

## Description

The present invention relates to a method and apparatus for deep compacting soil, and preferably such a method and apparatus for compacting soil at its natural frequency or one of its overtones.

In a method generally known today for deep compacting of soil strata there is used a rod or pipe, which is several meters long and over its entire length provided with one or a plurality of radially projecting fins or brackets. The arrangement is driven down as a unit into the soil stratum. A vibrator is mounted at the upper end of the rod with the aid of a crane or the like. The vibrator operates at constant frequency, usually around 20 Hz, a certain compaction taking place of a region having the shape of a cone with its apex downwards and concentric with the rod and fins, as these cause the soil to accompany them in their movement.

The disadvantages with the known method and apparatus, which is still known under the designation "vibro-wing method" are that compaction proceeds relatively slowly, that the effective surface over which the vibrations are propagated is small, in turn resulting in that the volume of compacted material will be limited to the extent of the fins, that the rods or pipes must be arranged close to each other with a spacing of approximately 1.5—2 meters, that compaction takes place at a constant frequency demanded by the vibrators available on the market today and which do not take into account the special properties of the soil stratum, and in that it may be difficult to withdraw the rod or pipe from the soil after terminated compaction, because the compacted stratum effectively locks the radially projecting fins. Since it is a question of large volumes of soil, e.g. sand or silt, which are to be compacted, it is important that the number of compaction means is kept to a minimum, i.e. the spacing of the rods or pipes driven into the ground should be as large as possible without deteriorated compaction as a result, and that the compaction time should be as short as possible. Furthermore, the apparatus should be implemented so that the compaction means can easily be withdrawn from the soil stratum.

The DE-A-27 27 880 describes an apparatus for compaction of a soil stratum at the natural frequency of the latter. As with the apparatus already described, this apparatus includes a pipe which can be driven into the ground. A vibrator is mounted on the upper end of the pipe, on the surface of which axially extending fins are arranged. The vibrator is connected to the pipe at a certain angle in relation to the longitudinal axis of the pipe and/or eccentrically to this axis, the tube thus being given a radial, oscillating deflection during operation. Compaction thus takes place by the radial deflection of the pipe and not, as is the case with the present invention, by combined movements in the axial direction of the pipe. Since the pipe of the known apparatus is

provided with axially distributed radially extending fins a stiffening of the pipe is obtained which contributes to deteriorate the compacting properties thereof.

In the method and apparatus in accordance with the invention the above mentioned disadvantages are mitigated, while compaction is made more efficient. According to the invention, compaction of soil strata takes place with the aid of a rod or pipe (hereinafter designated "bar") driven into the ground, the length of the bar being alternately increased and decreased, with respect to its length in the unloaded condition, during the compaction operation. It is preferable that the bar is caused to oscillate by vibrator at the natural frequency of the earth stratum or at one of its overtones, thus providing the most effective compaction result. The axial stiffness of the bar can thus be adjusted so that it is favourably suited to the stiffness of the soil stratum. When the bar oscillates at the natural frequency of the soil stratum, the soil will also begin to oscillate at its natural frequency while using low vibration energy, without fins or brackets being needed along the bar to grip and cause the soil to accompany the movements thereof. The vibrations will propagate themselves through a larger region at the same time. According to certain calculations, the soil will oscillate at a distance of up to 10 meters from the centre of the bar. The natural frequency of a soil stratum in Hertz can be calculated from the formula:

$$f = \frac{C}{4H}$$

where C is the wave velocity of the material in meters per second and H is the total depth of the soil stratum in meters.

In a simple calculation example it may be assumed that a soil stratum of 10 meters consists solely of water-saturated sand, which is to be compacted. In this case the wave velocity of the material is approximately 1500 meters per second. This gives a natural frequency of 37,5 Hz. Accordingly, the vibrator should oscillate in an initial phase at about 37,5 Hz, or a frequency corresponding to an overtone thereof, for the most effective compaction result. If compaction is carried out at the lowest natural frequency of the soil stratum, assuming that it is not homogenous, it only has one oscillation node. By increasing the compaction frequency to one of the overtones of the soil stratum there will be more oscillation nodes, whereby the compaction process can be made more efficient. The structure of soil strata can be complex, however, and in practice a soil stratum does not generally consist of a single homogenous layer, but of a mixture of different layers, e.g. sand, clay, gravel etc. This means that the wave velocity of the stratum will vary during compaction, which may also be the case even for one that is homogenous. It is therefore of importance that the compaction frequency can be varied

continuously to suit varying wave velocities, thus obtaining the optimum compaction frequency.

