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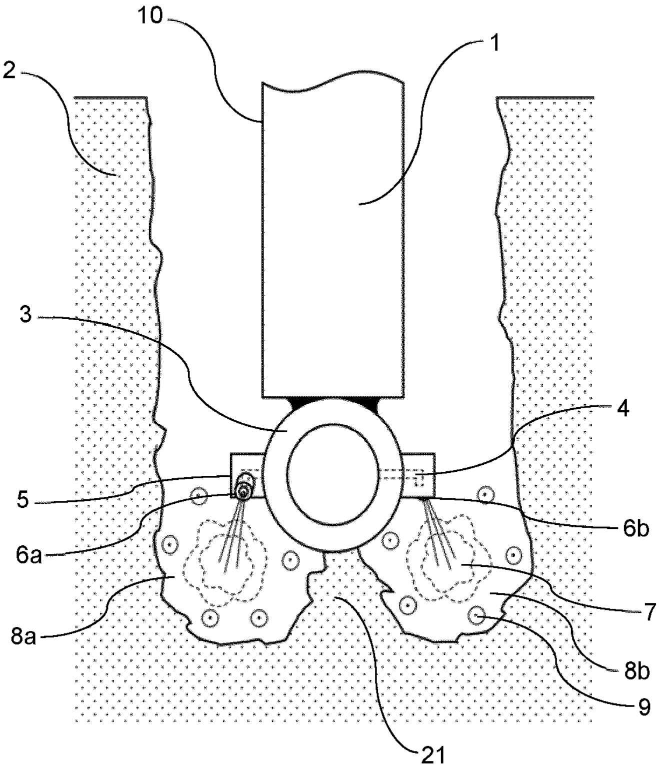
(54) FOUNDATION FOR A STRUCTURE AND METHOD OF INSTALLING THE SAME

(57) A foundation (10) for a structure including a body (1) for insertion into a soil (2) in an insertion direction during installation, the body (1) having a toe (3) at its distal end. An array of nozzles (6) are provided at the distal end for jetting a fluid, with the nozzles (6) in the array being configured such that their fluid jets (7) are complementarily directed for generating a fluid stream (8) ahead of the toe (3) which flows in a direction perpendicular to the insertion direction to erode the soil below the pile toe.

Fig. 1



EP 4 296 432 A1

Description

[0001] The present invention concerns a foundation for a structure and a method for installing the same. In particular, the present invention concerns structural foundations, such as piles, tubular piles, monopiles, jacket piles, suction bucket/caisson foundations and suction anchors, skirted foundations, sheet walls, berthing dolphins, and other types of temporary and permanent shallow or deep water foundations, that may be inserted into a soil for supporting structures such as buildings, walls, offshore structures, and wind turbines. The present invention is particularly suited to offshore foundations, and more particularly to open ended tubular foundation types, such as monopiles, jacket piles and suction buckets, and most particularly to offshore wind turbine foundations.

[0002] Structural foundations are typically installed by forcing the foundation into the ground using a piling or hydraulic impact hammer to apply a series of axial impacts for driving the foundation down into the soil in an insertion direction. Once installed, the foundation is axially supported by the friction applied to the lateral surfaces of the foundation's body and, to a lesser extent, the resistance to further penetration at the foundation's toe.

[0003] With conventional installation techniques, the toe at the distal end of the foundation displaces soil as it is driven down. This compresses the soil in the surrounding region. However, as the foundation is driven deeper, and pressure increases, the forces required to continue displacing soil at the foundation's toe also increase. At the same time, the lateral surface area of the foundation in contact with the soil increases, leading to an increase in the shear forces required to overcome the frictional resistance to driving. As a result, the bearing resistance increases as the foundation is installed deeper into the soil.

[0004] In recent years, there has been a trend towards having larger monopile and other foundations, and this has exacerbated the above challenges of their installation. For example, higher impact forces and/or a higher number of hammer strikes are required for pile driving larger foundations. This in turn imposes significant failure resistance requirements on the foundation. At the same time, the noise generated by the larger impacts is also increased, which presents significant environmental and safety hazards.

[0005] In view of the above, various methods and systems have been proposed for making the installation of foundations easier. For example, electro-osmosis has been proposed as a mechanism to lower shaft resistance during pile installation by attracting pore water to the foundation body. This thereby lubricates the interface between the soil and the foundation surface. However, whilst research in this area continues, electro-osmosis may not be suitable in all circumstances. As such, there remains a need for other methods and systems for reducing installation resistance during installation of a foundation.

[0006] The present invention therefore seeks to address the above issues.

[0007] According to a first aspect, there is provided a foundation for a structure comprising: a body for insertion into a soil in an insertion direction during installation, the body having a toe at its distal end; and an array of nozzles provided at the distal end for jetting a fluid, wherein the nozzles in the array are configured such that their fluid jets are complementarily directed for generating a fluid stream ahead of the toe which flows in a direction substantially perpendicular to the insertion direction.

