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(54) Foundation pile

(57) A shoe is disclosed for driving a bore for a foundation pile into the ground, the shoe comprises an interface portion for interfacing with a driving element; and an outer profile having an array of indentations or protrusions for creating at least one channel or ridge in the wall of the bore. Various parameters defining the form of the outer profile which may be beneficial are disclosed. A method of forming a foundation pile using the shoe of the present invention, as well as a foundation pile formed according to the method, are disclosed, in addition to a mandrel arranged to create the pile of the present invention.

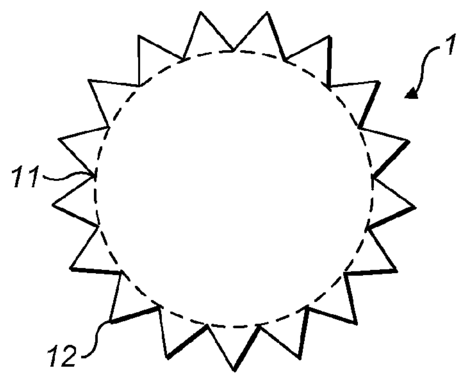

FIG. 1

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Description

[0001] The present invention relates to the field of shoes for driving into the ground to create a foundation pile for a building. In particular, the invention relates to a driven shoe, for driving a bore into the ground, having a particular form of outer profile.

[0002] It is known to create a continuous displacement pile (CHD), where a bore is formed in the ground by an enlarged section at the end of a stem. This enlarged section and stem is drilled into the ground and displaces the soil as it progresses. Once it reaches the required depth, concrete may be pumped through the stem to the base of the enlarged section and the enlarged section is gradually withdrawn as a settable material is pumped to the base to fill the bore. A top driven pile is also known, where a steel tube or concrete section is driven in to the ground with a top hammer, acting on the top of the section, similarly to a hammer driving a nail. A bottom driven pile is also known, where a steel tube or casing is driven in to the ground by a drop weight acting on the bottom of the casing. Once the desired depth is reached, the weight is withdrawn from the casing and a settable material can be placed within the tube. A driven cast in place pile is also known, in which a hollow lining is driven in to the ground with a cap or plug at its bottom end, to prevent soil entering the liner. Once the desired depth is reached, the cap or plug is removed, concrete is placed and the liner is then pulled out of the ground.

[0003] NL1018792 describes a foundation pile made by sinking an empty hollow tube in to the ground, the tube having its bottom end sealed with a shoe having a diameter greater than the external perimeter of the tube. A grout tube is provided on the outer perimeter of the hollow tube for delivering grout to the outer perimeter. The above described methods are generally used to create a foundation pile having a substantially smooth outer surface and most commonly having a generally cylindrical outer profile.

[0004] Attempts have been made to improve the adhesion of foundation piles to the surrounding soil. Known methods include screw piles, which are most commonly metal sections screwed into the ground. Many rotary drilling systems utilise teeth to provide increased pressure on the material drilled and to facilitate clearance of the drilled material from the resulting bore. The resulting bores are generally smooth. Attempts have been made to improve the adhesion of foundation piles to the surrounding soil. Known methods include rotary CHD piles and screw piles, which are rotary methods, as opposed to the driven approach described herein.

[0005] EP1063358 describes a method of forming a foundation pile, comprising the steps of creating a cylindrical bore in the ground, pressing indentations into the wall of the bore and placing settable material in to the bore to form a pile.

[0006] According to the present invention, there is provided a shoe for driving a bore for a foundation pile, the shoe comprising:

an interface portion for interfacing with a driving element; and

an outer profile having an indentation or a protrusion for creating at least one channel or ridge in the wall of the bore.

[0007] The advantage of a shoe according to the present invention is that, when the shoe is driven into the ground to create a bore for a foundation pile, the indentation or protrusion in the outer profile of the shoe will create a channel or ridge in the wall of the bore. When a foundation pile is formed to fill the bore created by the shoe, this channel or ridge will provide an increase in the contact surface area between the foundation pile and the surrounding ground and this will create an increase in the friction forces occurring between the foundation pile and the surrounding ground. This can improve the effective adhesion which is achieved between the settable material and the surrounding soil as compared to that which would be created by a shoe which had a substantially smooth outer profile.

[0008] The outer profile may comprise an array of indentations or protrusions arranged at the different locations around the outer profile. The provision of an array of indentations or protrusions can create an even greater overall increase in contact surface area between the resulting pile and surrounding ground, further increasing the beneficial effect as compared to a single indentation or protrusion. This can bring an even greater increase in the effective adhesion methods achieved between the resultant foundation pile and the surrounding ground.

[0009] The shoe may have a plane perpendicular to an axis of the shoe, the outer profile of the shoe having an average perimeter in that plane, and wherein:

the indentations or protrusions are configured such that the distance along the surface of the outer profile of the shoe in the plane is substantially 10% greater than the distance along the average perimeter. This particular optional arrangement of the outer profile of the shoe can result in a substantially 10% greater area of surface contact between the foundation pile and the surrounding ground as compared to a pile having a substantially smooth outer profile. A related increase in the adhesion between the foundation pile and the surrounding ground can be achieved.

[0010] The indentations or protrusions may be configured such that the distance along the surface of the outer profile of the shoe in the plane is significantly increased relative to the distance along a substantially straight, curved or circular profile around the pile. The increase may be in the order of 20% or 40% greater than the distance along the average perimeter, or more in some embodiments. This arrangement can result in a foundation pile having a contact surface area with the surrounding soil substantially 20% or 40% greater than the contact surface area achieved with a foundation pile having a substantially smooth outer surface. Alternative increases in this distance can be achieved in the order of 10%, 50%, two times (i.e. 100%) or even greater than this according to the present invention. These increases can therefore result in a related increase in the effective adhesion achieved between the foundation pile and the surrounding ground.

