

DESCRIPTION
SOIL IMPROVEMENT METHOD

Technical Field

The present invention relates to a soil improvement method in a land improvement technique of a construction field, and aims at increasing strength of the soil by supplying a grout material such as air cement milk and a foaming material from the ground into the soil.

Background Art

Generally safety and economic efficiency of work in the underground, such as groundwork of civil engineering and construction, a subway, and an underground shopping area heavily depend on the right or wrong of groundwater countermeasures.

Conventionally, a waterproof method in which an impervious wall prevents the groundwater from flowing in or a groundwater-level lowering method in which the groundwater is drained to the ground to lower the ground water level is well known as the groundwater countermeasures.

The following patents are granted to the inventor and the applicant.

Patent Document 1: Japanese Patent Publication Laid-Open No. 2000-27170 (Japanese Patent No. 3243501)

Patent Document 2: Japanese Patent Publication Laid-

Open No. 2001-11846 (Japanese Patent No. 3280935)

Disclosure of the Invention

Problems to be Solved by the Invention

The above-listed patents relate to a so-called super well point method, that is, a method for lowering the groundwater level to improve the soil.

An outline of the super well point method will be described below: the water is forcedly drained while a strainer portion is formed into a double-tube structure (special separate screen) to keep the well in a vacuum state.

A structural separate screen of the special separate screen has a double structure including an inner tube and a winding strainer. The groundwater flowing from the winding strainer is separated into air and water between the tubes, and the water flow into the well through vent holes located in a lower portion of the tube.

A negative pressure is applied to the inside of the double tube using a vacuum pump, which continuously enables vacuum drainage.

The super well point method which is of a deep underground vacuum drainage and consolidated dewatering method has the following effects. First, the development of the special separate screen can exert the vacuum effect in the deep underground, and the vacuum effect can widely be propagated to perform forced drainage. Second, unlike a well point method in which the depth is restricted up to 6

m to 7 m, the forced drainage can be performed in a vacuum in the depth equal to that of the deep well. Third, in the deep well, many wells are required because gravity drainage has poor well efficiency. On the contrary, in the super well point method, the number of wells can be decreased because the well effect is improved by the vacuum effect. Fourth, that the air enters the well to decrease the vacuum effect can be eliminated when the water level is lowered to a screen position by the vacuum deep well method. Fifth, in the super well point method, the forced drainage can be performed in the deep underground by the vacuum effect, the water pumping amount of the super well point method is larger 1.2 times to tens of times the conventional method according to a geologic condition, and the groundwater level can early be lowered in the wide range.

Means for Solving the Problems

In the present invention, at least two wells are provided while separated from each other, and the super well point method is performed to further improve the soil.

In accordance with a first aspect of the invention, a soil improvement method includes a step of constructing an impervious wall to a necessary depth so as to surround an underground of soil using a steel sheet pile, and of extending a perforated pipe to the underground in the impervious wall, a grout material being supplied to the underground from a ground surface of the soil through the perforated piping; a step of covering the ground surface of

the impervious wall with an airtight material such as an airtight sheet, a pavement with a concrete material or an asphalt material, and new sludge; a step of pumping groundwater through at least two wells to lower a groundwater surface to a necessary water level by a super well point method in which the wells are drilled in the underground in the impervious wall at a predetermined interval, the ground surface being covered with the airtight material in the impervious wall, and of putting the region in a vacuum state by deaerating unsaturated soil in a region by the groundwater pumping, the region being surrounded by the impervious wall, thereby vacuum-evaporating water of the underground to perform dewatering; a step of supplying a grout material such as air cement milk or a foaming material from the ground surface into the underground through the perforated pipe; and a step of recharging the groundwater into the underground to a natural groundwater level.

In accordance with a second aspect of the invention, the soil improvement method of the first aspect includes a step of extending the perforated pipe to the underground from the ground surface of the soil in polluted ground, the fresh air or fresh water being supplied to the underground through the perforated pipe; a step of covering the ground surface of the soil with the airtight material such as the airtight sheet, the pavement with the concrete material or the asphalt material, and the new sludge; a step of reducing a pressure in a peripheral region of the

underground while pumping the groundwater near the underground by a super well point method in which at least the two wells are provided in the underground at a predetermined interval, thereby putting the underground into a substantial vacuum state; a step of repeating the supply of the fresh air or fresh water through the perforated pipe of the grout material supplying facilities, the perforated pipe being extended from the ground surface to the underground; and a step of recharging the groundwater into the underground to the natural groundwater level.