[0008] In this way, the present invention provides a foundation that may be installed more easily. In particular, the generation of the fluid stream driven by high-pressure jetting from the nozzles provides a high velocity flow which erodes soil as it moves around a fluid channel formed in a plane ahead of the toe. As soil is eroded, coarse grains are accumulated in the suspension, increasing its abrasiveness, and further enhancing erosion. The toe may therefore progressively advance into the cavity formed by the flowing fluid. At the same time, the excess soil suspension caused by the persistent fluid influx is pushed upwards through the gap between the foundation wall and the soil that is created by the abrasive suspension flow. As such, soil particles are continually transported away from the installation front. Importantly, as the fluid flow is perpendicular to the installation direction, and the complementary configuration of the nozzles acts to enhance the speed of the fluid flow, the erosion of the fluid cavity walls is controlled and rapid. This contrasts with conventional jetting techniques which rely on high-power vertical jets to mechanically cut into and breakup the soil. Embodiments of the invention therefore allow for both improved installation speed and retention of the surrounding soil structure for providing a more stable support for the foundation once installed.

[0009] In embodiments, the fluid stream forms a fluid channel ahead of the toe in a plane perpendicular to the insertion direction by eroding soil as the fluid flows through the fluid channel in the direction perpendicular to the insertion direction.

[0010] In embodiments, soil is progressively eroded from the wall of the fluid channel as the toe advances in the insertion direction during installation.

[0011] In embodiments, the nozzles in the array are configured for generating the fluid stream flowing in a cyclic path in a soil region ahead of the toe. In this way, the fluid stream may form a continuous loop, allowing the fluid flow to be driven around by the nozzles in the respective array at a high velocity, with each nozzle feeding into the stream produced by the preceding nozzles.

[0012] In embodiments, the cyclic path is a circumferential path coaxial with the body. In this way, the fluid channel cavity formed by the fluid stream is aligned with the foundation's body for creating the space between the soil and the body as the foundation advances in the installation direction.

[0013] Preferably, the foundation is provided as a hollow foundation. More preferably, the foundation is a hollow pile foundation. Even more preferably, the foundation is a monopile. For example, the monopile may comprise a hollow tubular body.

[0014] In embodiments, the foundation further comprises a second array of nozzles provided at the distal end, wherein the nozzles in the second array are configured such that their fluid jets are complementarily directed for generating a second fluid stream ahead of the toe which flows in a direction perpendicular to the insertion direction and opposite to the first fluid stream. In this way, a second array of nozzles may be provided with their jetting thrust being applied in an opposite direction to the thrust applied by the first nozzle array. This thereby counteracts the torsional moment that would otherwise be applied by jetting in an uniform direction. At the same time, the generation of a second stream allows a wider cavity area to be formed for creating space between the soil and the foundation body.

[0015] In embodiments, the first array of nozzles is provided on an interior side of the body for generating the first fluid stream in a path in line with an interior lateral surface of the body, and the second array of nozzles is provided on an exterior side of the body for generating the second fluid stream in a path in line with an exterior lateral surface of the body. In this way, the angle of the nozzles in each of the first and second arrays may be respectively directed for creating space between the soil and the interior and exterior lateral surfaces of the foundation body.

[0016] In embodiments, a fin provided at the distal end for separating the first fluid stream from the second fluid stream. In this way, efficiency may be improved as less jetting energy is dissipated by the turbulent interface between the opposing streams. At the same time, the respective nozzles of each of the arrays may be angled more closely together, thereby providing a narrower combined fluid channel cavity, and in turn allowing the soil structure surrounding the foundation body to be better preserved.

[0017] In embodiments, the foundation further comprises a manifold at the distal end of the foundation and wherein the nozzles are mounted to the manifold for being fed fluid thereby. In this way, pressurised fluid may be fed to the nozzles at the distal end of the foundation, with the shape of the manifold defining the shape of the path of the fluid channel cavities formed during jetting. That is, the shape of the manifold in a horizontal plane determines the shape of the fluid channel in a horizontal plane. At the same time, the pressurised fluid applied acts to maintain the shape of the interior bore within the manifold itself.

[0018] In embodiments, the nozzles are directed downward in the range of 1-40 degrees about the radial axis from the tangential direction. Preferably, the nozzles are directed in the range of 10-30 degrees from the tangential direction. In this way, rather than being directed into the soil ahead of the toe, the jetted fluid from nozzles in each array is directed diagonally down for driving the fluid suspension flow in a lateral plane. For example, for round foundations, the fluid suspension flow is driven circumferentially. In embodiments, the nozzles are directed in the range of -10 to +10 degrees about an axial axis from the tangential direction.

[0019] In embodiments, the nozzles are distributed around the perimeter of the toe. In this way, the velocity of the fluid stream formed by the fluid jetting may be maintained throughout the fluid circuit for providing uniform soil erosion.

[0020] In embodiments, the foundation further comprises a pressurised fluid supply for supplying pressurised fluid to the nozzles. Preferably, this pressurised fluid supply is in excess of 10 bar relative to the ambient fluid pressures, and more preferably above 100 bar relative to the ambient fluid pressures, and even more preferably above 200 bar relative to the ambient fluid pressures.