[0011] The indentations or protrusions may be configured such that the distance along the surface of the outer profile of the shoe in the plain is substantially twice the distance along the average perimeter. This shoe configuration can create a bore and foundation pile combination with a contact surface area between the foundation pile and the surrounding ground which is twice as large as that created by a shoe having a smooth outer profile.

[0012] The outer profile of the shoe may have at least two outer extremities and the distance along the outer profile between the outer extremities may be 10% greater than the distance along a straight line joining the outer extremities. The outer extremities may be local outer extremities, also known as adjacent outer extremities, located relatively close to one another on a part of the outer profile of the shoe. The outer profile of the shoe between those outer extremities may create an apparent recess in the outer profile in the shoe and the distance along the outer profile between the two extremities may be increased. This configuration can therefore create a local increase in the contact surface area between a foundation pile created using the shoe and the surrounding ground.

[0013] The distance along the outer profile between the extremities may be 20% or 40% greater than the distance along a straight line between the outer extremities or, alternatively, the distance may be twice the distance along a straight line joining the outer extremities, or more than twice that distance. The greater the increase in distance between the outer extremities, the greater the increase in contact surface area between the resultant foundation pile and the surrounding ground may be. However, it can be more expensive to manufacture a shoe having a more complex outer profile configured to provide significant increases in distance along the outer profile as compared to the distance along a straight line or average perimeter along the outer profile. Further, if the outer profile of the shoe is excessively complex, or creates very narrow, sharp edged features in the outer profile of the resulting foundation pile, the resulting extremities in the outer surface of the foundation pile may be liable to damage and breakage. Further, in the same way, if the shoe is configured to create excessively narrow, sharp-edged protrusions in the outer profile of the resulting bore, then the ground which makes up those protrusions may be liable to break or collapse and the desired increase in contact surface area between the pile and the surrounding ground can be lost. This may therefore reduce the overall beneficial effect created, since the increase in effective adhesion may be reduced.

[0014] The outer profile may be selected to induce in an equal degree of slippage within a surrounding material as between a pile filling the bore created by the shoe and the surrounding materials. Adhesion between a foundation pile and the surrounding ground is generally lower than the adhesion of the surrounding material to itself. However, with an appropriate configuration of the outer profile of the shoe of the present invention, the contact surface area between the foundation pile and surrounding material can be increased, such that there is equal slippage within the surrounding material as between the surrounding material and the resulting foundation pile. This will create the most effective foundation pile, since the resulting effect is similar to that achieved if all slippage is within the surrounding material, as would be found with, for example, a ribbed or screw pile. The present invention can therefore create a near-equivalent increase in effective adhesion to a screw-pile or ribbed pile, without the complexities associated with installing a screw pile or a ribbed pile.

[0015] The outer profile of the shoe may comprise an external included angle of less than 180°. The inclusion of such an angle in the outer profile of the shoe allows the desired increase in distance along the outer profile to be created.

[0016] This outer profile may further comprise an acute inner angle. The use of an acute inner angle can also provide a further increase in the desired distance along the outer profile of the shoe.

[0017] The array of indentations or protrusions provided around the outer profile of the shoe may comprise at least one external included angle of the outer profile of the shoe of less than 180°.

[0018] The array of indentations or protrusions provided around the outer profile of the shoe may comprise at least one external included angle of the outer profile of the shoe of less than 160°. An external included angle of 160° can result in an increase in contact area of around 1.5% as compared to a straight line segment, as will be described later in this specification. An external included angle of 130° can result in an increase in contact area of around 10% as compared to a straight line segment. An external included angle of 115° can result in an increase in contact area of around 19% as compared to a straight line segment, as will be described later in this specification.

[0019] The array of indentations or protrusions may comprise an array of external included angles of less than 180° in the outer profile of the shoe. The provision of an array of external included angles of less than 180° can further permit the distance around the outer profile of the shoe to be increased without the need to increase the overall external diameter of the shoe by the same amount.

[0020] The array of external included angles may comprise a plurality of external included angles of greater than 20° and less than a 180°. The provision of external included angles of less than 20° in the outer profile of the shoe can create very thin and weak protrusions in the surface of the bore created by the shoe. These protrusions are liable to be damaged, or to simply to collapse and the beneficial effect of the providing them at the interface between the resultant foundation pile and the surrounding ground is potentially lost. It can therefore be beneficial to use external included angles of greater than 20°.

[0021] The array of external angles may further occupy ranges between 20° and 60°, or 20° and 115° or 60° and 115°.

[0022] The array of external included angles may comprise at least one external included angle of between 30° and around 90°. The provision of external included angles of between around 30° and around 90° can allow an increase in contact surface area between the resultant pile and surrounding ground, but without creating protrusions which are so thin as to be excessively weak. The array of external included angles may comprise a plurality of angles between around 30° and around 90°. The provision of a plurality of external included angles in this range can increase the contact surface area between the resultant foundation pile and the surrounding material without excessively weakening the foundation pile or the surrounding soil.

[0023] In practice the array of external included angles realises a majority of the advantages described herein when selected within the range of around 40° and around 80°. This selection of ranges can allow a pile to be created having an outer profile with a more limited range of angles to reduce complexity of manufacture, while still realising a majority of the desired benefits of the arrangements described herein.

[0024] The array of angles may be selected to induce an equal degree of slippage within the surrounding material as between the pile filling the bore created by the shoe and the surrounding material. As stated above, when the shoe is configured in this way, the greatest benefit of increasing the contact surface area can found where the friction forces between the foundation pile and the surrounding material is equal to the friction force within the material itself.

[0025] The shoe may have a depth a and a diameter d and the depth a may be at least 50% of diameter d. The depth a may further be at least equal to the diameter d.

[0026] The present invention further provides a method of forming a foundation pile, comprising the steps of:

driving a shoe according to any one of the preceding claims into the ground to form a bore having at least one longitudinal channel or ridge in a wall of the bore;
filling the bore with a settable material such that the settable material flows into the channel or around the ridge; and
allowing the settable material to set to form a foundation pile which has a complementary form to the channel or ridge.

