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Kniep

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[54] **METHOD AND DEVICE FOR SOIL COMPACTING**

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[52] **U.S. Cl.** **404/133,** 175/56, 404/72

[51] **Int. Cl.** **E01c 19/34**

[58] **Field of Search** 404/133; 175/55, 56, 19

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Primary Examiner—Nile C. Byers, Jr.
Attorney, Agent, or Firm—James E. Nilles

[57] **ABSTRACT**

Method and device for compacting the soil by means of vibration transmitted to the soil particles through a tube open or closed at its lower end and having at its upper end a vibration source with an adjustable counter-weight, said source being capable of generating vibrations in the longitudinal sense of the tube; around the lower portion of the tube a number of radial plates are rigidly connected, the dimensions of said plates being determined such in relationship with the vibration source, that the frequency of said source is tuned to the own vibration frequency (also called resonancy) of the surrounding soil or of said radial plates in the lower portion of said tube or to a multiple of it; the tube is lowered into the ground only by gravitational force during the operation of the vibration source.

20 Claims, 8 Drawing Figures

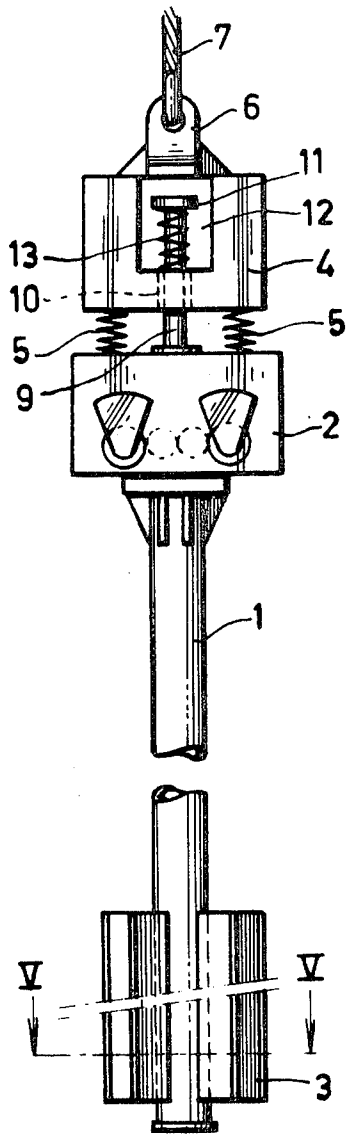
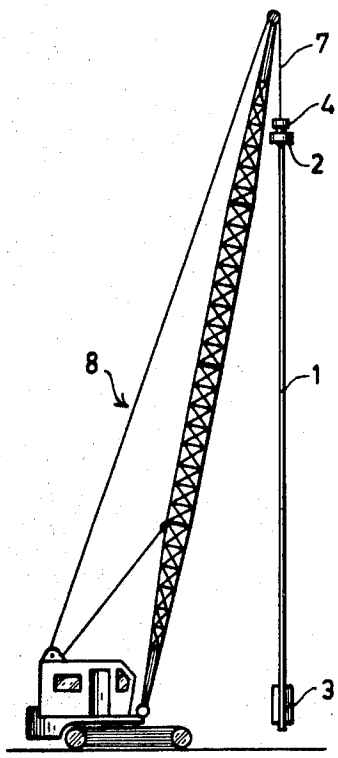


Fig. 1.



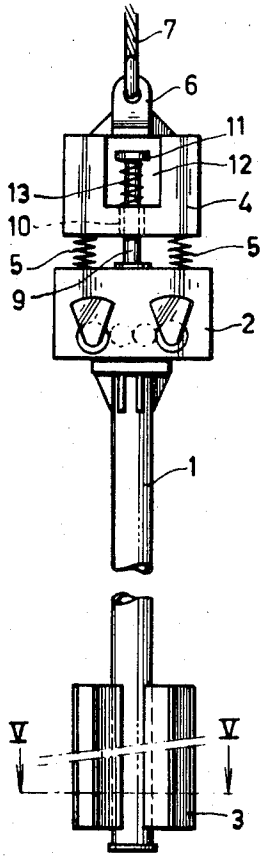


Fig. 2.

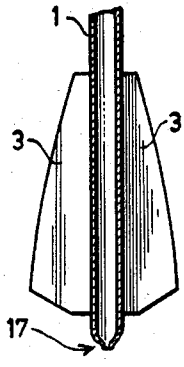


Fig. 3.