[0021] In embodiments the nozzles have a diameter of 1.5-5mm. It will be understood that, the larger the nozzle diameter, the greater the influx. In a preferred embodiment, the nozzles have a diameter of 2.8mm. In such embodiments, the fluid may be supplied at a pressure of around 250bar. Such embodiments may be implemented with a 9m diameter monopile having two rows of nozzles pointing in the different directions and each nozzle being spaced 15cm apart.

[0022] In embodiments, the foundation further comprises a controller for controlling one or more of: an installation speed, a ballast weight, and a fluid pressure of fluid supplied to the nozzles.

[0023] Preferably, the fluid comprises water. The fluid may be, for example, seawater, or an aqueous solution or suspension. In this respect, a controller may be provided for controlling the pressure, flow rate and/or composition of the fluid delivered through the nozzles.

[0024] In embodiments, the foundation may further comprise an additive delivery system for delivering additives to the fluid stream. For example, abrasion increasing additives may be introduced into the fluid flow for enhancing soil erosion. Such additives may be introduced into the fluid supply or using a separately delivery path. For example, it is envisaged that abrasion increasing additives, such as coarser grains, fine gravel, or steel shot, could be deposited on the seabed near the pile wall before or during installation. Such additives may then trickle down the annulus to the erosion front as it progresses downwards for enhancing soil erosion.

[0025] According to a second aspect of the present invention, there is provided a method of installing the above foundation, where the method comprises: inserting the toe into the soil; supplying the fluid to the array of nozzles to jet fluid for generating the fluid stream ahead of the toe which flows in a direction perpendicular to the insertion direction; and controlling movement of the body in the insertion direction to maintain the formation of a fluid channel by the fluid stream as the toe advances in the insertion direction.

[0026] In embodiments, the method further comprises the step of supplying the fluid to the second array of nozzles for generating the second fluid stream ahead of the toe which flows in a direction perpendicular to the insertion direction and opposite to the first fluid stream.

[0027] Illustrative embodiments of the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 shows a cross-sectional view of a distal end of a foundation according to a first embodiment of the invention;
Figure 2 shows an enlarged isometric view of a section of the fluid manifold shown in Figure 1 during fluid jetting;
Figure 3 shows a cross-sectional plan view of a section of one array of nozzles and the associated fluid flows in the embodiment shown in Figure 1;
Figure 4 shows a schematic illustration for explaining the jetting angles of the nozzles;
Figure 5 shows a sequence of the foundation of the foundation shown in Figure 1 being installed; and
Figure 6 shows a cross-sectional view of a distal end of a foundation according to a second embodiment of the invention.

[0028] Figure 1 shows a cross-sectional view of the distal end region of a foundation according to a first embodiment of the invention. In this embodiment, the foundation 10 is a monopile.

[0029] The foundation 10 comprises a hollow tubular body 1 having an exterior lateral surface, and an interior lateral surface that defines an interior cavity in the form of a bore. The distal end of the body 1 forms a toe, which comprises a manifold 3 for feeding jetting fluid to a plurality of nozzles 6. The manifold 3 is fed by a pressurised fluid supply (not shown) which delivers pressurised fluid to the distal end of the foundation 10, for example, from a pump provided on a nearby installation vessel. Typically, the fluid supplied through the manifold 3 is seawater.

[0030] The nozzles 6 are each supported on a lateral extension 5 which extends out from the manifold 3 and includes an internal fluid pathway 4 connecting between the interior of the manifold 3 and the outlet of each nozzle 6. As such, pressurised fluid from the manifold 3 is jetted out through the nozzles 6.

[0031] In this embodiment, the nozzles 6 are arranged in two arrays, with an interior set of nozzles 6a provided on the interior lateral surface side of the body 1 and an exterior set of nozzles 6b provided on the exterior lateral surface side. Each array of nozzles 6 are circumferentially distributed around the manifold 3 so that they are spaced evenly around the distal end of the body 1. In this respect, Figure 2 shows an enlarged isometric view of a section of the fluid manifold shown in Figure 1 during fluid jetting. In this figure, two of the set of exterior nozzles 6b are most visible, with backs of the lateral extensions 5 for the set of interior nozzles 6a being visible on the opposing side. As shown, the nozzles 6 within each array are angled to direct their fluid jets 7 diagonally downward and in the direction of the stream of the adjacent fluid jet. As such, all the nozzles 6 within each of the interior and exterior arrays are uniformly angled in a complementary configuration.

[0032] The above described configuration is shown more clearly in Figure 3 which shows a cross-sectional plan view of a section of one array of nozzles 6 and the associated fluid flows generated thereby. It will be understood that there is also a flow going the opposite direction generated by the other array of nozzles. As shown, when pressurised fluid is supplied via the manifold, each nozzle 6 produces a fluid jet 7. As the jetted fluid travels diagonally down and further away from each nozzle 6, it spreads and dissipates into the fluid suspension below the toe of the foundation. The diagonal angling of the fluid jets 7 by the nozzles 6 means that each jet, rather than cutting into the soil below the foundation, feeds diagonally into the fluid suspension beneath the adjacent nozzle 6. As such, in use, this drives the fluid suspension in a plane substantially perpendicular to the insertion direction and thereby generates a high velocity circulating fluid stream 8 below the respective array of nozzles. This stream 8 flows in the jetting direction in a path defined by the manifold 3. In embodiments, flow velocities of 30m/s may be generated. Accordingly, a high-speed circulating fluid annulus is created by each array of nozzles 6, with the fluid annuluses being coaxial with the foundation body 1. As shown in Figure 2, the interior and exterior nozzle arrays 6a,6b have nozzles angled in different directions, and therefore their respective fluid streams 8a,8b will also flow in opposite directions. This configuration in which opposing flows are generated acts to counteract the torsional moment forces that would otherwise be applied to the distal end of the foundation body 1 if the jetting thrusts from all the nozzles were directed in the same rotational direction.

