

Method and arrangement for producing gravel columns

TECHNICAL FIELD

The present invention relates to a soil improvement method. More specifically, the present invention relates to a method of producing gravel
5 columns, such as stone columns, with the aim of improving the soil. The invention also relates to a corresponding system with which the method can be carried out.

BACKGROUND OF THE INVENTION

The main goal of most soil improvement techniques is to densify the
10 soil and/or to improve its drainage capacity. There exist several techniques to achieve this, but this invention concerns building gravel columns in the soil. This can generally be achieved by a technique called vibroflotation combined with a gravel backfill which results in the formation of stone columns.

Vibroflotation involves the use of a vibrating probe that can
15 penetrate the soil to be improved down to the required depth. The vibrating probe penetrates to the required depth by vibration and jetting action of air. The vibrations of the probe cause the soil structure to collapse or to be pushed aside, thereby densifying the soil surrounding the probe.

There are two basic methods to introduce the gravel in the column.
20 The first one, usually named "top feed" method, consists of just pushing the gravel at ground level into the annulus around the probe previously lowered in the ground. However, with the top feed method, there is no control whether the gravel actually reaches the bottom of the probe.

Nowadays, the second method named "bottom feed" is the most
25 commonly specified as it enables to ensure that the gravel has actually been placed and compacted at the bottom of the probe. When using the bottom feed technique, the gravel is added through a pipe, generally called a follow-up pipe, which runs alongside and all the way down the vibrating probe. The

outlet of the gravel is therefore placed directly below the vibrating probe. The gravel column is then created by feeding of successive gravel batches below the probe, with each batch being compacted by the probe before the next batch is fed. The column diameter can vary depending on the initial stiffness or
5 density of the soil. It is possible to allow more gravel to be placed in weaker soil regions. The obtained stone columns not only increase the amount of densification, but also provide a degree of reinforcement and a potentially effective means of drainage.

When using the bottom feed technique a feed tank for the gravel is
10 usually located on top of the follow-up pipe. The gravel can then be fed into the follow-up pipe from this tank. A stockpile of gravel is usually located on the ground. From this stockpile the gravel has to be somehow transported to the feed tank on top of the follow-up pipe. The most commonly used method consists of using a skip which is filled with a backhoe or loader at ground level,
15 then lifted up and emptied into the feed tank at the top of the follow-up pipe. However, this method is cumbersome and has the disadvantage of producing lots of dust which leads to increased pollution. Another method to do this is to transport the gravel from a reservoir (called blow-tank) at ground level to the feed tank by using pressurized air. However, gravel is not easily transported
20 by air and blockages due to accumulation of gravel in the transfer pipes are frequent.

Another difficulty in the known methods of creating gravel columns relates to the actual feeding of the gravel into the soil. Especially in the case of soft clayey or silty soil, the end of the follow-up pipe becomes easily clogged by
25 the soil material, which impairs the gravel feeding operation into the soil.

It is the object of the present invention to overcome the problems identified above related to building material columns.

SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided a
30 method of building a gravel column in soil for consolidating the soil by using a

soil improvement system comprising a reservoir connected by a first pipe to a separation hopper, the method comprising:

- 5 • transferring the gravel through the first pipe, by using liquid as a transfer medium, from the reservoir into the separation hopper;
- separating at least some liquid from the gravel in the separation hopper; and
- feeding either directly or indirectly at least some gravel from the separation hopper to the soil.

10 The proposed method offers a solution allowing gravel columns to be created very efficiently. For instance as the feeding medium for feeding the gravel into the separation hopper is not air, but liquid, pollution can be drastically reduced as the existence of dust particles can be essentially eliminated. The liquid transfer medium can be e.g. water. This has the further
15 advantage that this kind of transfer medium is easily available and is inexpensive.

 According to a second aspect of the invention, there is provided a system where the method according to the first aspect can be carried out.

