

METHOD OF REDUCING MOISTURE CONTENT OF SOIL

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority of US provisional application No. 61/974,632 filed on 3 April 2014, the content of which is incorporated herein by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] Various embodiments relate to a method of reducing moisture content of soil.

BACKGROUND

[0003] During underground excavation work, exposed surface of soil may collapse or slump rapidly to pose challenges to the excavation work. This is particularly so for soft soil, which typically has high water content and collapses easily if unsupported. While engineering solutions may be available for open cut excavation, lateral excavation for underground tunneling may be problematic. In view of the above, it is desirable for soil to be strengthened and its moisture content reduced prior to start of excavation work.

[0004] Soil strengthening refers to a process through which sediment is compacted (dewatering or consolidation). There are several natural processes that may cause soil to be compacted by forcing pore water out of the soil pores. An example is through consolidation. This approach, however, usually results in vertical settlement which may not be desirable.

[0005] *In situ* soil strengthening may be carried out in several ways, such as use of prefabricated vertical drains (PVDs) with surcharge or vacuum loading, jet grouting or ground freezing. Each of these methods has its own limitations.

[0006] For example, the above-mentioned methods may cause some ground movement one way or another, and thus may not be suitable for constructions under or below built-up areas, or where there is low or zero tolerance for ground movement.

[0007] Further, if the target soil stratum is located some tens of meters below the ground surface or where treatment from ground surface is not possible due to limited accessibility, soil improvement works may need to be carried out from a down shaft, and the target soil stratum approached in a horizontal manner.

[0008] In view of the above, there exists a need for an improved method to carry out soil strengthening such as by reducing moisture content of soil that overcomes or at least alleviates one or more of the above-mentioned problems.

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SUMMARY

[0009] In a first aspect, a method of reducing moisture content of soil is provided. The method includes placing a device having a flexible, water-permeable membrane defining an enclosure for receiving a water swellable material, and a water swellable material received within the enclosure in soil.

10 [0010] In a second aspect, use of a method according to the first aspect in soil strengthening, underground excavation, underground mining, underground tunneling, or construction is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

15 [0011] The invention will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

[0012] **FIG. 1** is a schematic diagram of a prefabricated geosynthetic reinforced sleeve and water absorbing gel (GSWAG) **100** before swelling and/or prior to insertion into wet soil according to embodiments disclosed herein. In the figure, **101** refer to an enclosure defined by a flexible, water-permeable membrane for receiving a water swellable material **103**. **103** refers to a water swellable material received within the enclosure, and **105** refers to restraining stitching. The restraining stitching **105** may use the same material or a similar material to that used for the flexible, water-permeable membrane.

25 [0013] **FIG. 2** is a schematic diagram of a prefabricated geosynthetic reinforced sleeve and water absorbing gel (GSWAG) **200** according to embodiments disclosed herein, after swelling and/or after insertion into wet soil. **205** refers to restraining stitching. As shown in the figure, the water swellable material **203** received within an enclosure **201** defined by the flexible, water-permeable membrane of the device absorbs water that has passed through the membrane to result in swelling of the material. This expansion in volume of the material pushes against the membrane, which in turn exerts force on surrounding soil and the soil matrix is compacted. In so doing, compaction of the soil matrix may be achieved while bulk

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volume of the soil medium is maintained. As swelling of the water swellable material is restrained by the membrane and the restraining stitching, expansion in volume of the device may not be uniform throughout. For example, extent of volume expansion of the device may be greater in regions where there is less resistance to expansion, such as a non-border region.

5 In some embodiments, the expanded device after swelling and/or after insertion into wet soil has an ellipse cross-sectional area shape, such as that depicted in the figure.

DETAILED DESCRIPTION

[0014] Various embodiments refer in a first aspect to a method of reducing moisture
10 content of soil.

