

VERTICAL DRAINS

FIELD OF INVENTION

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This invention relates to a vertical drain and more particularly to a vertical drain for use in consolidating weak or soft soils.

BACKGROUND

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Before infrastructure or buildings can be developed in an area, the ground upon which the development is to take place must be adequately consolidated in order to take the load of the infrastructure or building. This is especially true where construction is to take place on reclaimed land. Large amounts of clay, silty clay, or marine clay may be found in many areas inland and onshore where land is to be reclaimed. Before
15 construction can take place, the high water content of such weak and soft soils must be reduced to consolidate the ground.

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An early approach to ground consolidation involves the use of sand drains. Sand drains are vertical bores filled with sand which extend down into the layer of weak and soft soil to be consolidated. A surcharge load such as a large volume of soil is deposited
20 over the bores on the ground to be consolidated. The pressure exerted by the sand on the ground forces water in the weak and soft soils to flow into and up the sand drains, thereby consolidating the ground.

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In another approach, sand drains are replaced with pre-fabricated vertical drains (PVD). FIG. 6a illustrates a cross-section of a corrugated core PVD 1. As illustrated in
25 FIG. 6a, the PVD 1 comprises an elongate plastic corrugated core 2 surrounded by a filter cloth 3. Water permeates through the filter cloth 3 directly into the corrugations of the plastic core 2. The corrugations define a series of open channels in the core. The open channels are next to and exposed to the filter cloth 3. When installed into the ground, the open channels are oriented substantially vertically and form a substantially
30 vertical path along which fluid flows up along and out of the PVD 1. The water in the PVD 1 is forced up through the open channels to the surface by the pressure of the surcharge load placed on the ground being consolidated or can be drawn up the PVD 1 by use of a vacuum suction system.

Additionally, an electroosmotic consolidation process may be used with the PVD. FIG. 6b illustrates a cross-section of a corrugated core PVD 1 with filter 3, electrically conductive strips 4, and open channels 5. Electrically conductive strips 4 used as electrodes can be attached or embedded to the corrugation core 2 along the length of the corrugated core 2 to effectuate electroosmotic consolidation of the ground. Electrical potential between the electrodes attracts fluid to the PVD 1. The electrically conductive strips 4 run continuously from one end of the PVD 1 along the length of the plastics core to other end of the PVD 1. Instead of utilising electrically conductive strips, the corrugated core 2 can be electrically conductive. When installed into the ground, fluid is attracted to the corrugated core 2, passing through the filter, and flows up and out of the PVD 1 via the vertically-oriented open channels 5 of the corrugated core 2. The corrugated core PVDs may be placed in an array, with some corrugated core PVDs used as cathodes, and other PVDs used as anodes. Each of the cathode PVDs is paired with an anode PVD. The anode vertical drains may comprise solid cores without corrugations.

Unfortunately, the main pathways through which fluid flows upwards in the corrugated core PVDs are the open channels of the corrugated core, which are exposed to the filter and soil pushing against the filter. Soil pushing against the sides of the vertical drain may force the filter into the open channels of the corrugated core. The open channels may thereby become obstructed. The upward passage of fluid along the open channel may be inhibited, reducing the efficiency of fluid removal.

SUMMARY

One aspect of the present invention provides a vertical drain for draining fluid from ground soil, comprising: a tubular structure defining a circumferential wall of an internal fluid conduit; a filter surrounding said tubular structure; and a conductive element extending within and along said internal fluid conduit; wherein said tubular structure comprises a plurality of openings for passage of fluid filtered by said filter into said internal fluid conduit.

Said tubular structure of said the vertical drain may include corrugations that define channels circumferentially surrounding an exterior side of said tubular structure to allow filtered fluid to flow circumferentially around said tubular structure.

Said plurality of openings of said vertical drain for passage of fluid filtered by said filter into said internal fluid conduit may be located on said channels defined by said corrugations.

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Said vertical drain of said vertical drain may have one end attached to an anchor shoe.

Said anchor shoe of said vertical drain may comprise a substantially flat anchor plate with a handle such that said vertical drain can be securedly attached to said handle.

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Said tubular structure of said vertical drain may include channels that are located on an exterior side of said tubular structure to allow fluid to flow to said plurality of openings, and said conductive element of said vertical drain is located within said tubular structure.

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Said tubular structure of said vertical drain may have a substantially cylindrical shape.

