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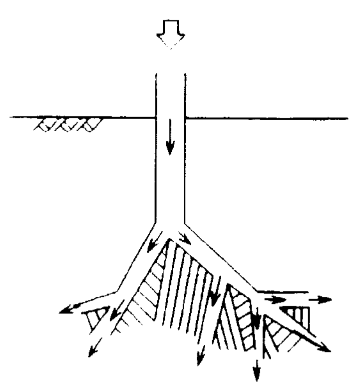
(54) Method for providing consolidation of ground

(57) A method for providing consolidation of ground comprises injecting the ground with a predetermined amount of a cement and mortar based material through an array of injection points preselected for ground improvement the amount of material injjected and the pressure being controlled according to ground improvement deign so that, simultaneously with injection of the material, the ground is broken to form crevices while the material fills in the crevices thereby to achieve instanteneously a desired consolidation of the ground.

FIG. 8



EP 0 774 543 A1

Description

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to a method fo providing consolidation of ground whereby, in a short period, soft ground is reconstructed to form stable ground in an economical manner.

Description of the prior art

In geographical areas where the ground is soft there is a problem in developing infrastructures, such as roads and railways, and in maintaining existing facilities. It is thus necessary to provide a method for consolidating stable ground economically and within a very short period.

In US-A-4309129 and US[A-4540316 there is described one or more methods for reconstructing ground by impregnation which involve (1) chemcial fluid impregnation, (2) mixing and stirring of a chemcial fluid and (3) impregnation of cement and mortar based material.

A typical chemical fluid mpregatniton method is generally broken down into two types depending on chemical fluids having varying solidification time, one wherehin a chemical fluid is solidified instantaneously upon injection and the other wherein solidification of a chemical fluid proceeds over a long period. In either case, it is required to impregnate ground with a chemical fluid within a period during which it is allowed to solidify. In other words, this method is ntohing other than a local impregnation process for reasons of a limited impregnation range. In addition, the chemical fluid is injected between voids, or into a veinlike structure or crevices. Thus, the chemical fluid impregnation method does not lend itself to a wide range of ground improvement, e.g., to river improvement, and preparation of specific land sites.

The chemical impregnation method is a stop-gap process primarily designed to inject a chemical fluid between soil particles, or into crevices or voids existing in ground for water stop purposes, and so has a defect that the solidification strength achieved is not any permanent strength, and becomes low with time.

The mixing and stirring method, as typically shown in FIG. 16, is a pile-foundation process also called a deep mixing and stirring process wherein the ground to be reconstructed is dug out at diameters of about 1 meter, and a mixture of the excavated soil with cement or mortar is injected into the holes to form solidified piles. With this method, however, no integral ground structure is obtained because the solidified piles are separate from unsolidified regions between them. In other words, the reconstructed ground, because of having no homogeneous structure, is sensitive to horizontal resistance produced by traffic or seismic vibrations, for instance.

The ground improvement method using impregnating material based on cement, and mortar, as typically shown in FIG. 17, is characterized in that a fluid body formed vertically during impregnation of ground plays a piling structure role in place of a piling load. However, its real action or consolidation mechanism, and its real effect on ground improvement (what ground it is applicable to and how it works) has yet to be fully clarified.

A primary object of the present invention is to provide an instantaneous consolidation method by impregnation of ground which enables soft ground to be instantaneously converted into ground having the required strength over the range required in view of design and construction, thereby eliminating the aforesaid problems with the prior art.

SUMMARY OF THE INVENTION

According to the present invention, the aforesaid object of the invention is achievable by the provision of an instantaneous consolidation method by impregnation of ground wherein a certain amount of an impregnating material selected from the group consisting of a cement material, a mortar material, and a mixed cement and mortar material is injected at a certain pressure through an array of injection points preselected for ground improvement into a very soft, viscous ground or a loose sandy ground, said injection amount and pressure controlled according to ground improvement design, so that simultaneously with the injection of said impregnating material, the soft ground is broken to form crevices therein while the impregnating material is filled in the crevices to thereby achieve a desired degree of consolidation instantaneously depending on said controlled injection amount and pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of the original ground.

FIG. 2 is a schematic of a consolidation method using a piling structure.

FIG. 3 is a schematic of low-density ground upon reconstructed.

FIG. 4 is a schematic of high-density ground upon reconstructed.

FIG. 5 is a graph showing the injection pressure vs. undrained shearing strength/pre-consolidation relation.

FIG. 6 illustrates a process wherein using a specific impregnation machine, a specifically formulated impregnating material is injected into ground by a consolidation impregnation method controlled according to the design and construction standards, so that there can be obtained a homogeneously stable yet complex ground zone in which a solidified portion is united with an overconsolidated portion obtained by compression effect due to in-situ dehydration and drainage by consolidation, and post-injection in-situ replacement and solidification effect.

FIG. 7 illustrates a process wherein by effecting the aforesaid consolidation impregnation method using the impregnating material being injected as a load in place of a piling or other load, a soft and viscous ground zone or a loose sandy ground zone can be destroyed to form crevices therein.