In accordance with a third aspect of the invention, the soil improvement method of the first aspect, lower-layer soil is drilled with a curve boring machine to make a hole toward a horizontal direction from the right and left of an already-existing construction foundation and an aboveground structure which are placed in the ground surface, the perforated pipe is inserted into the hole to lay the perforated pipe between the right and left of the already-existing construction foundation, and the grout material is injected from the perforated pipe into the underground to lift up the unevenly-settled construction.

Effect of the Invention

The present invention has the following effects because of the above-described configurations. That is, various vacuum effects are generated when the water pumping and the consolidated dewatering are performed with a high

vacuum level P_v of about -0.085 Mp in the deep underground. When the vacuum effects are utilized, the consolidated dewatering can be performed early, and the new soil improvement is achieved in a multiple manner using the feature of the vacuum effects.

When at least the two super well point methods suck the cohesive soil by the vacuum effects, it can be desired that the water level is partially largely lowered. Therefore, the cohesive soil is improved by not a method for pressurizing the cohesive soil with a mound, but a method for lowering a pumping pressure in a lower portion of the cohesive soil to increase the stress load. Further, in accordance with the aspect of the invention, the polluted ground can efficiently be purified.

The evenly-settled construction can be lifted up and corrected by the permanent grout material.

At least the two super well point methods can suck the cohesive soil to promote the settlement of a remaining settlement amount of cohesive soil even in the already-existing construction. The water level is lowered to a deep position to make an unsaturated soil by a combination of at least the two super well point methods, the impervious wall surrounding the super well point methods, and the airtight material with which the ground surface is covered in the impervious wall, so that a shock can be propagated to the deep position to widely improve the soil.

Brief Description of the Drawings

FIG. 1 is a flowchart illustrating a soil improvement method according to an embodiment of the invention.

FIG. 2 is a sectional view illustrating a configuration including a well, an impervious wall, a vertical perforated pipe, and an airtight sheet in the soil improvement method according to the embodiment of the invention.

FIG. 3 is a sectional view illustrating a configuration including a well, an aboveground construction, a curved perforated pipe, and a pavement in the soil improvement method according to the embodiment of the invention.

FIG. 4 is a partial sectional view illustrating a relationship among soil particles, free water, adsorption water, and an air bubble in a steady state in the soil improvement method according to the embodiment of the invention.

FIG. 5 is a partial sectional view illustrating a relationship between the soil particles and adsorption water in a state in which groundwater (free water) and the air bubble are eliminated in the soil improvement method according to the embodiment of the invention.

FIG. 6 is a partial sectional view illustrating a relationship among the soil particles, the adsorption water, and air in an air supply state in the soil improvement method according to the embodiment of the invention.

FIG. 7 is a partial sectional view illustrating a relationship among the soil particles, the free water, the adsorption water, and the air bubble in a water recharge state in the soil improvement method according to the embodiment of the invention.

FIG. 8 is a sectional view illustrating a well (super well point method) used in a step of pumping the groundwater and a step of reducing a pressure in soil in the soil improvement method according to the embodiment of the invention.

FIG. 9 is a schematic diagram illustrating lift-up work in which a permanent grout material is injected into a foundation region of a gate-shape crane that is of a construction by the soil improvement method according to the embodiment of the invention.

FIG. 10 is an enlarged transverse sectional view of part of FIG. 9.

FIG. 11 is an explanatory view illustrating a conventional sandy soil improvement method.

FIG. 12 is an explanatory view illustrating a sandy soil improvement method.

FIG. 13 is a schematic explanatory view illustrating the invention in which a swing cleaning system is adopted.

FIG. 14 is a schematic explanatory view illustrating the invention in which a swing cleaning system is adopted in at least two wells (super well point method).

FIG. 15 is an analysis diagram illustrating grain sizes of soil particles after swing cleaning of FIG. 13.

