

## DESCRIPTION

### GROUND IMPROVEMENT METHOD AND DECOMPRESSION VESSEL

#### TECHNICAL FIELD

[0001]

The present invention relates to a ground improvement method by vacuum consolidation and a decompression vessel that can be adopted in the ground improvement method.

#### BACKGROUND ART

[0002]

A suction apparatus in which a vacuum pump is used is well known as an apparatus that generates a suction power to suck and drain water. In a conventional method of the background art, for example, after a vertical drain is driven into a soft ground, a ground is decompressed by action of a negative pressure with the suction using vacuum pump, thereby promoting consolidation of the ground (for example, see Patent Literatures 1 to 3). As disclosed in Patent Literature 4, one of the inventors and another inventor have proposed a suction power generator in which a vertical pipe is inserted in a decompression chamber and an air-liquid two-phase flow formed in the vertical pipe to facilitate a siphon function.

#### CITATION LIST

##### PATENT LITERATURES

[0003]

Patent Literature 1: Japanese Patent Application Laid-Open  
No. 2000-328550

Patent Literature 2: Japanese Patent Application Laid-Open  
No. 2001-226951

Patent Literature 3: Japanese Patent Application Laid-Open  
No. 2002-138456

Patent Literature 4: Japanese Patent Application Laid-Open  
No. 2010-090696

#### SUMMARY OF THE INVENTION

#### TECHNICAL PROBLEM

[0004]

In the case that both the vacuum pump and the suction power of the siphon are used to suck and drain water as described in Patent Literature 4 of the subject ground in a land area, a decompression vessel including a vertical long drain pipe is necessary to facilitate siphon function. In the case that the decompression vessel is introduced for the purpose of soft ground improvement in the land area, it is necessary to install the decompression vessel in the earth. Therefore, methods for producing and installing the decompression vessel become troublesome. Particularly, in the case that the decompression vessel is produced in the field, frequently it is difficult to produce the decompression vessel having sufficient strength and airtightness. Additionally, it is necessary that the siphon

function stably because of a construction condition in which air is apt to be mixed by a leakage of airtightness and vaporization of a dissolved gas in a high negative pressure, or the like.

[0005]

In view of the foregoing, an object of the invention is to provide a decompression vessel that can be produced in the ground improvement of subject area with sufficient strength and airtightness, and a ground improvement method enabling to install the decompression vessel.

#### SOLUTION TO PROBLEM

[0006]

In order to solve the problem, a ground improvement method is characterized in that:

a decompression vessel in the earth is completed through: a step of driving a steel pipe into the earth, the steel pipe including a ring portion projecting from inner surface in an upper portion thereof; a step of removing soils from the driven steel pipe; a step of installing a bottom plate on a bottom side of the steel pipe; and a step of putting a cover on the ring portion of the steel pipe while a drain pipe connected to a lift pump accommodated in the steel pipe, a suction pipe connected to a vacuum pump, and a vertical pipe through which a siphon functions, project through the cover,

the cover is brought into close contact with the ring portion

of the steel pipe by negative pressure generated in operating the vacuum pump, and

a suction power by the vacuum pump and a suction power by a siphon function of the vertical pipe are exerted to extract and drain pore water in a ground to be improved through a vertical drain member placed into the ground.

[0007]

According to the ground improvement method, the easily-available steel pipe having a strength is driven into the ground, and the cover is put on the ring portion of the steel pipe, so that the decompression vessel can easily be completed in the earth. The cover is brought into close contact with the ring portion by operating the vacuum pump, and the airtightness of the decompression vessel can be ensured with no use of attaching and fixing means such as bolting and welding. The vessel body in which the vertical pipe, through which the siphon functions, is accommodated can be constructed by the steel pipe. Therefore, the decompression vessel can easily be produced in the ground area subject for improvement, and the ground can easily be improved by the vacuum consolidation method.

[0008]

In the ground improvement method, an airtight member made of an elastic material is provided between the cover and the ring portion. Therefore, the airtightness of the decompression vessel can be enhanced.