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Said tubular structure of said vertical drain may surround and separate said internal fluid conduit from said filter.

Said conductive element of said vertical drain may be covered by electrical insulation starting from a point of said conductive element that is above ground, extending along said the conductive element to also cover a segment of said conductive element below ground.

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A further aspect of the present invention provides an array of vertical drains and conductive strips comprising: a plurality of vertical drains according to claim 1 connected to a selected terminal of a power source, and a plurality of conductive strips connected to another terminal of said power source.

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Each vertical drain of said array may be paired with a conductive strip.

A further aspect of the present invention provides a method of consolidating soft soil comprising using a vertical drain as in any one of claims 1-9. The method may be performed with the application of vacuum suction onto the vertical drain directly or indirectly.

A further aspect of the present invention provides a method of consolidating soft soil comprising using an array of vertical drains and conductive strips as in any one of claims 10-11. The method may be performed with the application of vacuum suction onto the vertical drains directly or indirectly.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

FIG. 1a illustrates a vertical drain with a tubular structure defining a circumferential wall of an internal fluid conduit, according to an embodiment.

FIG. 1b illustrates the filter wrapped around the tubular structure, according to an embodiment.

FIG. 2a illustrates a cross-sectional view of the corrugated tubular structure defining a circumferential wall enclosing an internal fluid conduit, according to an embodiment.

FIG. 2b illustrates a partial cutout view of the tubular structure, according to an embodiment.

FIG. 3a and FIG. 3b illustrate the anchor shoe with a top view and a side view, according to an embodiment.

FIG. 3c, FIG. 3d, and FIG. 3e illustrate a vertical drain with the anchor shoe, according to an embodiment.

FIG. 4a illustrates an array of vertical drains and conductive elements, according to an embodiment.

- 5 FIG. 5a illustrates an installation of an array of vertical drains and conductive elements, according to an embodiment. Figure 5b illustrates execution with a power supply, and Figure 5c illustrates end results of ground consolidation after treatment.

FIG. 6a illustrates a cross-section of a corrugated core PVD.

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FIG. 6b illustrates a cross-section of a corrugated core PVD with electrically conductive strips.

DETAILED DESCRIPTION

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Embodiments of the invention will be discussed hereinafter with reference to the figures.

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FIG. 1a illustrates a vertical drain 100 with a tubular structure 102 defining a circumferential wall 104 of an internal fluid conduit 106, according to an embodiment. A filter 108 surrounds the tubular structure 102. The tubular structure 102 is substantially cylindrically shaped. A conductive element, in the form of rod or wire or any solid material with any cross-sectional shape 110 extends within and along the internal fluid conduit 106. Openings 112 located on the tubular structure 102 allow water filtered by the filter 108 to pass through the tubular structure 102 into the internal fluid conduit 106. The circumferential wall 104 defined by the tubular structure 102 surrounds, along the axial length of the tubular structure 102, both the conductive element 110 and the internal fluid conduit 106, with an exposed opening 111 at one end of the tubular structure 102 for fluid to leave the vertical drain. The tubular structure 102 advantageously surrounds and separates the internal fluid conduit 106 from the filter 108. The tubular structure 102 also provides the stability of internal fluid conduit against the pressure of soil that may push against filter 108, when vertical drain 100 is installed in the ground.

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The conductive element 110 is preferably manufactured from steel, copper, or some other material that allows an electrical current to flow. The conductive element 110 preferably has a diameter that ranges from 0.5 to 25 mm, or any cross-

section with dimensions that ranges from 0.1 to 30 mm. The conductive element 110 need not be of uniform cross-section size throughout the length of the conductive element 110. The conductive element 110 substantially extends at least from one end of the tubular structure 102 to the other end, and the conductive element 110 is surrounded by the tubular structure 102 substantially along the length of the conductive element 110. One end of the conductive element 110 can be attached to and tied to an anchor shoe 114. The other end of the conductive element 110 is attached to a terminal of a power source. Electrical insulation (not illustrated) can be used to cover a portion of the conductive element 110. Preferably, the electrical insulation covers the conductive element 110 starting from a point of the conductive element 110 that is above ground, extending along the conductive element 110 to also cover a segment of the conductive element 110 below the ground.

