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(72) Inventors HAKUMI HAGIMOTO, TETSUYA SUGIE, MASAO SUZUKI,
YUTAKA KASHIMA and TSUTOMU TOMIZAWA
and TSUTOMU TOMIZAWA

(54) METHOD AND APPARATUS FOR EXCAVATING HORIZONTAL TUNNELS

(71) We, DAIHO CONSTRUCTION CO., LTD., a corporation organized under the laws of Japan, of 24-4, Shinkawa 1-chome, Chuo-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method and a machine for excavating horizontal tunnels in a ground formation, and in particular soft and weak ground formations having a high water content.

Typically, so-called shield tunnel boring systems using a boring machine having a cylindrical shield body have been generally practiced for making horizontal tunnels in soft and weak ground formations. In such systems, the ground at the tunnel face is excavated while pressing a boring head portion of the machine shield into the ground by propelling forward the shield, a bored tunnel wall appearing to the rear of the propelled shield being supported and reinforced by means of a plurality of tunnel segments or linings which are assembled in overlapping relationship with the tail end of the steel cylinder and are joined so as to be cylindrical for forming the horizontal tunnel in the soft and weak ground layer.

In this kind of boring system, specifically when the machine shield is propelled, it has been necessary for the purpose of ensuring safe and smooth advance of the boring work, to positively prevent accidents such as collapse of the ground layer at the tunnel face, and underground water gushing into the shield from the tunnel face, from occurring and thus to resist ground or underground water pressure at the tunnel face. In order to meet such requirements, it has already been suggested to use a so-called hydraulic boring system wherein a hydraulic chamber is provided in the front

portion of the shield and to apply water pressure to the tunnel face from the chamber. However, in this system, there is a problem in providing for the necessary disposal of the fluid mixture of fed water and excavated ground material. Further, as a constant water pressure must be kept in the hydraulic chamber, the chamber cannot be provided with a large diameter inlet for the fluid mixture and thus large size gravels, stones and the like contained in the ground formation are not able to be smoothly discharged.

Discharging the fluid mixture in large quantities as it is, will never be allowed when carrying out the system particularly in a city or like area. Further, in respect of the conveying equipment and disposal, it is difficult to convey the mixture fluid as it is. Therefore, it is necessary to dehydrate the mixture so that it is solidified, that is, to make it into dry earth which can more easily be conveyed.

In such a case, dehydrating equipment, or other plant on a large scale, for receiving the mixture from the underground tunnel will have to be built at ground level with the result that the costs of making the tunnel will be high and the building time will be extended. The present invention seeks to solve these problems.

According to the present invention, there is provided a method of boring a horizontal tunnel with a shield type tunnel boring machine having a substantially cylindrical shield body rotary cutting and kneading means at an axially open forward end of the shield body, a kneading chamber positioned between said rotary means and a bulkhead provided in the shield body, and an injection pipe extending through the bulkhead to feed a muddying agent into the kneading chamber, the method comprising the steps of propelling the machine forward in a step-by-step manner into a ground formation so that the cutting means ex-

cavate ground material, passing the ground material and muddying agent into the kneading chamber, mixing and kneading in the kneading chamber the excavated ground material and the muddying agent to produce mud of high viscosity, filling and maintaining filled the kneading chamber with said highly viscous mud to provide, in the kneading chamber, a pressure which is such as to resist collapse of the ground formation adjacent the rotary means, and is such as to resist underground water pressure, and conveying the viscous mud out of the kneading chamber.

Preferably, the muddying agent is bentonite or CMG (carboxymethyl cellulose) which is mixed and kneaded with the excavated material so as to form a mud having a favourable plastic fluidity, water-impermeability and high pressure so that, by applying the mud pressure to tunnel face ground layer, any collapse of the layer face can be positively prevented and, as the mud is made to have a water-impermeability, any gushing underground water can be prevented from entering into the shield type tunnel boring machine.

A coagulant such as cement or lime may be mixed with the mud flowing in from the kneading chamber and the mud is discharged while having the fluidity thereof gradually reduced so that, even if the work is carried out in a very soft and weak ground formation, the discharged ground material can be easily conveyed to the exterior of the tunnel.

