

SOIL-VOLUME REDUCTION METHOD

DESCRIPTION

TECHNICAL FIELD

[0001]

The present invention relates to a soil-volume reduction method and more specifically to a soil-volume reduction method capable of significantly reducing the volume of soil in comparison to conventional methods.

BACKGROUND ART

[0002]

In recent years, there has been a shortage of sites for disposing surplus soil resulting from dredging work and the like. Since it is difficult to find new disposal sites or large disposal sites, it is necessary to efficiently use limited disposal sites. One way to solve this problem is soil volume reduction. For example, when an offshore disposal site is constructed, the volume of the reclamation soil is sometimes reduced by a vacuum consolidation method to increase the capacity of the disposal site (see Patent Document 1, for example).

[0003]

In the vacuum consolidation method, many vertical drains are installed in target soil, and a vacuum pump is then operated with the ground surface covered with an airtight sheet or the like to thereby discharge pore water in the soil to the outside through the vertical drains. As a result, the consolidation of the target soil is promoted and its volume is accordingly reduced. In other words, in this method, a negative pressure load with respect to atmospheric pressure is applied to the soil. This means that the method only allows volume reduction based

on the generally-known relationship between pressure and consolidation settlement amount and therefore cannot achieve further volume reduction. For this reason, there has been a demand for a different method to achieve significant volume reduction which has been desired today.

[0004]

As another volume reduction method, a fill surcharge method has been known in which fill is placed on top of target soil to reduce its volume. In this method, however, since the soil is consolidated by the load from the fill, it is difficult to significantly reduce the volume of the target soil.

PRIOR ART DOCUMENT

PATENT DOCUMENT

[0005]

Patent Document 1: Japanese patent application Kokai publication No. 2009-167707

SUMMARY OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0006]

An object of the present invention is to provide a soil-volume reduction method capable of significantly reducing the volume of soil in comparison to conventional methods.

MEANS FOR SOLVING THE PROBLEM

[0007]

To achieve the above object, according to a first aspect of the present invention, a soil-volume reduction method of the present invention is characterized in that the soil-volume reduction method includes: agitating target soil to a prescribed depth in a prescribed range to thereby form a disturbed region in the target soil, 30% to 80% inclusive of

the volume of the target soil being formed into the disturbed region; and then installing a drain in the target soil and discharging water in the target soil out

of the target soil through the drain to thereby increase an amount of consolidation of the target soil and thus reduce a volume thereof.

[0007a]

According to a third aspect of the present invention, a soil-volume reduction method is characterized in that the soil-volume reduction method comprises: agitating target soil to a prescribed depth in a prescribed range to thereby form a disturbed region in the target soil, 50% or more of the volume of the target soil being formed into the disturbed region; and then installing a drain in the target soil and discharging water in the target soil out of the target soil through the drain to thereby increase an amount of consolidation of the target soil and thus reduce a volume thereof.

[0008]

Here, a drain method performed under atmospheric pressure can be used for the discharge of the water in the target soil out of the target soil through the drain. Alternatively, a vacuum consolidation method performed under a negative pressure can be used. Also, a downward load can be applied to the target soil after the discharge of the water in the target soil out of the target soil through the drain. For example, the downward load is applied by placing dirt on the target soil in which the disturbed region is formed. To form the disturbed region, an agitating blade of a soil improving apparatus is rotated in the target soil, for example. For example, 30% to 80% inclusive of the volume of the target soil is formed into the disturbed region. Alternatively, 50% or more of the volume of the target soil is formed into the disturbed region.

EFFECTS OF THE INVENTION

[0009]

According to the present invention, as the initial step, the disturbed region is formed in the target soil to thereby artificially destruct the structure between clay particles in the soil and significantly reduce the durability (resistance) thereof against external force (load). Then, the drain is installed in the target soil and the water in the target soil is discharged out of the target soil through the drain. Thus, it is possible to achieve a higher level of volume reduction effect, rather than an extension of the volume reduction effect based on the generally-known relationship between pressure and

consolidation settlement amount. Also, in a case where a sand layer is present in the target soil, performing a vacuum consolidation method as the initial step makes it difficult to ensure airtightness such that a sufficient volume reduction effect might not be achieved. In the present invention, however, such a problem never occurs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

[Fig. 1] Fig. 1 is an explanatory view exemplarily showing an agitating step of the present invention of agitating on-land target soil.