 Other aspects of the invention are recited in the dependent claims
20 attached hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

 Other features and advantages of the invention will become apparent from the following description of non-limiting exemplary embodiments, with reference to the appended drawings, in which:

- Figure 1 is a schematic side view of a gravel feeding system according to an embodiment of the present invention;
- Figure 2 is a schematic perspective view showing the reservoir shown in Figure 1;
- 5 - Figure 3 is a schematic top view showing the reservoir of Figure 2.
- Figure 4a is a schematic cross-sectional side view illustrating the separation hopper (first tank) and the pressurisable or pressurising tank (second tank) shown in Figure 1, where a valve in the pressurisable tank is
10 closed while another valve is open;
- Figure 4b is a schematic cross-sectional side view illustrating the separation hopper and the pressurisable tank shown in Figure 1, where the valve in the pressurisable tank is open while the other valve is closed;
- Figure 5 is a flow chart illustrating the method of building gravel
15 columns according to an embodiment of the present invention; and
- Figure 6 is a schematic side view illustrating a twin assembly for building gravel columns according to another embodiment of the present invention.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

20 Some embodiments of the present invention will be described in the following in more detail with reference to the attached figures. Identical functional and structural elements which appear in the different drawings are assigned the same reference numerals.

25 The purpose of the system or apparatus explained below is to transfer aggregate, such as gravel, from a source tank, hereinafter referred to as a reservoir, to one or more receiving tank(s), hereinafter referred to as

separation hoppers, using a liquid, such as water, as a transfer medium through a suitably sized hose or pipe leading to the separation hopper(s). The word gravel in the present description and in the claims is understood to cover other granular materials suitable for the intended application of the method.

5 Examples of these materials are crushed rubble, concrete, broken glass, etc. The size of the gravel particles in a specific application may be dependent on the diameter of the column to be built. For instance, the larger the diameter of the column is, the larger the particles are that are used to build the column. However, often there is no link between column diameter and gravel size. The
10 gravel size is often governed by the availability/price in the area of the project, and is limited by the size of the piping and follow-up pipes so as to avoid blockages.

In some applications the liquid transfer medium flows continuously while the gravel is fed in batches into the fluid medium in a controlled manner,
15 using for instance a screw feed system which is started and stopped in cycle with the operation of the double valve system described later. Feeding the liquid transfer medium continuously has the advantage that there is no need to turn on/off the related pump. If the screw feed system is used, then the density of the "fluid+gravel" mix is controlled by adjusting the rotational speed of the
20 screw relative to the fluid medium flow. The quantity of gravel sent in each batch is controlled by the number of screw rotations in each cycle.

Figure 1 illustrates a system for building gravel columns according to one embodiment of the present invention. Only the elements relevant for understanding the present invention are shown. Thus, for instance a vibrator probe is omitted in that figure. A storage tank 101, hereinafter referred to as a
25 reservoir 101, is used for storing the gravel and the liquid transfer medium, such as water. The reservoir 101 is shown in more detail in Figures 2 and 3. Just outside the reservoir 101 there is shown a motor 103 for operating the screw that is used for feeding the gravel into a feed pipe 105. The feed pipe
30 105 is connected in the vicinity of the reservoir 101 to a pump 106 that is arranged to pump the gravel and liquid into a separation tank, hereinafter called separation hopper 107. In some implementations the pump 106 is submerged in water, and is below the water surface in the reservoir 101. The

pump can be located, for example, below the surface level of a sea, a river, a lake or a pond, so that supply of liquid medium is such that it does not necessitate being recycled. It is possible to place the reservoir 101 on a barge, and to submerge the pump 106 in the sea, for instance, so that the pump is
5 located below the reservoir 101. Thus, the pump can have one inlet for the gravel that comes from the reservoir and another inlet for the water from the sea for running the pump 106.

In the hopper 107 the gravel is separated from the liquid transfer medium, which is then returned to the reservoir 101, through one or more
10 suitable return pipes 109. The separation process is explained in more detail later on. Instead of returning the liquid back to the reservoir, it could also be disposed of. This could be the case for instance if the reservoir 101 is submerged in water, for instance placed on the seabed or suspended from a barge. The purpose of the separation process is to simply evacuate the excess
15 liquid from the separation hopper 107, since otherwise it could fill quickly. The liquid feed rate could be in the range of 4000 to 8000 litres per minute and the capacity of the separation hopper 107 could be 1 to 3 m³, for example. However, it is not necessary to separate all the liquid from the gravel.