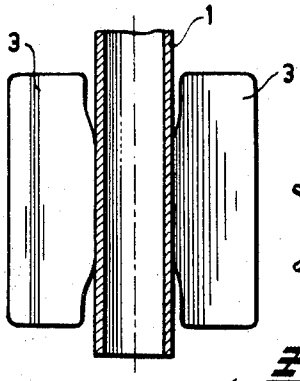


Fig. 4.

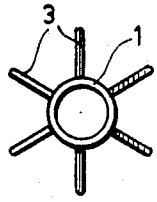


Fig. 5.

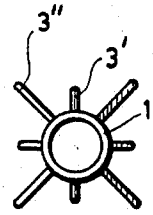


Fig. 6.

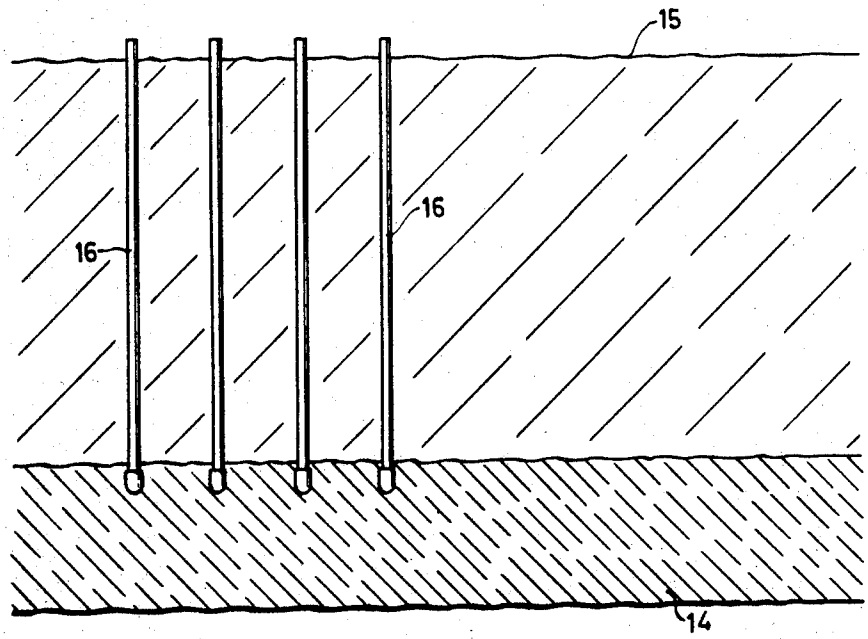


Fig. 7.

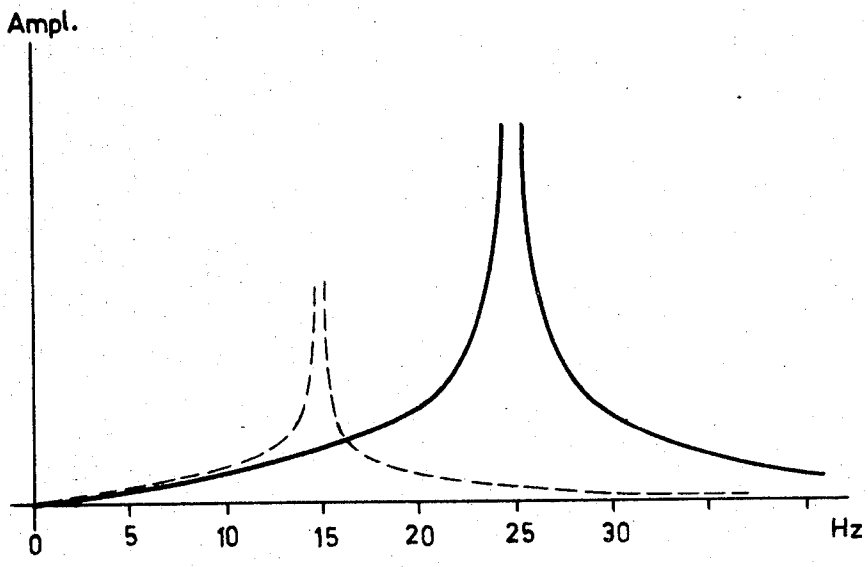


Fig. 8.