By the statement that the bar is constructed so as to be alternately increased and decreased in length, with respect to its length in the unloaded condition, by the vibratory forces applied to it, there is intended in the following that the bar may be either telescopically or resiliently implemented. By resilient implementation is intended, for example, that the material in the bar is elastic or that the bar is formed helically so that it functions as a spring which may be compressed or extended. Bars with combinations of the mentioned properties are also conceivable within the scope of the present invention. Thus, the axial variation of a bar, i.e. its mobility in this direction, may be realized in a plurality of different ways. For example, the bar may be formed as a pipe made from a material with great resilience. The axial flexibility of such a pipe can be further improved by providing the pipe with a plurality of holes or openings along its cylindrical surface. Alternatively, the bar may be telescopically implemented or comprise a plurality of mutually coupled resilient tubular sections, which may be in mutual communication via a resilient material layer. It is also possible to form the bar as a helix. If the bar is made hollow, it can also function as a liquid conduit, particularly if its cylindrical surface is provided with a plurality of through openings. In this way a liquid can be led in any direction through the bar.

The characterizing features of the invention are apparent from the accompanying claims.

The invention will now be described in more detail in connection with the accompanying drawings, on which

Figure 1 schematically illustrates an embodiment of the apparatus;

Figures 2a-c illustrate three alternative embodiments of bars which are variable in their axial extension; and

Figure 3 is a further embodiment of a bar in accordance with the invention.

For operating at the optimum compaction frequency of the soil stratum during the entire procedure, i.e. at its natural frequency or one of its overtones, the apparatus includes a vibrator 1 with a variable frequency, mounted on a bar 2, driven into the soil stratum. One or more sensors 3 are arranged in the area about the bar, on or under the ground surface 4. The sensors continuously monitor the oscillation amplitude of the ground. An analyzer 5, which is in communication with the sensors via lines 10, 11, analyzes the frequency content of the signals from the sensors. With the aid of the analyzer the natural frequency of the earth stratum, or one of its overtones, may be continuously determined. In its turn the analyzer is connected via the line 12 to a vibrator control means 6, controlling the frequency and amplitude of the vibrator 1.

Since the inventive bar lacks the previously used radial fins or bracks distributed along the entire length of the bar, it is able to be

implemented so that it is variable axially, e.g. it is axially resilient, which contributes to a considerable increase in the efficiency with which the soil stratum is compacted. The withdrawal of the bar from the stratum after it has been compacted is facilitated at the same time, since no fins brake the withdrawal movement. If compaction also takes place such that the frequency of the vibrator 1 is adjusted to the natural frequency of the soil stratum during the entire compaction process, this frequency being calculated by the analyzer 5 from the signals of the sensors 3, there is obtained a further increase in the effectiveness of the compaction of the stratum by the bar 2 driven into the ground. The compaction frequency of the bar will thus change in response to the varying dynamic properties of the soil. To facilitate initiation of compaction the bar 2 may be provided at its downward end 7, or in the vicinity thereof with pivotably attached radial rods 8, which, as indicated by the double arrow 9, lie retracted against the surface of the bar when it is driven into the ground and during vibration open out in a radial direction with respect to the longitudinal axis of the bar, and are released from the bar to remain in the soil when the bar is withdrawn.