If the condition of the soil in which the gravel columns are to be built
20 is too soft and necessitates preventing ingress of soil at the bottom tip of a gravel feed pipe, another tank 111, hereinafter named pressurisable tank, becomes necessary.

The granular material, possibly together with some liquid, is then transferred from the separation hopper 107 to the pressurisable tank 111
25 situated below the separation hopper 107 by gravity through a first valve 113 situated between the separation hopper 107 and the pressurisable tank 111. The capacity of the pressurisable tank 111 is bigger than, or at least the same as, the capacity of the separation hopper 107. The pressurisable tank 111 can be pressurised, as will be explained later in more detail.

30 From the pressurisable tank 111 the gravel, possibly together with some liquid, is fed by gravity into an outlet tube 115, hereinafter a gravel pipe

115, alongside a vibratory probe follow-up pipe 114, or directly into a vibratory probe follow-up pipe 114 through a second valve 401 situated at the bottom of the pressurisable tank 111 (see Figures 4a and 4b). The second valve could also be immediately below the pressurisable tank 111, if a “gate” type valve is used, as the one shown for the first valve 113. In the illustrated example, the pipe 114 that has the vibratory probe at its distal end (the end remote from the pressurisable tank 111) is different from the gravel pipe 115 that is used for feeding the gravel into the soil. These two pipes run parallel next to each other leading to the soil. In other configurations, the gravel can fall directly down the vibratory probe follow-up pipe 114, then diverted alongside the vibratory probe, i.e. only at the distal (bottom) section of the assembly.

In Figure 1 there is also shown a compressor 117 for producing compressed air which can be led to the gravel pipe 115 through a pressure pipe 119. A pressurisable inlet is provided at the top of the gravel pipe 115, below the second valve 401. The pressurisable medium may be either compressed air or liquid, e.g. water. In the case of a liquid, and depending on the application, control of flow may be used in lieu of pressure.

If the condition of the soil in which the gravel columns are to be built is such that ingress of soil and clogging at the bottom tip of the gravel pipe are not a likely issue, the pressurisable tank 111 and the second valve 401 would not be required. In such a case, the gravel pipe 115 may be connected directly below the first valve 113, or if the first valve 113 is not used, then the gravel pipe 115 would be connected directly to the separation hopper 107.

Figures 2 and 3 illustrate the reservoir 101, Figure 2 being a perspective view, whereas Figure 3 is a top view. As can be seen from these figures, the reservoir 101 in this example comprises two compartments: a first compartment 201 for the gravel, and a second compartment 202 for the liquid. These compartments are separated by a wall 203. The purpose of the wall 203 is to keep the outlet 207 free of gravel and to enable free flow of liquid only when a screw feed system 205 is stopped. As the opening in the wall 203 for the screw feed system 205 does not prevent the liquid from entering the first

compartment 201, the gravel in the first compartment 201 may be partially submerged. However, this is not an issue.

The motor 103 is arranged to drive a screw feed system 205 which is arranged to feed the gravel from the first compartment 201 through a first
5 opening in the wall 203 into the second compartment 202, and more specifically to the outlet 207 (second opening 207) located at the bottom of the second compartment 202 as shown in Figure 3. The feed pipe 105 is in the state of operation connected to this second opening 207. Thus, the gravel together with the liquid as a transfer medium are arranged to leave the
10 reservoir through the outlet 207 at the bottom of the reservoir 101.

It can be determined how much gravel is transferred to the feed pipe 105 by each rotation of the screw. Thus, by calculating the number of rotations of the screw, the quantity of gravel can be accurately determined. This point is actually a significant advantage of the present method from a quality control
15 viewpoint, compared to prior art solutions, where the quantity of gravel is controlled by number of hopper or backhoe bucket fillings, which may not always be fully or equally filled. By adjusting the rotational speed of the screw with respect to the liquid flow through the bottom opening 207, the density of the "liquid and gravel" mix can be controlled.