According to the invention furthermore, there is provided a shield type tunnel boring machine adapted to be propelled through a ground formation to bore a tunnel there-through, comprising a substantially cylindrical shield body, rotary cutting and kneading means mounted at an axially open forward end of said shield body, a kneading chamber positioned between said rotary means and a bulkhead provided in said shield body, an injection pipe extending through said bulkhead to feed a muddying agent into the kneading chamber, said muddying agent, when the machine is in use, being mixed with excavated ground material cut and fed into the kneading chamber by the rotary means to convert said ground material into a highly viscous mud capable of providing, in the kneading chamber, a pressure sufficient to resist collapse of the ground formation adjacent the rotary means, and to resist underground water pressure, a conveying cylinder in communication with the kneading chamber and having a discharge port externally of the kneading chamber, and a conveyor screw arranged within the conveying cylinder.

It is hereby defined that, in the disclosure

and appended claims of the present invention:

The term "muddying agent" used herein shall mean the agent of a liquid or powdery material contributing to impart high viscosity, plastic fluidity and water-impermeability to the highly water-containing excavated ground material when mixed therewith.

The term "mud" shall mean the viscous and plastically fluid mixture prepared by mixing and kneading the "muddying agent" with the excavated material so as to provide sufficient pressure resisting ground or underground water pressure exerted on the tunnel face and yet to be capable of being smoothly discharged and conveyed in a solid form out of tunnel working area through a discharging path.

Other objects and advantages of the present invention will become clear from the following explanations thereof detailed with reference to preferred embodiments of the present invention shown in accompanying drawings, in which:

Figure 1A is a schematic sectioned view of an embodiment of a machine for working the method for excavating horizontal tunnels of the present invention;

Fig. 1B is an end elevation of the machine shown in Fig. 1A as seen from the front;

Fig. 2 is a sectional view of a liquid pressure gauge used in the present invention;

Fig. 3A is a schematic sectioned view of another embodiment in which the mud discharging path in the machine for working the method for excavating horizontal tunnels of the present invention is altered;

Fig. 3B is a partial end view of the machine shown in Fig. 3A as seen from the front;

Fig. 4A is a schematic sectioned view of another embodiment to be applied to make horizontal tunnels of large diameters in which the position of the discharging path of the machine for working the method for excavating horizontal tunnels of the present invention is altered;

Fig. 4B is an end view of the machine shown in Fig. 4A as seen from the front;

Fig. 5A is a schematic sectioned view of a further embodiment to be applied to make horizontal tunnels of larger diameters in which the position of the discharging path of the machine for working the method for excavating horizontal tunnels of the present invention is altered;

Fig. 5B is an end view of the machine shown in Fig. 5A as seen from the front.

In Figs. 1A and 1B, there is shown a machine for excavating horizontal tunnels wherein a substantially cylindrical shield body 1 of the tunnel boring machine is

propelled into the ground to form a horizontal tunnel of some length and bored tunnel wall surface in the ground to the rear of the shield is reinforced by a plurality of segments or linings which are joined together to form a cylinder. A kneading chamber 3 is provided by means of a bulkhead 2 in the front portion of the shield body 1 which is generally made of a steel plate, and this chamber 3 is open over substantially all the front surface and contains, for example, a cruciform wing member 4. This wing 4 has a plurality of cutters 5 on the front surface and a plurality of kneading blades 6 on the reverse or inside surface, and is secured to a driving shaft 7 passing through its axial center portion and rotatable through the bulkhead 2 via a bearing 8 so that the wing 4 will be rotatably held within the kneading chamber 3. On the other hand, a muddying agent injecting pipe 9 opens out from the front surface side of the bulkhead 2 and is extended back from the bulkhead 2 to an agent supplying means (not shown) disposed behind the shield 1.

A large gear 10 is secured to the outer peripheral surface of the driving shaft 7 and is provided to mesh with a pinion 12 secured to an output shaft of an hydraulic motor 11 so that, when the hydraulic motor 11 is driven, the wing 4 will be rotated.

An inclined conveying cylinder 13 communicates with the kneading chamber 3 is connected with a portion of the bulkhead 2. A screw conveyer 14 is contained in the conveying cylinder 13 and is connected with an output shaft of an hydraulic motor 15 secured to the rear portion of the conveying cylinder 13 so as to be rotated when the hydraulic motor 15 is driven. A discharging port 16 is formed in the rear portion of the conveying cylinder 13. Further, a belt conveyer 18 having a hopper 17 opposite to the discharging port 16 is provided in parallel with the conveying cylinder 13. A coagulant injecting pipe 19 extending to the rear of the shield cylinder 1 is connected with the front portion of the conveying cylinder 13.