FIG. 8 illustrates a process wherein with a further continued injection of the impregnating material on the same breaking criteria, the ground zone is successively destroyed to cause quantitative and qualitative growth of the crevices, so that the impregnating material starts to flow while the crevices are filled therewith, thereby creating a sheet form of fluid body in an oblique or vertical direction.

FIG. 9 illustrates a process where while the fluid body flows through passages and grows, ground portions contiguous to the breaking interfaces are in situ subjected to forcibly rapid loading and dehydration actions in a transverse direction.

FIG. 10 illustrates a process wherein by the in-situ loading and dehydration actions of the fluid body, pore water is entrained, simultaneously with the injection of the impregnating material, from the ground to be consolidated into the fluid body, and then dynamically discharged, and during the injection of the impregnating material, the water is discharged mainly through water discharge passages formed by boundaries between the ground to be consolidated and the fluid body, and then discharged into underground, and ground-surface sand layers together with water separated from the impregnating material.

FIG. 11 illustrates a process where by a chain effect of the fluid body on in-situ loading, dehydration and drainage, the ground to be improved can be instantaneously consolidated without being disturbed at all, resulting in a successive ground strength increase, and the fluid body itself is solidified within 24 hours in its as-injected state to create an in-situ solidified replacement skeleton structure in the ground to be consolidated.

FIG. 12 is diagram showing the relation between consolidation yield stress Pc in tf/m^2 and pre-consolidation stress Pc' in tf/m^2 for an example of the inventive method applied to clay of marine origin.

FIG. 13 is diagram showing the relation between consolidation yield stress Pc in tf/m^2 and pre-consolidation stress Pc' in tf/m^2 for an example of the inventive method applied to clay of river origin.

FIG. 14 is diagram showing the relation between consolidation yield stress Pc in tf/m^2 and pre-consolidation stress Pc' in tf/m^2 for an example of the inventive method applied to peat or humus soil.

FIG. 15 is a schematic of a conventional chemical fluid impregnation method in which a chemical fluid is injected into crevices or a veinlike structure.

FIG. 16 is a schematic of a conventional deep mixing and stirring method.

FIG. 17 is a schematic of a conventional consolidation impregnation method by impregnation of ground.

DETAILED EXPLANATION OF THE PREFERRED EMBODIMENTS

One embodiment of the present invention will now be explained at great length with reference to the accompanying drawings.

As already noted, the present invention provides an instantaneous consolidation method by impregnation of ground wherein a certain amount of an impregnating material selected from the group consisting of a cement material, a mortar material, and a mixed cement and mortar material is injected at a certain pressure through an array of injection points preselected for ground improvement into a very soft, viscous ground or a loose sandy ground, said injection amount and pressure controlled according to ground improvement design, so that simultaneously with the injection of said impregnating material, the soft ground is broken to form crevices therein while the impregnating material is filled in the crevices to thereby achieve a desired degree of consolidation instantaneously depending on said controlled injection amount and pressure.

(1) Some load is required to improve the nature of ground itself to take effect on its consolidation, and so piling or other loading means have been used so far in the art. In the inventive method, however, such consolidation effect is achieved by the impregnating material injected into the ground, which is tantamount to the piling structure (soil) laid on the ground, and the injection pressure which is tantamount to the load corresponding to the thickness of the soil laid on the ground. See FIGS. 1 to 4, and 5.

As schematically shown in FIG. 1, the original ground is composed of soil particles (black), and voids (white). Upon a load or a piling structure P_0 laid on the original ground as shown in FIG. 2, the original ground is compressed by that load, as shown by S_1.

Here a void ratio e_0 is defined as a ratio V_0/V_s where V_0 is the volume of soil particles forming one part of the original ground and V_S is the volume of voids forming another part. When the original ground subsides (shown by S_1) followed by compression, there is no change in the volume of soil particles, but the volume of voids V_0 is compressed to V_1, so that the heigth of the original ground decreases from H_0 to H_1 corresponding to an amount of compression S_1.

In the instantaneous consolidation method by impregnation of ground based on this principle, the amount of compression S_1 of the piling structure is taken as the impregnating material S_2 which is being injected into the ground while an amount of the piling load P_0 is deemed as an injection pressure P_1, so that ground improvement can be planned with any desired combination of the impregnating material S_2 with the injection pressure P_1 according to design. See FIGS. 3, and 4.

(2) By consolidation, the ground is so dehydrated that pore water is discharged. For this reason, natural drainage due to a piling load applied on the ground has

conventionally been used alone or in combination with a drain. In the inventive method, however, the impregnating material being injected into the ground is used as dehydration and discharge means.

A detailed account will now be given of the mechanisms for consolidation dehydration, drainage, and solidification/replacement according to the present invention.