20 One example of a method of building stone columns is now explained in more detail with reference to Figures 1 to 4a and 4b and to the flow chart of Figure 5. In step 501 the first valve 113 is closed. Once this is done, then in step 503 the gravel pipe 115 can be pressurised. If the second valve 401 is open, this also means that the pressurisable tank 111 is also
25 pressurised. Now in step 505 the pump 106 is turned on to feed liquid, in this example water, into the separation hopper 107. In step 507 the motor 103 is turned on in order to turn the screw 205 and thereby to feed gravel into the separation hopper 107. In other words, the gravel is pumped together with water into the separation hopper 107. Now the separation hopper 107 fills with
30 gravel.

In step 509 the gravel is separated from the water in the separation hopper 107. This separation may be done by using one or more filter screens, which can be simple meshes. In the example of Figures 4a and 4b, there are shown two inclined filter screens 403 inside the separation hopper 107. The gravel is arranged to travel on the surface of the screens while the water falls through the screens to be fed out of the separation hopper 107. The inclination of the filter screens 403 can be adjusted if necessary. As shown in Figures 4a and 4b there are further provided liquid guides 405, which can be simply plates for guiding the water into the return pipes 109 to be fed back to the reservoir 101 (step 511). The purpose of these plates 405 is also to prevent gravel from going upwards inside the separation hopper 107 due to a possible whirling motion of the gravel and water inside the separation hopper 107. It would also be possible to separate the gravel from the water by gravity sedimentation, in which case return outlets for the return pipes 109 would be situated in the upper part of the separation hopper 107. In step 511, instead of feeding the water back to the reservoir 101, it can be disposed of.

In step 513 it is determined whether the required amount of gravel has been sent from the reservoir 101 to the separation hopper 107. If the required amount has not been sent, then the process continues in step 509. On the other hand, if the required amount has been sent, then the motor 103 is turned off in step 515 to stop feeding gravel into the separation hopper 107. In step 517 it is determined whether all the gravel that was sent is received at the separation hopper 107. As the feed pipe 105 can be quite long, there can be some delay between the moment of time when the last batch was sent from the reservoir 101 and the moment of time when this batch is received by the separation hopper 107. If not all the gravel has been received, then this step is repeated until all the gravel has been received. Once all the gravel has been received at the separation hopper 107, then the process continues in step 519 by opening the first valve 113 to feed the gravel by gravity from the separation hopper 107 into the pressurisable tank 111.

In step 521 it is determined whether the pressurisable tank 111 is full. If the pressurisable tank 111 is not full, then this step is repeated. If, on the other hand, the pressurisable tank 111 is full, then the process continues in

step 523 by closing the first valve 113. After this, in step 525, the second valve 401 is opened. The second valve 401 is shown in the open state in Figure 4b, where it is in the down position. Now the gravel can be fed by gravity from the pressurisable tank 111 into the gravel pipe 115 to be fed into the soil.

5 In step 527 it is determined whether the pressurisable tank 111 is empty. If the pressurisable tank is not empty then this step is repeated. If this tank is empty, then in step 529 the second valve 401 is closed. In Figure 4a the second valve 401 is shown in its closed state. At least one of the two valves is kept closed at all times. This makes it possible to keep the follow-up
10 pipe 115 pressurised at all times. This has the effect of facilitating the gravel feed operation into the soil. In this example the second valve 401 is a conical valve that is arranged to move up and down. When it is in the up position as shown in Figure 4a, the valve is closed. From step 529 the process continues in step 519.

15 From step 523 the process continues also in step 531. In this step it is determined whether more gravel is needed. If more gravel is needed, then the process continues in step 507. If, on the other hand, in step 531, it is determined that no more gravel is needed, then in step 533 the pump 106 and the pressurisation of the gravel pipe 115 are turned off. After this step the
20 method comes to an end. It is to be noted that step 531 runs in parallel with step 525.

 The above process can be modified in several ways. For instance, in the separation hopper 107 there can be a sensor for measuring the quantity of gravel in that tank. This sensor can send a signal to the motor 103 in order
25 to turn it off, once the separation hopper 107 contains the desired quantity of gravel. Also, the gravel feed from the reservoir 101 could be restarted immediately after closing the first valve 113, or in some implementations the gravel could be fed into the separation hopper 107 while opening the first valve 113.