[0027] The bore may be filled with the settable material simultaneously with the driving of the shoe into the ground. This can help to avoid the collapse of the walls of the bore prior to the settable material being added.

[0028] The shoe may be driven by a driving element having an outer profile smaller than the outer profile of the shoe, such that a void is created between the wall of the bore and the driving element along the length of the bore. The creation of the void allows the settable material to be added simultaneously with the driving of the bore.

[0029] The present invention further provides a mandrel for driving a bore for a foundation pile of the present invention, the mandrel having an outer profile substantially the same as the outer profile of the foundation pile of the invention, for creating the channels and/or the ridges of the pile when driven into the ground.

[0030] The present invention further provides a method of forming a foundation pile according to the present invention, comprising the steps of:

driving a mandrel of the present invention into the ground to form a bore;
withdrawing the mandrel; and
filling the bore with a settable material to form the foundation pile.

[0031] The mandrel may comprise an opening arranged towards the driving end of the mandrel, arranged to deliver settable material to the bore as the mandrel is withdrawn

[0032] The present invention further provides a foundation pile having an outer profile substantially the same as the outer profile of the shoe of the present invention and a foundation pile formed by the above-described method of the present invention.

[0033] As will be appreciated in reading this full specification, a foundation pile may be created by any of the methods described herein, having an array of channels or ridges, which may be elongate substantially in the direction of the longitudinal axis of the pile arranged around its periphery and displaying an outer profile according to any of the arrangements of the shoe or mandrel described herein. Such an outer profile will be present in the channels and ridges created on the outer profile of the pile, when viewed in the direction of the axis of the pile as illustrated in the later figures. The array of channels or ridges may extend over the length of the foundation pile. The direction of the channels or ridges in the present invention may be substantially in the longitudinal direction of the pile since no rotation of the shoe or mandrel is required as it is driven in to the ground to form the pile. Instances may exist where the channels or ridges do not extend over the absolute full length of the pile, such as toward the lower end, where a mandrel forming the bore has a reduced end section to facilitate driving of the mandrel. Alternatively, the pile may be formed in sections having the same or differing diameters resulting in discontinuities in the channels or ridges in the pile. Minor imperfections in the ground, or discontinuities created by minor collapse of the wall of the bore may also induce minor breaks in the channels or ridges. If the bore opens out toward the surface of the ground to a diameter greater than the ridges of the pile, then the pile may comprise a portion at its upper end which does not comprise the channels or ridges of the present invention. All of these examples and other minor lack of channels or ridges over the length of the pile are encompassed within the meaning of extending substantially over the length of the pile.

[0034] The outer profile of the pile may be substantially entirely comprised of the array of ridges or channels. This arrangement is different from an arrangement where a small number of ridges or channels is arranged over a part of the outer surface of the pile, or small ridges or channels are relatively widely spaced around the outer surface. The term encompasses small spaces between ridges and/or channels of up to one or two channel- or ridge-widths. The aim of the invention is to minimise the amount of the outer surface of the pile which extends in a substantially straight or circumferential direction between channels or ridges, but it does encompass such relatively small gaps created between channels or ridges.

[0035] Certain embodiments of the invention will now be described with reference to the following figures in which:

Figure 1 shows an example of an outer profile for a shoe according to the present invention:
Figure 2 shows an alternative profile for a shoe according to the present invention;
Figure 3 shows a portion of an alternative outer profile for a shoe according to the present invention;
Figure 4 shows a portion of an alternative outer profile for a shoe according to the present invention;
Figure 5 shows a portion of an alternative outer profile for a shoe according to the present invention;
Figure 6 shows a portion of a further alternative outer profile for a shoe according to the present invention;
Figure 7 shows an optional apparatus for use with the present invention;
Figure 8 shows a preferred shoe according to the present invention; and
Figures 9A and 9A show a further apparatus for use in a method of creating a pile according to the present invention.

[0036] Figure 1 shows a particular embodiment of the present invention. A shoe 1 is shown, viewed along an axis extending in the direction in which the shoe will be driven to create a bore for a foundation pile. In this particular example, the shoe has a substantially circular outer form, and a series of indents 11 and protrusions 12 is provided on the outer profile of the shoe. When the shoe is driven into the ground in the direction of the axis along which it is viewed in Figure 1, a bore will be created in the ground having features corresponding to the outer profile of the shoe. If the shoe is driven into the ground by a driving element having an outer profile smaller than the outer profile of the shoe, then a void will be created between the wall of the bore and the driving element as the shoe is driven. The bore may be filled with a settable material, such as concrete or any other suitable material, either during the driving process or after the driving process is complete, if conditions allow. There will then be created a foundation pile of settable material having a surface, interfacing with the surrounding ground, which takes the form of the outer profile of the shoe.

[0037] Figure 2 shows an alternative embodiment, wherein the indentations 11 1 and protrusions 12 have smoother transitions, such that there are no sharp angles in the outer profile of the shoe. The optional smooth transitions can improve the likelihood that all indentations in the wall of the bore created by the shoe are filled correctly with concrete and in this way a more consistent interface between the concrete and the surrounding ground can be created. If the indentations or protrusions in the wall are too small, they risk collapse if the integrity of the ground is insufficient. Further, if the indentations in the wall of the bore are too thin, this will create very thin sections of foundation pile, which may be liable to failure under stress.