METHOD AND DEVICE FOR SOIL COMPACTING

BACKGROUND OF THE INVENTION

Due to the growing earth population, there is an increasing demand for useful ground either above or below water level, said ground serving to support buildings, harbour facilities, high ways, dams, dikes, artificial islands, exploration rigs etc. In many regions a rather small percentage of the ground surface is sufficiently firm to be used for the above purposes. The remaining surfaces cannot be used, unless complicated structures, such as piling were applied for producing the required supporting capacity. This latter method however, besides being rather costly, is only applicable when a firm lower earth layer can be found at some depth on the aimed site. My invention aims at providing a method as well as a device for compacting the soil, so as to improve its usefulness by rendering the ground firmer and thus more capable of supporting artificial structures. My invention further aims to realise a compacting of the soil without any addition of auxiliary substances.

DISCUSSION OF THE PRIOR ART

It is known to make a hole into the ground by suspending a torpedo-shaped element on a cable, said element having internally a rotating eccentric weight so as to generate a circulating rotary movement mainly lying in a horizontal plane. This element performs a rolling movement, thereby creating alternating pressure forces in the earth wall surrounding said torpedo-shaped element. It is also known to lower a hollow tube into the ground and to increase the penetrating speed by imposing a vibratory movement upon the upper end of the tube. In both cases there might occur some slight degree of compacting the soil, provided the property of the soil, permits an easy change in relative position of adjacent earth particles. It is further known to obtain a compacting of the upper layer of a temporarily dug and subsequently closed ditch by means of a beating action. To this end an explosive hammer is used or a vibrating plate, which is slowly advanced upon the freshly dumped ground.

SUMMARY OF THE INVENTION

My invention provides a novel method and device for transmitting a substantial amount of energy upon the soil lying under the earth surface and situated at a considerable depth going even to 100 feet or more. This energy, transmitted to the earth particles provides a sufficient relative movement to these particles to obtain a more stable position towards neighbouring particles, thus creating a compacting action. This object is realised according to my invention by the combination of the following features:

vibrating a tube having radial plates at one end, the vibrations being generated in the longitudinal sense of said tube;

lowering the vibrating tube into the earth surface;

adapting the frequency and the intensity of the vibrations on the one hand, and the resonancy of said radial plates in the lower extreme portion of the tube on the other hand such that these plates are capable of transmitting energy to the ground.

The gist of my invention resides mainly in the increased capacity of the lower portion of the tube to transmit energy to the surrounding earth particles. A possible explanation can be found in the fact that the radial plates will swing in a tangential direction, thereby transmitting energy to the adjacent ground portions. Due to my invention it is possible to emit this energy in an annular zone around the lower portion of the tube, said zone having a diameter of at least 3–5 times, and often 10 times or more the diameter of the tube. The rate of energy transmission is such that within a rather short time lapse, the compacting is locally completed so that the lowering or the raising of the tube can be continued. Some grounds do not easily "accept" or take up the energy radiated by the plates in the lower portion of the tube. Under these circumstances the addition of water increases the capacity of the ground to take up the vibratory energy so that the earth particles move sufficiently to force them into the desired more compact configuration.

SURVEY OF THE DRAWINGS

FIG. 1 shows a complete installation comprising a crane carrying the device for compacting the soil.

FIG. 2 is a side view of the device suspended in the installation according to FIG. 1.

FIGS. 3 and 4 are partial views of variants of the lower portion of the device shown in FIG. 2.

FIG. 5 is a cross section along the line V—V in FIG. 2.

FIG. 6 is a cross section similar to FIG. 5 of a different embodiment of the lower portion of the device.

FIG. 7 illustrates an interesting aspect of the invention consisting of compacting a subterranean layer for supporting piles.

FIG. 8 is a diagram showing possible resonancy generated in the ground or in the radial plates.

DESCRIPTION OF PREFERRED EMBODIMENTS

The device shown in FIGS. 1 and 2 comprises a tube 1 having rigidly secured to its upper extremity a source 2 of vibrations. This vibration source, although being important, does not form an object of this invention. It must be capable of creating powerful vibrations in the order of 30 – 300 metric tons (mainly corresponding to 35 – 350 s.t.). Near the lower extremity of the tube 1 a number of radial plates 3 are rigidly connected to said tube, for instance by welding. FIG. 5 shows that six mainly identical plates 3 are equally spaced around the tube 1.

The device further comprises a ballast-weight 4 resiliently connected to the vibration source 2 by means of a plurality of springs 5. On top of the weight 4 a lug 6 is mounted for connection with a cable 7 from a crane 8. A stem 9 rigidly connected to the vibration source 2 passes through a hole 10 in the weight 4 and terminates in a head 11 accommodated in a space 12 within the weight. Between the head 11 and the body of the weight 4 a compression spring 13 is situated.