(i) Using a specific impregnation machine, a specifically formulated impregnating material is injected into ground by the consolidation impregnation method controlled according to the design and construction standards. Through the mechanisms explained in (ii)-(vi) below and shown in FIGS. 6-11, there can be obtained a homogeneously stable yet complex ground zone in which a solidified portion is united with an over-consolidated portion obtained by compression effect due to in-situ dehydration and drainage by consolidation, and post-injection in-situ replacement and solidification effect. See FIG. 6.
(ii) By effecting the aforesaid consolidation impregnation using the impregnating material being injected as a load in place of a piling or other load, a soft and viscous ground zone or a loose sandy ground zone can be destroyed to form crevices therein. See FIG. 7.
(iii) With a further continued injection of the impregnating material on the same breaking criteria, the ground zone is successively destroyed to cause quantitative and qualitative growth of the crevices, so that the impregnating material starts to flow while the crevices are filled therewith, thereby creating a sheet form of fluid body in an oblique or vertical direction. See FIG. 8.
(iv) While the fluid body flows through passages and grows, ground portions contiguous to the breaking interfaces are in situ subjected to forcibly rapid loading and dehydration actions in a transverse direction. See FIG. 9.
(v) By the in-situ loading and dehydration actions of the fluid body, pore water is entrained, simultaneously with the injection of the impregnating material, from the ground to be consolidated into the fluid body, and then dynamically discharged. During the injection of the impregnating material, the water is discharged mainly through water discharge passages formed by boundaries between the ground to be consolidated and the fluid body, and then discharged into underground, and ground-surface sand layers together with water separated from the impregnating material. See FIG. 10.
(vi) By a chain effect of the fluid body on in-situ loading, dehydration and drainage, the ground to be improved can be instantaneously consolidated without being disturbed at all, resulting in a successive ground strength increase. On the other hand, the fluid body itself is solidified within 24 hours in its as-injected state to create an in-situ solidified replacement skeleton structure in the ground to be consolidated. See FIG. 11.

FIGS. 12-14 show examples of the inventive instantaneous consolidation method by impregnation of ground through an accumulation of experimental data. Hereinafter, the applicability of the inventive method to clay of marine origin, clay of river origin, and peat or humus soil typical of soft ground will be explained, together with the effect of the inventive method, with reference to the examples shown in FIGS. 12-14.

In FIG. 12, the numbers on the abscissa indicate a consolidation load or, more exactly, a consolidation yield stress Pc of the original ground found by soil testing, and a consolidation yield stress, again found by soil testing, of the ground improved by the application of the inventive method of impregnation of ground. In FIG. 12, the latter consolidation yield stress is denoted as preconsolidation stress Pc' to define around the former consolidation yield stress. The numbers on the left ordinate stand for void ratio e and a compression index Cc while the numbers on the right ordinate represent undrained shearing strength Cu. Data on void ratio e, compression index Cc, and undrained shearing strength Cu of the ground before and after reconstruction are plotted with respect to the consolidation load on the abscissa. White symbols refer to the original ground before reconstruction, and ground with a piling structure laid on it, while black symbols refer to the ground after reconstruction. It is here to be noted that the ground with a soiling structure laid on it was created before seven years with a piling structure of 4.5 meters in height.

Similarly, FIGS. 13 and 14 show the results of the inventive method applied to clay of river origin and peat or humus soil, respectively.

For the clay of marine origin shown in FIG. 12, the ground before and after reconstruction is compared in terms of one strength property, viz., undrained shearing strength. The distribution range of the undrained shearing strength of the original ground is Cu = 1.2 to 2.2 tf/m^2, and that of the ground with a piling structure laid thereon is Cu = 2.1 to 2.6 tf/m^2. In the ground improved by the inventive method, however, Cu = 2.7 to 5.0 tf/m^2 or more.

On the other hand, the compressibility or consolidation yield stress of the original ground, and the ground with a piling structure laid thereon is Pc < 10 tf/m^2. However, the consolidation yield stress of the ground upon reconstructed is Pc' > 10 to 18 tf/m^2.

For the clay of river origin shown in FIG. 13, the ground before and after reconstruction is compared in term of one strength property or undrained shearing strength. The undrained shearing strength of the original ground is Cu = 0.6 to 1.6 tf/m^2, whereas that of the ground upon reconstructed is increased to Cu' = 2.08 to 5.0 tf/m^2 or more. The compressibility or consolidation yield stress of the original ground is Pc = 4.1 to 9.9 tf/m^2, whereas that of the ground upon reconstructed is increased to Pc' = 11.1 to 22.0 tf/m^2.

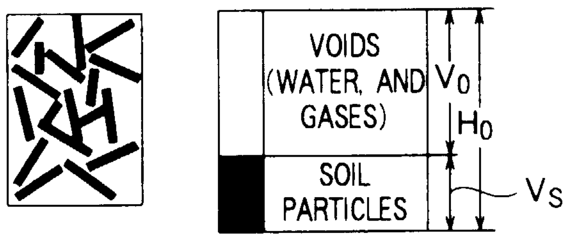
For the peat or humus soil shown in FIG. 14, the ground before and after reconstruction is compared in term of one strength property or undrained shearing strength. The undrained shearing strength of the original ground is Cu = 0.44 to 1.04 tf/m^2, whereas that of the ground upon reconstructed is increased to Cu' = 1.0 to 4.25 tf/m^2. The compressibility or consolidation yield stress of the original ground is Pc = 1.3 to 3.1 tf/m^2, whereas that of the ground upon reconstructed is increased to Pc' = 3.3 to 12.6 tf/m^2.