[0038] Figure 3 shows a section of an example of an outer profile for a shoe in accordance with the present invention. In the illustrated embodiment, the shoe has a generally arcuate outer profile, the inner perimeter, or "base line" of which is indicated by curved line 31. However, the present invention may equally be applied to shoes having generally straight sections to their outer form. A series of protrusions 32 are shown extending from the outer profile of the shoe. The outer profile has an external included angle 33, which will be generally referred to in this specification as θ and each protrusion has an inner angle 34, which will be generally referred to as β. Angles θ and β may be the same or different to one another. Where an external included angle is less than 180°, the outer profile deviates away from the inner perimeter, or base-line outer profile, which is indicated by line 31, to create an inclusion in the outer profile of the shoe. In the illustrated example of Figure 3, the external included angle is obtuse and is less than 180°. This creates relatively gentle variations in the outer profile from the base-line outer profile. The profile has local outer extremities 35 and 36. The distance between point 35 and 36 following the outer profile of the shoe is greater than the distance between those points along a straight line and also greater than the distance along a line of 'average perimeter' of the outer profile, which would run substantially along the mid-point of the peaks in the profile as indicated by dashed line 37. An external included angle θ of 130° can create a particular increase in length along the outer profile between outer extremities 35 and 36 as compared to straight line 38 joining those two points. A line perpendicular to line 38 may be drawn to bisect angle 33. If angle 33 is 130°, then half of the angle is 65°. The opposite side to angle 33 (half of line 38) in the resultant right-angled triangle can be taken to be 1. The hypotenuse to the triangle is then the side of protrusion 32 and this can be calculated as 1 / sin(65), which is approximately 1.1, giving a 10% increase in distance along the side of protrusion 32 as compared to along a line 38 connecting the outer extremities 35 and 36. By a similar calculation, if angle 33 is around 160°, then the increase in the distance will be around 1.5%. This choice of internal angle therefore gives some increase in distance, but a relatively small increase, which can have limited benefits. By the same calculation, with an angle θ of around 115°, an increase in distance of around 19% can be achieved. The effects of the increase in distance are more beneficial when the increase in distance is 20% and above and therefore the benefits of the present inventions are more significant for angles θ below around 115°. With an angle θ of around 90°, an increase in distance of around 40% can be achieved and this can provide further improved benefits.

[0039] Figure 4 shows a further example of an outer profile for a shoe according to the present invention. In the illustrated example, both the internal angles and the included external included angles θ of the protrusions 41 and 42 are in the region of 60°. This condition can create a particular case, where the distance along line 43, between the outer extremities of protrusions 41 and 42 of the outer profile is approximately equal to the distance along a side 44 or 45 of protrusions 41 and 42. If a shoe having this outer profile is driven through the ground and the resultant bore is filled with a foundation pile as described above, then the outer surface of the foundation pile will have the illustrated profile. There then exists an interface between the ground and the foundation pile along sides 44 and 45, and line 43 illustrates a line extending through the ground itself. A coefficient of adhesion α will exist along each of lines 43, 44 and 45. The coefficient of adhesion of the ground to itself, along line 43, is generally 1. Generally, the coefficient of adhesion between the foundation pile and the ground along lines 44 and 45 will be something between 0 and 1. In the illustrated case, lines 44 and 45, in combination, represent twice the length of line 43. If line 43 has a length L, then the sum of lines 44 and 45 will be approximately 2L. The effective adhesion along line 43 can be equated to α x L = 1 x L = L. In the case where the coefficient of adhesion between the foundation pile and the soil is 0.5, then the effective adhesion achieved along lines 44 and 45 is 2L x α = 2L x 0.5 = L. Therefore the effective adhesion achieved between the foundation pile and the surrounding ground in this case is approximately equal to the effective adhesion achieved within the ground itself. If a foundation pile as created in this case is loaded sufficiently that it is displaced within the soil, then the slippage between the foundation pile and the ground, along lines 44 and 45, will be approximately equal to the slippage within the ground itself, along line 43. Depending upon the actual value of the coefficient of adhesion α between the ground and the foundation pile, the actual ranges of angles required to achieve the same effective adhesion between the foundation pile and the soil, as within the soil itself, will change. For example, if α were 0.25, then the distance along lines 44 and 45 would need to be four times the distance along line 43 to achieve the same conditions as are described above. Using the above equations in a case in which α = 0.25, 1 L (effective adhesion in soil) = α x 4L (effective adhesion at soil-pile interface). Therefore, the total distance along lines 44 and 45 will need to be 4L. A corresponding external included angle 46 can then be calculated accordingly, in this case, $\sin^{-1}(0.25)$ = 14.48° and so an external angle 46 of around 29° may be appropriate. As described above, angles θ of less than 20° can cause collapse of the structure of the bore and can therefore be practically unworkable. In the illustrated example, line 43 intersects with lines 44 and 45 at the outer-most points on the outer profile, intersecting with dashed line 48. However, line 43 may be drawn to connect any connecting points at substantially equal radial distances from angle 46 and may, alternatively, intersect the line of average perimeter, 47. The resultant effect can still be calculated as described above.

[0040] The most appropriate angle to be selected may vary depending upon a number of other factors. For example, the various ground conditions into which it is envisaged the shoe of the present invention will be used vary enormously and include: Highly plastic clays; medium plastic clays; low plastic clays; over consolidated clays; boulder clays; glacial clays; silty clays; sandy clays; gravely clays; clay strengths being geologically described as soft, firm, still, very stiff and hard; and soft rocks such as Marl and chalk.

[0041] These materials all react differently with the pile surface and in particular with a pile face with vertical grooves, channels or indentations as created by the shoe of the present invention. Optimisation of the adhesion between the settable material of the pile and the ground is achieved by choosing the correct outer profile for the shoe, which may, for example, be defined by the choice of the external included angle θ. For example, optimisation would be achieved for some soils with an angle θ of 40°, while others would work best with an angle θ of 60°. The range of useful angle θ (equivalent to 33 of Figure 3, 46 of Figure 4 or 62 of Figure 6), varies between 160° and 20° to address the difference in ground conditions and the type of settable material.

[0042] The type of settable material also influences adhesion between the surrounding ground and the pile formed in the bore created by the shoe of the present invention. The type of settable material may also influence the choice of angle θ. For example, a high fines content settable material would work well with smaller angles.