Jacks 20 which are extended to propel the shield cylinder 1 forward are mounted between the bulkhead 2 and the foremost set of tunnel wall segments 21, the latter of which are installed in overlapping relationship with the inside tail end of the shield 1 into cylindrical shape and are joined with each other at their adjacent flanges with bolts and nuts so as to reinforce and support the bored tunnel wall surface to the rear of the shield cylinder 1 as the latter is propelled forward.

A pressure gauge 22 as is particularly shown in Fig. 2, is positioned in the bulkhead 2 with pressure measuring surface 23

disposed on the kneading chamber 3 side. The pressure gauge 22 includes a bottomed cylinder 24 having a flange portion 25 on the front surface. A piston 26 having a front surface plate 27 is reciprocatably contained in the bottomed cylinder 24. An elastic sealing plate 28 covering the front surface of the pressure gauge 22 is secured over the flange portion 25 of the bottomed cylinder 24 through screws 29 and the front surface plate 27 of the piston 26 through screws 30. It is preferable that a circular pad and annular pad are attached to the front surface of the sealing plate 28.

A feeding pipe 31 and discharging pipe 32 are also connected with the bottomed cylinder 24 and are provided respectively with valves 33 and 34. Further, a screw portion 37 of a piston returning rod 36 in contact with the front surface plate 27 of the piston 26 through the bottom plate of the cylinder 24 is screwed in a supporting cylinder portion 35 provided to project on the bottom plate of the cylinder 24. A handle 38 is secured to the rear end of the piston rod 36 so as to align the front surface plate 27 of the piston 26 with the flange portion 25 of the cylinder 24 when the handle 38 is shifted from the dotted line position to the solid line position shown in Fig. 2. In such case, a spacer 39 positioned between the supporting cylinder portion 35 and the handle 38 will ensure a proper moving distance of the piston returning rod. Further, a spacer 40 arranged on the inner bottom surface of the cylinder 24 controls any excessive retraction of the piston 26. Also, an oil pressure detector 41 is connected through a pipe 42 with the bottom plate of the cylinder 24 so as to measure the oil pressure in the cylinder 24.

Therefore, in order to measure the pressure of the ground or mud in the chamber 3 applied to the pressure measuring surface of the gauge 22, the handle 38 is rotated to advance to coordinate the front surface plate 27 of the piston 26 with the flange portion 25 of the cylinder 24. Then, while feeding an oil through the feeding pipe 31, air in the cylinder 24 is discharged out through the discharging pipe 32 to completely fill the cylinder 24 with the oil and the valves 33 and 34 are closed. That is to say, in this case, the indicated value of the oil pressure detector 41 will be made zero. Further, the handle 38 is rotated to be retracted to the dotted line position in Fig. 2 so as to establish a measuring state.

A well known lining erector device 43 operating through a structure member 45 by a motor 44 for the erector is fitted within the shield cylinder 1 so that the arcuate segments 21 can be assembled to be cylindrical.

The operation of the present invention is as follows.

When the wing 4 is rotated by driving the hydraulic motor 11, the cutters 5 will contact the tunnel face ground layer to excavate the layer. The muddying agent is fed into the kneading chamber 3 through the injecting pipe 9 simultaneously with driving the hydraulic motor 11, the muddying agent will be mixed and kneaded by means of the kneading blades 6 with ground material excavated by the cutters 5 and introduced into the kneading chamber 3. The well kneaded mixture of the ground material and the muddying agent will become a mud having a favourable plastic fluidity and water-impermeability. The mud filling the kneading chamber 3 as well as the screw conveyor 14 will have a pressure resisting any collapse of the ground material at the tunnel face and any gushing underground water pressure. The mud pressure in the kneading chamber 3 will be read by the pressure gauge arranged in the bulkhead 2. In case the mud pressure is sufficient to resist the ground layer collapse as well as gushing underground water pressure, it will be able to detect any state which requires a reduction of the number of revolutions of the screw conveyor or an increase in the propelling rate of the shield jacks 20.