Three alternative embodiments are illustrated in Figures 2a-c of bars which are variable in their length and with which the method in accordance with the invention is realized. In Figure 2a there is illustrated a pipe 13 connected to a vibrator 1, which transfers vibrations to the pipe in the direction of the double arrow P. The pipe illustrated in the example is provided with a plurality of through holes or openings 14, which further increase the resilient properties of the pipe. With the aid of the pipe bore and the openings 14, liquid can be led in any direction. During driving down the pipe 13 into the ground, liquid can thus be taken into the pipe and flushed out through the openings 14, which contributes to more rapid driving of the pipe into the ground. When the pipe has been driven to a desired level and the vibrator 1 is started, the pipe then varying its length due to its resilient properties during the vibrations, there is obtained a very effective compaction of the soil stratum at a considerable distance from the pipe. By "varying" there is intended here that the length of the pipe increases and decreases in relation to the length the pipe has in an unloaded i.e. unvibrated state. In the case of water-saturated soil, and in other cases as well, it is necessary to lead water away from the region being compacted, if compaction is to be successful. This can be done simply by the holed pipe also functioning as a drain. If an increased liquid content is required in one or more soil strata, liquid or a liquid mixed with another material such as lime, cement or polyurthane may also be injected into the soil via the pipe in question.

In Figure 2b there is illustrated a helically formed bar 15, this also being connected to a vibrator 1 at its upper end. Due to its helical implementation the bar 15 has considerably greater resilient properties in its axial direction

an other bars, and it can also be made as a pipe with openings similar to those in Figure 2a for draining and/or injecting liquid.

A third embodiment of an inventive bar is illustrated in Figure 2c, the length of this bar also being alternately increased and decreased during vibration compaction. In this example the bar comprises a plurality of sections 16a, b, c, d coupled to each other. Four sections are illustrated in the Figure but of course more or less sections can be coupled to each other. This bar can be provided with holes along certain or all the participating sections for draining and/or injecting liquid. To increase the resilient properties of the bar, elastic spacers 17 can be arranged between respective sections. Apart from the illustrated examples, it is of course conceivable within the scope of the invention to form the apparatus telescopically extendable.

In Figure 3 a pipe 18 similar to the pipe 13 illustrated in Figure 2 has been provided with a stamping means 19 connected to the lower part of the pipe, the task of this means being to facilitate driving and withdrawing the pipe from the soil stratum. The stamping means 19 can be connected to a rod 20 co-axially arranged in the pipe. Without the stamping means 19 it may be difficult to withdraw a resilient or substantially flexible pipe from the ground. With the aid of the rod 20 and means 19 this withdrawal is thus greatly facilitated. The stamping means may of course be arranged with any embodiment within the scope of the invention. Furthermore, the perforated pipes can be provided with filters which prevent soil particles from accompanying the liquid draining off through the pipe.

The invention shall thus not be regarded as restricted to the embodiments described above but may be varied within the scope of the accompanying claims.

#### Claims

1. A method of compacting with the aid of vibrations a soil stratum consisting of one or more layers through which at least one vibration-transferring member (2) is driven into the soil stratum and that a vibration-generating means (1) transfers vibrations to the vibration-transferring member (2) which in turn activates surrounding earth strata, characterized by causing the length of the vibration-transferring member (2) to be alternately increased and decreased, with respect to its length in the unloaded condition, by the vibrations applied thereto.

2. Method as claimed in claim 1, characterized in that the length of the vibration-transferring member (2) is changed elastically, resiliently or telescopically or by a combination thereof.

3. Method as claimed in any one of the preceding claims, characterized in that the length in conjunction with compaction is varied regulatably with relation to the stiffness of the soil stratum.

4. Method as claimed in one or some of claims 1-3, characterized in that the liquid or other

material can be led through the vibration-transferring member (2) and out into surrounding earth strata, alternatively from surrounding earth strata through the member for injecting alternatively draining liquid or other material.

5. Method as claimed in any one of the preceding claims, characterized in that the frequencies of the vibration-generating means (1) and the vibration-transferring member (2) are continuously adjusted into agreement with the natural frequency of the soil, or with one of its overtones, said frequency varying with the wave velocity of the soil stratum.

6. Apparatus for compacting with the aid of vibrations a soil stratum consisting of one or more layers, said apparatus including at least one vibration-transferring member (2) which may be driven into the soil stratum, and a vibration generating means (1) connected to the vibration activating apparatus, characterized in that the vibration-transferring member (2) is constructed so as to be alternately increased and decreased in length, with respect to its length in the unloaded condition, by the vibratory forces applied to it.

