the cavitation effect in the case of enclosing air with a water jet when compared to the case of enclosing a water jet with air, since they are more efficiently mixed in the former case.

The result was obtained even when the result of the above room test was compared with that of a practical test.

Text Example 1

This experiment is to solidify sludge on a very weak river bottom under the constant conditions of a jet pressure of 200 kg/cm², a jet delivery of 80 l/min. and a rotation of the nozzle of 20 rpm, while changing the amount of wind and shape of the nozzle and measuring the resulting radius of a formed pile in the earth. At the result of the test, there were obtained the results shown in Figure 2 wherein a small circle illustrates a test when air is enclosed with a high pressure jet and a small triangle denotes a test when a high pressure jet is enclosed with air. In the case of $Q_a = 1.2 \text{ m}^3/\text{min.}$, one of the three jets is not solidified. And in the case of $Q_a = 1.5 \text{ m}^3/\text{min.}$, none of them are solidified.

These test results show that the radius of the underground pile in the case of the jet including air is 2.2 - 4.2 times that in the case of the jet not including air and that the effect of using included air is extremely great. Even the wind amount in the case of including air is about half of that not including air, it provides more effect thereto.

Figure 3, where the small circles and triangles have the same meaning as in Figure 2, shows measured results of wind amount in relation to discharged sludge amount (i.e. ratio of amount of discharged sludge to amount of jetted material) wherein the discharged sludge amount is not related to the nozzle shape and is constant if the wind amount is equal, but the amount of discharged sludge increases to exceed the amount of jetted material in proportion to the increase of the wind amount so as to exceed a wind amount of $1.2 \text{ m}^3/\text{min.}$

As the result, much cost is required to exclude the discharged sludge. In addition, one of three jets is not solidified under $1.2 \text{ m}^3/\text{min.}$ and all of three jets are not under $1.5 \text{ m}^3/\text{min.}$, thereby producing a cavity or cavities in the ground.

Test Example 2

This test is an experiment for forming an underground pile in a weak silt layer with $N = 0$ through 2, and has been performed with varying wind amount and nozzle shape under conditions of a jet pressure of 200 kg/cm^2 , a jet amount of 30 l/min. and a jet rotation of 20 rpm.

Let us consider two kinds of jets, i.e. one jet consisting of air enveloped with a consolidation agent and the other jet of a consolidation agent enveloped with air. Test results are shown in Figure 4 and prove that the diameter of a pile formed in the ground by the former is larger than that of a pile formed in the ground by the latter and further that the strength of a pile formed by the former is greater by one and a half times or so than that of a pile formed by the latter in the case of constructing piles with the same diameter. In Figure 4, reference A depicts a curve showing the diameter of a pile when air is enclosed with a high pressure jet is enclosed with air, C depicts compression strength when air is enclosed with a high pressure jet and D compression strength when a high pressure jet is enclosed with air.

Referring to the above test results, an apparatus embodying them will now be described with reference to Figure 5 to 7. A pipe 2 is inserted into the center of a rod 1 as an injection pipe so that double pipes (treble pipes in the case of using two liquids A and B having different flash setting characteristics) may be constructed. The lower end of the rod 1 is closed by means of a head crown 3. The rod 1 further comprises a joint pipe 6 which is divided into a liquid chamber 4 connected to the pipe 2 and an air chamber 5 and both the chambers 4, 5 are connected with each other. In the joint pipe 6, provision is made for a nozzle means 9 having at its center a nozzle 7 a ring-shaped nozzle 8 (Figure 6) or a plurality of nozzle 8' (Figure 7) connected to the liquid chamber 4, of which each opening is positioned in the external wall. The injecting shaft is designed such that the air in the air chamber 5 may be jetted through the center nozzle 7, that the consolidation agent of the liquid chamber 4 supplied from the hollow chamber 2 may be jetted through the nozzle 8 or nozzles 8' and that the air may be enveloped with the consolidation agent. For example 100 of consolidation agent may be manufactured by mixing cement (760 kg) and water 760) with a dispersing agent. The injecting shaft may be constructed such that a jet opening and a differential pressure valve are provided at the end of the injecting shaft whereby a lubricating agent is jetted downward when the injecting shaft is inserted into the earth and then the downward jetting is changed to lateral jetting.

As will be clearly understood from the above mentioned experimental results, air is jetted near the exit of the nozzle so that the pressure attenuation of the consolidation agent by the high-speed jet in the rod 1 may be reduced by the jet enveloping the air and so that the air and the consolidation agent are completely mixed, so that the cavitation effect is increased, resulting in the pulverization of the earth with a great impact strength. In other words, this invention provides a valuable effect using a combination of the impact strength of the jetted liquid, the water wedge effect and the cavitation phenomenon by using the air together with the consolidation agent.

WHAT I CLAIM IS:-

1. Method of forming a pile in the earth comprising inserting into the ground an injecting shaft member comprising telescoped pipes providing a plurality of stream passages and a jet nozzle connected with each stream passage in the peripheral wall of the lower portion of said injecting shaft member and rotatively lifting and lowering said injecting shaft member simultaneously with jetting air from a central opening of said nozzle and consolidation liquid agent from an opening or openings of said nozzle surround said central opening under high pressure so that the jet of air is surrounded by a jet or jets of said consolidation liquid agent.

2. Method of forming a pile in the earth according to claim 1, wherein said consolidation liquid agent is jetted through an annular opening.

3. Method of forming a pile in the earth according to claim 1, wherein said consolidation liquid agent is jetted through a plurality of openings arranged around said central opening.

4. Method of forming a pile in the earth according to claim 1, 2 or 3, wherein a lubricant is jetted below said jet nozzle while said injecting shaft member is inserted in the earth.