[Fig. 2] Fig. 2 is an explanatory view exemplarily showing a step of discharging water in the target soil in which a disturbed region is formed, out of the target soil under atmospheric pressure through drains.

[Fig. 3] Fig. 3 is an explanatory view exemplarily showing a state where the volume of the target soil in Fig. 2 is reduced.

[Fig. 4] Fig. 4 is an explanatory view exemplarily showing a step of adding a downward load to the target soil, in which the disturbed region is formed, by placing dirt on the target soil.

[Fig. 5] Fig. 5 is an explanatory view exemplarily showing an agitating step of the present invention of agitating seafloor target soil.

[Fig. 6] Fig. 6 is an explanatory view exemplarily showing a step of discharging water in the seafloor target soil in which a disturbed region is formed, out of the target soil through drains.

[Fig. 7] Fig. 7 is an explanatory view exemplarily showing a step of discharging the water in the target soil, in which

the disturbed region is formed, above the ground by a vacuum consolidation method.

[Fig. 8] Fig. 8 is an explanatory view exemplarily showing a state where the volume of the target soil in Fig. 7 is reduced.

[Fig. 9] Fig. 9 is a plan view exemplarily showing the target soil in which the disturbed region is formed.

[Fig. 10] Fig. 10 is a plan view showing another example of the target soil in which the disturbed region is formed.

[Fig. 11] Fig. 11 is a plan view showing still another example of the target soil in which the disturbed region is formed.

[Fig. 12] Fig. 12 is a side view exemplarily showing the target soil in which the disturbed region is formed.

[Fig. 13] Fig. 13 is a side view showing another example of the target soil in which the disturbed region is formed.

[Fig. 14] Fig. 14 is a graph showing the relationship between the void ratio of and the consolidation pressure on each of sample specimens in a standard consolidation test.

[Fig. 15] Fig. 15 is a graph showing the relationship between the volume strain of and the consolidation pressure on each of the sample specimens in the standard consolidation test.

[Fig. 16] Fig. 16 is a graph showing the relationship between the volume strain of and the consolidation pressure on the actual soil.

[Fig. 17] Fig. 17 is a graph explaining the volume reduction effect by the present invention and a vacuum consolidation method.

MODES FOR CARRYING OUT THE INVENTION

[0011]

A soil-volume reduction method of the present invention will be explained below based on embodiments shown in the

drawings.

[0012]

As exemplarily shown in Fig. 1, in the soil-volume reduction method of the present invention, initially, target soil 5 is agitated to form a disturbed region 6 in the target soil 5. The target soil 5 is mainly cohesive soil. In this agitating step, the target soil 5, which has been selected in advance, is agitated to a prescribed depth in a prescribed range by using a soil improving apparatus 1, for example.

[0013]

The soil improving apparatus 1 includes agitating blades 3 mounted on a rotary shaft 2, and the rotary shaft 2 is rotationally driven by a hydraulic motor 4. The agitating blades 3 are mounted at two levels on the upper and lower sides of the rotary shaft 2 but the number of levels to mount the agitating blades 3 can be one, three, or any other suitable number. The number of agitating blades 3 provided along the horizontal direction at each level is two in this embodiment but the number can be one, three, or any other suitable number. The number of rotary shafts 2 is not limited to one and can be two or more.

[0014]

By lowering this rotary shaft 2 to a prescribed position and rotating the agitating blades 3 in the target soil 5, a cylindrical disturbed region 6 is formed. When the agitating blades 3 (rotary shaft 2) are rotated and raised above the ground, the agitating step at one spot ends. Thereafter, the agitating blades 3 (rotary shaft 2) are moved to a different position on the plane. At this different position, similarly, the rotary shaft 2 is lowered and the agitating blades 3 are rotated in

the target soil 5 to thereby form another disturbed region 6. Similar processes are sequentially repeated to form disturbed regions 6 to the prescribed depth in the prescribed range in the target soil 5.

[0015]

The agitating step of forming the disturbed regions 6 can be performed not only by means of the soil improving apparatus 1 but by means of various other apparatuses and methods. For example, it is possible to employ penetration and pulling of a rod with vibration with a sand compaction pile apparatus, penetration and pulling of a rod with a PBD (plastic board drain) apparatus, agitation with an earth auger, or rotational agitation or drilling with a boring machine. Alternatively, it is possible to employ a combination of these apparatuses and methods including the soil improving apparatus 1.