[0015] The method of reducing moisture content of soil according to embodiments disclosed herein may result in *in situ* ground improvement of soft soil. By placing a device having a flexible, water-permeable membrane defining an enclosure for receiving a water swellable material and a water swellable material received within the enclosure in soil, the
15 water swellable material received within the flexible, water-permeable membrane of the device may absorb water contained in pores from surrounding soft soil to result in swelling of the material. At the same time, the soil particles may move in closer to one another to enhance soil strength.

[0016] As net volume of the soil medium may remain unchanged in the process, ground
20 heaving or settlement may be absent. Compaction of the soil matrix may be achieved while bulk volume of the soil medium is maintained. The device and the more compact soil matrix improve ground conditions and strengthen soil for subsequent excavation and/or mining work.

[0017] Advantageously, methods according to embodiments disclosed herein are passive processes, and do not introduce chemical and chemical reactions in the treated soil. Ground
25 improvement may be achieved without draining water from soil, and bulk volume of the soil medium may be unchanged.

[0018] With the above in mind, the method according to the first aspect comprises placing a device having a flexible, water-permeable membrane defining an enclosure for receiving a water swellable material, and a water swellable material received within the enclosure in soil.

30 [0019] The term “flexible” as used herein refers to materials which are compliant and respond in the presence of external forces by deforming readily. For example, the flexible, water-permeable membrane may flex or bend readily upon application of a force on the

membrane, and is able to return at least substantially to its original non-extended configuration after removal of the force.

[0020] The term “membrane” as used herein refers to a semi-permeable material that selectively allows certain species to pass through it while retaining others within or on the material. A membrane therefore functions like a filter medium to permit a component separation by selectively controlling passage of the components from one side of the membrane to the other side.

[0021] The membrane according to embodiments disclosed herein is water-permeable. For example, it may be porous to allow fluid communication between the soil and water swellable material, so that water may flow from the soil to the water swellable material through the pores of the membrane. While allowing water to flow through, pore size of the membrane may not be sufficient for the water swellable material to pass through, thereby retaining the water swellable material within the enclosure defined by the flexible, water-permeable membrane.

[0022] The pores of the membrane may be of any suitable shape and size. For example, the pores may have a regular shape such as a circle, a square, and/or a diamond, to name only a few. The pores may alternatively be irregularly shaped.

[0023] Size of the pores may be defined as a maximal dimension of each pore in any direction. In some embodiments, the pores of the membrane are essentially monodisperse.

Pore size of the membrane may generally be expressed as an average value and may depend on the type of soil present. In various embodiments, size of pores of the membrane is in the range of about 0.05 mm to about 0.15 mm, such as about 0.08 mm to about 0.12 mm, or about 0.09 mm to about 0.11 mm. In some embodiments, size of pores of the membrane is about 0.1 mm.

[0024] Thickness of the membrane is not particularly limited. It may, for example, be in the range of about 1 mm to about 10 mm, such as about 1 mm to about 8 mm, about 1 mm to about 5 mm, about 3 mm to about 10 mm, about 5 mm to about 10 mm, about 3 mm to about 7 mm, or about 2 mm to about 6 mm.

[0025] The flexible, water-permeable membrane may be formed of any suitable material that is able to deform to cater for volumetric expansion of the water swellable material contained within. In various embodiments, the flexible, water-permeable membrane is selected from the group consisting of a textile, synthetic fibres, weaved or needle punched

fibrous material such as geotextile, an elastomeric polymer, a plastic mesh, and combinations thereof.

[0026] For example, the flexible, water-permeable membrane may comprise or consist of a textile. As used herein, the term "textile" refers to a material formed of a network of interlacing fibers. The textile may be composed of natural fibers such as wool or cotton, synthetic fibers such as nylon, or blends of natural fibers and synthetic fibers such as rayon. The textile may be woven or non-woven. In its woven form, pores or voids defined by fibers of the textile may render the textile water-permeable. In its non-woven form, the textile may be made porous, such as by needle punching, to allow water to flow from the soil to the water-swellaible material through the pores of the textile.