[0009]

In the case that the decompression vessel is installed in the soft ground such that the distance between a position of the bottom plate of the steel pipe and a lower end position of the steel pipe becomes more than at least a half of a diameter of the steel pipe, stability of the decompression vessel can be ensured even an upward buoyancy is applied to the decompression vessel.

[0010]

In order to solve the problem, a decompression vessel for being installed in the earth and an inside of the vessel being decompressed by a vacuum pump, characterized by comprising:

a steel pipe to be placed as a vessel body in the earth;  
a bottom plate provided on a bottom side of the vessel body; and  
a cover for closing the vessel body,

wherein the cover has a structure in which the cover is put on a placed portion of the vessel body, and the cover is brought into close contact with the placed portion by a negative pressure generated in operating the vacuum pump.

[0011]

According to the decompression vessel, the vessel body using the vertical pipe, through which the siphon functions, is accommodated can be constructed by the easily-available steel pipe having a strength, and the cover has the structure that put on the placed portion of the vessel body, and the cover is brought into close contact with the placed portion by operating the vacuum

pump, so that the decompression vessel can be produced in the ground area subject to improvement with sufficient strength and airtightness.

[0012]

In the decompression vessel, preferably the steel pipe includes a ring portion provided so as to project from an inner surface in an upper portion thereof, the cover is put on the ring portion while the ring portion is used as the placed portion, and it is preferable that an airtight member made of an elastic material is placed between the cover and the ring portion. Therefore, the airtightness of the decompression vessel can be enhanced by simple configuration.

[0013]

The airtightness of the decompression vessel can further be enhanced such that the airtight member includes a high packing that is easily deformed and a low packing that is hardly deformed.

[0014]

The ground improvement method can be performed by installing the decompression vessel in the earth.

#### EFFECT OF THE INVENTION

[0015]

Accordingly, the invention can provide a decompression vessel that can be produced in the ground area subject to improvement with the sufficient strength and airtightness, and

the ground improvement method enabling to install the decompression vessel.

#### BRIEF DESCRIPTION OF DRAWINGS

[0016]

Fig. 1 is a schematic illustration of a configuration of vacuum consolidation ground improvement system including a decompression vessel in which a ground improvement method by vacuum consolidation according to an embodiment can be performed.

Fig. 2(a) is a top view of a steel pipe of the decompression vessel in Fig. 1 when viewed from top, and Fig. 2(b) is a top view of a rubber packing section on a ring portion of the steel pipe.

Fig. 3 is a flowchart for explaining steps S01 to S12 of the ground improvement method by vacuum consolidation of the embodiment in which the vacuum consolidation ground improvement system in Fig. 1 is used.

Fig. 4(a) is a top view illustrating another example of the configuration of the packing in Fig. 2(b), and Fig. 4(b) is a vertical section of a main part of the packing.

Fig. 5 is a vertical section illustrating the main part of a packing different from the packing in Fig. 4.

Fig. 6 is a view for explaining an example of a configuration in which a lower end position of the steel pipe is sufficiently deeper than the bottom plate position of the steel pipe after the steel pipe in Fig. 1 is driven.

Fig. 7(a) is a view for explaining the problem in the case that the lower end position of the steel pipe is insufficiently deeper than the bottom plate position of the steel pipe after the steel pipe in Fig. 1 is driven, and Fig. 7(b) is a view for explaining the effect in the case of configuration in Fig. 6.

Fig. 8 is a view for explaining a bottom plate that is installed on a bottom side of the steel pipe in Fig. 1.

#### DESCRIPTION OF EMBODIMENTS

[0017]

Hereinafter, an embodiment of the invention will be described with reference to the drawings. Fig. 1 is a schematic illustration of a configuration of vacuum consolidation ground improvement system including a decompression vessel in which a ground improvement method by vacuum consolidation of the embodiment can be performed. Fig. 2(a) is a top view of a steel pipe of the decompression vessel in Fig. 1 when viewed from top, and Fig. 2(b) is a top plan of a state of a rubber packing provided on the a ring portion of the steel pipe.