The tubular structure 102 is corrugated such that channels 116 are circumferentially formed around the tubular structure 102 for the flow of fluid around the sides of tubular structure 102. The channels 116 encircle the tubular structure 102 such that the direction of fluid flow along each of channels 116 is substantially orthogonal to the length axis of tubular structure 102. Filtered fluid advantageously travels substantially along the circumferential wall 104 within the channels 116, until the filtered fluid encounters one of openings 112. The filtered fluid enters the internal fluid conduit 106 through one of openings 112. The fluid then moves up and out of the tubular structure 102. The channels 116 are substantially horizontal when the tubular structure 102 is installed in the ground. The corrugations also advantageously provide stability for the tubular structure 102 when installed in the ground.

FIG. 1b illustrates the filter 108 wrapped around the tubular structure 102, according to an embodiment. The corrugations 115, when not covered by filter 108, are clearly visible in FIG. 1b. The filter 108 can comprise filter cloth that is manufactured from a geotextile material. The filter cloth is preferably manufactured from polypropylene or polyethylene or other synthetic fibres. Preferably, the filter cloth is sufficiently porous to allow water to permeate through the filter cloth, flow along the channels 116, and into the internal fluid conduit 106. Preferably, the average pore size of the filter 108 is approximately 50 to 200 microns.

FIG. 2a illustrates a partial cross-sectional view of the corrugated tubular structure 102 defining a circumferential wall 104 enclosing an internal fluid conduit 106, according to an embodiment. The corrugated tubular structure 102, as depicted in the cross-sectional view of FIG. 2a, is depicted as two concentric rings 204, 206. The inner concentric ring 204 represents a valley of the corrugations 115 (FIG. 1b). The outer concentric ring 206 represents a peak of the corrugations 115. The peaks and valleys of the corrugations form the channels 116 that encircle tubular structure 102.

FIG. 2b illustrates a partial cutout view of the tubular structure 102, according to an embodiment. Peaks 210 and valleys 212 are clearly visible in this figure. The channels 116 are defined by the peaks and valleys of the corrugations 115. The channels 116 are each of the valleys surrounded by two peaks. The peaks of the corrugations advantageously prevent the filter from sagging into the channels 116. The openings 112, of any dimension, are located along the valleys 212. The corrugations 115 (including the channels 116) are preferably made from a non-conductive material, such as plastic. The channels 116 that are located on the exterior side of tubular structure 102 allow filtered fluid to flow to openings 112. The conductive element 110 is located within the interior side of tubular structure 102.

The partial cutout view (FIG. 2b) of tubular structure 102 includes openings 112 as seen on both interior and exterior sides. The rectangular shape openings 112 runs along the channels 116. In some embodiments, the openings 112 may be other shapes, such as round holes.

FIG. 3a and FIG. 3b illustrate the anchor shoe 114 with a top view (FIG. 3a) and a side view (FIG. 3b), according to an embodiment. The anchor shoe 114 is used in installation of a vertical drain, such as vertical drain 100 (FIG. 1). Prior to installation of the vertical drain 100 into ground, the vertical drain 100 is securely attached to anchor shoe 114. That is, the filter, tubular structure, and conductive element of vertical drain 100 are fastened to the anchor shoe 114. The vertical drain 100 is inserted into and enclosed within an installation mandrel (not illustrated). The vertical drain 100 and installation mandrel are inserted into the ground. The installation mandrel is then retrieved by pulling the installation mandrel up and out of the ground, leaving behind the vertical drain 100. The vertical drain 100 remains immobile in the ground, staying approximately at the same depth

where the installation mandrel is retrieved from. The anchor shoe 114 advantageously prevents the vertical drain 100 from being pulled out of the ground, since the filter, tubular structure, and conductive element are fastened to the anchor shoe 114.

5 The anchor shoe 114 has an anchor plate 304 that advantageously resists upward pulling when the installation mandrel is retrieved, and a handle 306 to securely attach the filter, tubular structure, and conductive element of vertical drain 100 to the anchor shoe 114. In some embodiments, only a subset of the filter, tubular structure, and conductive element of vertical drain 100 need be securely
10 attached to the anchor shoe 114. The anchor shoe is preferably manufactured from steel. The length of the anchor shoe 114 is approximately 160 mm. The width of the anchor shoe 114 is approximately 70 mm. The height of the handle is approximately 10 mm. The thickness of the material used to manufacture the anchor plate 304 and the handle 306 is approximately 1 mm.