The vibration source 2 is of known construction and forms the subject of an earlier patent application. The source 2 operates with revolving eccentric masses driven by one or more electric motors. The source comprises means (not-shown) for changing the frequency of the vibrations for instance by polar-commutation. The source also comprises means (not-shown) for changing the amplitude of the vibrations. A conventional system is described in British Pat. No. 1,120,143. In a vibration source driven by hydraulic motors, it will be possible to realise a stepless adjust-

ment of the frequency and of the amplitude of the vibrations. These adjustments are important for my invention and are disclosed in a copending patent application. The significance of the adjustments will now be described in detail.

One of the most important aspects of my invention resides in the phenomenon of resonancy occurring around the lower extreme portion of the hollow tube **1.** The dimensions of the radial plates **3** are determined such that their own frequency corresponds with at least one frequency of the vibration source **2.** According to a useful embodiment the frequency of the source **2** is 25 Hz (corresponding to 1500 impulses per minute). By determining the own frequency of the radial plates **3** upon or near this value, a reasonancy will occur in the plates **3,** which will swing in tangential direction. This renders it possible to radiate or emit a substantial amount of energy into the ground surrounding this lower extremity of the tube **1.** The tube **1** acts as a prolongation of the vibration source **2** and only the plates **3** will resonate. The intergranular friction of the soil will thus be overcome, even under difficult conditions when the conventional methods fail by their incapacity to transmit sufficient energy.

During operation, the tube **1,** after having been lowered to the desired depth, will be gradually and stepwise raised so as to realize a compacting of a column of ground, having a diameter of at least 3 – 5 times and often 10 times or more the diameter of the tube. By using a number of mutually spaced devices, or by repeating the operation of one or more devices in a regular pattern, it will be possible to obtain a compacting of the soil over any desired surface.

The introduction of the tube **1** with the plates **3** into the ground is also performed by vibration. However, this introduction should not create a compacting, as otherwise it will be difficult to lift the tube out of the ground, after having reached the full depth. To this end the frequency of the vibration source **2** can be adjusted for instance by polar-commutation of the driving electro motor, thus raising the above mentioned value of 25 Hz to 50 Hz (corresponding to 3000 impulses per minute). With this frequency, the plates **3** will perform a reduced swinging movement, which is however, sufficient to obtain a penetration of the tube **1** with the plates into the ground.

By using a vibration source capable of a stepless frequency adjustment, the possibilities of adapting the device to the specific conditions of the ground will of course considerably increase. FIG. **7** illustrates one interesting embodiment of the method according to my invention. The object is to compact a subterranian layer **14** with a thickness of 15 ft. (4,5 meter) lying at a depth of 50 ft (15 meter) under the earth surface **15.** This layer **14** may then support a number of piles **16** forming the foundation of a building (not shown). The device will be lowered into the ground to a depth of 65 ft (about 20 meter) with the vibration device **2** operation with a frequency away from the own frequency of the plates **3.** After having reached this depth, the frequency of the vibration source **2** is adjusted to a value corresponding with the aimed resonancy of the plates **3.** The tube **1** is gradually raised over a height of 15 ft, after which the frequency of the source **2** is again adjusted to avoid resonancy and the tube is completely lifted out of the ground.

One of the functions of the ballast-weight **4** is to influence the weight of the suspended element composed of the vibration source **2,** the tube **1** and the plates **3.** This is important for the penetration of the tube **1** into the ground, during the initial stage of the compacting operation. A further function of this ballast weight **4** is to render it possible to transmit a great amount of energy into the ground. As soon as a resonancy is occurring around the lower portion of the tube **1,** the power of the vibration source can be raised thereby simultaneously slackening the cable **7,** so as to increase the pressure upon the springs **5** in order to counter balance the energy output of the source **2.** This energy output or intensity of the resonancy can be further increased by adjusting the amplitude of the longitudinal vibrations. Reference is made to the vibration source described in my above mentioned copending patent application.