[0018]

As illustrated in Fig. 1, a vacuum consolidation ground improvement system 1 includes a vertical drain member 11 that is placed in a ground G to be improved and a vacuum decompression device 10 that includes a decompression vessel 20 installed in the earth.

[0019]

The vacuum decompression device 10 includes a vertical drain pipe 21, a horizontal drain pipe 22 that is connected to an upper end of the vertical drain pipe 21, a vacuum pump 23 and a suction pipe 26 that are suction installations, a lift pump 24 and a drain pipe 25 that are drainage installations, and the decompression vessel 20 that is installed in the earth. The vacuum decompression device 10 is installed in a ground G1 near the ground G to be improved. The chamber (inner space) of the decompression vessel 20 is decompressed by the vacuum pump 23, whereby the vacuum decompression device 10 acts as a decompression generation source.

[0020]

The decompression vessel 20 includes a cylindrical steel pipe 29 that constitutes a vessel body and is constructed in the ground G1, a disk-shaped cover 30 that placed on an upper side of the steel pipe 29 in order to close the vessel body to seal the chamber, and a bottom plate 27 provided on a bottom side of the steel pipe 29.

[0021]

After the steel pipe 29 is driven into the earth to remove soils in the steel pipe 29, a solidifying material such as concrete is installed on the bottom side of the steel pipe 29, thereby constructing the bottom plate 27. Therefore, the strength and waterproof can be ensured in a bottom portion of the decompression vessel 20.

[0022]

As illustrated in Figs. 1 and 2(a), a ring portion 28, which is installed into a ring shape so as to project radially from an inner circumferential surface, is provided in an inner surface in an upper portion of the steel pipe 29, and the cover 30 is put on the ring portion 28 while the ring portion 28 is used as support holder of the cover 30. That is, the vertical drain pipe 21, the drain pipe 25, and the suction pipe 26 are attached projecting through the cover 30, and the cover 30 is put on the ring portion 28 provided in the upper portion inside the inner surface of the steel pipe 29. In this case, the cover 30 has a structure in which the cover 30 is simply put on the ring portion 28 of the steel pipe 29 without attaching and fixing means such as bolting and welding.

[0023]

As described above, a steel pipe having a strength is used as the vessel body of the decompression vessel 20, so that the strength of the vessel body can be ensured. Additionally, because the steel pipe is relatively easily available, the steel pipe is suitable for production of the decompression vessel 20 in the field (ground improvement subject area).

[0024]

The cover 30 is put on the ring portion 28 of the steel pipe 29, and the cover 30 comes into close contact with the ring portion 28 by negative pressure action in operating the vacuum pump 23,

thereby maintaining airtightness in the decompression vessel 20. The step of placing the cover 30 by welding or bolt fixing is eliminated, so that the decompression vessel 20 can easily be produced in the field.

[0025]

As illustrated in Fig. 2(b), a packing (O-ring) 31 made of rubber that is an elastic material is provided as an airtight member between the cover 30 and the ring portion 28 of the steel pipe 29, which allows the airtightness to be enhanced between the cover 30 and the ring portion 28.

[0026]

The vertical drain member 11 in Fig. 1 is placed in the soft ground G in order to extract pore water in the soft ground G subject to be improved. An air non-permeable unit 12 connected to the upper end of the vertical drain member 11 is located at a ground water level H0. The upper end of the air non-permeable unit 12 is connected to the horizontal drain pipe 22 of the vacuum decompression device 10 at a ground level S.

[0027]

The plural vertical drain members 11 are placed in soft ground G as needed basis, and the vertical drain members 11 and the air non-permeable unit 12 can constitute, for example, the configuration disclosed in Patent Literatures 2 and 3.

[0028]

The pore water extracted in a direction a in the soft ground

G by the vertical drain member 11 flows in a direction b through the horizontal drain pipe 22 and the vertical drain pipe 21, the pore water is drained from a lower end 21a of the vertical drain pipe 21, and the pore water is reserved in a bottom of the decompression vessel 20. The trapped water is drained outside by the lift pump 24 by flowing in a direction c through the drain pipe 25.