Explanations of Letters or Numerals

1 Soil

1a Ground surface

1b Underground

1c Groundwater surface

1₁ Sand layer

1₂ Cohesive soil layer

1₃ Sand layer below cohesive soil layer

2 Well (super well point)

2a Casing

2b Airtight cover

2c Strainer

2d Sediment pit

2e Water pump

2f Drain pump

2g Vacuum pump

2h Water piping

2i Piping

2j Water tank

3 Facilities supplying grout such as air cement milk and foaming material

3a Perforated pipe

3b Piping

3c Valve

4a Soil particles

4b Free water (groundwater)

4c Adsorption water

4d Air or air bubble

- 4e Vacuum portion
- 5 Impervious wall
- 6 Airtight material
- 7 Construction foundation
- 8 Aboveground structure
- 8' Support post
- 8" Horizontal beam
- 9 Grout material

Best Mode for Carrying Out the Invention

In the above-described configurations of the invention, the best mode for carrying out the invention is as described below.

The case, in which a ground surface is covered with an airtight material, two wells having high water pumping efficiency are drilled as groundwater pumping means to utilize the super well point method, and a perforated pipe is laid between two wells, will be described as the best mode for carrying out the invention with reference to the drawings.

FIG. 1 is a flowchart illustrating a soil liquefaction preventing method according to an embodiment of the invention. In FIG. 1, cohesive soil improvement work in the embodiment is performed as follow: Step (1): an impervious wall is constructed as preparatory work so as to surround target soil. Step (2): plural wells (super well points) are placed. Step (3): facilities supplying a grout material such as air cement milk and a foaming material 9 are placed on the ground and in the soil. Step (4): the ground surface is covered with an airtight material. Step (5): groundwater in the soil is pumped and an air bubble in the soil is removed by the super well point method placed in Step (2). Step (6): a grout material 9 is osmosed into underground by supplying a liquid substance such as the air cement milk and the foaming material through a perforated pipe of the grout material supplying facilities placed in Step (3). The liquid substance is evenly vacuum-osmosed

into the underground. Step (7): part or the whole of the airtight material provided in Step (4) is removed. Step (8): supplying facilities placed in Step (3) are removed. Step (9): the groundwater in the soil is recharged to a natural water level. Step (10): the two wells placed in Step (2) are removed. Step (11): the impervious wall constructed in Step (1) is removed.

In the embodiment, sometimes Steps (1) and (4) and Steps (7) and (11) corresponding thereto may be omitted depending on a structure of the target soil and a construction existing on the ground or a ground surface state. Steps of the cohesive soil improvement work will be described in detail, and then a state change in underground will be described.

Example

(Step (1): construction of impervious wall 5)

As illustrated in FIG. 2, an impervious wall 5 is constructed up to a necessary depth with a steel sheet pile so as to surround underground 1b of laminated-layer soil 1 which is the improvement target including sand layers 1₁ and 1₃ and a cohesive layer 1₂. At this point, it is assumed that the impervious wall 5 is constructed such that a top end height of the impervious wall 5 is projected from a ground surface 1a, and it is assumed that an impervious property is ensured between components such as the steel sheet pile constituting the impervious wall 5.

(Step (2): placement of well 2 (super well point))

Then plural (two in the illustrated example) wells 2 (super well point) are placed in the impervious wall 5 constructed in Step (1).

As illustrated in FIG. 8, the well 2 (super well point), which is a large-capacity and high-pump-head pumping system, mainly includes a casing 2a, an airtight cover 2b, a strainer 2c, a sediment pit 2d, a water pump 2e, a vacuum pump 2g, pieces of piping 2h and 2i, and a water tank 2j. In the large-capacity, high-pump-head pumping system, the independent vacuum pump 2g and water pump 2e satisfy a function of collecting the water into the well 2 and a function of pumping the water to the outside of the well 2. The inventor proposed the large-capacity, high-pump-head pumping system (see Patent Document 1). FIG. 8 illustrates the state in which a groundwater surface 1c is lowered, and arrows in FIG. 8 indicate the groundwater and air flow directions. FIG. 8 also illustrates the state in which a negative pressure is propagated in a lower portion of the well 2. In FIG. 2, aboveground facilities shown in FIG. 8 are omitted.