Further, the screw conveyor 14 is rotated so that the mud having a high viscosity will move into the conveyer cylinder 13 and be conveyed by the conveyor 14 to the discharging port 16 in the rear portion thereof, from which the mud will drop into the hopper 17 of the belt conveyor 18. Having a high viscosity, the discharged mud can be conveyed as it is without any need to be dehydrated. Further, the pressure of the mud in the kneading chamber 3 will be applied to the tunnel face to prevent the collapse and resist the underground water pressure. As the kneading chamber 3 and conveying cylinder 13 are filled with the mud without any voids, the underground water will positively be prevented from flowing into the shield cylinder 1.

Then, the shield cylinder 1 is driven forward by the shield jacks 20 to gradually extend the horizontal tunnel while supporting and reinforcing the surface of bored tunnel wall by means of the segments 21 assembled sequentially overlapping relationship with the tail end of the shield cylinder 1.

In case the ground in which the horizontal tunnel is to be formed is so soft and weak that the fluidity of the mud as discharged is too high, a coagulant is fed through the injecting pipe 19 in the front portion of the conveying cylinder 13 so that the fluidity of the mud will be gradu-

ally reduced and solidification of the mud will be accelerated to enable it to be conveyed at the discharging port.

Figs. 3A, 3B, 4A, 4B, 5A and 5B show respectively other embodiments of the present invention. However, they are of design modifications adapted to increase the diameter of the horizontal tunnel or, in other words, the increase of the amount of the ground material excavated and introduced into the shield cylinder, and are exactly the same in the respective actions of the preventing the collapse of the face and the inflow of the underground water with the application of the mud pressure to the tunnel face and of discharging the mud solidified enough to be conveyable.

In the apparatus shown in Figs. 3A and 3B, the same members as in the first embodiment are shown by the same respective corresponding numerals with symbols "a" attached to them. In this embodiment, there is provided a conveying cylinder portion 13a' of a diameter larger than that of a conveyor cylinder 13a is made integral with the front portion of the conveying cylinder 13a and a screw conveyor 14a' mounted on an extended shaft of a screw conveyor 14a is contained also in the conveyor cylinder 13a' of larger diameter. The screw conveyor 14a' is provided with a spiral peripheral edge as serrated or properly cut so as to further knead the mud flowing in the larger diameter conveying cylinder 13a' to increase its viscosity. Therefore, even if the amount of the mud increases, it will be kneaded in stages to ensure sufficient viscosity of the mud.

In the apparatus shown in Figs. 4A and 4B, the same members as in the first embodiment are shown by the same respective corresponding numerals with symbols "b" attached to them. In this embodiment, a kneading chamber 3b is formed as a recessed inward step and is provided so as to be connected with a horizontal conveying cylinder. Kneading blades 6b are attached to a wing 4b' secured to an extended shaft of a screw conveyor of the conveying cylinder instead of a wing 4b to which cutters 5 are secured. Further, other kneading blades 6b' extending in radial directions are secured to the extended shaft of the screw conveyor. The conveying cylinder comprises a conveying cylinder 13b in the rear and another conveying cylinder 13b' of a diameter larger than the conveying cylinder 13b but smaller than the recessed kneading chamber 3b. A screw conveyor 14b' contained in the larger diameter conveying cylinder 13' is provided with a spiral peripheral edge which is serrated in the same manner as in the second embodiment. Therefore, even if the amount of the mud increases, sufficient mud will be able to be

contained and a sufficient viscosity of the mud will be maintained.

In the embodiment shown in Figs. 4A and 4B, the wing 4b is rotated integrally with the cylinder 3b' rotated through an hydraulic motor 11b, pinion 12b and large gear 10b and the kneading blades 6b secured to the wing 4b' and the radial kneading blades 6b' are driven by an hydraulic motor 15b for driving the screw conveyor.

The embodiment shown in Figs. 5A and 5B is similar to the third embodiment shown in Figs. 4A and 4B. As compared with the third embodiment, a conveying cylinder 13c of which discharging port 16c is opposite to a conveyor 18c and a conveying cylinder 13c' of a larger diameter communicating with a kneading chamber 3c are provided on respectively separate shafts and are connected with each other through a communicating port 13c". Further, a screw conveyor 14c' contained in the larger diameter conveying cylinder 13' is connected with an output shaft of another hydraulic motor 15c' and is provided with a spiral peripheral edge which is serrated. Therefore, a large amount of the mud can be contained and a sufficient viscosity of the mud is ensured.

In the respective embodiments of the present invention, the wing members and conveyors are made to be driven by hydraulic motors but other power plant such as, for example, an electric motor could be used.