[0033] As shown in Figure 1, in this embodiment, the interior and exterior nozzles 6a,6b are also angled slightly outward, away from each other, so that the fluid streams 8a,8b generated thereby are separated. That is, the nozzles are angled so that a nib 21 of the soil 2 below the manifold 3 remains between the two streams 8a,8b, which thereby avoids interference between them.

[0034] Figure 4 shows a schematic illustration for explaining the jetting angles of the nozzles in further detail. As shown, the foundation body 1 defines an axial axis 21 which is coincident with the insertion direction of the foundation. Perpendicular to this is the radial axis 22 of the body 1, and the tangential direction 23 is also shown. In this embodiment, the nozzles are angled in a jetting direction 24 by a jetting angle 25 that is 20 degrees below the tangential direction rotated about the radial axis 22. In other embodiments, the jetting angle 25 may be 0 to 40 degrees and preferably 10 to 30 degrees. As mentioned above, the nozzles may also be angled slightly outward or inwardly, for example by an angle of -10 to +10 degrees about the axial axis 21.

[0035] In use, as shown in Figure 1, particles 9 from the soil will become suspended in the fluid streams 8a, 8b as the foundation body 1 is driven into the soil. Accordingly, the fluid streams 8a,8b contain a suspension of abrasive soil grains, which flow at high speed in two concentric rings with opposing flows formed by the interior and exterior nozzle arrays 6a,6b. As such, the fluid streams 8a,8b, accelerated by the fluid jets 7, have an abrasive effect on the soil 2 below, causing further soil particles to be broken away from the walls of the fluid channel. This has the effect of maintaining the space for the fluid streams 8a,8b as the toe of the foundation 10 advances deeper into the soil 2. As a result, the soil 2 is rapidly eroded away ahead of the foundation 10, allowing the foundation 10 to move downward more easily through the soil.

[0036] In this connection, figure 5 shows a sequence of the foundation 10 being installed in an offshore location. As shown in Figure 5(a), the foundation 10 is lowered through the water 10 so that its distal end inserts into the soil 2. Prior to engaging with the seabed, the fluid jets 7 are started, albeit at a relatively lower pressure, such as 50 bar. This initial jetting flow prevents soil from entering the jetting system. After the foundation's toe engages with the seabed, it penetrates down to an initial depth under its own weight. This depth may be, for instance, around 2 meters.

[0037] Once the initial depth is reached, the fluid jetting pressure is increased up to 300 bar. As shown in Figures 5(b) and 5(c), with the high-pressure jetting established, the toe of the foundation 10 penetrates axially downward in an insertion direction through the soil 2. As discussed above, the water jets act to accelerate the flow of the soil suspension located below and around the toe of the body 1 forming at least one fluid channel cavity with high velocity circulating flow streams. These streams 8 around the circumference of the toe region are loaded with abrasive soil grains in suspension and act to erode the walls of the fluid channels. This thereby forms annuluses either side of the body 1, which separates the soil from the foundation's interior and exterior surfaces. The excess soil suspension caused by the persistent fluid influx through the jetting nozzles 6 also generates upward fluid flows through the gaps formed between the body's wall and the soil. Soil is thereby transported up the body of the foundation. These combined effects result in much lower frictional resistance during foundation installation.

[0038] The speed of insertion may be controlled by, for example, controlling the rate that the foundation 10 is lowered by a crane 12. For example, an installation rate of 2m/min may be maintained through this phase of installation. Typically, the foundation's own weight will be sufficient to drive the toe downward. However, in some scenarios, a ballast (not shown) may be connected the proximal end of the foundation 10 to help drive installation.

[0039] In this connection, depending on the erodibility of the soil and the foundation installation velocity, the size of the fluid channel cavities formed by the fluid jets 7 can be varied. If the installation velocity is too fast, the cavity can become too small such that the suspension flow will eventually stall, and the erosion rate drops. In this case, the installation velocity can be reduced or stopped to allow for a new cavity to form and the suspension stream to develop. For instance, in use, if a rapid increase in installation resistance is detected during the driving phase, the crane 12 may be used to stop installation and lift the foundation, for example by 10cm, before restarting the lowering process of the pile. This thereby lifts the foundation to create space to reestablish the fluid streams 8, and thereby allow their abrasive effect to restart. This scenario may arise, for example, when conditions change from granular to a more cohesive soil during installation. As the toe passes through the cohesive soil layer, the erodibility will be reduced, which could otherwise trigger a runaway effect. By swiftly reducing the installation rate, stalling of the circumferential flow may be avoided and, once the more cohesive layer is passed, the installation rate can be gradually increased to return back to an optimal rate. It will be understood that if the installation rate is too fast for the crane 12or the associated mechanisms, the jetting pressure may be reduced.