7. Apparatus as claimed in claim 6, characterized in that the vibration-transferring member (2) is increasingly and decreasingly elastic, resilient or telescopic or a combination thereof.

8. Apparatus as claimed in claim 6 or 7, characterized in that the vibration-transferring member (2) comprises a pipe or rod-shaped means.

9. Apparatus as claimed in claim 8, characterized in that the means is helically formed.

10. Apparatus as claimed in claim 8 or 9, characterized in that the means comprises a plurality of sections (16a, b, c, d).

11. Apparatus as claimed in one or some of claims 8-10, where the vibration-transferring member (2) is a pipe-shaped means, characterized in that the cylindrical surface of the means has holes, slots or other openings (14).

12. Apparatus as claimed in claim 11, characterized in that each hole or opening (14) is covered by a filter.

13. Apparatus as claimed in one or some of claims 8-12, characterized in that the vibration-transferring member (2) is provided at its lower end with a stamping means (19).

14. Apparatus as claimed in claim 10, characterized in that mutually adjacent sections of the means are separated by a resilient element (17).

15. Apparatus as claimed in one or some of claims 6-14, characterized in that it includes the vibration transferring member (2), which is in communication with one or more sensors (3), an analyzer (5) and a control means (6) for continuously adjusting the vibrations of the vibration activating apparatus into agreement with the natural frequency of the soil stratum or one of its overtones, said frequency varying with the wave velocity of the soil stratum.

#### Patentansprüche

1. Verfahren zum Verdichten einer aus einer

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#### Claims

1. A method of compacting with the aid of vibrations a soil stratum consisting of one or more layers through which at least one vibration-transferring member (2) is driven into the soil stratum and that a vibration-generating means (1) transfers vibrations to the vibration-transferring member (2) which in turn activates surrounding earth strata, characterized by causing the length of the vibration-transferring member (2) to be alternately increased and decreased, with respect to its length in the unloaded condition, by the vibrations applied thereto.

2. Method as claimed in claim 1, characterized in that the length of the vibration-transferring member (2) is changed elastically, resiliently or telescopically or by a combination thereof.

3. Method as claimed in any one of the preceding claims, characterized in that the length in conjunction with compaction is varied regulatably with relation to the stiffness of the soil stratum.

4. Method as claimed in one or some of claims 1-3, characterized in that the liquid or other

material can be led through the vibration-transferring member (2) and out into surrounding earth strata, alternatively from surrounding earth strata through the member for injecting alternatively draining liquid or other material.

5. Method as claimed in any one of the preceding claims, characterized in that the frequencies of the vibration-generating means (1) and the vibration-transferring member (2) are continuously adjusted into agreement with the natural frequency of the soil, or with one of its overtones, said frequency varying with the wave velocity of the soil stratum.

6. Apparatus for compacting with the aid of vibrations a soil stratum consisting of one or more layers, said apparatus including at least one vibration-transferring member (2) which may be driven into the soil stratum, and a vibration generating means (1) connected to the vibration activating apparatus, characterized in that the vibration-transferring member (2) is constructed so as to be alternately increased and decreased in length, with respect to its length in the unloaded condition, by the vibratory forces applied to it.

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#### Patentansprüche

1. Verfahren zum Verdichten einer aus einer



oder mehr Lagen bestehenden Erdbodenschicht mit Hilfe von Schwingungen, bei dem wenigstens ein Schwingungen übertragendes Teil (2) in die Erdbodenschicht getrieben wird und eine Schwingungen erzeugende Einrichtung (1) Schwingungen zu dem Schwingungen übertragenden Teil (2) leitet, welches seinerseits die umgebenden Erdschichten aktiviert, dadurch gekennzeichnet, daß die Länge des Schwingungen übertragenden Teils (2) im Hinblick auf seine Länge im unbelasteten Zustand durch die in es eingeleiteten Schwingungen abwechselnd vergrößert und verkleinert wird.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Länge des Schwingungen übertragenden Teils (2) elastisch, federnd, teleskopisch oder durch eine Kombination davon geändert wird.