[0029]

Steps S01 to S12 of the ground improvement method by the vacuum consolidation of the embodiment in which the vacuum consolidation ground improvement system in Fig. 1 is to be adopted, will be described below with reference to a flowchart in Fig. 3.

[0030]

Firstly, the ring portion 28 in Fig. 2(a) is provided in the upper portion in the inner surface of the steel pipe 29 (S01). A steel pipe having a diameter of about 800 mm to about 1000 mm is suitable for use as the steel pipe 29, and a general-purpose product for civil engineering and construction such as a steel-pipe pile (SKK400 and SKK490) and a steel-pipe piling board (SKY400 and SKY490) can be used as the steel pipe 29.

[0031]

The steel pipe 29 is driven into the earth near the target ground to be improved with a vibratory hammer and the like (S02). For example, the steel pipe 29 is driven into the ground G1 with a depth of about 4 m. Then, the soils in the steel pipe 29 are

dug out and removed with an auger drill or a hammer grab (S03). Therefore, a decompression chamber 20a is formed in the steel pipe 29 driven into the earth. The dug earth and sand are temporarily stored in a neighborhood of the construction location in order to reuse as backfill the earth and sand after the ground improvement construction. The dug earth and sand may be utilized as a preload materials.

[0032]

Then, a solidifying material such as concrete is constructed on the bottom side of the steel pipe 29 to provide the bottom plate 27 (S04). Therefore, the strength of the bottom surface of the decompression vessel 20 is ensured. Next, the lift pump 24 connected to the drain pipe 25 is accommodated in the bottom of the steel pipe 29 (S05).

[0033]

Next, the cover 30 is put on the ring portion 28 with projecting drain pipe 25, the suction pipe 26, and the vertical drain pipe 21 (S06). In this case, the cover 30 is not fixed to the steel pipe 29 by bolting or welding. A steel plate or a PC (Precast Concrete) plate is suitable to use as the cover 30, and prefabricated in a plant. As to a method for putting the cover 30 on the ring portion 28, for example, a suspension wire is hung on a hook attached to the cover 30, and the cover 30 is put on the ring portion 28 while the suspension wire is slowly lowered.

[0034]

In the step S06, when the rubber packing 31 in Fig. 2(b) adheres previously to the lower region of the cover 30 corresponding to the ring portion 28, handling is facilitated in disposing the packing 31 in the field, and maintenance of the packing 31 is improved. The waterproof is improved when the packing is placed on the ring portion 28 of the steel pipe 29. The packing 31 can be made of a rubber material. Alternatively, the packing 31 may be made of another material such as silicon. [0035]

As described above, the decompression vessel 20 is completed (S07). At the same time as or prior installation of the decompression vessel 20, the vertical drain member 11 is placed in the soft ground G to be improved as illustrated in Fig. 1. The horizontal drain pipe 22 extended from the decompression vessel 20 is connected to the leading end of the air non-permeable unit 12 with a connection unit (not illustrated) overlapping (S08). [0036]

The vacuum pump 23 is operated to decompress the decompression vessel 20 (S09), whereby a negative pressure as high as about  $-70$  to  $-85 \text{ kN/m}^2$  acts on the cover 30. Therefore, the cover 30 and the ring portion 28 of the steel pipe 29 comes into close contact with each other (S10), and the airtightness in the decompression vessel 20 is secured. [0037]

Both the suction power generated by the vacuum pump 23 and

the suction power generated by the siphon function of the vertical drain pipe 21 are exerted and used (11), and the pore water in the soft ground G is extracted and drained (S12), thereby performing the ground improvement by vacuum consolidation. The drained water is reserved in the bottom of the decompression vessel 20, and drained outside through drain pipe 25 with the lift pump 24.