[0027] In various embodiments, the flexible, water-permeable membrane comprises or consists of an elastomeric polymer. The elastomeric polymer may be in the form of woven sheets or non-woven porous sheets. The elastomeric polymer may, for example, be formed by polymerizing monomers or prepolymers selected from the group consisting of (poly)siloxanes, (poly)epoxides, (poly)urethanes, and the like, and combinations thereof. In some embodiments, the elastomeric polymer comprise or consist of polymers formed from polymerizing monomers or prepolymers of polydimethylsiloxane, epoxy resins, polysulfide rubber, silicone rubber, urethane rubber, urethane plastic, and combinations thereof. In specific embodiments, the elastomeric polymer may comprise or consist of polysiloxanes, polyepoxides, polysulfide rubber, polyurethanes, and combinations thereof.

[0028] In addition to or apart from the above-mentioned, the flexible, water-permeable membrane may be formed of a plastic mesh. The plastic mesh may be flexible enough to allow expansion of the water swellaible material upon absorption of water.

[0029] As mentioned above, the flexible, water-permeable membrane defines an enclosure for receiving a water swellaible material. The term "enclosure" as used herein refers to a structure defining a cavity that is able to contain or hold an object or a material.

[0030] The enclosure may be of any suitable shape and size. For example, the enclosure may have a regular shape such as a cylinder, a cube, a cuboid, or a sphere, to name only a few. The enclosure may also be irregularly shaped.

[0031] Size of the enclosure is not particularly limited. In various embodiments, the enclosure may have a length in the range of about 50 mm to about 200 mm, and a cross-sectional area in the range of about 25 mm² to about 75 mm². As used herein, the term "cross-

sectional area” refers to that area transverse to the central longitudinal axis of the enclosure. In some embodiments, the enclosure has a length of about 100 mm and a cross-sectional area of about 50 mm².

[0032] The enclosure may be formed by any suitable method depending on material of the flexible, water-permeable membrane. For example, the enclosure may be formed by molding such as in the case of elastomeric polymers, or stitching such as in the case of textiles.

[0033] In various embodiments, the enclosure may contain a restraining stitching. The restraining stitching may function to limit bulking or expansion of the water swellable material, and may be used to increase rigidity and strength of the enclosure and/or the device.

Suitable materials for forming the restraining stitching include materials that may be used for the flexible, water-permeable membrane. The restraining stitching may, for example, be sewed or stitched on the flexible, water-permeable membrane, prior to or after forming the enclosure. As mentioned above, expansion in volume of the device may not be uniform throughout, as swelling of the water swellable material may be restrained by the membrane and/or the restraining stitching. Therefore, in embodiments where restraining stitching is used, there may be greater expansion of the water swellable material in regions on the enclosure where restraining stitching is not present due to a lower resistance to expansion.

[0034] The enclosure may be partly, at least substantially, or completely filled with the water swellable material. In some embodiments, the enclosure is at least substantially filled with the water swellable material. For example, up to about 90 %, about 95%, or about 99% by volume of the enclosure may be filled with the water swellable material. This may be the case, for example, where the water swellable material is in the form of particles, where voids may be present between the particles.

[0035] Upon expansion of volume due to water absorption by the water swellable material, the swollen material contained within the enclosure may exert an outwardly force and push against the flexible, water-permeable membrane of the enclosure. As a result, dimensions of the enclosure may be extended. Advantageously, this may result in soil strengthening due to compaction of soil matrix. At the same time, water from pores of soil may be removed through absorption by the water swellable material. As net volume of the soil medium may not change in the process, there may be absence of ground heaving or settlement. In so doing, compaction of the soil matrix may be achieved while bulk volume of the soil medium is maintained.

[0036] In various embodiments, cross-sectional area of an enclosure defined by the flexible, water-permeable membrane may be extended by up to about 200 % of its original cross-sectional area, such as up to about 180 %, about 150 %, or about 120 %. In some embodiments, cross-sectional area of an enclosure defined by the flexible, water-permeable membrane may be expanded by an extent in the range of about 120 % to about 200 %, about 150 % to about 200 %, about 170 % to about 200 %, about 120 % to about 180 %, about 120 % to about 150 %, or about 130 % to about 160 % of its original cross-sectional area.