(Step (3): placement of grout material supplying facilities 3)

Then, as illustrated in FIG. 2, necessary pieces of perforated pipe 3a are placed in the impervious wall 5 constructed in Step (1) by a hole drilling method such as boring work, and pieces of piping 3b and 3b and a valve 3c are disposed in an upper end portion of the perforated

pipings 3a, thereby forming grout material supplying facilities 3 acting as a passage through which the grout material is introduced from the ground. The valve 3c is closed in a stage in which the supplying facilities 3 supplying the grout material such as the air cement milk and foaming material is placed. In FIG. 2, arrows indicate a direction in which the grout material 9 flows from the ground surface 1a to the underground 1b. In the grout material supplying facilities 3 of FIG. 3, from one of the two wells between which an aboveground structure 8 placed in an already-existing construction foundation 7 is sandwiched toward the other well, the perforated pipe 3a is a horizontally laid from the ground surface 1a in the underground 1b while passed below the already-existing construction foundation 7 and 8 by the hole drilling method such as the boring work. The grout material supplying facilities 3 can also be used to supply fresh air or fresh water.

(Step (4): coverage with airtight material 6)

The ground surface 1a of the underground 1b becomes the liquefaction preventing target, and the ground surface 1a of the underground 1b is surrounded by the impervious wall 5 constructed in Step (1). The ground surface 1a of the underground 1b is covered with an airtight material 6, and the airtight material is retained in an end portion of the airtight material and some of openings generated by the perforated pipe 3a and well 2. Therefore, the passage through which the grout material 9 is passed from the

ground is limited to one system of the supplying facilities 3 placed in Step (3). For example, an airtight sheet, a pavement made of an asphalt material or a concrete material, and new sludge which does not smell bad may be used as the airtight material 6. Examples of the grout material 9 include the air cement milk and the foaming material.

In a predetermined range of the target underground 1b, an area whose side portion and top portion are sealed is constructed through Steps (1) to (3).

(Step (5): groundwater pumping and removal of air bubble)

The well 2 placed in Step (2) by utilizing the super well point method is caused to function to collect the groundwater existing in the underground 1b into the well 2 and to pump up the groundwater collected in the well 2 to the ground, thereby lowering the groundwater surface 1c up to the required groundwater level. At this point, in the state of the underground 1b, the groundwater existing in the underground 1b in an area above the groundwater surface 1c is pumped up and removed, and the grout material 9 existing in the underground 1b is also removed. Therefore, a highly vacuum state (hereinafter referred to as "substantially vacuum") is established although soil particles constituting the underground 1b exist. FIG. 8 illustrates the state in which the groundwater surface 1c becoming the natural groundwater level is lowered.

(Step (6): supply of grout material 9 such as air cement milk and foaming material)

The valve 3c is opened, and the supplying facilities 3 placed in Step (3) utilizes a pressure difference to supply the grout material 9 such as the air cement milk and the foaming material from the ground to the underground 1b through the pieces of piping 3b and 3b and perforated pipe 3a. At this point, the pumping and degassing functions of the well 2 are stopped before Step (6) in which the grout material 9 is supplied to the underground 1b. Because the underground 1b is in the substantial vacuum state as described above, the underground 1b is filled with the grout material 9 at remarkably high diffusion speed. The supplying facilities 3 are also used when the fresh air or fresh water is supplied instead of the grout material 9.

(Step (7): removal of airtight material 6)

Then the airtight material 6 provided in Step (4) is removed. At this point, because the pressure near the ground surface 1a of the underground 1b comes close to an atmospheric pressure due to Step (6), the pressure difference between the underground 1b and the ground is eliminated to easily remove the airtight material 6.

(Step (8): removal of grout material supplying facilities 3)

Then, the grout material supplying facilities 3 are removed to perform back-filling of the piping pit.

(Step (9): water recharge)

The groundwater pumped in Step (5) is recharged to the groundwater surface 1c becoming the natural groundwater level using the well 2. In Step (9), in the case of a small water head difference between the groundwater surface 1c after pumping the groundwater and the groundwater surface 1c in the natural state, the flow may go to next Step (10) without recharging the groundwater taken from the well 2, and Step (9) depends on a scale of the work.