15 FIG. 3c, FIG. 3d, and FIG. 3e illustrate a vertical drain 100 (FIG. 1) with the anchor shoe 114, according to an embodiment. In FIG. 3c, a segment 308 of the vertical drain 100, including portions of the tubular structure 102, conductive element 110 (FIG. 1), and filter 108 (FIG. 1), are slipped through the handle 306 of the anchor shoe 114. In FIG. 3d, the segment 308 of the vertical drain 100 is folded
20 around handle 306 back towards the vertical drain 100 and stapled to the tubular structure 102. Other types of fasteners can also be used to fasten the folded segment to the tubular structure 102. In FIG. 3e, the vertical drain 100 with the anchor shoe 114 is depicted in an upright position.

FIG. 4a illustrates an array of vertical drains and conductive strips 402,
25 according to an embodiment. The conductive strips can be made of any conductive material in the form of a strip, of about 10 to 150 mm width and 0.1 to 5 mm thickness, that can be inserted into the ground using the same installation mandrel as vertical drain 100. The array preferably comprises alternating rows of vertical drains and conductive strips. Preferably, the number of vertical drains in each row
30 of vertical drains is the same as the number of conductive strips in each row of conductive strips. The distance between a vertical drain 404 of one row and a conductive strip 406 of a neighbouring row is approximately one (1) metre. In the depicted example, the spacing between each row of vertical drains and a neighbouring row of conductive strips is approximately one (1) metre. The distance

between two conductive strips 408, 410 in the same row of conductive strips is approximately one (1) metre. Likewise, the distance between two vertical drains 414, 416 is also approximately one (1) metre. Preferably, the distance between a conductive strip of one row and a corresponding paired vertical drain of a neighbouring row is approximately 0.5 to 3.5 metres, the distance between two conductive strips of the same row are approximately 0.5 to 3.5 metres, and the distance between two vertical drains of the same row are approximately 0.5 to 3.5 metres.

The conductive strips and vertical drains are connected to a power supply to form cathodes and anodes. Each vertical drain is connected to one terminal of the power supply through electrical connections that connect rows of vertical drains to the power supply. Each conductive strip is connected to the other terminal of a power supply through electrical connections that connect rows of conductive strips to the power supply. The conductive strips are preferably manufactured from conductive material. Each of the vertical drains is paired with a conductive strip or placed between two conductive strips. FIG. 4b illustrates an example vertical drain 412 that may be used in quantity for constructing the array of vertical drains. The arrow extending from FIG. 4b to FIG. 4a shows that each circular representation in FIG. 4a is representing a vertical drain.

While the array of vertical drains and conductive strips has been described as a square array, different array patterns are possible. For example, the array pattern can be a triangular grid pattern in which a row of vertical drains forms a zigzag pattern. Each of the rows of conductive strips can also form a zigzag pattern. Embodiments of the invention are not limited to the array patterns described herein. The example array patterns are provided for illustration only, and the array pattern in an embodiment may be of other different patterns to suit different circumstances.

FIG. 5a illustrates an installation of an array of vertical drains and conductive elements, according to an embodiment. FIG. 5b illustrates execution with a power supply, and FIG. 5c illustrates end results of ground consolidation after treatment.

As depicted in FIG. 5a, rows of vertical drains 504 are inserted into the ground to be consolidated. Each of the vertical drains may be, for example, the vertical drain as described with respect to FIG 1a-FIG 1b and FIG 2a-FIG 2b. In FIG. 5a, six (6) rows of vertical drains 504 are depicted as inserted into the ground. Five (5) rows of conductive strips 506 are depicted as inserted into the ground. The

rows of vertical drains 504 alternate with rows of conductive strips 506. That is, each row of vertical drains 504 is installed between a row of conductive strips 506. Thus, the array comprises alternating rows of vertical drains and conductive strips.

A surcharge load, such as sand 508, can optionally be placed over the area of ground to be consolidated. Placing the surcharge load on the ground begins the hydraulic consolidation process for the ground beneath the surcharge load. Water passes through the filter wrapped around each tubular structure into the internal fluid conduit of the vertical drains, and the water moves up and out of the vertical drains.

As part of the electroosmotic consolidation process, a power source connected to the vertical drains is switched on. During the electroosmotic process, the motion of water is induced by the application of an electric potential created by the electrically connected vertical drains and conductive strips. The water is attracted to the vertical drains. Furthermore, during the electroosmotic consolidation process, a certain amount of hydraulic consolidation continues to occur. Thus, water moves to the vertical drains both through the optional hydraulic consolidation process and the electroosmotic consolidation process. Advantageously, using the vertical drains with the tubular structure and conductive element described herein, the surcharge load process may be skipped entirely to directly start the electroosmotic process.