[0043] The size of the grooves, channels or indentations in the wall of the bore, or lengths of lines equivalent to 44 (referred to as A) and 45 (referred to as B) in Figure 4 are also factors which influence the adhesion and workability of the system. Ground water conditions also influence the shoe specification. For example, high water tables with rapid inflows would require a greater value of A and B than dry conditions, as the influence of water will have a more adverse effect on a greater number of small grooves than on a smaller number of larger grooves. The lengths of A and B can be described as a percentage of the radius of the shoe, where the shoe has a generally circular form, or as a percentage of half of its width when it has a non-circular form. These values can range between 10% and 100% depending on ground conditions as will be described in the following.

[0044] There are therefore a number of parameters of the shoe of the present invention, which may be governed by the ground, ground water and the type of settable material to be used for the pile formed by the shoe of the present invention. There a number of ranges into which the described parameters may fall. The external included angle θay be between 160° and 115° for cohesive soils with gravel and the harder Marls and chalk. Angle θ may advantageously be between 115° and 60° for most clays, except hard, low plastic silty clays and weaker/softer rocks. Angle θ may advantageously be between 60° and 20° for hard low plastic clays. The dimensions A and B may advantageously be between 10% and 30% for hard materials and high ground water; between 30% and 60% for medium strength materials; and between 60% and 80%, or up to 100% or greater for very soft materials, especially with high water conditions. These figures are for guidance and circumstances may be such that the most advantageous shoe configurations described above may vary. Further, there are often substantial variations within each soil classification. For example, soft rocks contain hard flints and so a smaller value of A and B and a larger angle θ may be chosen. The ranges described can address the different ranges of ground conditions encountered.

[0045] Figure 5 shows an alternative external profile for a shoe according to the present invention. As is shown in the figure, it is not necessary for the internal angles and the external included angles to be equal, and there need not be any particular relationship between the two. The desired increase in the distance along the outer profile of the shoe, as compared to the base line 53, or to the average profile of the shoe 54, can be created with a range of angles. The increase in contact surface length can also be calculated with respect to the straight line connecting points 51 and 52, as well as along the outer arc connecting those points.

[0046] Figure 6 shows an embodiment of the present invention wherein the outer profile of the shoe is made of smooth curves to create smooth indentations and protrusions around the average perimeter 61 of the outer profile of the shoe. The invention may be realised with either this smoothed outer profile, or with the previously illustrated examples made up of teeth having straight sides. It can be seen in Figure 6 that although there are no sharp angles in the outer profile, lines may be drawn at any point along the outer profile to measure the internal angles 63 (β), or external included angles 62 (θ). The lines drawn to calculate the angles θ and β may be tangential lines drawn at a point at which the outer profile of the shoe is substantially straight, at a point where the profile changes from being concave to convex, at a point substantially half way between the inner and outer extremities of the outer profile as indicated by dashed line 61, or lines drawn from a local outer extremity to a local inner extremity, as shown in Figure 6. In the illustrated example of Figure 6, it can be seen that the length along the outer profile between two outer extremities 64 and 65 is a greater distance than the distance along a straight line between those two outer extremities and the detail of the profile following the line of the outer profile can be selected to create the desired increase in length around the actual outer profile of the shoe as compared to the base line perimeter 66, the average perimeter 67, or the maximum outer perimeter 68 of the outer profile of the shoe. The calculation of the exact variation in distance around the outer profile of the shoe as compared to a distance along each of those lines will differ slightly, however the benefits of the invention can be realised by an increase in distance along the actual outer profile of the shoe as compared to any one of those lines.

[0047] Figure 7 shows a side view of a shoe being driven into the ground as intended for the present invention. Driving element 71 is of smaller outer diameter than the shoe 72 in order that a void is created behind shoe 72 as it is driven in the direction of arrow 73. As shoe 72 is driven in to the ground, particles in the ground may tend to rotate as illustrated by arrows 74. This rotating motion can result in the particles tending to rotate into the void behind the shoe. This can result in the bore created by the shoe having a cross-section which is no-longer similar to the outer profile of the shoe once the shoe has passed. The benefits of the interface between the resulting foundation pile and the surrounding soil having a similar form to the outer profile of the shoe are then lost.

[0048] Figure 8 illustrates an optional advantageous arrangement of the shoe of the present invention. The shoe 81 is shown having a diameter d and a depth a. The depth a of the shoe may be at least 50% of diameter d, this can be particularly sufficient for cohesive soils and may be beneficial up to 100% of diameter d. The depth a may further be equal to or greater than the diameter of the shoe. This may be particularly advantageous for more granular materials. The shoe may have a flat central section 82, although this is not essential. The particles can be seen to rotate around this flat section similarly to the illustration in Figure 7. However, with the depth of the shoe, the particles may have stopped rotating once they reach the smoothed section denoted by arrows 83 and 84. A shoe having a sufficient depth will present the open bore to the soil particles once they have finished rotating.

This can minimise the effects of the particles rotating into the bore once the shoe has passed. The shoe may have a smoothly curved outer shape along its depth to present a smooth transition from the point of minimum width or diameter of the shoe to its point of maximum diameter, as shown in Figure 8. The outer shape of the shoe may comprise a straight section, substantially parallel with the driving axis, extending in a direction away from the front driving face of the shoe as indicated in the region of arrow 83. The substantially straight section may extend back along the direction of the driving axis, away from the direction of the driving face of a simple flat shoe illustrated in figure 7. In this case, the smooth curved section adjacent arrow 84 may not be necessary.