[0037] Suitable types of enclosure for receiving the water swellable material may depend on the water swellable material used. Generally, the enclosure may be closed on all sides to form a bag or sachet for containing the water swellable material. In such embodiments, the enclosure forms a closed enclosure such that the water swellable material is contained entirely within the enclosure, even upon absorption of water by the water swellable material. As pores of the membrane may only allow water to flow through, the water swellable material is kept within the enclosure. Upon absorption of water, the water swellable material may expand in volume, which may in turn extend dimensions of the enclosure.

[0038] In this regard, it is noted that a sandwich structure comprising a water swellable material sandwiched between two layers of flexible, water permeable membrane does not work as described herein, since the water swellable material is not contained within an enclosure. Upon expansion due to absorption of water, the water swellable material is not able to push against the membrane to exert force on the surrounding soil matrix and compact the soil.

[0039] A water swellable material is received within the enclosure, whereby the term “water swellable material” refers to a material which is able to absorb or adsorb and retain water upon hydration, and which undergoes an increase in volume while doing so. The term “water” as used herein includes water as well as aqueous solutions of any form that contain ions in at least small amounts.

[0040] In various embodiments, the water swellable material is selected from the group consisting of bentonite such as sodium bentonite and calcium bentonite, acrylate such as polyacrylate/polyacrylamide copolymers or sodium polyacrylate, urethane, cellulosic-based superabsorbent materials, gel, hydrogel, and combinations thereof.

[0041] In some embodiments, the water swellable material comprises or consists of a gel. For example, the water swellable material may comprise or consist of a hydrogel.

[0042] As used herein, the term "hydrogel" refers to a broad class of polymeric materials, that may be natural or synthetic, which have an affinity for an aqueous medium such as water, and may absorb large amounts of the aqueous medium, but which do not normally dissolve in the aqueous medium.

5 [0043] Generally, a hydrogel may be formed by using at least one, or one or more types of hydrogel-forming agent, and setting or solidifying the one or more types of hydrogel-forming agent in an aqueous medium to form a three-dimensional network, wherein formation of the three-dimensional network may cause the one or more types of hydrogel-forming agent to gel so as to form the hydrogel. By cross-linking the hydrogel-forming agent, a three-dimensional
10 network matrix may be formed, thereby entrapping water molecules to form a hydrogel. The term "hydrogel-forming agent", also termed herein as "hydrogel precursor", refers to any chemical compound that may be used to make a hydrogel.

[0044] The hydrogel-forming agent may comprise a physically cross-linkable polymer, a chemically cross-linkable polymer, or mixtures thereof.

15 [0045] Physically cross-linking may take place via, for example, complexation, hydrogen bonding, desolvation, *van der Waals* interactions, or ionic bonding. Examples of physically cross-linkable polymer that may be used include, but are not limited to, gelatin, alginate, pectin, furcellaran, carageenan, chitosan, derivatives thereof, copolymers thereof, and mixtures thereof.

20 [0046] Chemical crosslinking may take place via, for example, chain reaction (addition) polymerization, and step reaction (condensation) polymerization. The term "chemical cross-link" as used herein refers to an interconnection between polymer chains via chemical bonding, such as, but not limited to, covalent bonding or ionic bonding. Examples of chemically cross-linkable polymer that may be used include, but are not limited to, starch,
25 gellan gum, dextran, hyaluronic acid, poly(ethylene oxides), polyphosphazenes, derivatives thereof, copolymers thereof, and mixtures thereof.

[0047] As mentioned above, water may be extracted from soil and held in the water swellable material. The water swellable material may swell up to 200 % of its original volume, such as up to about 180 %, about 150 %, or about 120 %.