WHAT WE CLAIM IS:—

1. A method of boring a horizontal tunnel with a shield type tunnel boring machine having a substantially cylindrical shield body, rotary cutting and kneading means at an axially open forward end of the shield body, a kneading chamber positioned between said rotary means and a bulkhead provided in the shield body, and an injection pipe extending through the bulkhead to feed a muddying agent into the kneading chamber, the method comprising the steps of propelling the machine forward in a step-by-step manner into a ground formation so that the cutting means excavate ground material, passing the ground material and muddying agent into the kneading chamber, mixing and kneading in the kneading chamber the excavated ground material and the muddying agent to produce mud of high viscosity, filling and maintaining filled the kneading chamber with said highly viscous mud to provide, in the kneading chamber, a pressure which is such as to resist collapse of the ground formation adjacent the rotary means, and is such as to resist underground water pressure, and conveying the viscous mud out of the kneading chamber.

2. A method according to claim 1,

wherein said muddying agent is bentonite, CMG (carboxymethyl cellulose) or clay powder or a mixture thereof which imparts a plastic fluidity and water impermeability to said mud.

3. A method according to claim 1 or claim 2, wherein said mud pressure is calculated to be the sum of the ground pressure and underground water pressure exerted at the tunnel face whilst measuring the mud pressure in the kneading chamber.

4. A method according to any one of claims 1 to 3, wherein a coagulant is mixed with said mud to gradually reduce its fluidity in a path in which the mud is discharged from said kneading chamber.

5. A shield type tunnel boring machine adapted to be propelled through a ground formation to bore a tunnel therethrough, comprising a substantially cylindrical shield body, rotary cutting and kneading means mounted at an axially open forward end of said shield body, a kneading chamber positioned between said rotary means and a bulkhead provided in said shield body, an injection pipe extending through said bulkhead to feed a muddying agent into the kneading chamber, said muddying agent, when the machine is in use, being mixed with excavated ground material cut and fed into the kneading chamber by the rotary means to convert said ground material into a highly viscous mud capable of providing, in the kneading chamber, a pressure sufficient to resist collapse of the ground formation adjacent the rotary means, and to resist underground water pressure, a conveying cylinder in communication with the kneading chamber and having a discharge port externally of the kneading chamber, and a conveyor screw arranged within the conveying cylinder.

6. A machine according to claim 5, wherein said rotary cutting and kneading means comprise a wing member secured to a driving shaft extending axially through the kneading chamber and the bulkhead cutting elements being provided on the outer surface of the wing member and kneading blades being provided on the inner surface of the wing member to extend into the kneading chamber.

7. A machine according to claim 5 or claim 6, wherein a pressure gauge is arranged in the bulkhead, said gauge comprising a bottomed cylinder, a piston reciprocable within said cylinder, elastic sealing plates secured respectively to said bottomed cylinder and said piston to cover the front surface of the gauge, a reciprocable piston-returning rod for returning said piston to a measurement commencing position, and a detector communicating with said cylinder to measure pressure applied to said sealing plate.



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contained and a sufficient viscosity of the mud will be maintained.

In the embodiment shown in Figs. 4A and 4B, the wing 4b is rotated integrally with the cylinder 3b rotated through an hydraulic motor 11b, pinion 12b and large gear 10b and the kneading blades 6b secured to the wing 4b and the radial kneading blades 6b' are driven by an hydraulic motor 15b for driving the screw conveyor.

The embodiment shown in Figs. 5A and 5B is similar to the third embodiment shown in Figs. 4A and 4B. As compared with the third embodiment, a conveying cylinder 13c of which discharging port 16c is opposite to a conveyor 18c and a conveying cylinder 13c' of a larger diameter communicating with a kneading chamber 3c are provided on respectively separate shafts and are connected with each other through a communicating port 13c''. Further, a screw conveyor 14c contained in the larger diameter conveying cylinder 13' is connected with an output shaft of another hydraulic motor 15c' and is provided with a spiral peripheral edge which is serrated. Therefore, a large amount of the mud can be contained and a sufficient viscosity of the mud is ensured.

In the respective embodiments of the present invention, the wing members and conveyors are made to be driven by hydraulic motors but other power plant such as, for example, an electric motor could be used.