[0038]

In the vacuum consolidation ground improvement system 1 in Fig. 1, in addition to the suction power generated by decompressing the decompression chamber 20a of the decompression vessel 20 with the vacuum pump 23 of the vacuum decompression device 10, a suction power is generated by a siphon function caused by a differential water-level  $\Delta H$  ( $= H_0 - H_1$ ) between the ground water level  $H_0$  and a water level  $H_1$  in the decompression vessel 20, the pore water in the soft ground G is extracted by the suction powers to consolidate the soft ground G. When the vacuum consolidation is compared to the case that the water is sucked only with the vacuum pump 23, the water can be sucked by the larger suction power because of the additional suction power caused by the differential water-level  $\Delta H$ . In the case that the water level  $H_1$  in the decompression vessel 20 does not reach the lower end 21a of the vertical drain pipe 21, the differential water-level  $\Delta H$  is a difference between the ground water level  $H_0$  and the lower end 21a.

[0039]

According to the conventional vacuum consolidation ground improvement construction method, in the case that the suction power becomes insufficient only by use of vacuum pump, a load is applied by banking. On the other hand, in the embodiment, because the load of the banking can be reduced or eliminated by simultaneously use of the suction power that is a natural power by the siphon function, economy of the material and machine to be used and shortening of a work period can be expected. The suction power is increased compared with the conventional construction method, so that a ground improvement period in which the soft ground reaches predetermined strength can be shortened.

[0040]

In the embodiment, desirable length of the vertical drain pipe that functions as the siphon is set to at least about 3 m in order that a negative pressure of at least about  $-80 \text{ kN/m}^2$  acts on the vertical drain member 11 even the negative pressure generated by the vacuum pump 23 is lowered to about  $-50 \text{ kN/m}^2$ .

[0041]

As described above, the relative length of vertical drain pipe 21 is accommodated in the decompression vessel 20 in order to exert the siphon function, and the vessel body in which the vertical drain pipe 21 is accommodated is constructed by the steel pipe, so that the decompression vessel 20 can easily be produced in the field. Therefore, the production of the decompression

vessel 20 has a little influence on the work period of the ground improvement.

[0042]

It is desirable that the decompression vessel 20 has a structure in which the airtightness is maintained. According to the embodiment, the vessel body of the decompression vessel 20 is constructed by the steel pipe 29, the cover 30 has the structure in which the cover 30 is put on the ring portion 28 of the steel pipe 29, and the cover 30 is brought into close contact with the ring portion 28 by negative pressure action in operating the vacuum pump 23, so that the airtightness of the decompression vessel 20 can be maintained. Accordingly, in order to maintain the airtightness of the decompression vessel 20, because the fixing of the cover 30 by welding or bolting is eliminated, the decompression vessel 20 can easily be produced in the field.

[0043]

As described above, the steel pipe is used as the vessel body in order that the decompression vessel 20 is easily produced in the field and to ensure the strength. Even if the diameter of the steel pipe that is available in the field is slightly larger, the decompression vessel 20 can be easily produced in the field by adjusting an outer diameter and an inner diameter of the ring portion 28 relative to the steel pipe, and it is only necessary to prepare the cover 30 having uniform diameter. Because the cover 30 is not fixed to the steel pipe by welding and the like,

in the case that the lift pump is broken down in the decompression vessel in the long-term ground improvement period, the cover is easily detached to replace the pump.

[0044]

The decompression vessel 20 is produced in the field, and dismantled after the construction is completed. That is, when the construction is not performed, only the cover 30 put on the steel pipe 29, the lift pump 24, the vertical drain pipe 21, the suction pipe 26, and the drain pipe 25 connected to the lift pump 24 may be stored and managed. It is not necessary to store the steel pipe 29. Because the steel pipe 29 is the vessel body of the decompression vessel 20 with the large volume, the management is easy to perform.

[0045]

Preferred embodiments of the configuration in Figs. 1 and 2 will be described below with reference to Figs. 4 to 7.

[0046]

Fig. 4(a) is a top view illustrating another example of the configuration of the packing in Fig. 2(b), and Fig. 4(b) is a vertical section of a main part of the packing. Fig. 5 is a vertical section illustrating a main part of a packing that is different from the packing in Fig. 4.