(Step (10): removal of well 2 (super well point))

Then the well 2 is removed to perform the back-filling of the well pit.

(Step (11): removal of impervious wall 5)

Finally the water sealing wall 5 is removed to end the series of steps. In cases where the need for periodically repeating the action of improving the soil 1 arises, the perforated pipe 3a of the supplying facilities 3, the well 2, and the impervious wall 5 may be left in order to decrease the number of man-hours for the next work.

Another embodiment in an environment different from that of Steps (1) to (10) will be described below. However, an overlapping portion is omitted and only a changed portion is described.

As illustrated in FIG. 3, the ground surface 1a is paved by the airtight material 6 such as the concrete and the asphalt, the construction foundation 7 and the aboveground structure 8 such as a large oil tank and a lime tank are constructed in the underground 1b that becomes the

improvement target, and the improvement target covers the wide range of the underground 1b. An example of each of the cases will be described below.

In such cases, Steps (1), (4), (7), and (11) may be omitted. Because of the wide range of the underground 1b, the action can be taken without constructing the impervious wall 5 in Step (1) by lowering the groundwater surface 1c in the surroundings of the target underground 1b, and necessity of the removal of the impervious wall 5 in Step (11) is also eliminated. The ground surface 1a is covered with the airtight material 6, and a vinyl sheet, a waterproof tent, the pavement made of the cement or asphalt, the fresh sludge which does not smell bad, or the like is used as the airtight material 6 according to the target or ease of procurement. Even if the airtight material 6 is not constructed, in the case of a soil structure in which a highly-airtight impervious layer is widely formed in the upper-layer area of the target underground 1b of the soil improvement, the airtight material 6 may be replaced by the impervious layer (not illustrated).

However, because the already-existing construction foundation 7 and aboveground structure 8 are located in the ground surface 1a of the underground 1b of the laminated-layer soil 1 including the sand layers 1_1 and 1_3 and the cohesive layer 1_2 which become the improvement target, the configuration of the supplying facilities 3 in Step (3) is changed to perform curve boring to the lower-layer soil below the construction foundation 7 unlike the perforated

pipe 3a vertically disposed as illustrated in FIG. 2, and the perforated pipe 3a is horizontally placed while laying between the right and left of the construction foundation 7. Therefore, the permanent grout 9 such as the foaming material can be effectively supplied in Step (6).

Other configurations are similar to those of Steps (2), (3), (5), (6), and (8) to (10).

A physical phenomenon generated in the underground 1b that becomes the soil improvement target will microscopically be described along with the function that is exerted more effectively by adopting the super well point method as the groundwater pumping step in the embodiment.

As illustrated in FIG. 4, soil particles 4a mainly constituting the underground 1b, groundwater 4b in the form of free water, adsorption water 4c adsorbing adsorbed to the soil particles 4a with a physicochemical (electric) binding force, and an air bubble 4d existing in the free water 4b exist in a steady state before the soil improvement construction.

As illustrated in FIG. 5, in the state of the underground 1b after the pressure-reducing action of the underground 1b and the pumping of the groundwater 4b are performed in Step (5), the groundwater 4b is collected into the well 2 because the groundwater 4b is in the state of the free water 4b, and only the soil particles 4a and the adsorption water 4c exist. At this point, the pressures in fields of the soil particles 4a and the adsorption water 4c

substantially become a vacuum state 4e. The improvement of the vacuum level makes a difference between the well point method and the super well point method, which allows the grout material 9 such as the air cement milk and the foaming material to be smoothly supplied to the underground 1b to maximize the supply of the grout material (Details will be described later). Therefore, the improvement of the vacuum level becomes extremely effective means in the condition that the super well point method can be adopted.

As illustrated in FIG. 6, in the state in which the grout material is supplied to the underground 1b from the ground surface 1a in Step (6), the area that is temporarily put in the substantial vacuum state 4e is filled with the supplied air.