FIG. **3** shows an embodiment of the lower portion of the tube **1,** in which the radial dimension of the plates **3** is not uniform over the height of the plates. This embodiment is different from FIG. **2** in that the bottom of the tube **1** is not closed with a flat cover (as in FIG. 2) but has a somewhat spherical shaped end. In the center of this dome a nozzle **17** is mounted. This nozzle can be used to inject a fluid such as water into the ground in order to increase the capacity of the soil to "accept" vibration energy from the plates **3.** In the prior art (for instance with the torpedo-shaped element, mentioned herebefore) it is known to use water. However, this water serves to weaken the soil so as to enable the torpedo to sink into the ground. In my device the water only serves to increase the firmness of the ground during the stage of maximum energy transmission through the radial plates. The alternating forces in the tube **1** generated by the vibration source **2** will amount from at least 33 s.t. (corresponding to 30 metric tons) to 350 s.t. and higher if the condition of the soil permits such an energy transmission. The radiated energy will lie between 25000 and 300.000 ft.lbs./sec. (equivalent to about 50 – 500 horse power).

FIG. **4** is an other embodiment, differing in two aspects from the lower tube portion of the FIGS. **2** and **3.** In the first place it is shown that the connection of the plates **3** to the tube **1** does not extend over the full height of the plates. It is only the middle part which is fixed (by welding) to the tube. This way of connecting influences the vibration behaviour of the plates and may permit a greater amplitude of the vibration in tangential direction. In the second place, the tube **1** is open at its lower extremity. Experiments have shown that sometimes an open tube may be useful either for the speed of operation, or for the introduction of additional ground for compensating the decrease in volume of the compacted soil.

FIG. **5** shows the presence of six equal plates **3** in the embodiment according to FIG. **2.** It is however, sometimes advantageous to use two kind of plates as shown in FIG. **6** in which three plates **3'** have a reduced radial dimension in comparison with the larger plates **3''.** The own frequency of the plates **3'** may lie at 50 Hz and of the plates **3''** at 25 Hz. In performing the method illustrated in, and described with reference to FIG. **7** the device comprising the tube **1** with the vibration source **2** and the plates **3', 3''** will be lowered with a frequency of 50 Hz. The plates **3''** will be exited, enabling the lower portion of the device to penetrate easily into the

ground. Once the full depth reached, the frequency of the source **2** is changed to 25 Hz and the intensity of the vibrations is increased in order to realise a compacting of the soil.

It is sometimes useful to take advantage of the own frequency of the soil surrounding the lower portion of the tube **1.** This frequency is substantially lower than 25 Hz and lies sometimes on the level of 15–16 Hz. I have illustrated this phenomenon in FIG. **8** in which the dotted line represents the relationship between the frequency, and the amplitude of the surrounding soil, whereas the full line shown this relationship for the plates **3.** Under these circumstances it is highly favourable to use a vibration source capable of a stepless frequency control.

In this connection is is observed that by using a test probe, one may first obtain useful information about the soil properties and conditions, before determining the number and the dimensions of the radial plates. The effective frequency can also be determined, so that within a short time period all the essential data for an efficient soil compacting operation will become available.

It is also possible with my invention to increase the supporting capacity of the ground lying under existing building structures. The vibrating tube will then not be introduced in a vertical position, but with an inclination.

During the compacting operation the volume of the soil may slightly or considerably decrease. This is sometimes an advantage, when the earth surface must be locally lowered. It is however, possible to supply additional ground either around or through the tube, in order to maintain the original ground level.

The diameter of the tube **1** can be determined in conformity with the operating depth and the vibration force. The minimum diameter with a length of the tube **1** of 50 ft. is 12 inch (corresponding to 30 cm). With a tube length between 50 and 100 ft, the minimum diameter will be about 15 – 16 inch. This is sufficient for alternating forces (P_0) created by the vibration source **2,** lying at 33 s.t. (equivalent to 30 metric tons). With increased intensity of the vibrations (P_1), the diameter of the tube rizes with the root of the ratio between P_1 and P_0. The wall thickness of the tube **1** increases proportionally with its diameter.

The surface of the plates **3** must be determined such that the ratio between the vibration energy is horse power (h.p.) and the total surface of the blades in square meters (m^2) does not substantially exceeds **20,** which means that the surface is bound to a minimum value, depending upon the maximum energy available for the compacting operation. However, the total surface will mostly not be greater than 20 $ft.^2$/s.t. (equivalent to 2 m^2/metric tons) vibration force P_1. The ratio of the dimensions of the plates **3** parallel to the tube and perpendicular thereto is generally smaller than **6.**

According to a useful embodiment the mass of the tube **1** is about 10.000 kg (equivalent to 11 s.t.) whilst the vibration source **2** and the ballast-weight **4** each have a mass of about 5.000 kg (equivalent to 5,5 s.t.). The relationship between these masses of 2 : 1 : 1 will remain valid with a different mass of the tube **1.**

I claim:

1. A method for compacting the soil, comprising the steps of: vibrating a tube having radial plates near the lower extreme end portion thereof, the vibrations being generated in the longitudinal sense of said tube; lowering the vibrating tube into the earth surface; and adjusting the frequency and the intensity of the vibrations with respect to the resonancy of said radial plates so that said plates effect transmitting of energy to the ground to effect soil compaction.