As mentioned above, clay of marine origin, clay of river origin, and peat or humus soil are all improved by the inventive method.

Claims

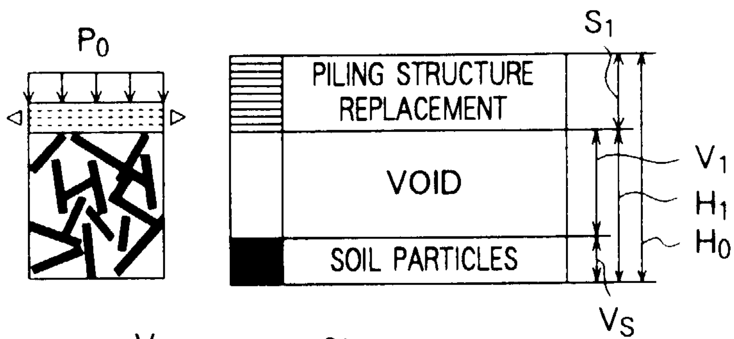
1. A method for providing consolidation of ground comprising injecting the ground with a cement and mortar based material characterised in that the material is injcected at a predetermined pressure through an array of injection points preselected for ground imrpovement, the amount of material injected and the pressure being controlled according to ground impovement design so that, simultaneously with injection of the material, the ground is broknen to form crevices while the material fills in the crevices thereby to achieve instantaneiously a desired consolidation of the ground.

FIG. 1



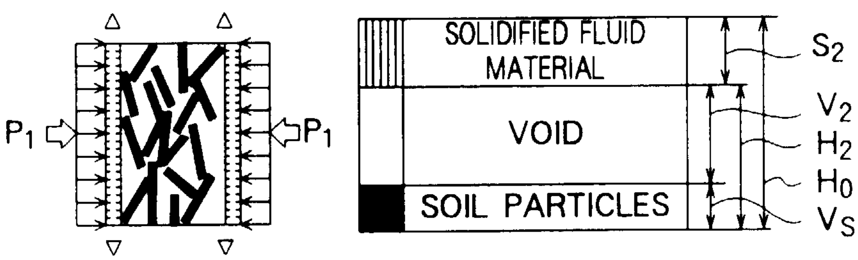
$$e_0 = \frac{V_0}{V_S}$$

FIG. 2



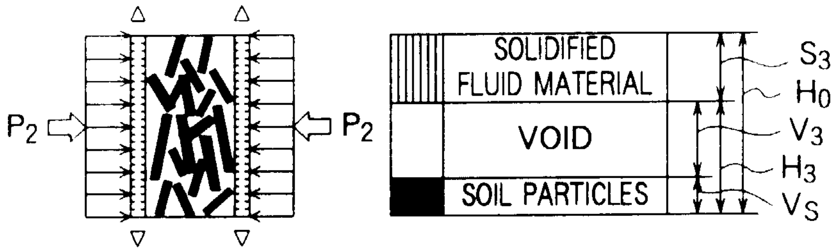
$$e_1 = \frac{V_1}{V_s} \qquad S_1 = \frac{e_0 - e_1}{1 + e_0} \times H_0$$