30 [0048] In embodiments where volume of expansion of the water swellable material corresponds to volume of water extracted from pores of the soil in which the device is placed, bulk volume of soil may be maintained. In specific embodiments, volume of expansion of the

water swellable material upon absorption of water is at least substantially the same as volume of water extracted from the soil. As mentioned above, this allows compaction of the soil matrix to be carried out while maintaining bulk volume of the soil medium.

[0049] The method includes placing the device having a flexible, water-permeable membrane defining an enclosure for receiving a water swellable material, and a water swellable material received within the enclosure in soil.

[0050] Placing the device may be carried by any suitable process such as by a horizontal drilling process or via an underground service tunnel. In various embodiments, placing the device in soil is carried out from a ground surface of the soil by a horizontal drilling process.

[0051] Horizontal drilling may be used for installing a wide variety of utilities underground without the need for digging a trench and disrupting the ground surface. This is made possible by drilling of several laterals from only one point on the surface (surface drilling pad) which minimises the impact and scale of activity on the above ground.

[0052] Generally, horizontal drilling involves wellbores with a terminal drill hole completed as a lateral that extends parallel with the rock layer containing the substance to be extracted. When the target distance is reached, the drill pipe may be removed and more steel casing may be inserted through the full length of the well bore and, once again, the casing may be cemented in place.

[0053] Once the drilling is finished and the final casing has been installed, the drilling rig may be removed and preparations may be made for the next steps of well completion.

[0054] In some embodiments, placing the device in soil is carried out from an underground service tunnel. The device may be inserted through a modified drilling rig, which may be similar to one that is used to perform drilling or boring to install items such as rock bolt.

[0055] In some embodiments, the device may be relatively small and/or has a flat structure, such that it does not provide an arching effect due to minimal disturbance and displacement to the soil.

[0056] Various embodiments refer in a second aspect to use of a method according to the first aspect in soil strengthening, underground excavation, underground mining, underground tunneling, or construction.

[0057] Limitations of state of the art methods to achieve ground improvement through soil compaction/consolidation directed to heaving and/or settlement may be addressed using

methods disclosed herein. Compaction of soil matrix and removal of pore water may be carried out while maintaining bulk volume of the soil medium. As a result, ground improvement may be achieved without undesirable effects of heaving or settlement.

[0058] Various embodiments disclosed herein are applicable in ground improvement works, and are especially useful in cases where soft soil with high water content is involved. Soft soil with a high water content may refer to soil that has more than 30 % water content, such as more than 35 %, more than 40 % or more than 50 %.

[0059] Advantageously, methods according to embodiments disclosed herein are passive processes, and do not introduce chemical and chemical reactions in the treated soil. Ground improvement may be achieved without draining water from soil, and bulk volume of the soil medium is not changed. As a result, there is no soil heave or settlement.

[0060] Upon completion of the excavation and/or construction works, the device may be easily separated from soil, which facilitates its removal and/or disposal.

[0061] Hereinafter, the present invention will be described more fully with reference to the accompanying drawings, in which exemplary embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the exemplary embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, lengths and sizes of layers and regions may be exaggerated for clarity.

[0062] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. The invention illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms "comprising", "including", "containing", etc. shall be read expansively and without limitation. Additionally, the terms and expressions employed herein have been used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the inventions embodied

therein herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention.

[0063] The invention has been described broadly and generically herein. Each of the narrower species and subgeneric groupings falling within the generic disclosure also form part of the invention. This includes the generic description of the invention with a proviso or negative limitation removing any subject matter from the genus, regardless of whether or not the excised material is specifically recited herein.

[0064] Other embodiments are within the following claims and non-limiting examples. In addition, where features or aspects of the invention are described in terms of Markush groups, those skilled in the art will recognize that the invention is also thereby described in terms of any individual member or subgroup of members of the Markush group.

EXPERIMENTAL SECTION

[0065] Various embodiments relate to hydraulics and geotechnical methods for improving soft soil for certain engineering work such as underground mining.

[0066] By way of example only, a prefabricated geosynthetic reinforced sleeve with embedded special water absorption gel (WAG) was fabricated. The water swellable material, with its holding capacity for water, creates a turgid sleeve.