[0016]

The disturbed regions 6 are regions in which the bond between soil particles has weakened, thereby making it easier for pore water to move, as compared to before the disturbance. The degree of disturbance of the target soil 5 can be adjusted by the speed of raise and lowering of the agitating blades 3 and the speed of rotation of the agitating blades 3. The degree of disturbance may be increased by rotating the agitating blades 3 while reducing the speed of raise and lowering of the agitating blades 3 or fixing the agitating blades 3 at a given position (increasing the time for which the agitating blades 3 are fixed). Alternatively, the degree of disturbance may be increased by agitating the soil while increasing the speed of rotation of the agitating blades 3. The degree of disturbance may be reduced by performing operation opposite to the operation to

increase the degree of disturbance.

[0017]

During the agitating step, water can be added to the target soil 5 to make it easier to form the disturbed regions 6. For example, ejection ports may be provided in the agitating blades 3 and water may be ejected through these ejection holes to add water to the target soil 5.

[0018]

As exemplarily shown in Fig. 2, after the agitating step, a water discharging step is performed by installing drains 7 in the target soil 5. In this embodiment, a general drain method is used in which a water discharging step is performed using the drains 7 under atmospheric pressure. Known drains can be used as the drains 7 and a known installing apparatus can be used to install the drains 7. The drains 7 are vertically installed at suitable intervals to positions near the bottoms of the disturbed regions 6.

[0019]

Under atmospheric pressure, water (pore water) W in the target soil 5 is discharged above the ground through the drains 7. The discharged water W is transferred to a different location by using horizontal drains or the like and discharged there.

[0020]

In the disturbed regions 6, the bond between clay particles has been artificially destructed, and the target soil 5 is therefore loose as compared to before the disturbance. Since the drains 7 are installed in this loose target soil 5, the discharge of the pore water between clay particles above the ground through the drains 7 is promoted, so that the amount

of consolidation accordingly increases and downward settlement occurs. Specifically, the volume of the disturbed regions 6 is reduced as exemplarily shown in Fig. 3.

[0021]

According to the present invention in which the agitating step is initially performed to form the disturbed regions 6, it is possible to achieve a higher level of volume reduction effect as will be described later, rather than an extension of the volume reduction effect based on the generally-known relationship between pressure and consolidation settlement amount. Hence, the present invention is capable of significantly reducing the volume of the target soil 5 in comparison to conventional methods. Thus, in a case of constructing an offshore disposal site or the like, the present invention is preferable for increasing its capacity.

[0022]

Also, in a case where a sand layer is present in the target soil 5, performing a vacuum consolidation method as the initial step makes it difficult to ensure airtightness such that a sufficient volume reduction effect might not be achieved. In the present invention, however, even if a sand layer is present in the target soil 5, the sand layer is disturbed with the cohesive soil by the agitating step, which is performed initially. For this reason, the problem of being unable to achieve a sufficient volume reduction effect never occurs.

[0023]

Assume for an example a case where ground with contaminated soil is excavated, and the dirt resulting therefrom need to be transported and disposed outside the site. In this case, an extremely high disposal cost is required.

However, by applying the present invention to reduce the volume of the soil, it is possible to avoid the transport and disposal of the dirt outside the site.

[0024]

After the water W in the target soil 5 is discharged above the ground through the drains 7, a downward load can be applied to the top of this target soil 5. By doing so, the amount of consolidation of the target soil 5 can be further increased and its volume can be accordingly reduced. In this loading step, as exemplarily shown in Fig. 4, dirt 8 such as dirt resulting from construction or dirt resulting from dredging is placed on the target soil 5, in which the disturbed regions 6 are formed. The weight of the placed dirt 8 applies a downward load to the target soil 5. Alternatively, rocks, concrete masses, or the like can instead be placed on top of the target soil 5 to apply a downward load thereto. Since a downward load is persistently applied to the target soil 5 by simply placing the dirt 8 or the like on top of the target soil 5, the man-hours for the loading step are significantly reduced.