[0040] As shown in Figure 5(d), once the foundation 10 reaches a predetermined depth threshold slightly ahead of its target depth, the fluid jets 7 may be turned off. For example, the predetermined depth threshold may be 30cm above the target depth. This thereby minimises the disturbance of the soil at the target depth, allowing the foundation 10 to sink down to its final target depth without overly weakening the soil structure in this region. The foundation 10 will resist further installation once the target depth has been reached. Once the insertion phase is completed, the soil 2 will relax to refill the space formed by the fluid streams. As shown in Figure 5(e), a test load 13 may then be applied to verify the initial axial load bearing capacity of the foundation 10. Over time, the axial load bearing capacity of the foundation will progressively increase as the load cycles from wave loading act to recompact the soil in the annulus formed by the fluid streams.

[0041] Figure 6 shows a cross-sectional view of a distal end of a foundation according to a second embodiment of the invention. This second embodiment is substantially the same as the first embodiment, but the toe of the foundation 10 is further provided with a fin 31 for dividing the interior and exterior fluid streams 8a,8b. The fin 31 is used to separate the opposing suspension fluid streams for avoiding interference between them. This may thereby allow the respective nozzles of each of the arrays to be angled more closely together, thereby providing a narrower combined fluid channel cavity. This may allow the soil structure surrounding the foundation body to be better preserved. At the same time, it also provides for increased efficiency since less jetting energy is dissipated by the turbulent interface between the opposing streams.

[0042] It will be understood from the above that the inventive arrangements disclosed herein allow a foundation to be installed into the soil more easily. This reduces cost and allows installation noise to be minimised.

[0043] In this connection, with embodiments of the present invention, the soil failure mechanism at the foundation toe can continue throughout the pile installation process as the foundation penetrates deeper. As such, the need for pile driving or large ballasts to reach target installation depths are avoided. After the foundation has been installed to the required depth, the fluid jetting system may be turned off to allow water to drain from the soil around the foundation body. The suspended soil particles will then settle to form a sediment which may compact over time through cyclic shake down effects, thereby restabilising the soil strength.

[0044] Importantly, as the fluid jets are used to form fluid streams which erode the soil, rather than directly cutting into the soil themselves, the structure of the soil outside the formed fluid channels is largely undisturbed, with the suspension pressure acting to stabilize the adjacent soil. This soil is therefore able to maintain its structure for supporting the foundation. This contrasts with conventional liquid excavation techniques where a body of soil is cut into using pressurised liquid to excavate space for a foundation. With this type of conventional methodology, soil is removed in an uncontrolled manner, and the excavated site is effectively refilled with reclaimed soil once the foundation is in place. However, as the soil re-filling the space is newly located, it has little developed structure and will therefore be inherently weaker as a result.

[0045] It will be understood that the embodiments illustrated above show applications of the invention only for the purposes of illustration. In practice the invention may be applied to many different configurations, the detailed embodiments being straightforward for those skilled in the art to implement.

[0046] For example, it will be understood that by adjusting the jetting direction of the nozzles, the location and shape of the fluid channel formed beneath the toe can be adjusted. For example, by locating the nozzles on the inside of the foundation, the fluid cavity will be shifted more towards the inside of the foundation body. Conversely, by locating the nozzles on both the interior and exterior sides, and pointing them slightly away from the foundation wall, a wider cavity may be created by the suspension flow, or two individual cavities may be formed, as shown in Figure 1.

[0047] Furthermore, in some embodiments, additives may be added to the fluid streams formed at the toe of the foundation, for instance by introducing them to the fluid supply or separately using an additive delivery system. For example, an abrasive additive may be used to introduce a more coarse/angular material for improving the abrasiveness of the fluid streams. This may be advantageous for tackling soil types which do not easily erode, such as silt, clay, chalk, soft bedrock. Grout may also be introduced towards the end of the installation process for improving the in-place performance of the foundation.

[0048] It will also be understood that additional mechanisms and systems may be also used in combination with the described fluid jetting system for further reducing driving resistance. For instance, the foundation may further incorporate electrodes for electro-osmosis. Furthermore, the fluid jetting system may work synergistically with the electro-osmosis system.

[0049] Finally, although in the above illustrative embodiments, the foundation was a monopile, it will nevertheless be understood that other foundations are also possible, such as bucket foundations.

Claims

1. A foundation for a structure comprising:

    a body for insertion into a soil in an insertion direction during installation, the body having a toe at its distal end; and
    an array of nozzles provided at the distal end for jetting a fluid, wherein the nozzles in the array are configured such that their fluid jets are complementarily directed for generating a fluid stream ahead of the toe which flows in a direction substantially perpendicular to the insertion direction.

2. A foundation according to claim 1, wherein the fluid stream forms a fluid channel ahead of the toe in a plane perpendicular to the insertion direction by eroding soil as the fluid flows through the fluid channel in the direction perpendicular to the insertion direction.