FIG. 3



$$e_2 = \frac{V_2}{V_S} \qquad S_2 = \frac{e_0 - e_2}{1 + e_0} \times H_0$$

FIG. 4



$$e_3 = \frac{V_3}{V_S} \qquad S_3 = \frac{e_0 - e_3}{1 + e_0} \times H_0$$

FIG. 5

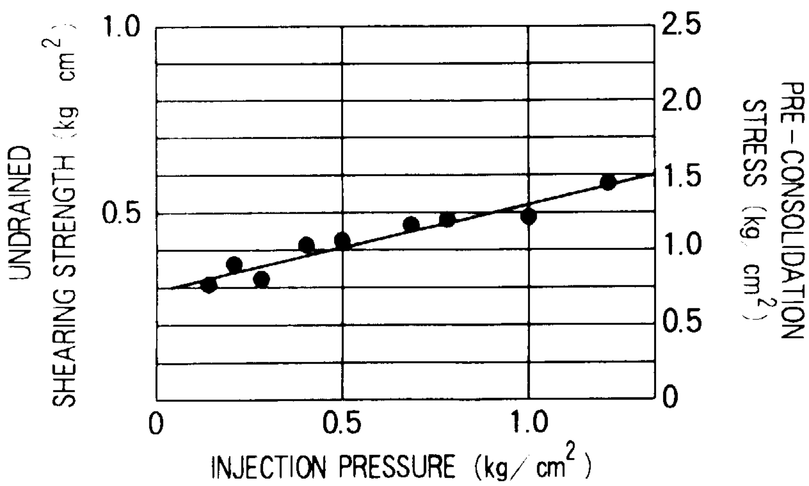


FIG. 6

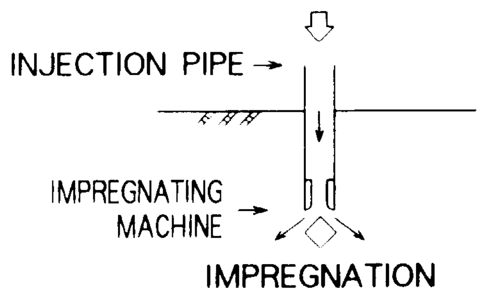


FIG. 7

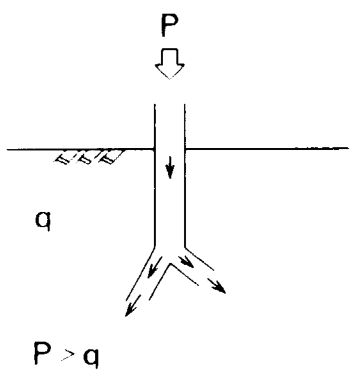