[0047]

In the example in Figs. 4(a) and 4(b), the airtight member provided on the ring portion 28 of the steel pipe 29 is constructed

by two kinds of packing, that is, the airtight member of the example in Fig. 4 constructed by a high rubber packing 32 having low hardness and a low rubber packing 33 having high hardness. For example, the rubber packing 32 is made of a low-hardness rubber material having hardness of about 10 degrees or less, and the rubber packing 33 is made of a high-hardness rubber material having hardness of about 70 degrees or more. The rubber packing 32 is higher than the rubber packing 33.

[0048]

Possibly the airtightness is not enhanced, because not of a strong compression force but a weak compression force mainly generated by the deadweight of the cover 30 acts on the airtight member between the cover 30 and the ring portion 28 until the decompression vessel 20 is decompressed to a certain degree. On the other hand, as described above, the airtight member provided on the ring portion 28 of the steel pipe 29 is constructed by two kinds of the soft rubber packing 32 and the hard rubber packing 33, the low-hardness rubber packing 32 can be deformed to enhance the airtightness even under the weak compression force, and the high-hardness rubber packing 33 is lower than the rubber packing 32 is also provided. Therefore, a compression failure of the low-hardness rubber packing 32 can be prevented even under the condition in which a strong compression force is exerted such that the negative pressure is enhanced to the theoretically maximum negative pressure of  $-100 \text{ kN/m}^2$  in the decompression vessel 20.

[0049]

The hardness of the rubber material is measured with a durometer according to a rule of "hardness test method for vulcanized rubber and thermoplastic rubber" (JIS K6253). For example, the hardness of 10 degrees is expressed by A10, and the hardness of 70 degrees is expressed by A70.

[0050]

During the decompression of the decompression vessel 20, it is necessary that the low-hardness rubber packing 32 is initially deformed. Therefore, as illustrated in Fig. 4(b), the low-hardness rubber packing 32 is higher than the high-hardness rubber packing 33. The high-hardness rubber packing 33 is deformed after the low-hardness rubber packing 32 is deformed to become as high as the rubber packing 33. A degree of the deformation of the rubber packing 33 is lower than that of the rubber packing 32, so that the rubber packing 33 can contribute to the improvement of the airtightness while excessive compression of the rubber packing 32 is prevented and the airtightness can further be enhanced.

[0051]

The rubber packing 32 and the rubber packing 33 may have a rectangular shape in section. Alternatively, the rubber packing 32 and the rubber packing 33 may have a circular shape or an oval shape in section. In Figs. 4(a) and 4(b), the rubber packing 32 is located in the inner circumference of the rubber

packing 33 in the ring portion 28. Alternatively, the rubber packing 32 may be located in the outer circumference.

[0052]

As illustrated in Fig. 5, a packing 34 constructed by a hollow rubber may be used instead of the low-hardness rubber packing 32 in Fig. 4(b). The hollow-rubber packing 34 is higher than the rubber packing 33. In this case, the packing 34 may be made of the rubber material having the same hardness as the rubber packing 33, and the hollow-rubber packing 34 deforms easily than the solid rubber packing 33.

[0053]

Fig. 6 is explaining an example of a configuration in which the lower end position of the steel pipe is sufficiently deeper than the bottom plate position of the steel pipe after the steel pipe in Fig. 1 is driven. Fig. 7(a) is explaining a problem in the case that the lower end position of the steel pipe is insufficiently deeper than the bottom plate position of the steel pipe after the steel pipe in Fig. 1 is driven, and Fig. 7(b) is explaining the effect in the case of the configuration in Fig. 6.

[0054]

As described above, the steel pipe 29 is driven, and the bottom plate 27 is installed, which allows the decompression chamber 20a to be ensured. However, as illustrated in Fig. 6, in a positional relationship between the installation position

of the bottom plate 27 and the lower end position 29a of the steel pipe 29, preferably a length  $h$  between the lower surface position 27a of the bottom plate 27 and the lower end position 29a of the steel pipe 29 becomes more than at least a half of a diameter  $d$  of the steel pipe 29. That is, assuming that the length  $h$  is an embedded length, an embedded ratio (embedded length  $h$ /steel pipe diameter  $d$ ) of the steel pipe 29 is set to  $1/2$  or more. The steel pipe 29 is placed to install the bottom plate 27 such that the embedded ratio is obtained.