30 As explained above, the purpose of the first and second valves 113, 401 is to make it possible to keep the gravel pipe 115 pressurised at all times

whilst enabling passage of the gravel successively from the separation hopper 107 to the pressurisable tank 111 (the first valve 113 opens when the second valve 401 is closed), then from the pressurisable tank 111 to the gravel pipe 115 (the first valve 113 is closed, the second valve 401 opens). Thus, an
5 overpressure with respect to the surrounding environment is always kept in the gravel pipe 115. To achieve this, the pressure inlet (where the pressure pipe 119 is connected to the gravel pipe 115) is located below the second valve 401. The process of successively opening and closing the valves is repeated in a cycle so that in the illustrated example the gravel is fed in batches. Also
10 the operations of the valves 113, 401 and the operation of the screw feed system 205 at the reservoir 101 are synchronised. However, it is also possible to have a solution where the gravel is continuously fed from the reservoir 101 into the separation hopper 107. In this case, however, the gravel feed rate should be slow enough to avoid wasting the gravel by filling the separation
15 hopper 107 too quickly.

In the description above, a system was described comprising one separation hopper 107 and one pressurisable tank 111. In Figure 6 some parts of a twin assembly are shown, where the assembly comprises among other elements two separation hoppers 107 and two pressurisable tanks 111. In this
20 figure there is also shown a suspending means 601, such as a pulley, for raising or lowering the assembly by use of a crane, for example. As shown, the suspending means 601 is located at the level of the separation hopper 107, but well below the upper surfaces 603 of the separation hoppers 107. This arrangement has the particular advantage that the overall height of the
25 assembly becomes smaller compared to a situation where the suspending means 601 is located above the separation hopper 107. Thanks to the twin assembly, the arrangement remains balanced even after insertion of the suspending means 601 between the separation hoppers 107.

In the twin assembly both sides (one side comprising one separation
30 hopper and one pressurisable tank) are independent. The sides may or may not operate synchronously. For instance, while filling on one side the separation hopper, on the other side the pressurisable tank can be emptied. However, in the twin assembly it is also possible that one of the sides is used

only when there is a defect on the other side. The gravel pipes 115 from the pressurisable tank 111 can merge into a single pipe, or two separate pipes can run parallel to the soil. Also there can be one individual feed pipe 105 for each side, or, alternatively, there could be only one common feed pipe for both
5 sides. In the latter case, the position of the feed pipe 105 can be switched from side to side to feed both sides, if necessary. In this case, the gravel flow from the reservoir 101 could actually be continuous.

As described above, the proposed method consists essentially of using a liquid, generally water, to transport the gravel from ground level up to
10 the separation hopper 107, then of separating most of the liquid from the gravel and either disposing of the liquid or recycling it, depending on site conditions. The gravel retained in the separation hopper 107 may then be fed to an intermediate tank 111, which can be pressurised together with the gravel pipe 115 below in order to prevent ingress of soil material and clogging at the
15 bottom tip of the gravel pipe 115. Depending on existing soil conditions, such pressurisation may not be necessary, in which case this intermediate pressurisable tank 111 may not be required.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to
20 be considered illustrative or exemplary and not restrictive, the invention being not limited to the disclosed embodiments. Other embodiments and variants are understood, and can be achieved by those skilled in the art when carrying out the claimed invention, based on a study of the drawings, the disclosure and the appended claims. For instance, instead of having the inclined filter screens in
25 the separation hopper(s) 107, it is possible to eliminate these screens and to simply put a mesh in front of the liquid outlet to block any gravel from entering the return pipes 109. Also, triple (comprising three separation hoppers and three pressurisable tanks), quadruple (comprising four separation hoppers and four pressurisable tanks) and so forth assemblies are also possible. In this
30 case the number of the screw feed systems in the reservoir 101 can be equal to the number of the sides in the assembly. It is also to be noted that the present invention is not limited to the use of the screw feed system, but other feed systems can also be used.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that different features are recited in mutually different dependent claims does not indicate that a combination of these features cannot be
5 advantageously used. Any reference signs in the claims should not be construed as limiting the scope of the invention.