2. A method according to claim **1** in which the amplitude of the longitudinal vibrations in the tube is adjusted in conformity with the capacity of the ground to take up energy from the vibrating radial plates.

3. A method according to claim **1** in which the frequency of vibrations in the tube is adjusted so as to obtain a condition in which said frequency is substantially tuned to the resonant frequency of said radial plates.

4. A method according to claim **1** in which the tube is lowered into the earth surface in a substantial vertical position.

5. A method according to claim **1** additionally comprising:

continuing the vibrating action until an open space is formed around said tube;

filling said space with additional ground material and slowly raising the tube whilst maintaining the vibrations.

6. A method according to claim **1** in which the frequency as well as the intensity of the vibrations are steplessly adjusted to conform with the desired energy emission by the radial plates.

7. A method for compacting the soil, comprising the steps of: vibrating a tube having radial plates at one end, the vibrations being generated in the longitudinal sense of said tube; lowering the vibrating tube into the earth surface; adjusting the frequency and the intensity of the vibrations to a value in which nearly no energy is transmitted to the ground, so as to lower the tube to a predetermined depth without any substantial compacting action; re-adjusting the frequency and the intensity of the vibrations so that the frequency is related to the resonant frequency of said radial plates in order to enable the radial plates to reach a condition in which vibration energy is transmitted to the ground to effect soil compaction.

8. A method according to claim **7** in which a liquid is injected into the ground in the zone of the vibrating radial plates for increasing the capacity of the ground to take up energy from said plates.

9. A device for compacting the soil comprising: a tube having a source of vibrations rigidly secured to one extremity of said tube, said source being capable of generating longitudinally directed vibrations in said tube; a number of radial plates being rigidly connected near the opposite extremity of said tube, said plates having a resonant frequency; means co-operating with said vibration source for regulating the frequency of vibration thereof to cause said plates to vibrate substantially at their resonant frequency and apply the energy output to effect soil compacting; a ballast-weight, and means for selectively applying said ballast-weight to said source of vibrations to increase the energy output of said radial plates.

10. A device according to claim **9,** in which the dimensions of the radial plates are such that said plates are mainly resonantly tuned to one frequency of said vibration source.

11. A device according to claim **9** in which the means for regulating the vibration source include means to obtain an adjustment of the amplitude of the vibrations.

12. A device according to claim 11 in which said means for regulating the vibration source permit a stepless adjustment of the frequency and the amplitude of the vibrations generated in said vibration source.

13. A device according to claim 9 in which the resonant frequency of the plates is determined such that it corresponds with at least one frequency of the vibration source or with a multiple thereof.

14. A device according to claim 9 in which the mass of the ballast-weight is at most one seventh of the alternating force of the vibration source and at least one third of the combined weight of said tube, said source and said ballast-weight together.

15. A device for compacting the soil comprising: a tube having a source of vibrations rigidly secured to one extremity of said tube, said source being capable of generating longitudinally directed vibrations in said tube of at least two frequencies; a number of radial plates being rigidly connected near the opposite extremity of said tube, the dimensions of said plates being such that these plates are mainly reasonantly tuned to one of said two frequencies of said vibration source; means co-operating with said vibration source for changing the frequency of said vibration source to one of said two frequencies to cause said plates to vibrate substantially at their resonant frequency and apply the energy output to effect soil compacting; a ballast-weight, and means for selectively applying said ballast-weight to said source of vibrations to increase the energy output of said radial plates.

16. A device according to claim 15, in which the radial dimensions of the plates vary in the longitudinal direction of the tube.

17. A device according to claim 15, in which one plate is arranged in at least three radial planes of the tube.

18. A device according to claim 15, in which the radial plates have a thickness of less than 15 mm, and in which the ratio of the dimension of the plates parallel to the tube and the radial dimension of the plates is smaller than 6 : 1.

19. A device according to claim 15, in which the active surface of all radial plates together is less than 2 m^2 per ton vibration generating alternating force emitted by the source of vibrations.

20. A device according to claim 15 in which the lower extremity of the hollow tube is closed with the exception of at least one nozzle communicating with the interior of said tube.

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