[0055]

As illustrated in Fig. 7(a), when the embedded ratio of the steel pipe 29 is small (the length  $h$  between the lower surface position 27a of the bottom plate 27 and the lower end position 29a of the steel pipe 29 is short), an upward buoyancy  $F$  acts on the decompression vessel 20 including the chamber 20a therein in the case that the ground  $G1$  is soft. Therefore, a risk of floating the decompression vessel 20 occurs losing the stability of the decompression vessel 20. On the other hand, when the embedded ratio of the steel pipe 29 is increased (the length  $h$  between the lower surface position 27a of the bottom plate 27 and the lower end position 29a of the steel pipe 29 is long), the steel pipe 29 is extended into a skirt shape as illustrated in Fig. 7(b), and a suction force  $F1$  works because the inside of the decompression vessel 20 is sealed. Therefore, the steel pipe 29 can be prevented from moving by the suction force  $F1$  and a

circumferential friction force  $F_2$ . That is, even the buoyancy  $F$  acts on the decompression vessel 20 in the case that the ground  $G_1$  is soft, the risk of floating the decompression vessel 20 occurs, and the decompression vessel 20 is stabilized. It is conceivable that the previously-produced cylindrical decompression vessel is carried out in the field and embedded in the earth. The stability of the decompression vessel 20 is enhanced compared with such cases.

[0056]

As illustrated in a reference literature (Hiroyuki Yamazaki, Yoshiyuki Morikawa, Fumikatsu Koike, Masakazu Izuno, Gaku Yazawa (2003): Basic experiment of suction structure, Report of Port and Airport Research Institute, Vol. 42, No. 1), Hiroyuki Yamazaki et al. perform an experiment in which a relationship between a load and a displacement is investigated by applying the load to a suction basic structure under the condition that the embedded ratio expressed by embedded length/steel pipe diameter is 0.0, 1/4, 1/2, and 1/1. As a result of the experiment, the displacement and a tilt angle with respect to the load are decreased with increasing embedded ratio, and the stability is enhanced against an external force.

[0057]

Fig. 8 is explaining the bottom plate that is installed on the bottom side of the steel pipe in Fig. 1. As described above, the bottom plate 27 installed in the bottom side of the steel pipe

29 in Fig. 1 is made of solidifying material such as concrete. As illustrated in Fig. 8, when the decompression chamber 20a in the decompression vessel 20 is decompressed, an upward force  $F_3$  acts on the bottom plate 27 by the negative pressure, a risk of a heaving failure or a waterproof leakage is occurs in the bottom plate 27. Therefore, desirable solidifying material (bottom plate 27) has a thickness of about 0.5 m in order to prevent the heaving failure or the waterproof leakage. Desirably, in order to enhance adhesiveness, a tenon is provided in the inner surface of the steel pipe 29 in a position in which the concrete of the bottom plate 27 comes into contact with the inner surface of the steel pipe 29.

[0058]

The embodiment of the invention is described above. The invention is not limited to the embodiment described above, but various modifications can be made without departing from the scope of the technical feature of the invention. In Fig. 1, the bottom plate 27 is installed on the bottom side after the steel pipe 29 is driven. Alternatively, for example, the steel pipe in which the bottom plate 27 is previously installed in a predetermined position may be prepared to ensure the airtightness and the strength on the bottom side. The cylindrical steel pipe is used in the embodiment. The steel pipe is not limited to the cylindrical steel pipe, but a steel pipe having a square-tube shaped may be used.

[0059]

In order to further improve the airtightness of the decompression vessel 20 in Fig. 1, a weight may be placed on the cover 30 or the upper portion of the cover 30 may be coated with cohesive soil slurry.

[0060]

Whether the siphon functions in the vertical drain pipe 21 can be made based on whether the gas-liquid two-phase flow is formed in the vertical drain pipe 21. Alternatively, at least part of the vertical drain pipe 21 may be made of a transparent material such that the forming situation of the gas-liquid two-phase flow can be observed and monitored from the outside without depending on the measurement device, or the cover may be made of transparent material.