[0049] Figures 9A and 9B illustrate an alternative method of creating a foundation pile having an array of grooves and ridges according to the present invention. The method is carried out using an apparatus 9 which comprises a mandrel 91, comprising at least one protrusion 94, and optionally a pathway through which a settable material may pass along the length of the mandrel, such as is indicated by arrow 95. A mandrel is known in the art and is a generally elongate member capable of transmitting large forces from a driven end, to which a hammer of vibration equipment or other driving means is applied, to a driving end, which engages with either a shoe or directly with the ground to drive a bore for a foundation pile. A valve 92 may be disposed at the driving end of the mandrel, the driving end being the end of the mandrel which is arranged to be driven into the ground. The mandrel may further comprise a valve actuating mechanism 93. The valve and/or the valve actuating mechanism are arranged to open and close the pathway through which settable material may pass. The protrusion or array of protrusions is/are arranged around the outer surface of the mandrel 91 such that, when driven into the ground, the mandrel creates a bore having an array of longitudinal channels or ridges in the wall of the bore. In a driving phase of the method illustrated in Figure 8, the mandrel 91 is driven into the ground, either by use of repeated impact from a driving device, such as a hammer, or alternatively the mandrel 91 may be vibrated in to the ground. It can be advantageous to vibrate the mandrel into the ground at a resonant frequency of the system made up of the ground and mandrel system, which facilitates smooth driving of the mandrel in to the ground with minimal disturbance to the surrounding soil and to the surrounding environment. The mandrel may be driven while either full or empty of settable material.

[0050] The protrusion(s) 94 arranged around the outer periphery of the mandrel can be arranged to create an outer profile of the mandrel equivalent to that illustrated in Figures 1 to 6 in relation to the shoe. Accordingly, by driving a hollow mandrel 91 having protrusions 94 arranged around its outer periphery in accordance with the outer profiles described in any of Figures 1 to 6, a bore can be created in the ground having a corresponding profile.

[0051] Figure 9B illustrates the apparatus 9 of Figure 9A during a withdrawing phase of the method of forming a pile. During the withdrawing phase, the mandrel 91 is withdrawn from the bore which has been created in the ground in an upward direction illustrated by arrow 97. During the withdrawing phase, the valve 92 is opened via the valve actuating mechanism 93, such that a settable material within the hollow mandrel 91 is able to flow into the bore 98 as the mandrel 91 is withdrawn from the bore. While the mandrel 91 is being withdrawn from the bore, a settable material is allowed to flow through an opening 96, which has been allowed to open by the valve 92. In this way, as the hollow mandrel 91 is withdrawn from the bore, concrete is allowed to flow from an opening 96 in the mandrel into the bore 98 to create a foundation pile of settable material having an outer profile which corresponds with that of the bore created in the soil by the outer profile of the hollow mandrel 91 and its protrusions 94.

[0052] It can be beneficial to arrange the protrusions 94 with a sloped first end 94a, arranged toward the direction in which the mandrel is being driven in order that the soil is gently deformed as the mandrel is driven. A sloped profile may be provided on a second end 94b of the protrusions 94, arranged in the direction of withdrawal of the mandrel. This allows the desired profiled of the bore to be created in the soil by a second pass of the protrusions 94 as the mandrel 91 is withdrawn from the bore.

[0053] The settable material may be allowed to flow through the opening 96 in the direction of arrows 99 either by force of gravity, by the vacuum created as the mandrel is withdrawn or, alternatively, it may pumped under pressure, which may help to avoid collapse of the bore as the mandrel 91 is withdrawn.

Claims

1. A foundation pile having an outer surface, the outer surface comprising:

   an array of channels or ridges generally extending in a direction of a longitudinal axis of the pile and arranged at different locations around the outer surface of the pile.

2. The foundation pile of claim 1 having a length in the direction of the longitudinal axis, wherein the array of channels or ridges in the outer profile extends substantially over the length of the foundation pile.

3. The foundation pile of claim 1 or claim 2, wherein the outer surface comprises an outer profile, in a plane perpendicular to the longitudinal axis, which is selected to induce an equal degree of slippage within a surrounding material as between the pile and the surrounding material.

4. The foundation pile of any preceding claim, the outer surface of the pile comprising, in a plane substantially perpendicular to the longitudinal axis, an outer profile comprising:

   an array of external included angles of less than 180°; or
   an array of external included angles of less than 160°; or
   an array of external included angles of less than 115°; and/or
   an external included angle of greater than 20°.

5. The foundation pile of any preceding claim, the outer surface of the pile comprising, in a plane substantially perpendicular to the longitudinal axis, an outer profile comprising an array of external included angles of:

   between around 20° and around 160°; or
   between around 20° and around 115°; or
   between around 20° and around 60°; or
   between around 60° and around 115°; or
   between around 30° and around 90°; or
   between around 40° and around 80°.

6. The foundation pile of any preceding claim, the outer surface of the pile comprising, in a plane substantially perpendicular to the longitudinal axis, an outer profile comprising an acute inner angle.

7. The foundation pile of any preceding claim, having a plane perpendicular to the longitudinal axis of the pile, an outer profile of the pile having an average perimeter in that plane, and wherein:

   the indentations or protrusions are configured such that the distance along the surface of the outer profile of the shoe in the plane is more than 10% greater than the distance along the average perimeter; or
   the distance along the surface of the outer profile of the shoe in the plane is more than 20% greater than the distance along the average perimeter; or
   the distance along the surface of the outer profile of the shoe in the plane is more than 40% greater than the distance along the average perimeter; or
   the distance along the surface of the outer profile of the shoe in the plane is substantially twice, or more than twice, the distance along the average perimeter.

8. The foundation pile of any preceding claim, the outer surface of the pile comprises, in a plane substantially perpendicular to the longitudinal axis, an outer profile having an array of outer extremities and wherein:

   the distance along the outer profile between adjacent outer extremities is 10% greater than the distance along a straight line joining the outer extremities; or
   the distance along the outer profile between adjacent outer extremities is 20% greater than the distance along a straight line joining the outer extremities; or
   the distance along the outer profile between adjacent outer extremities is 40% greater than the distance along a straight line joining the outer extremities; or
   the distance along the outer profile between adjacent outer extremities is twice, or more than twice, the distance along a straight line joining the outer extremities.