As depicted in FIG. 5b, the rows of vertical drains and conductive strips of the array 502 are attached to a power source by means of connector terminals which are exposed above the surface of the ground. The power supply can be, for example, high capacity wet cells, an on-site generator or a connection to a grid supply.

FIG. 5c depicts the soft soil after consolidation. The soft soil from which water is extracted and removed can be any kind of soil, such as marine clay, silty clay or any other kind of weak soil with undesirable high water content or peaty soil, sludge, or trailings. The types of ground that may be consolidated by means of extracting water is not limited to the examples presented herein.

The vertical drain can be manufactured in coiled lengths of several hundred metres or more. The vertical drain, including the conductive element, the filter, and the tubular structure, can be manufactured for any length that is appropriate for the depth of the ground to be consolidated. Preferably, the tubular structure is

manufactured from plastics material such as polypropylene or polyethylene or other extrudable plastics. The tubular structure 102 can be manufactured by extrusion.

Embodiments of the invention also include a method of consolidating soft soil comprising using a vertical drain as substantially described herein. An embodiment of the invention includes a method of consolidating soft soil comprising using the vertical
5 drain as in any one of claims 1-9. The methods of consolidating soft soil comprising using a vertical drain may be performed with the application of vacuum suction onto the vertical drain directly or indirectly.

Embodiments of the invention also include a method of consolidating soft soil
10 comprising using an array of vertical drains and conductive strips as substantially described herein. An embodiment of the invention includes a method consolidating soft soil comprising using an array of vertical drains and conductive strips as in any one of claims 10-11. The methods of consolidating soft soil comprising using an array of vertical drains and conductive strips may be performed with the application of
15 vacuum suction onto the vertical drains directly or indirectly.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects
20 to be illustrative and not restrictive. For example, it will be appreciated that embodiments are not limited to the example materials, shapes, and dimensions described herein.

CLAIMS

1. A vertical drain for draining fluid from ground soil, comprising:
 - 5 a tubular structure defining a circumferential wall of an internal fluid conduit;
a filter surrounding said tubular structure; and
a conductive element extending within and along said internal fluid conduit;
wherein said tubular structure comprises a plurality of openings for passage of fluid
filtered by said filter into said internal fluid conduit.
- 10 2. The vertical drain of claim 1, wherein said tubular structure includes corrugations
that define channels circumferentially surrounding an exterior side of said tubular
structure to allow filtered fluid to flow circumferentially around said tubular structure.
- 15 3. The vertical drain of claim 2, wherein said plurality of openings for passage of
fluid filtered by said filter into said internal fluid conduit are located on said channels
defined by said corrugations.
4. The vertical drain of claim 1, wherein one end of said vertical drain is attached to
20 an anchor shoe.
5. The vertical drain of claim 4, wherein said anchor shoe comprises a substantially
flat anchor plate with a handle such that said vertical drain can be securedly attached to
said handle.
- 25 6. The vertical drain of claim 2, wherein channels that are located on an exterior
side of said tubular structure allow fluid to flow to said plurality of openings, and said
conductive element is located within said tubular structure.
- 30 7. The vertical drain of claim 1, wherein said tubular structure has a substantially
cylindrical shape.
8. The vertical drain of claim 1, wherein said tubular structure surrounds and
separates said internal fluid conduit from said filter.

9. The vertical drain of claim 1, wherein electrical insulation covers a portion of said conductive element starting from a point of said conductive element that is above ground, extending along said conductive element to also cover a segment of said conductive element below ground.

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10. An array of vertical drains and conductive strips comprising:
a plurality of vertical drains according to claim 1 connected to a selected terminal of a power source, and a plurality of conductive strips connected to another terminal of said power source.

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11. The array of claim 11, wherein each vertical drain is paired with a conductive strip.

12. A method of consolidating soft soil comprising using a vertical drain as in any one of claims 1-9.

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13. The method of claim 12, wherein said method is performed with the application of vacuum suction onto the vertical drain directly or indirectly.

14. A method of consolidating soft soil comprising using an array of vertical drains and conductive strips as in any one of claims 10-11.

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15. The method of claim 14, wherein said method is performed with the application of vacuum suction onto the vertical drains directly or indirectly.