[0025]

The method of applying a downward load to the target soil 5 is not limited to the above method, and a different method can be used instead. For example, the target soil 5, in which the disturbed regions 6 are formed, can be subjected to vacuum consolidation by a known vacuum consolidation method to apply a downward load to the target soil 5.

[0026]

There are cases where the target soil 5 is not on-land soil but seafloor soil. In such cases, as exemplarily shown in Fig. 5, the target soil 5 is agitated in a similar manner

using the soil improving apparatus 1 mounted on a work ship 13 to form disturbed regions 6. After the agitating step, as exemplarily shown in Fig. 6, a water discharging step is performed under atmospheric pressure (water pressure is also added) by installing the drains 7 in the target soil 5 in a manner similar to the water discharging step performed on on-land soil. The subsequent steps are similar to those performed on on-land soil.

[0027]

The strength of the disturbed regions 6 which are formed by initially performing the agitating step has been decreased in comparison to that before the disturbance. In a case where the decrease in strength is large, the target soil 5 might be too unstable to perform the work of installing the drains 7 and the work of placing the dirt 8 on the target soil 5 thereafter. Here, in the case where the target soil 5 is seafloor soil, this problem never occurs since the workers, the apparatus, and other relevant elements are on the work ship.

[0028]

Thus, in the case where the decrease in strength of the disturbed regions 6 is large, a different embodiment is employed. In this different embodiment, the agitating step is initially performed as exemplarily shown in Fig. 1 to form the disturbed regions 6 in the target soil 5, and then the target soil 5, in which the disturbed regions 6 are formed, is subjected to vacuum consolidation by a known vacuum consolidation method as exemplarily shown in Fig. 7. In the vacuum consolidation method, drains 11 for vacuum consolidation are installed in the disturbed regions 6, and upper end portions of these drains 11 are coupled to a water collecting pipe 12 connected to a vacuum

pump 9. The top of the target soil 5 is covered with a seal layer 10 having good airtightness. As the method of forming the seal layer 10, a method has been known which involves covering the upper end portions of the drains 11 for vacuum consolidation with caps or cover members.

[0029]

By operating the vacuum pump 9 in this state, the water W in the target soil 5 is discharged above the ground through the drains 11 under negative pressure. As a result, as exemplarily shown in Fig. 8, the amount of consolidation of the target soil 5 is increased and its volume is accordingly reduced. With the volume reduction, the strength of the target soil 5 increases. Thus, various kinds of work can then be performed safely on the target soil 5. For example, as exemplarily shown in Fig. 4, the dirt 8 is placed on the target soil 5, in which the disturbed regions 6 are formed, to apply a downward load to the target soil 5. As a result, the amount of consolidation of the target soil 5 can be further increased and its volume can be accordingly reduced.

[0030]

To sufficiently reduce the volume of the target soil 5, the proportion of the disturbed regions 6 in the volume of the target soil 5 is set to 30% or more and more preferably 50% or more. The volume reduction can be maximized if the proportion of the disturbed regions 6 is 100%, but a sufficient volume reduction effect can be achieved and the man-hours for forming the disturbed regions 6 can also be reduced as long as the proportion is 30% or more and more preferably 50% or more. Considering the effect of volume reduction of the target soil 5 and the man-hours for the work in the agitating step, the

proportion of the disturbed regions 6 in the volume of the target soil 5 is set between 30% and 80% inclusive and more preferably between 50% and 80% inclusive.

[0031]

In the agitating step, the disturbed regions 6 can be formed in various patterns to account for the prescribed volume proportion in the volume of the target soil 5. For example, as shown in Fig. 9, the agitating step may be performed such that cylindrical disturbed regions 6 formed by the agitating blades 3 of the single rotary shaft 2 are arranged adjacently side by side in a matrix on the plane of the target soil 5. Alternatively, as exemplarily shown in Fig. 10, the agitating step may be performed such that cylindrical disturbed regions 6 formed by the agitating blades 3 of the single rotary shaft 2 overlap each other, and these disturbed regions 6 formed to overlap each other are arranged adjacently side by side in a matrix on the plane of the target soil 5. Still alternatively, as exemplarily shown in Fig. 11, the agitating step may be performed such that cylindrical disturbed regions 6 formed by the agitating blades 3 of the single rotary shaft 2 are arranged in a lattice pattern on the plane of the target soil 5. In the present invention, the pattern of the disturbed regions 6 is not limited to the above-mentioned patterns, and the disturbed regions 6 can be formed by randomly agitating the entire target soil 5.