[0061]

After the water drained from the decompression vessel 20 through the drain pipe 25 is reserved in a water tank, the water flows back into a drain passage in front of the vertical drain pipe 21, an air mixing rate is decreased to reduce a size of a bubble while a flow rate of the water is increased in the vertical drain pipe 21, which allows the siphon to function stably when the air is mixed.

[0062]

The ground improvement method of the invention can also be applied not only in inland ground but also the underwater ground

by installing a levee crown and the covering of the steel pipe in a water surface or above.

[0063]

In the decompression vessel of the invention, the suction power generated by the vacuum pump and the suction power generated by the siphon function can be obtained. Obviously the decompression vessel of the invention can be applied for the case when the ground is improved by vacuum consolidation when only using the suction power by the vacuum pump without utilizing the siphon function.

#### INDUSTRIAL APPLICABILITY

[0064]

According to the ground improvement method and decompression vessel of the invention, the decompression vessel that can be produced in the ground improvement subject area with sufficient strength and airtightness can be installed in the earth. Therefore, using both the suction power by the vacuum pump and the suction power by the siphon function, the ground can be improved by vacuum consolidation at low cost while the working period is shortened.

#### REFERENCE SIGNS LIST

[0065]

1 vacuum consolidation ground improvement system

10 vacuum decompression device  
11 vertical drain member  
20 decompression vessel  
20a decompression chamber  
21 vertical drain pipe (vertical pipe)  
23 vacuum pump  
24 lift pump  
25 drain pipe  
26 suction pipe  
27 bottom plate  
28 ring portion (placed portion)  
29 steel pipe  
30 cover  
31,32,33 rubber packing (airtight member)  
G ground, soft ground  
 $\Delta H$  differential water-level

## CLAIMS

1. A ground improvement method, characterized in that:
  - a decompression vessel in the earth is completed through:
  - a step of driving a steel pipe into the earth, the steel pipe including a ring portion projecting from inner surface in an upper portion thereof;
  - a step of removing soils from the driven steel pipe;
  - a step of installing a bottom plate on a bottom side of the steel pipe; and
  - a step of putting a cover on the ring portion of the steel pipe while a drain pipe connected to a lift pump accommodated in the steel pipe, a suction pipe connected to a vacuum pump, and a vertical pipe through which a siphon functions, project through the cover,
  - the cover is brought into close contact with the ring portion of the steel pipe by negative pressure generated in operating the vacuum pump, and
  - a suction power by the vacuum pump and a suction power by a siphon function of the vertical pipe are exerted to extract and drain pore water in a ground to be improved through a vertical drain member placed into the ground.
2. The ground improvement method according to claim 1, wherein an airtight member made of an elastic material is provided between

the cover and the ring portion.

3. The ground improvement method according to claim 1 or 2, wherein a distance between a position of the bottom plate of the steel pipe and a lower end position of the steel pipe becomes at least half of a diameter of the steel pipe.

4. A decompression vessel for being installed in the earth and an inside of the vessel being decompressed by a vacuum pump, characterized by comprising:

a steel pipe to be placed as a vessel body in the earth;

a bottom plate provided on a bottom side of the vessel body;

and

a cover for closing the vessel body,

wherein the cover has a structure in which the cover is put on a placed portion of the vessel body, and

the cover is brought into close contact with the placed portion by a negative pressure generated in operating the vacuum pump.

5. The decompression vessel according to claim 4, wherein the steel pipe includes a ring portion provided so as to project from an inner surface in an upper portion thereof,

the cover is put on the ring portion while the ring portion is used as the placed portion, and

an airtight member made of an elastic material is provided between the cover and the ring portion.

6. The decompression vessel according to claim 5, wherein the airtight member includes a high packing that is easily deformed and a low packing that is hardly deformed.

7. The ground improvement method as in any one of claims 1 to 3, wherein the decompression vessel as in any one of claims 4 to 6 is installed in the earth.