FIG. 8

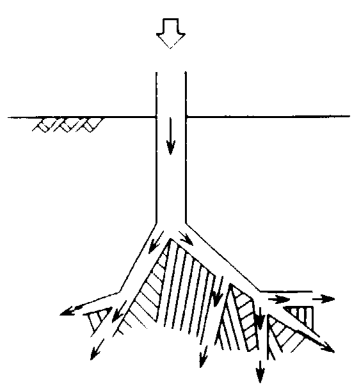


FIG. 9

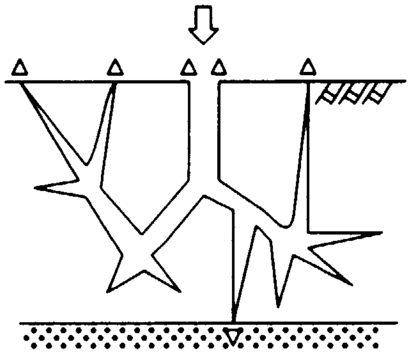


FIG. 10

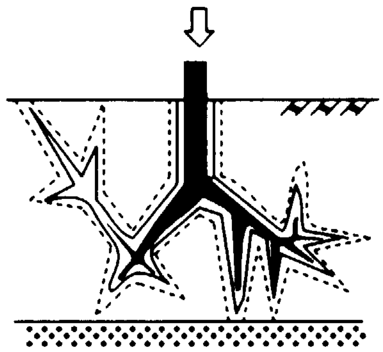


FIG. 11

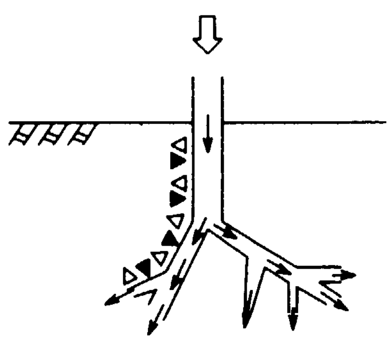


FIG. 12

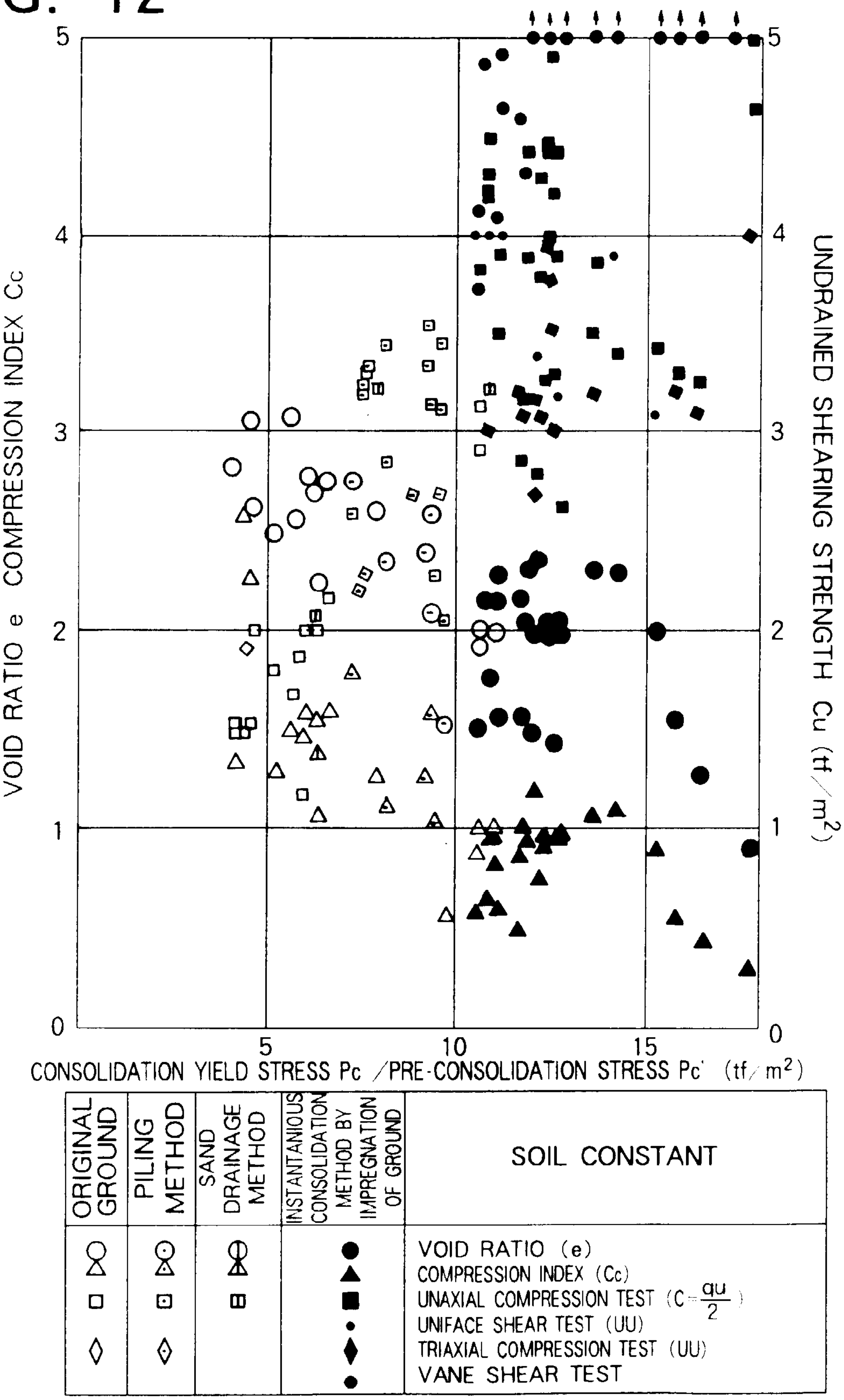
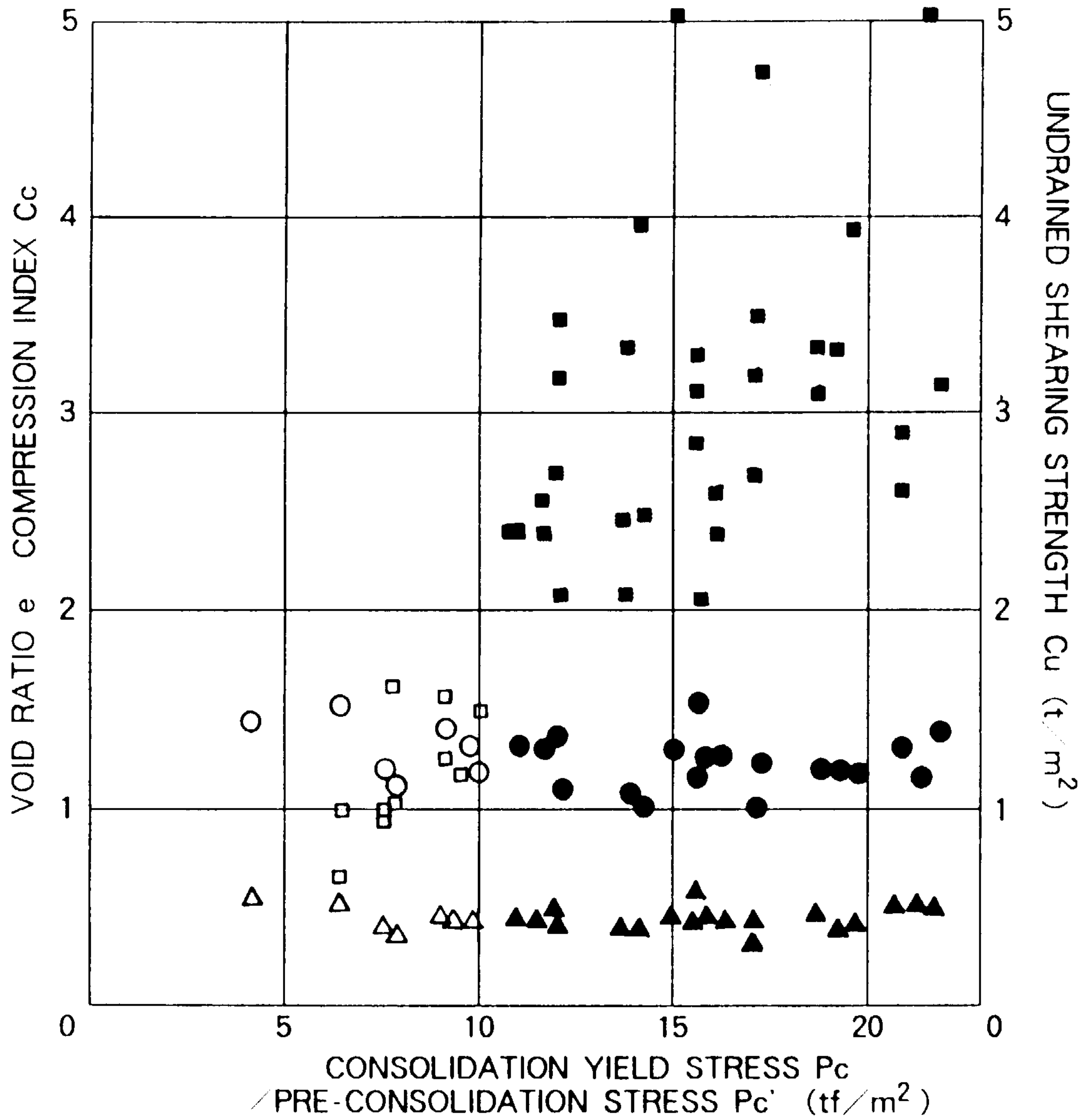