[0032]

As for the depth of the disturbed regions 6, as exemplarily shown in Fig. 12, the agitating step may be performed such that all of cylindrical disturbed regions 6 formed by the agitating blades 3 of the single rotary shaft 2 have the same prescribed

depth. Alternatively, as exemplarily shown in Fig. 13, the agitating step may be performed such that some or all of cylindrical disturbed regions 6 formed by the agitating blades 3 of the single rotary shaft 2 have different depths. For example, the proportion of the volume of the disturbed regions 6 in the volume of the target soil 5 may be set to the prescribed proportion by appropriately combining any of the states of formation of the disturbed regions 6 on the plane exemplarily shown in Figs. 9 to 11 and any of the states of formation of the disturbed regions 6 in the depth direction exemplarily shown in Figs. 12 and 13.

[0033]

Note that the volume of the target soil 5 in which to form the disturbed regions 6 is set in advance but may be determined as follows, for example. In the plane direction, the area of the region surrounded by a line connecting the outermost edges of disturbed regions 6 is determined as the area of the base. Specifically, in each of Figs. 9 to 11, the area of the region surrounded by the dotted line is determined as the area of the base. In the depth direction, the depth of the deepest position of the entire disturbed region 6 is determined as the height. Further, the volume calculated by multiplying the area of the base by the height mentioned above is determined as the volume of the target soil 5.

EXAMPLE

[0034]

A soil specimen (cylindrical cohesive soil with a height of approximately 100 mm) was collected from a field and subjected to a standard consolidation test (JIS A 1217: consolidation test using incremental loading), the soil

specimen being a homogeneous soil specimen in a near in-situ condition with minor disturbance. The properties of the soil specimen are shown in Table 1. Three types of sample specimens were prepared by taking out a center portion of the soil specimen in the height direction having a height of 30 mm and taking out portions above and below of the center portion each having a height of 30 mm. The first type of sample specimen (specimen A) was prepared by inserting the taken soil specimen into a consolidation ring with a prescribed size without processing it. The second type of sample specimen (specimen C) was prepared by agitating the entire soil specimen such that the entire soil specimen was completely remolded into a disturbed state without the water content changed, and then by inserting the soil specimen into the consolidation ring. The third type of sample specimen (specimen B) was prepared by agitating a half of the soil specimen such that the half of the soil specimen was completely remolded into a disturbed state without the water content changed, while cutting the other half into blocks with sizes of 3 mm to 5 mm square with a cutter, and then by evenly mixing the disturbed soil specimen and the undisturbed blocks of the soil specimen and inserting them into the consolidation ring.

[0035]

Figs. 14 and 15 show the results of the consolidation test on the specimens A, B, and C. In the figures, the circles represent the specimen A, the triangles represent the specimen B, and the diamonds represent the specimen C. σ'_{v0} (200 kPa) in the figures denotes an effective overburden pressure. Fig. 15 is a graph presenting the volume strain of the sample specimen on the vertical axis in place of the void ratio e in Fig. 14.

[0036]

[Table 1]

Soil Specimen Collection Depth (G.L.-m)		13.55
Density ρ_s (g/cm ³)		2.627
Liquid Limit (%)		97.1
Plastic Limit (%)		72.4
Shrinkage Limit (%)		36.5
Composition Ratio	Sand Fraction (% by weight)	1
	Silt Fraction (% by weight)	42
	Clay Fraction (% by weight)	57

[0037]

From the results in Figs. 14 and 15, it can be seen that the difference in the proportion of the disturbed portion among the sample specimens leads to greatly different consolidation pressure-void ratio curves (consolidation pressure-volume strain curves). Specifically, the larger the proportion of the disturbed portion, the farther the consolidation pressure-void ratio curve (consolidation pressure-volume strain curve) moves downward. It can be seen that at the same consolidation pressure, the void ratio e (or the volume strain) is smaller and the amount of consolidation is accordingly larger for the disturbed specimens B and C than for the undisturbed specimen A, and hence the disturbed specimens B and C are more advantageous for volume reduction than the undisturbed specimen A. It can be seen that the disturbed specimens B and C are even more advantageous for volume reduction than the undisturbed specimen A particularly under the effective overburden pressure.