As illustrated in FIG. 7, in the state in which the groundwater 4b is recharged into the underground 1b to recover the groundwater surface 1c up to the groundwater level in the steady state in Step (9), the free water 4b invades the area filled with the air, and the amount of air existing in the groundwater 4b is increased. Therefore, the air content of the groundwater 4b is increased. Because a degree of unsaturation of the groundwater 4b that is usually in the unsaturated state further progresses, a water ratio is relatively decreased to restrain an increase in water pressure of gap water existing between the soil particles, and a frictional force between soil particles is decreased. Therefore, the soil can be improved.

FIGS. 9 and 10 illustrates the gate-shape construction 8 such as a crane in which a horizontal beam 8" is supported by right and left support posts 8'. In FIGS. 9 and 10, after consolidated dewatering is performed early to uneven settlement of the foundation portions 7' supporting the construction by vacuum dewatering using at least the two super well point methods, the permanent grout material 9 such as the foaming material is injected below the foundation portion 7' by the curved perforated pipe 3a of FIG. 3, so that the foundation portion can be lifted up.

FIG. 11 illustrates comparison of the loose sandy soil improvement work. That is, in the case of only the conventional dynamic consolidation method (FIG. 11(b)), the strength is not increased too much because of a weak shock below the groundwater surface generated by the dynamic consolidation method, and it cannot be expected that the strength is increased in the cohesive soil and below. Therefore, as illustrated in FIG. 11(a), when at least the two super well point methods are used in addition to the dynamic consolidation method, the consolidated dewatering is performed early by the vacuum dewatering, and the groundwater level is lowered, so that the shock generated by the dynamic consolidation method can be transmitted to a deeper portion and the dewatering of the cohesive soil layer 1₂ can be performed by the vacuum effect.

Referring to FIG. 12, in at least the two super well point methods, a large amount of water ($Q \approx 1$ to 4.0 t/min) is delivered to the underground, and the vacuum suction is

performed at a high vacuum level ($P_v = -0.1$ to 0.08 MP). The water delivery is substantially equal to the vacuum suction in time.

A fine component of the sand is removed to adjust a matrix of the particles, thereby increasing the strength of the sandy soil (see FIG. 13). The decrease in strength of the sandy soil is attributed to the fact that the sand largely contains colloid and silt components. The hydraulic filling effect can be expected by the swing effect.

CLAIMS

1. A soil improvement method comprising:

a step of constructing an impervious wall (5) to a necessary depth so as to surround an underground (1b) of soil (1) using a steel sheet pile, and of extending a perforated pipe (3a) to the underground (1b) in the impervious wall (5), a grout material (9) being supplied to the underground (1b) from a ground surface (1a) of the soil (1) through the perforated pipe (3a);

a step of covering the ground surface (1a) of the impervious wall (5) with an airtight material (6) such as an airtight sheet, a pavement with a concrete material or an asphalt material, and new sludge;

a step of pumping groundwater through at least two wells (2) to lower a groundwater surface to a necessary water level by a super well point method in which the wells (2) are drilled in the underground (1b) in the impervious wall (5) at a predetermined interval, the ground surface (1a) being covered with the airtight material (6) in the impervious wall (5), and of putting the region in a vacuum state by deaerating unsaturated soil in a region by the groundwater pumping, the region being surrounded by the impervious wall (5), thereby vacuum-evaporating water of the underground (1b) to perform dewatering;

a step of supplying a grout material (9) such as air cement milk and a foaming material from the ground surface (1a) into the underground (1b) through the perforated pipe (3a); and

a step of recharging the groundwater into the underground (1b) to a natural groundwater level.

2. The soil improvement method according to claim 1, wherein an operation of the super well point method in which at least the two wells (2) are provided at the predetermined interval is stopped, or the airtight material (6) with which the ground surface (1a) is covered is removed while the operation of the super well point method is stopped, and

air is supplied by natural air supply generated by a difference in pressure between the underground (1b) and the ground surface (1a).

3. The soil improvement method according to claim 1, wherein lower-layer soil is drilled with a curve boring machine to make a hole toward a horizontal direction from the right and left of an already-existing construction foundation (7) and an aboveground structure (8) which are placed in the ground surface (1a),

the perforated pipe (3a) is inserted into the hole to lay the perforated pipe (3a) between the right and left of the already-existing construction foundation (7), and

the grout material (9) is injected from the perforated pipe into the underground (1b) to lift up the unevenly-settled construction (8).