VOID RATIO e COMPRESSION INDEX Cc
UNDRAINED SHEARING STRENGTH Cu (tf/m2)
CONSOLIDATION YIELD STRESS Pc /PRE-CONSOLIDATION STRESS Pc' (tf/m2)
0
1
2
3
4
5
10
15
ORIGINAL GROUND
PILING METHOD
SAND DRAINAGE METHOD
INSTANTANIOUS CONSOLIDATION METHOD BY IMPREGNATION OF GROUND
SOIL CONSTANT
VOID RATIO (e)
COMPRESSION INDEX (Cc)
UNAXIAL COMPRESSION TEST (C=qu/2)
UNIFACE SHEAR TEST (UU)
TRIAXIAL COMPRESSION TEST (UU)
VANE SHEAR TEST

FIG. 13



ORIGINAL GROUND	PRE-CONSOLIDATION IMPREGNATION METHOD	SOIL CONSTANT
○	●	VOID RATIO (e)
△	▲	COMPRESSION INDEX (Cc)
□	■	UNIAXIAL COMPRESSION TEST ($C = \frac{qu}{2}$)
◇	◆	TRIAXIAL COMPRESSION TEST (UU)

FIG. 14

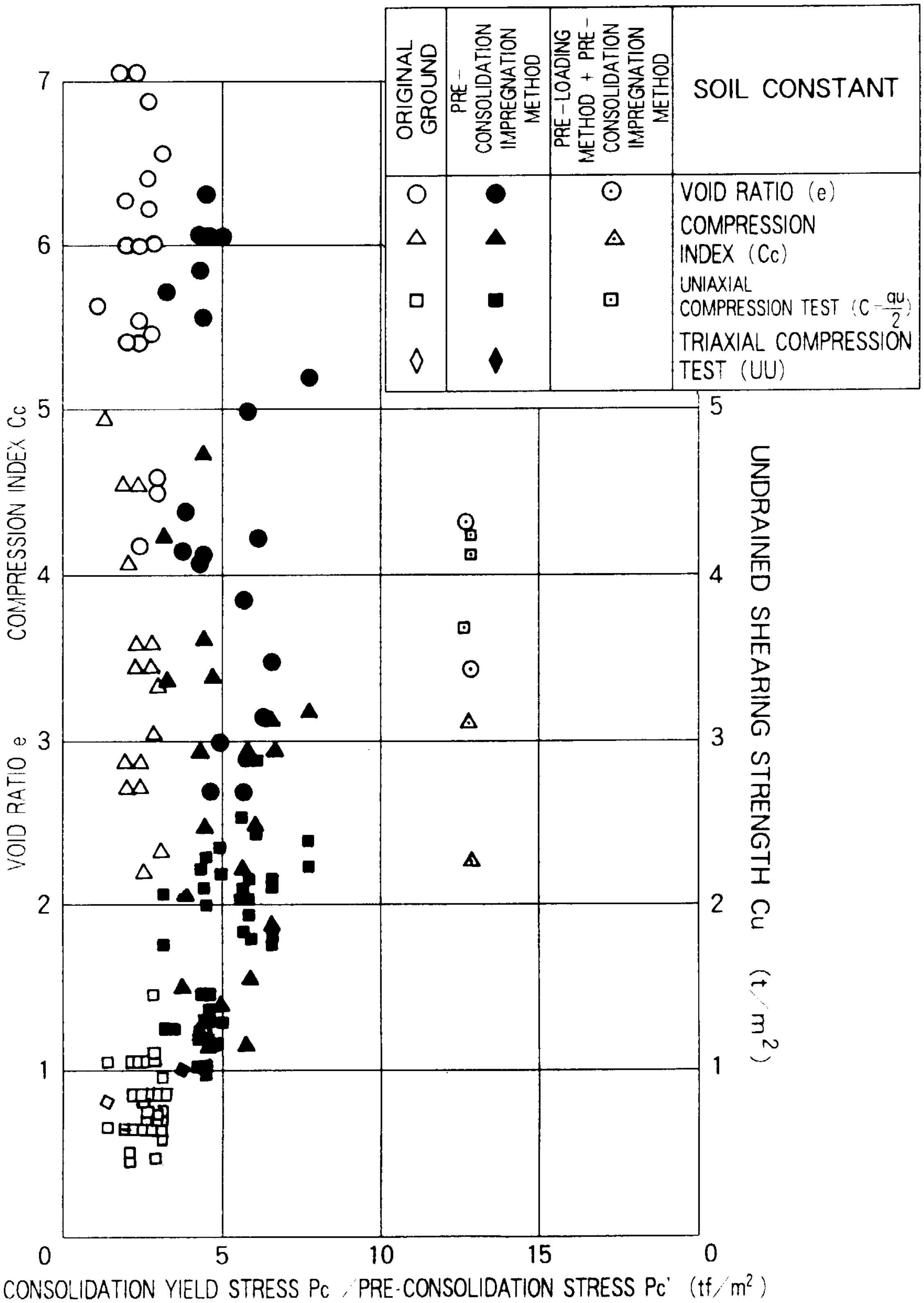

ORIGINAL GROUND
PRE-CONSOLIDATION IMPREGNATION METHOD
PRE-LOADING METHOD + PRE-CONSOLIDATION IMPREGNATION METHOD
SOIL CONSTANT
VOID RATIO (e)
COMPRESSION INDEX (Cc)
UNIAXIAL COMPRESSION TEST (C = qu/2)
TRIAXIAL COMPRESSION TEST (UU)
VOID RATIO e
COMPRESSION INDEX Cc
UNDRAINED SHEARING STRENGTH Cu (t/m²)