Claims

1. A method of building a gravel column in soil for consolidating the soil by using a soil improvement system comprising a reservoir (101) connected by a first pipe (105) to a separation hopper (107), the method
5 comprising:

- transferring (507) the gravel through the first pipe (105), by using liquid as a transfer medium, from the reservoir (101) into the separation hopper (107);
- 10 • separating (509) at least some liquid from the gravel in the separation hopper (107); and
- leading (519) at least some gravel from the separation hopper (107) to the soil.

2. A method according to claim 1, wherein the separation hopper (107) is connected by a first valve (113) to a pressurisable tank (111), which is
15 connected by a second valve (401) to a pressurisable second pipe (115) leading to the soil, wherein the gravel is led from the separation hopper 107 through the pressurisable tank (111) and through the pressurisable second pipe (115) to the soil, and wherein at least one of the valves (113, 401) is closed at any time instant.

20 3. A method according to claim 2, wherein the method further comprises:

- closing (501) the first valve (113) before transferring the gravel;

- closing (513) the second valve (401) after at least some gravel has been separated;
- opening (517) the first valve (113) to allow the gravel to be moved from the separation hopper (107) into the pressurisable tank (111);
- closing (519) the first valve (113); and
- opening (521) the second valve (401) to allow the gravel to be moved from the pressurisable tank (111) into the pressurisable second pipe (115) leading to the soil.

4. A method according to claim 2 or 3, further comprising pressurising (503) the pressurisable second pipe (115) after the first valve (113) and/or the second valve (401) has/have been closed.

5. A method according to claim 4, wherein the pressurisation is done by means of compressed air at a controlled pressure or by a controlled flow of liquid.

6. A method according to any one of the preceding claims, further comprising feeding the liquid transfer medium back to the reservoir (101) from the separation hopper (107).

7. A method according to any one of preceding claims, wherein in the process of building the gravel columns, the liquid transfer medium is fed continuously from the reservoir (101) to the separation hopper (107).

8. A method according to any one of the preceding claims, further comprising stopping (515) the gravel transfer and restarting it again to feed the gravel from the reservoir (101) into the separation hopper (107) in batches.

9. A method according to any one of the preceding claims, wherein
5 the reservoir (101) comprises a first compartment (201) which contains at least the gravel, and a second compartment (202) which contains the liquid transfer medium, and wherein the second compartment (202) has an opening (207) for the gravel and liquid to be fed to the first pipe (105).

10. A method according to any one of the preceding claims, further
10 comprising submerging a pump (106) used for feeding the gravel to the separation hopper (107) in water.

11. A method according to any one of the preceding claims, wherein the liquid transfer medium is water.

12. A system for building a gravel column in soil for consolidating the
15 soil, the system comprising:

- a reservoir (101);
- a separation hopper (107) connected by a first pipe (105) to the reservoir (101); and
- means for transferring (107, 115) the gravel to the soil,

20 wherein the gravel is arranged to be transferred from the reservoir (101) to the separation hopper (107) by using liquid as a transfer medium, and

wherein the separation hopper (107) comprises means to separate at least some liquid from the gravel.

13. A system according to claim 12, further comprising a pressurisable tank (111) connected to the separation hopper (107) by a first valve (113), and further comprising a pressurisable second pipe (115) leading to the soil and connected to the pressurisable tank (111) by a second valve (401), wherein at least one of the valves (113, 401) is arranged to be closed at all times.

14. A system according to any one of claims 12 to 13, wherein the reservoir (101) comprises a screw feed system (205) arranged to transfer gravel in batches from the reservoir (101) into the first pipe (105).

15. A system according to claim 14, wherein the reservoir (101) comprises a first compartment (201) and a second compartment (202) separated from the first compartment by a wall (203) having an opening, and the screw feed system is arranged to pass through this opening.

16. A system according to any one of claims 12 to 15, further comprising a pressurisation pipe (119) connected to the second pipe (115) below the second valve (401).

17. A system according to any one of claims 12 to 16, further comprising another separation hopper (107), another pressurisable tank (111) and a suspending means (601), wherein the suspending means (601) is arranged in a balanced manner below the top surface (603) of the separation hoppers (107) and between them.