9. The foundation pile of any preceding claim, wherein a height of a ridge, or a depth of a channel of the pile, is:

   between 10% and 100% of a radius or a half of a width of the shoe; or
   between 10% and 80% of a radius or a half of a width of the shoe; or
   between 10% and 30% of a radius or a half of a width of the shoe; or
   between 30% and 60% of a radius or a half of a width of the shoe; or
   between 60% and 80% of a radius or a half of a width of the shoe.

10. The foundation pile of any preceding claim, wherein the outer profile is substantially entirely comprised of the array of ridges or channels.

11. A shoe for driving a bore for a foundation pile, the shoe having an outer profile substantially the same as the outer profile of the foundation pile of any one of claims 1 to 10, for creating the channels and/or ridges of the pile.

12. A mandrel for driving a bore for a foundation pile of any one of claims 1 to 10, the mandrel having an outer profile substantially the same as the outer profile of the foundation pile, for creating the channels and/or the ridges of the pile when driven into the ground.

13. A mandrel according to claim 12, wherein the mandrel comprises an opening arranged towards the driving end of the mandrel, arranged to deliver settable material to the bore as the mandrel is withdrawn.

14. A method of forming a foundation pile according to any one of claims 1 to 10, comprising the steps of:

driving a shoe according to claim 11 into the ground to form a bore having an array of longitudinal channels or ridges in a wall of the bore;
filling the bore with a settable material such that the settable material flows into the channel or around the ridge; and
allowing the settable material to set to form the foundation pile.

15. A method of forming a foundation pile according to any one of claims 1 to 10 comprising the steps of:

driving a mandrel according to claim 12 into the ground to form a bore;
withdrawing the mandrel; and
filling the bore with a settable material to form the foundation pile.