[0067] In various embodiments, the prefabricated geosynthetic reinforced sleeve with water absorption gel (GSWAG) (see **FIG. 1**) may be inserted into a soil layer. The insertion may be carried out using an installation system similar to that for installing prefabricated vertical drains, but carried out in an inclined direction. For example, the installation of GSWAG may be carried out from the ground surface using a method similar to horizontal drilling or from an underground service tunnel. In embodiments where GSWAG is used for soft soil, the installation does not require much effort.

[0068] Upon absorption of water, the GSWAG may expand and create a tension in the geosynthetic reinforcement. The expanded geosynthetic reinforced sleeve and gel composite may form a very rigid inclusion in the soil to act as a piece of reinforcement to strengthen the ground. The shear strength of the surrounding soil may also be improved due to reduction in water content.

[0069] It is noted that volume of the soil may decrease due to reduction in water content. Settlement of the soil, however, may not take place due to expansion of the gel. The

expansion may be designed or tailored to be the same as the reduction in the volume of the soil so that the proposed process does not cause the ground to settle or heave.

[0070] Advantageously, the GSWAG reinforced soil may form an improved ground that is able to resist ground movement due to high tensile strength of the geosynthetic reinforcement.

5 When there is a small soil deformation due to excavation or other types of construction activity, the GSWAG may deform and mobilize its tensile strength to prevent further soil movement as a result of the arching effect. This effect is similar to the roof piping effect although the GSWAG tubes are not as rigid as steel pipes.

[0071] As disclosed herein, various embodiments relate to a method to improve and
10 reinforce soft ground causing minimal, negligible or no ground movement during excavation. The method may include inserting a prefabricated geosynthetic reinforced sleeve containing a water absorption gel (GSWAG) into the soft soil stratum. Through extraction of water from the soil and expansion of the geosynthetic reinforced sleeve using the GSWAG, soil strength may be increased, which may in turn strengthen the soft ground. The GSWAG may further
15 help the ground to reduce ground settlement or heave through its arching and its reinforcement effect.

[0072] Advantageously, it may be possible to provide better and safer ground conditions for subsequent mining and construction work. There may be little or no ground disturbance, in particular, ground settlement.

20 [0073] While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.

CLAIMS

1. A method of reducing moisture content of soil, the method comprising placing a device having a flexible, water-permeable membrane defining an enclosure for receiving a water swellable material, and a water swellable material received within the enclosure in soil, and removing water from pores of the soil through absorption by the water swellable material with net volume of the soil remaining unchanged, wherein the method of reducing moisture content of soil is a passive process carried out without introducing a chemical reaction to the soil and/or a chemical to the soil outside of the enclosure.
2. The method according to claim 1, wherein the flexible, water-permeable membrane is porous.
3. The method according to claim 1 or 2, wherein the flexible, water-permeable membrane is selected from the group consisting of a textile, synthetic fibres, weaved or needle punched fibrous material such as geotextile, an elastomer, a plastic mesh, and combinations thereof.
4. The method according to any one of claims 1 to 3, wherein the water swellable material comprises or consists of a gel.
5. The method according to any one of claims 1 to 4, wherein the water swellable material comprises or consists of a hydrogel.
6. The method according to any one of claims 1 to 5, wherein the water swellable material is selected from the group consisting of bentonite, acrylate, urethane, cellulosic-based superabsorbent materials, and combinations thereof.
7. The method according to any one of claims 1 to 6, wherein volume of expansion of the water swellable material upon absorption of water is at least substantially the same as volume of water extracted from the soil.

8. The method according to any one of claims 1 to 7, wherein placing the device in soil is carried out from a ground surface of the soil by a horizontal drilling process.
- 5 9. The method according to any one of claims 1 to 8, wherein placing the device in soil is carried out from an underground service tunnel.
10. Use of a method according to any one in claims 1 to 9 in soil strengthening, underground excavation, underground mining, underground tunneling, or construction.