Also, the volume reduction effect is smaller only slightly for the specimen B than for the specimen C, showing that a sufficient volume reduction effect can be achieved even for the specimen B (50% of the entire volume is disturbed).

[0038]

Note that the actual consolidation pressure-volume strain curve of this in-situ soil is as shown by the dotted line in Fig. 16. Specifically, even the undisturbed specimen A is affected by the disturbance resulting from the collection of the specimen (boring, release of strain, etc).

[0039]

In Fig. 17, e_1 represents the degree of decrease in the void ratio e as a result of simply using a vacuum consolidation method without disturbing the soil. In the vacuum consolidation method, a negative pressure of about 70 to 80 kPa is generally set. Then, the degree of decrease e_1 may be calculated as the difference between a point at the effective overburden pressure σ'_{v0} (200 kPa) on the curve representing the data on the specimen A and a point thereon moved by increasing the consolidation pressure by 75 kPa. In this figure, the degree of decrease e_1 in the void ratio e for the specimen A is about 0.07.

[0040]

On the other hand, in the case where 50% of the volume is disturbed by initially performing an agitating step (specimen B), the void ratio e moves downward from the point at the point at the effective overburden pressure σ'_{v0} (200 kPa) on the curve representing the data on the specimen A to the curve representing the data on the specimen B. Thus, the degree of decrease in the void ratio e for the specimen B relative to the

specimen A is e_2 , which is approximately 0.35, and significant volume reduction can be expected. In the case where 50% of the volume is disturbed (specimen B), the void ratio e thereafter decreases along the curve representing the data on the specimen B, so that the degree of decrease in the void ratio e relative to the specimen A reaches e_3 , for example. Even greater volume reduction can be expected for the same reason for the case where 100% of the volume is disturbed by initially performing an agitating step (specimen C). As described above, it can be seen that the present invention can achieve a significant volume reduction effect in comparison to the conventional vacuum consolidation method.

EXPLANATION OF REFERENCE NUMERALS

[0041]

- 1 soil improving apparatus
- 2 rotary shaft
- 3 agitating blade
- 4 hydraulic motor
- 5 target soil
- 6 disturbed region
- 7 drain
- 8 dirt
- 9 vacuum pump
- 10 seal layer
- 11 drain for vacuum consolidation
- 12 water collecting pipe
- 13 work ship

CLAIMS

[Claim 1] A soil-volume reduction method, characterized in that the soil-volume reduction method comprises:

agitating target soil to a prescribed depth in a prescribed range to thereby form a disturbed region in the target soil, 30% to 80% inclusive of the volume of the target soil being formed into the disturbed region; and

then installing a drain in the target soil and discharging water in the target soil out of the target soil through the drain to thereby increase an amount of consolidation of the target soil and thus reduce a volume thereof.

[Claim 2] A soil-volume reduction method, characterized in that the soil-volume reduction method comprises:

agitating target soil to a prescribed depth in a prescribed range to thereby form a disturbed region in the target soil, 50% or more of the volume of the target soil being formed into the disturbed region; and

then installing a drain in the target soil and discharging water in the target soil out of the target soil through the drain to thereby increase an amount of consolidation of the target soil and thus reduce a volume thereof.

[Claim 3] The soil-volume reduction method according to any one of claims 1 and 2, characterized in that the discharge of the water in the target soil out of the target soil through the drain is done by a drain method performed under atmospheric pressure.

[Claim 4] The soil-volume reduction method according to any

one of claims 1 and 2, characterized in that the discharge of the water in the target soil out of the target soil through the drain is done by a vacuum consolidation method performed under a negative pressure.

[Claim 5] The soil-volume reduction method according to any one of claims 1 to 4, characterized in that the soil-volume reduction method further comprises applying a downward load to the target soil after the discharge of the water in the target soil out of the target soil through the drain.

[Claim 6] The soil-volume reduction method according to claim 5, characterized in that the downward load is applied by placing dirt on the target soil in which the disturbed region is formed.

[Claim 7] The soil-volume reduction method according to any one of claims 1 to 6, characterized in that the disturbed region is formed by rotating an agitating blade of a soil improving apparatus in the target soil.