CONSOLIDATION YIELD STRESS Pc / PRE-CONSOLIDATION STRESS Pc' (tf/m²)
0
5
10
15
0
1
2
3
4
5
6
7

FIG. 15

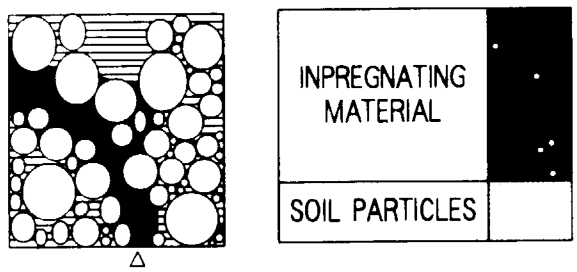


FIG. 16

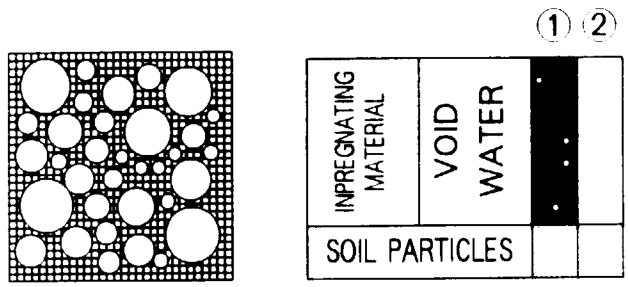
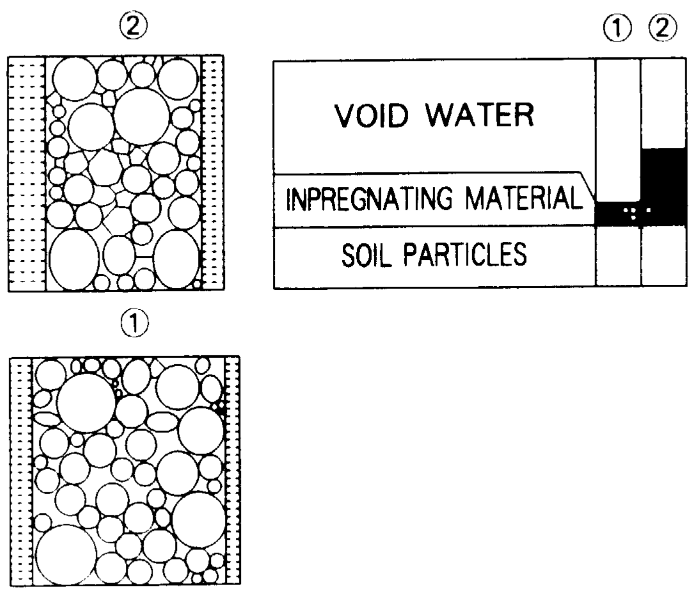


FIG. 17



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 30 8188

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X,D	US 4 540 316 A (TAKAHASHI YUICHIRO) 10 September 1985 * column 3, line 54 - column 7, line 24; figures 1-4C * ---	1	E02D3/12
D,A	US 4 309 129 A (TAKAHASHI YUICHIRO) 5 January 1982 * the whole document * ---	1	
A	GB 471 502 A (LES TRAVEAUX SOUTERRAINS) 7 October 1937 * the whole document * ---	1	
A	WO 92 13141 A (HALLIBURTON NUS ENVIRONMENTAL) 6 August 1992 * page 3, line 15 - page 11, line 18; figure 1 * -----	1	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

E02D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	19 February 1997	Tellefsen, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)