WHAT WE CLAIM IS:—

1. A method of boring a horizontal tunnel with a shield type tunnel boring machine having a substantially cylindrical shield body, rotary cutting and kneading means at an axially open forward end of the shield body, a kneading chamber positioned between said rotary means and a bulkhead provided in the shield body, and an injection pipe extending through the bulkhead to feed a muddying agent into the kneading chamber, the method comprising the steps of propelling the machine forward in a step-by-step manner into a ground formation so that the cutting means excavate ground material, passing the ground material and muddying agent into the kneading chamber, mixing and kneading in the kneading chamber the excavated ground material and the muddying agent to produce mud of high viscosity, filling and maintaining filled the kneading chamber with said highly viscous mud to provide, in the kneading chamber, a pressure which is such as to resist collapse of the ground formation adjacent the rotary means, and is such as to resist underground water pressure, and conveying the viscous mud out of the kneading chamber.

2. A method according to claim 1,

wherein said muddying agent is bentonite, CMG (carboxymethyl cellulose) or clay powder or a mixture thereof which imparts a plastic fluidity and water impermeability to said mud.

3. A method according to claim 1 or claim 2, wherein said mud pressure is calculated to be the sum of the ground pressure and underground water pressure exerted at the tunnel face whilst measuring the mud pressure in the kneading chamber.

4. A method according to any one of claims 1 to 3, wherein a coagulant is mixed with said mud to gradually reduce its fluidity in a path in which the mud is discharged from said kneading chamber.

5. A shield type tunnel boring machine adapted to be propelled through a ground formation to bore a tunnel therethrough, comprising a substantially cylindrical shield body, rotary cutting and kneading means mounted at an axially open forward end of said shield body, a kneading chamber positioned between said rotary means and a bulkhead provided in said shield body, an injection pipe extending through said bulkhead to feed a muddying agent into the kneading chamber, said muddying agent, when the machine is in use, being mixed with excavated ground material cut and fed into the kneading chamber by the rotary means to convert said ground material into a highly viscous mud capable of providing, in the kneading chamber, a pressure sufficient to resist collapse of the ground formation adjacent the rotary means, and to resist underground water pressure, a conveying cylinder in communication with the kneading chamber and having a discharge port externally of the kneading chamber, and a conveyor screw arranged within the conveying cylinder.

6. A machine according to claim 5, wherein said rotary cutting and kneading means comprise a wing member secured to a driving shaft extending axially through the kneading chamber and the bulkhead, cutting elements being provided on the outer surface of the wing member and kneading blades being provided on the inner surface of the wing member to extend into the kneading chamber.

7. A machine according to claim 5 or claim 6, wherein a pressure gauge is arranged in the bulkhead, said gauge comprising a bottomed cylinder, a piston reciprocable within said cylinder, elastic sealing plates secured respectively to said bottomed cylinder and said piston to cover the front surface of the gauge, a reciprocable piston-returning rod for returning said piston to a measurement commencing position, and a detector communicating with said cylinder to measure pressure applied to said sealing plate.

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8. A machine according to any one of claims 5 to 7, wherein said conveying cylinder is provided to be of a larger diameter in a front portion thereof and a spiral peripheral edge of a screw conveyor contained in said larger diameter front portion is cut with kneading surfaces. 25
9. A machine according to claim 5, wherein said kneading chamber is formed to be recessed inward by one step, kneading blades separated from said cutters being contained in said kneading chamber, said kneading chamber further being provided with a series of conveyor cylinders in which a larger diameter conveyor cylinder is provided in a front portion and said kneading blades are rotated by an extended shaft of said screw conveyor within said conveying cylinder. 30
10. A machine according to claim 8, wherein said spiral peripheral edge of the screw conveyor in said larger diameter conveyor is cut with kneading surfaces. 35
11. A machine according to claim 5, wherein said kneading chamber is formed to be recessed inward by one step, kneading blades separated from said cutters being contained in the kneading chamber, and a conveying cylinder having a discharging port and a conveyor cylinder of a larger diameter communicating with the kneading chamber are provided respectively on separate shafts and are connected with each other through a communicating port. 40
12. A method of excavating horizontal tunnels, substantially as described herein with reference to the accompanying drawings. 35
13. A machine for excavating horizontal tunnels, substantially as described herein with reference to the accompanying drawings. 40

For the Applicants,
CARPMAELS & RANSFORD,
Chartered Patent Agents,
43 Bloomsbury Square,
London, WC1A 2RA.

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