3. Verfahren nach einem der vorangegangenen Ansprüche, dadurch gekennzeichnet, daß die Länge in Verbindung mit dem Verdichten im Verhältnis zur Festigkeit der Erdbodenschicht regelbar verändert wird.

4. Verfahren nach einem oder mehreren der Ansprüche 1 bis 3, dadurch gekennzeichnet, daß die Flüssigkeit oder anderes Material durch das Schwingungen übertragende Teil (2) hindurch und hinaus in die umgebenden Erdbodenschichten geleitet werden kann, alternativ von den umgebenden Erdbodenschichten durch das Schwingungen übertragende Teil hindurch, um entweder Flüssigkeit oder anderes Material einzuspritzen oder abfließen zu lassen.

5. Verfahren nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß die Frequenzen der Schwingungen erzeugenden Einrichtung (1) und des Schwingungen übertragenden Teils (2) kontinuierlich im Einklang mit der natürlichen Frequenz des Erdbodens oder mit einem von seinen Obertönen eingestellt werden, wobei die Frequenz mit der Wellen(ausbreitungs)geschwindigkeit in der Erdbodenschicht variiert.

6. Vorrichtung zum Verdichten einer aus einer oder mehr Lagen bestehenden Erdbodenschicht mit Hilfe von Schwingungen, wobei die Vorrichtung wenigstens ein Schwingungen übertragendes Teil (2), welches in die Erdbodenschicht getrieben werden kann, und eine Schwingungen erzeugende Einrichtung (1) aufweist, die mit dem Schwingungen übertragenden Teil verbunden ist, dadurch gekennzeichnet, daß das Schwingungen übertragende Teil (2) so ausgebildet ist, daß es in seiner Länge im Hinblick auf seine Länge im unbelasteten Zustand durch die in es eingeleiteten Schwingungskräfte wechselseitig vergrößert und verkleinert wird.

7. Vorrichtung nach Anspruch 6, dadurch gekennzeichnet, daß das Schwingungen übertragende Teil (2) elastisch, federnd teleskopisch oder in einer Kombination davon vergrößer oder verkleinerbar ist.

8. Vorrichtung nach Anspruch 6 oder 7, dadurch gekennzeichnet, daß das Schwingungen übertragende Teil (2) ein Rohr oder ein stangenförmiges Bauteil aufweist.

9. Vorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß das Bauteil schraubenfederförmig ist.

10. Vorrichtung nach Anspruch 8 oder 9, dadurch gekennzeichnet, daß das Bauteil eine Mehrzahl von Abschnitten (16a, b, c, d) aufweist.

11. Vorrichtung nach einem oder mehreren der Ansprüche 8 bis 10, wobei das Schwingungen übertragende Teil (2) ein rohrförmiges Bauteil ist, dadurch gekennzeichnet, daß die zylindrische Oberfläche des Bauteils Löcher, Nuten oder andere Öffnungen (14) hat.

12. Vorrichtung nach Anspruch 11, dadurch gekennzeichnet, daß jedes Loch oder Öffnung (14) von einem Filter abgedeckt ist.

13. Vorrichtung nach einem oder mehreren der Ansprüche 8 bis 12, dadurch gekennzeichnet, daß das Schwingungen übertragende Teil (2) an seinem unteren Ende mit einem stampfenden Bauteil (19) versehen ist.

14. Vorrichtung nach Anspruch 10, dadurch gekennzeichnet, daß angrenzende Abschnitte des Bauteils gegenseitig durch ein federndes Element (17) getrennt sind.

15. Vorrichtung nach einem oder mehreren der Ansprüche 6 bis 14, dadurch gekennzeichnet, daß sie das Schwingungen übertragende Teil (2) umfaßt, welches in Verbindung mit einem oder mehr Sensoren (3), einem Auswerter (5) und einem Steuergerät (6) ist, um eine fortlaufende Regulierung der Schwingungen des die Schwingungen übertragenden Teils im Einklang mit der natürlichen Frequenz der Erdbodenschicht oder einem von ihren Obertönen zu bewirken, wobei die Frequenz mit der Wellen (ausbreitungs)geschwindigkeit in der Erdbodenschicht variiert.