3. A foundation according to claim 2, wherein soil is progressively eroded from the wall of the fluid channel as the toe advances in the insertion direction during installation.

4. A foundation according to any preceding claim, wherein the nozzles in the array are configured for generating the fluid stream flowing in a cyclic path in a soil region ahead of the toe.

5. A foundation according to claim 4, wherein the cyclic path is a circumferential path coaxial with the body.

6. A foundation according to any preceding claim, further comprising a second array of nozzles provided at the distal end, wherein the nozzles in the second array are configured such that their fluid jets are complementarily directed for generating a second fluid stream ahead of the toe which flows in a direction

perpendicular to the insertion direction and opposite to the first fluid stream.

7. A foundation according to claim 6, wherein the first array of nozzles is provided on an interior side of the body for generating the first fluid stream in a path in line with an interior lateral surface of the body, and the second array of nozzles is provided on an exterior side of the body for generating the second fluid stream in a path in line with an exterior lateral surface of the body.

8. A foundation according to claim 6 or 7, further comprising a fin provided at the distal end for separating the first fluid stream from the second fluid stream.

9. A foundation according to any preceding claim, further comprising a manifold at the distal end of the foundation and wherein the nozzles are mounted to the manifold for being fed fluid thereby.

10. A foundation according to any preceding claim, wherein the nozzles are directed downward in the range of 1-40 degrees about the radial axis from the tangential direction.

11. A foundation according to any preceding claim, further comprising a pressurised fluid supply for supplying pressurised fluid to the nozzles.

12. A foundation according to any preceding claim, further comprising a controller for controlling one or more of: an installation speed, a ballast weight, and a fluid pressure of fluid supplied to the nozzles.

13. A foundation according to any preceding claim, further comprising an additive delivery system for delivering additives to the fluid stream.

14. A method of installing a foundation according to any one of claims 1-13, the method comprising:

inserting the toe into the soil;
supplying the fluid to the array of nozzles to jet fluid for generating the fluid stream ahead of the toe which flows in a direction perpendicular to the insertion direction; and
controlling movement of the body in the insertion direction to maintain the formation of a fluid channel by the fluid stream as the toe advances in the insertion direction.

15. A method according to claim 14 when depending via claim 7, further comprising the step of supplying the fluid to the second array of nozzles for generating the second fluid stream ahead of the toe which flows in a direction perpendicular to the insertion direction and opposite to the first fluid stream.