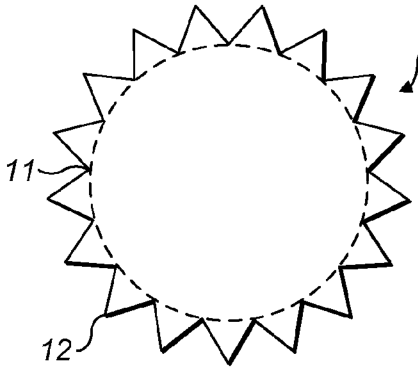

FIG. 1

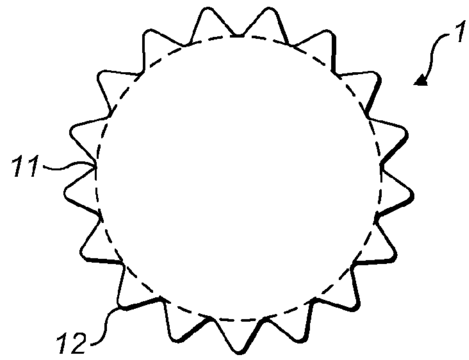

FIG. 2

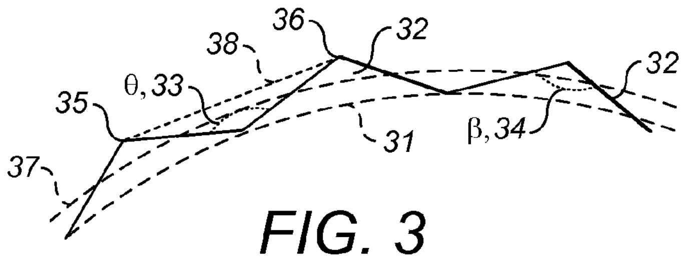

FIG. 3

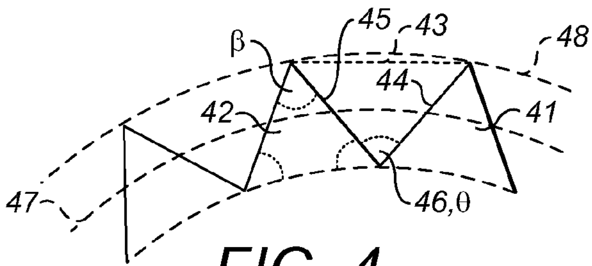

FIG. 4

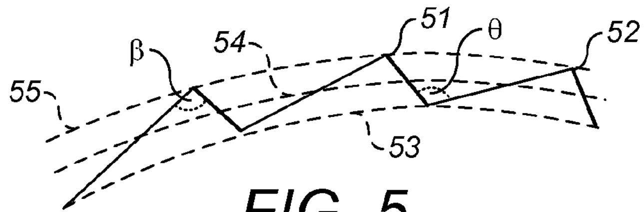

FIG. 5

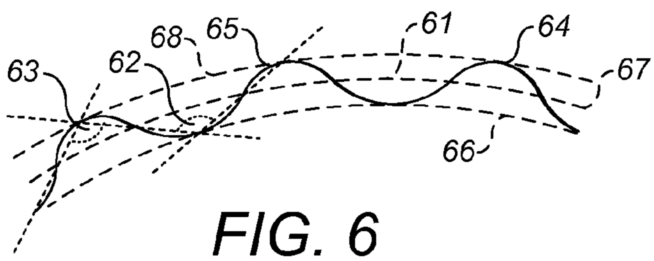

FIG. 6

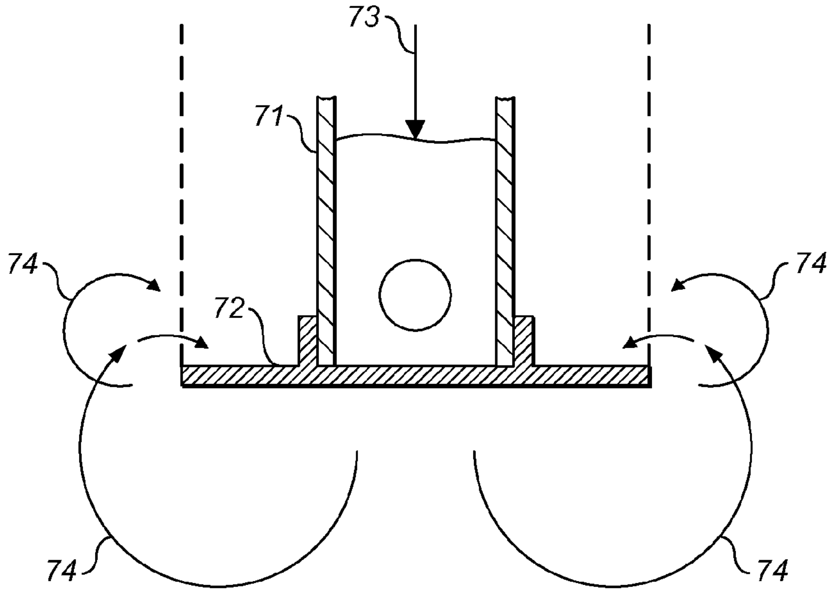

FIG. 7

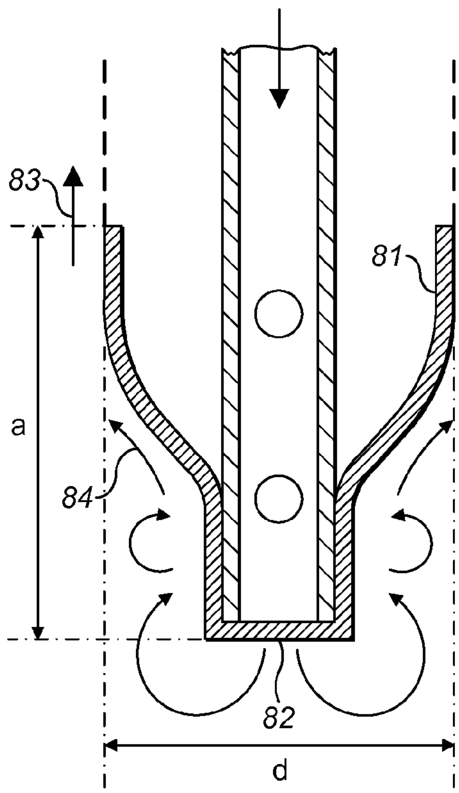

FIG.8

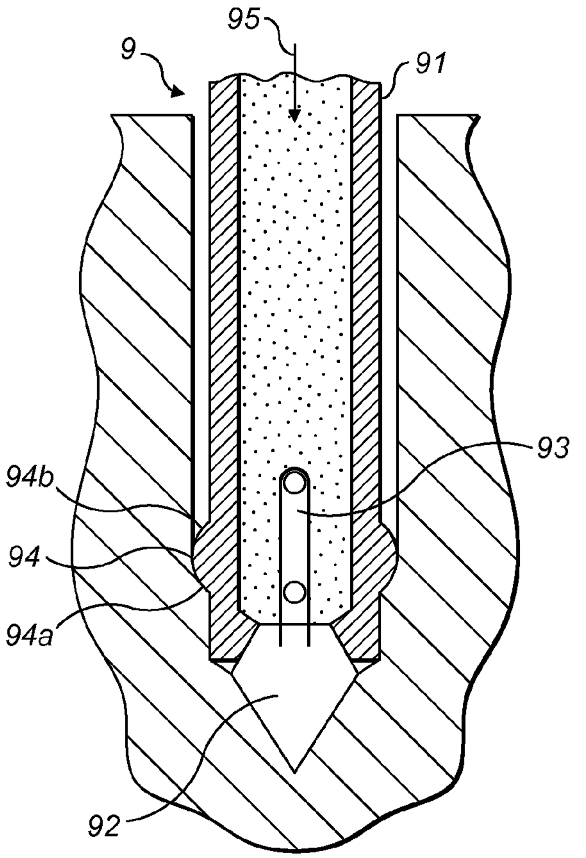

FIG. 9A

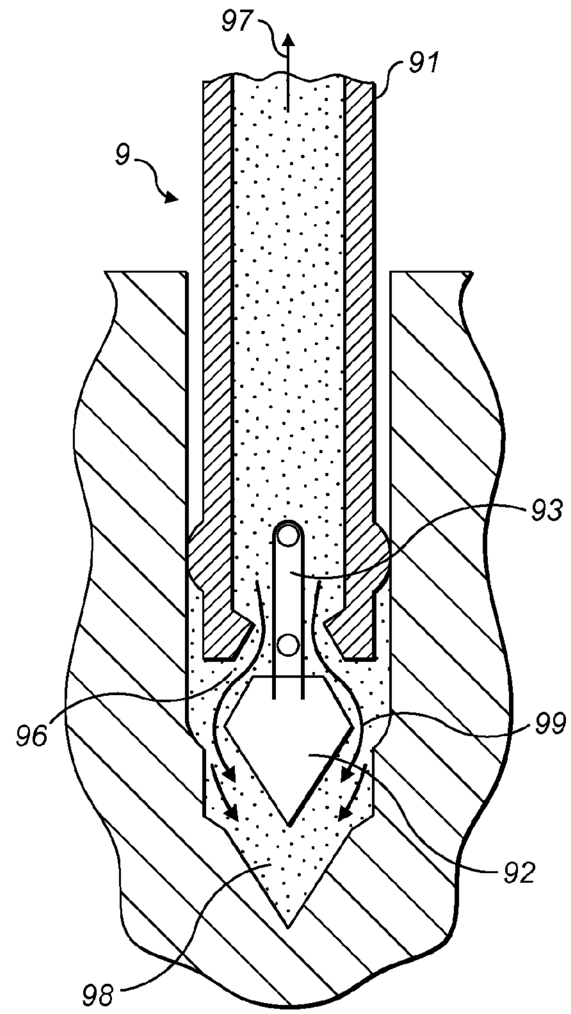

FIG. 9B

REFERENCES CITED IN THE DESCRIPTION

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- NL 1018792 **[0003]**
- EP 1063358 A **[0005]**