5. Injecting shaft member for forming a pile in the earth, comprising a telescoped hollow pipe and a rod, at the lower end of which injecting shaft member a head crown is provided so as to close that opening end of said injecting shaft member, a jointing pipe divided into a chamber for consolidation liquid agent connected to said hollow pipe and an air chamber connected to the interior of said rod, a central opening connected to said air chamber in the side wall of said jointing pipe, and a single annular opening or a plurality of small openings arranged around said central opening and connected to said liquid consolidation agent chamber.

6. An injecting shaft member according to claim 5, wherein said injecting member further comprises a jet opening at the lower end thereof for jetting a lubricant in the downwards direction and a differential pressure valve provided at the jet opening for the lubricant.



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Test Example 2

This test is an experiment for forming an underground pile in a weak silt layer with $N = 0$ through 2, and has been performed with varying wind amount and nozzle shape under conditions of a jet pressure of 200 kg/cm^2 , a jet amount of 30 l/min. and a jet rotation of 20 rpm.

Let us consider two kinds of jets, i.e. one jet consisting of air enveloped with a consolidation agent and the other jet of a consolidation agent enveloped with air. Test results are shown in Figure 4 and prove that the diameter of a pile formed in the ground by the former is larger than that of a pile formed in the ground by the latter and further that the strength of a pile formed by the former is greater by one and a half times or so than that of a pile formed by the latter in the case of constructing piles with the same diameter. In Figure 4, reference A depicts a curve showing the diameter of a pile when air is enclosed with a high pressure jet is enclosed with air, C depicts compression strength when air is enclosed with a high pressure jet and D compression strength when a high pressure jet is enclosed with air.

Referring to the above test results, an apparatus embodying them will now be described with reference to Figure 5 to 7. A pipe 2 is inserted into the center of a rod 1 as an injection pipe so that double pipes (treble pipes in the case of using two liquids A and B having different flash setting characteristics) may be constructed. The lower end of the rod 1 is closed by means of a head crown 3. The rod 1 further comprises a joint pipe 6 which is divided into a liquid chamber 4 connected to the pipe 2 and an air chamber 5 and both the chambers 4, 5 are connected with each other. In the joint pipe 6, provision is made for a nozzle means 9 having at its center a nozzle 7 a ring-shaped nozzle 8 (Figure 6) or a plurality of nozzle 8' (Figure 7) connected to the liquid chamber 4, of which each opening is positioned in the external wall. The injecting shaft is designed such that the air in the air chamber 5 may be jetted through the center nozzle 7, that the consolidation agent of the liquid chamber 4 supplied from the hollow chamber 2 may be jetted through the nozzle 8 or nozzles 8' and that the air may be enveloped with the consolidation agent. For example 100 of consolidation agent may be manufactured by mixing cement (760 kg) and water 760) with a dispersing agent. The injecting shaft may be constructed such that a jet opening and a differential pressure valve are provided at the end of the injecting shaft whereby a lubricating agent is jetted downward when the injecting shaft is inserted into the earth and then the downward jetting is changed to lateral jetting.

As will be clearly understood from the above mentioned experimental results, air is jetted near the exit of the nozzle so that the pressure attenuation of the consolidation agent by the high-speed jet in the rod 1 may be reduced by the jet enveloping the air and so that the air and the consolidation agent are completely mixed, so that the cavitation effect is increased, resulting in the pulverization of the earth with a great impact strength. In other words, this invention provides a valuable effect using a combination of the impact strength of the jetted liquid, the water wedge effect and the cavitation phenomenon by using the air together with the consolidation agent.

WHAT I CLAIM IS:-

1. Method of forming a pile in the earth comprising inserting into the ground an injecting shaft member comprising telescoped pipes providing a plurality of stream passages and a jet nozzle connected with each stream passage in the peripheral wall of the lower portion of said injecting shaft member and rotatively lifting and lowering said injecting shaft member simultaneously with jetting air from a central opening of said nozzle and consolidation liquid agent from an opening or openings of said nozzle surround said central opening under high pressure so that the jet of air is surrounded by a jet or jets of said consolidation liquid agent.

2. Method of forming a pile in the earth according to claim 1, wherein said consolidation liquid agent is jetted through an annular opening.

3. Method of forming a pile in the earth according to claim 1, wherein said consolidation liquid agent is jetted through a plurality of openings arranged around said central opening.

4. Method of forming a pile in the earth according to claim 1, 2 or 3, wherein a lubricant is jetted below said jet nozzle while said injecting shaft member is inserted in the earth.

5. Injecting shaft member for forming a pile in the earth, comprising a telescoped hollow pipe and a rod, at the lower end of which injecting shaft member a head crown is provided so as to close that opening end of said injecting shaft member, a jointing pipe divided into a chamber for consolidation liquid agent connected to said hollow pipe and an air chamber connected to the interior of said rod, a central opening connected to said air chamber in the side wall of said jointing pipe, and a single annular opening or a plurality of small openings arranged around said central opening and connected to said liquid consolidation agent chamber.

6. An injecting shaft member according to claim 5, wherein said injecting member further comprises a jet opening at the lower end thereof for jetting a lubricant in the downwards direction and a differential pressure valve provided at the jet opening for the lubricant.

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7. A method of forming a pile in the earth substantially as hereinbefore described with reference to the accompanying drawings.

8. An injecting member for forming a pile in the earth substantially as hereinbefore described with reference to the accompanying drawings.

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BATCHELLOR, KIRK & EYLES,
Chartered Patent Agents,
100 Great Russell Street,
London WC1B 3LA.
For the Applicant.

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