Fig. 1

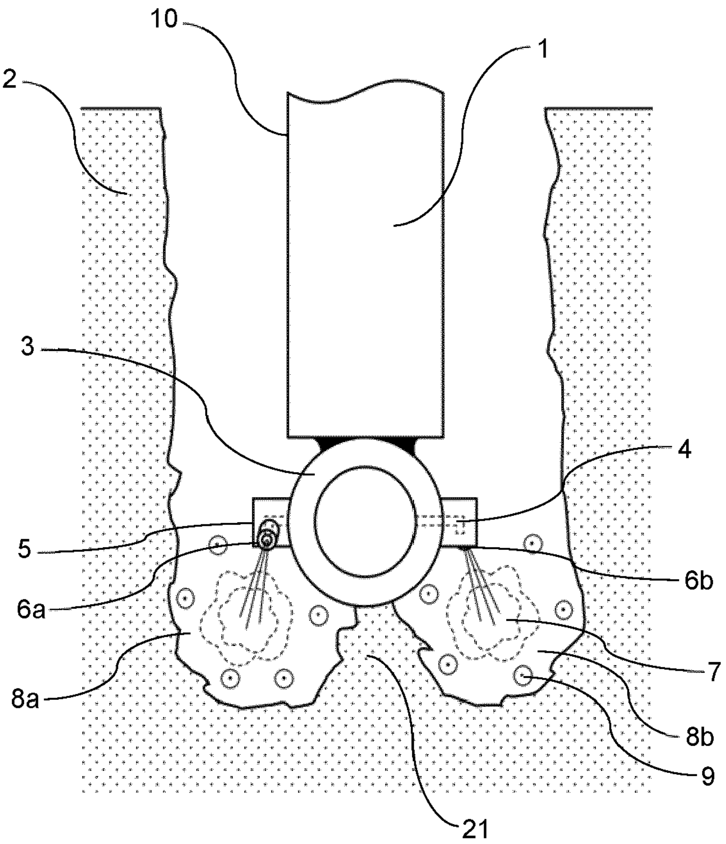


Fig. 2

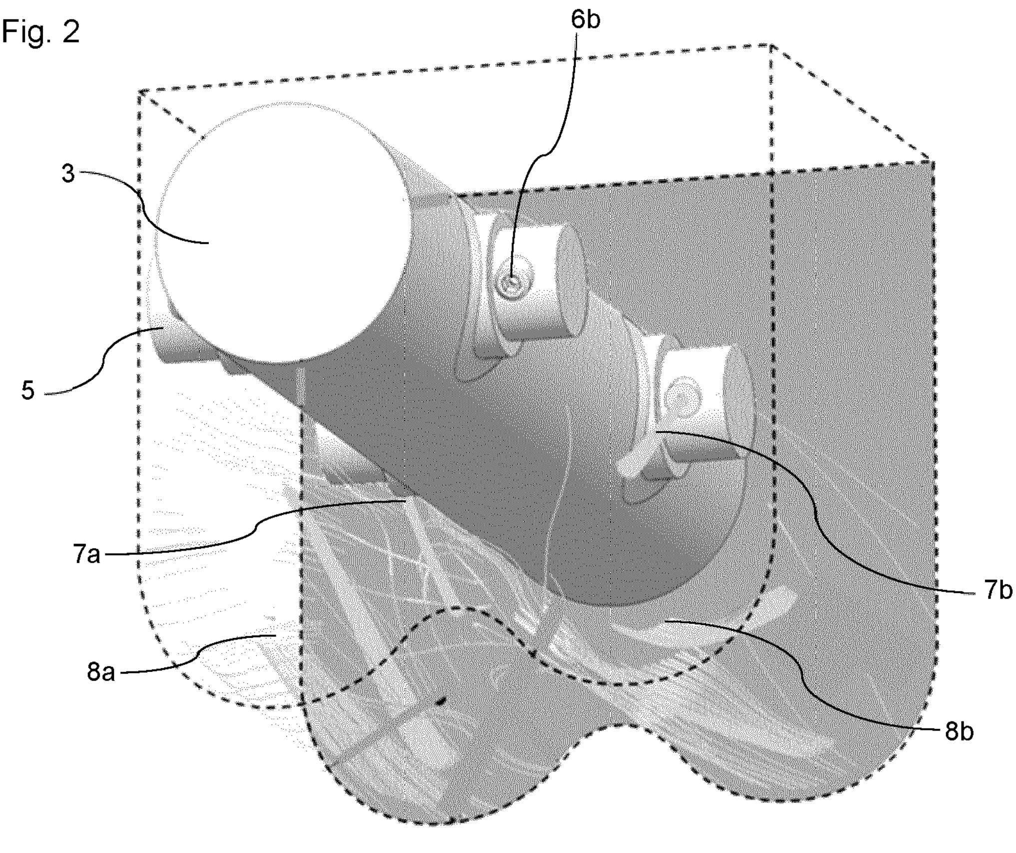


Fig. 3

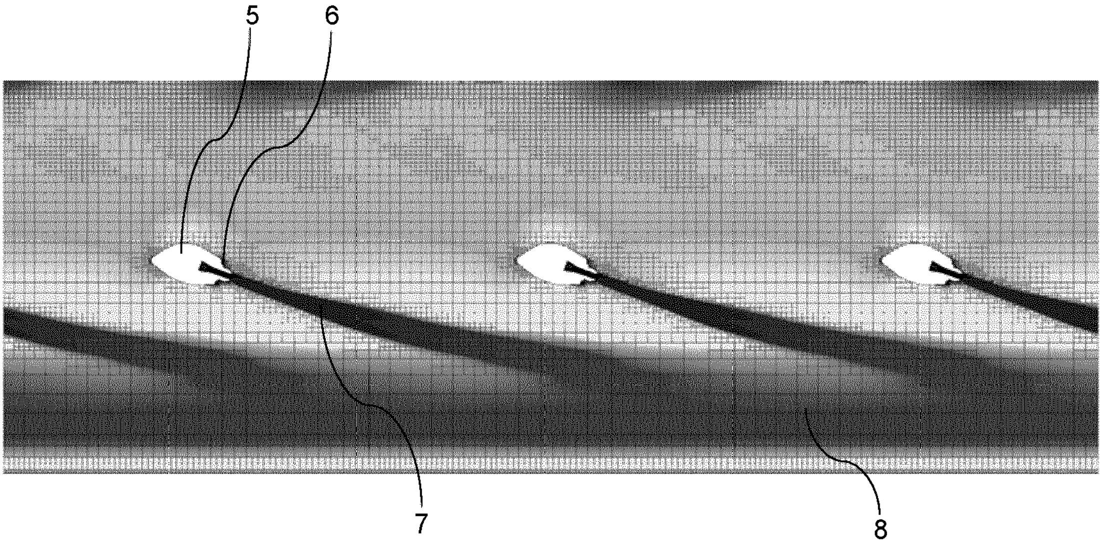


Fig.4

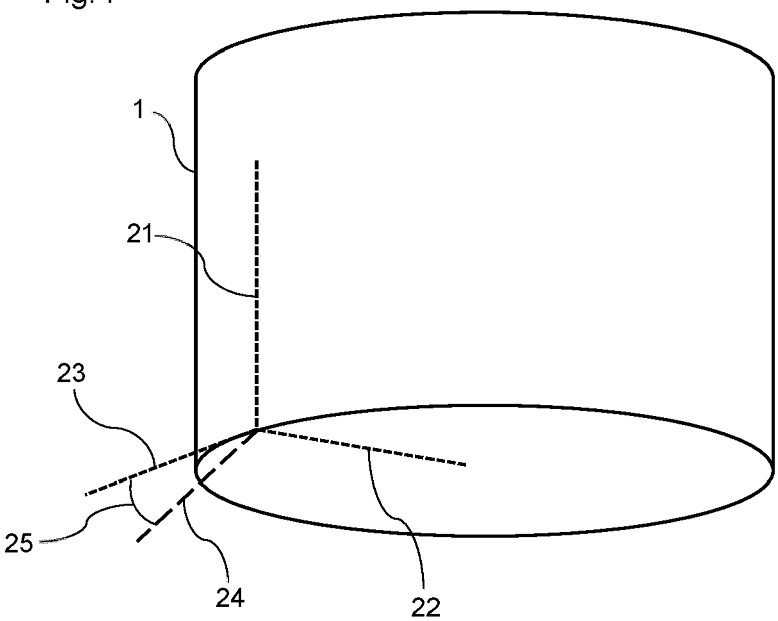


Fig. 5

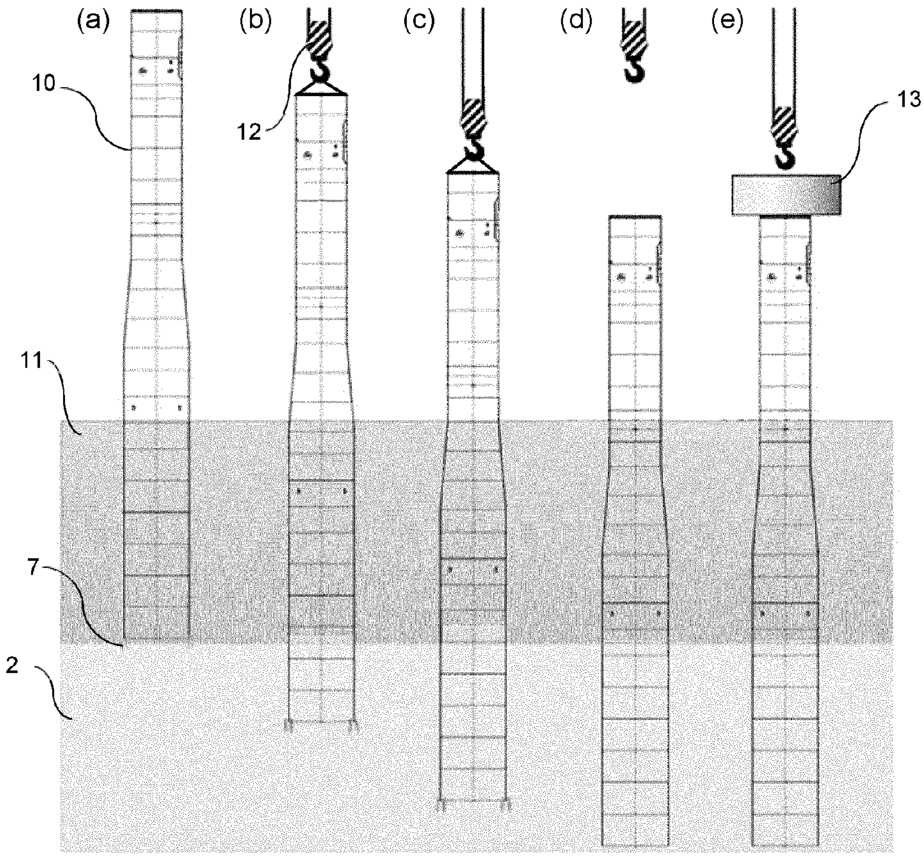
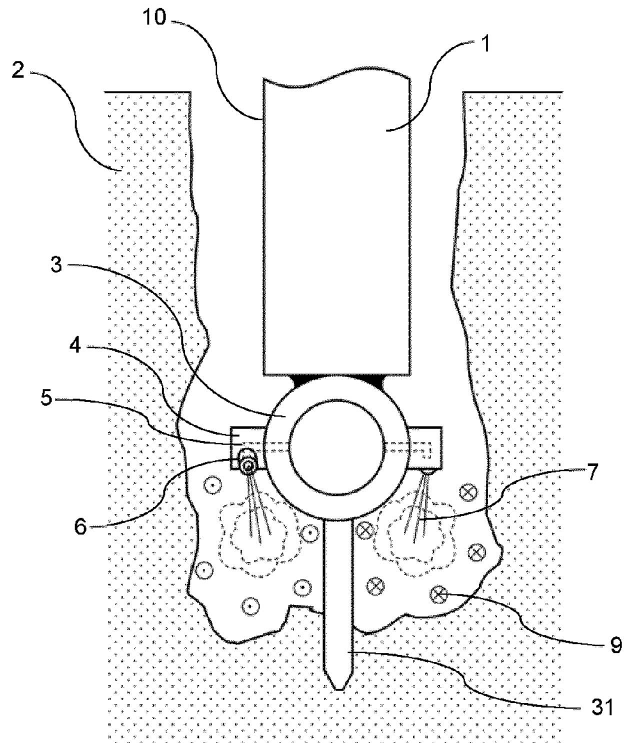


Fig. 6



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EUROPEAN SEARCH REPORT

Application Number
EP 22 18 0948

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Place of search	Date of completion of the search	Examiner
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