#### Revendications

1. Procédé pour compacter, à l'aide de vibrations, une strate de sol constituée d'une ou plusieurs couches à travers lesquelles on enfonce dans la strate de sol au moins un élément (2) pour transférer des vibrations, dans lequel un moyen (1) pour engendrer des vibrations transfère des vibrations à l'élément (2) pour transférer des vibrations, lequel, à son tour, active les strates de terre environnantes, caractérisé en ce que les vibrations qui sont appliquées à l'élément (2) pour transférer des vibrations font alternativement augmenter et diminuer la longueur de cet élément par rapport à sa longueur dans l'état sans charge.

2. Procédé selon la revendication 1, caractérisé en ce que la longueur de l'élément (2) pour transférer des vibrations change de façon élastique, résiliente ou télescopique, ou selon une combinaison de ces façons.

3. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que l'on fait varier la longueur conjointement avec le compactage, de façon réglable en fonction de la rigidité de la strate de sol.

4. Procédé selon l'une quelconque des revendications 1 à 3, caractérisé en ce que l'on peut



envoyer du liquide ou un autre matériau, par l'élément (2) pour transférer des vibrations, dans les strates de terre environnantes, ou bien des strates de terre environnantes dans l'élément, pour injecter, ou bien drainer, du liquide ou un autre matériau.

5. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que l'on règle de façon continue les fréquences du moyen (1) pour engendrer des vibrations et de l'élément (2) pour transférer des vibrations, pour les accorder avec la fréquence naturelle du sol, ou l'un des harmoniques de celle-ci, ladite fréquence variant avec la vitesse des ondes dans la strate du sol.

6. Appareil pour compacter, à l'aide de vibrations, une strate de sol constituée d'une ou de plusieurs couches, ledit appareil comportant au moins un élément (2) pour transférer des vibrations que l'on peut enfoncer dans la strate du sol, et un moyen (1) pour engendrer des vibrations relié à l'appareil d'activation des vibrations, caractérisé en ce que l'élément (2) pour transférer des vibrations est construit de façon à ce que sa longueur augmente et diminue alternativement, par rapport à sa longueur dans l'état sans charge, sous l'action des forces vibratoires qui lui sont appliquées.

7. Appareil selon la revendication 6, caractérisé en ce que l'élément (2) pour transférer des vibrations est de façon croissante ou de façon décroissante élastique résilient ou télescopique ou présente une combinaison de ces caractéristiques.

8. Appareil selon la revendication 6 ou 7, caractérisé en ce que l'élément (2) pour

transférer des vibrations comporte un tube ou d'un moyen en forme de tige.

9. Appareil selon la revendication 8, caractérisé en ce que le moyen est de forme hélicoïdale.

10. Appareil selon la revendication 8 ou 9, caractérisé en ce que le moyen comporte plusieurs tronçons (16a, b, c, d).

11. Appareil selon une ou plusieurs des revendications 8 à 10, l'élément (2) pour transférer des vibrations étant un moyen en forme de tube, caractérisé en ce que la surface cylindrique du moyen présente des trous, des fentes ou d'autres ouvertures (14).

12. Appareil selon la revendication 11, caractérisé en ce que chaque trou ou ouverture (14) est recouvert d'un filtre.

13. Appareil selon une ou plusieurs des revendications 8 à 12, caractérisé en ce que l'élément (2) pour transférer des vibrations présente à son extrémité inférieure un moyen de poinçonnage (19).

14. Appareil selon la revendication 10, caractérisé en ce que des tronçons voisins l'un de l'autre du moyen sont séparés par un élément élastique (17).

15. Appareil selon une ou plusieurs des revendications 6 à 14, caractérisé en ce qu'il comporte l'élément (2) pour transférer des vibrations qui est en communication avec un ou plusieurs détecteurs (3), un analyseur (5) et un moyen de commande (6) pour régler de façon continue les vibrations de l'appareil d'activation des vibrations, et les accorder avec la fréquence naturelle de la strate du sol ou l'un des harmoniques de celle-ci, ladite fréquence variant avec la vitesse des ondes dans la strate du sol.

