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SHIELD TUNNELING METHOD AND MACHINE THEREFOR

BACKGROUND OF THE INVENTION

This invention relates to a shield tunneling
5 method and a machine therefor, which excavate a tunnel
by causing a pressure to act on the tunnel face,
while preventing collapse of the tunnel face, the pressure
being such a level as balances an earth pressure and
underground water pressure in the face ground.

10 One of the known methods of preventing collapse of
the tunnel face in excavating a tunnel is to apply
a pressure with sludge, such as bentonite slurry, to
the face, as disclosed in U.S. Patent No. 3,946,605.
The other method is to apply a pressure to the face with
15 muck from the tunnel face, as disclosed in U.S. Patent
No. 4,167,289.

The former can effectively resist the underground
water, but, in the ground of a high permeability, such
as sandy ground, can not independently resist the face
20 earth pressure. The latter has been difficult in
resisting a water pressure in the ground in which the
underground water level is high.

With a view to solving the drawback of the conven-
tional method and machine, it is an object of the present
25 invention to provide tunneling method and machine for
excavating a tunnel against an earth pressure and a water

pressure in the face ground while maintaining the face stable, irrespective of the nature of soil in the face ground or the underground water level being high or low.

Regarding stability of the tunnel face, the inventor came to such a conclusion to be described below. If the mined spoil from the tunnel face is directly urged against the tunnel face so that a spoil pressure can balance the earth pressure in the tunnel face, then the tunnel face becomes stabilized as in the ground under the natural condition. On the other hand, a liquid is pressurized to such a level as to reach equilibrium with the underground water pressure, so as to resist outflow of underground water. The underground water thus can be maintained in a condition similar to the natural condition. By the use of the spoil and liquid which are pressurized to such a level as balancing the earth pressure in the face ground and the underground water pressure, stability of the tunnel face is extremely rationally maintained. If the spoil alone can be taken out of the tunnel face, without taking underground water out of the tunnel face or moving same, then excavation of a tunnel can be safely and efficiently proceeded with, without impairing stability of the tunnel face.

The invention provides a method of tunnelling, using a shield-type tunnelling machine which comprises cutting means at a leading end thereof, a working space between

said cutting means and a transverse wall, and a balancing chamber rearwardly of said transverse wall, the method comprising the steps of:-

5. operating the cutting means to detach spoil from a working face and introduce it into the working space; introducing a liquid to the balancing chamber to maintain therein first predetermined pressure; advancing the machine, whilst operating the cutting means, to apply to the spoil in the working chamber a second predetermined pressure which is higher than an active earth pressure in the face ground but lower than a passive earth pressure in the face ground; allowing spoil to pass through said transverse wall from the working chamber to the balance chamber when the pressure of
10. spoil in the working chamber exceeds said second predetermined pressure; and transferring a mixture of spoil and said liquid out of the balancing chamber for disposal whilst maintaining said first predetermined pressure in the balancing chamber.
15. 20. The invention also provides a shield tunnelling machine comprising:
 - a drive shaft rotatably carried by a transverse wall provided in the front portion of a shield body which can be thrust forward;
 25. a cutter head attached to the end of the drive shaft and allowing the passage of spoil therethrough and defining a working space between the cutter and the transverse wall; a balancing chamber (48, 142)

defined behind the transverse wall;

a spoil inlet provided in the transverse wall;

a cover member (50, 148, 149) adapted to open and close the spoil inlet;

5. an operating means adapted to exert on the cover member a predetermined second pressure higher than an active earth pressure in the face ground but lower than a passive earth pressure, thereby displacing said cover member to close said spoil inlet,
10. and adapted to displace said cover member to open said spoil inlet when the pressure acting on said diaphragm and said cover member by the spoil admitted into the shield body is raised above the predetermined level;
15. means for supplying a liquid into said balancing chamber, so that said chamber is usually filled with the liquid; and
- means for transporting liquid containing spoil out of the balancing chamber.

20. Fig. 1 is a longitudinal cross sectional elevational view of a preferred embodiment of shield tunnelling machine of the present invention;

Fig. 2 is a front view of the shield tunnelling machine of Fig. 1;

25. Fig. 3 is a transverse cross sectional view taken along the line 3-3 of Fig. 2;

- 5 -

Fig. 4 is a longitudinal cross sectional elevational view of a shield tunnelling machine for pipe jacking, to which the present invention is applied;

5. Fig. 5 is a front view, as seen from the line 5-5 of Fig. 4;

Fig. 6 is a transverse cross sectional view taken along the line 6-6 of Fig..4;

Fig. 7 is a cross sectional view taken along the line 7-7 of Fig. 6;

10. Fig. 8 is an illustration, showing qualitatively the relationship of rotation of a spoke versus the spoil pressure; and

15. Fig. 9 is a transverse cross sectional view of the machine in the modified form, which is similar to Fig. 6.

A shield body 10 of a shield tunnelling machine comprises a thrust ram or advancing jack 11 and a diaphragm 14 provided internally across the shield body in a portion spaced apart rearward from the front end 12 of the shield body 11. The transverse wall or diaphragm 14 has an upper opening 16 which is a spoil inlet. A bit or a scraper 17 is provided in the peripheral portion of the opening 16.

25. A bearing 18 is provided in the central portion of the diaphragm 14, and another bearing 22 is provided in a wall member 20 disposed substantially in parallel to the diaphragm 14 at the rear thereof and carried by the shield body 10. Both bearings 18 and 22 carry

a rotary shaft 26, on one end of which is mounted cutting means in the form of a spoke type cutter head 24. The cutter head 24 allows admission of spoil between the tunnel face and the diaphragm, 5. without interruption.. A main gear 28 is mounted on the other end of the rotary shaft 26 through the medium of a key 27. The main gear is coupled by way of a gear 30 and a reduction gear (not shown) to a reversible motor 32. The gears 28 and 30 are 10. provided in the casing attached to the wall member 20.

The cutter head 24 comprises three spokes 36 radially extending in three directions from a boss portion 34 fitted on the end of the rotary shaft 15. 26 and fixed thereto through the medium of a key 33. A train of right-turn bits 38 and a train of left-turn bits 40 are attached to the front face of respective spoke, as best seen in Fig. 2. A center cutter 44 is mounted on a cap 42 fitted on the rotary 20. shaft end. Provided at the rear of respective spokes 36 is a rib 45 which serves as an agitating blade for the spoil from the tunnel face.

The wall member, the diaphragm 14 and a member 46 interposed therebetween constitute a casing 49 25. which defines a balancing chamber 48 behind the diaphragm, the balancing chamber usually charged with a liquid. The opening 16 in the diaphragm 14 is an inlet through which the spoil is introduced into

the balancing chamber 48. The spoil inlet is closed and opened by a cover member 50.

- The cover member 50 is coupled to a piston rod 54 of an operation device consisting of a dual
5. hydraulic piston cylinder device attached to the wall member 20. A hydraulic pressure circuit (not shown) for introducing a liquid pressure of a predetermined level into a cylinder is connected
10. to the operation device 52, in order to retain the piston in a given position within the cylinder so that the cover member 50 may usually close the spoil inlet 16. So far as a pressure of the spoil charged between the face and the diaphragm 14 is maintained in a level capable of preventing collapse of the
15. face, more specifically within the range of pressure larger than an active earth pressure in the face ground but smaller than a passive earth pressure thereof, the cover member 50 consistently closes the spoil inlet 16. When the pressure of the spoil is raised
20. over the predetermined level, the cover member 50 is urged by the spoil to open the spoil inlet 16, thereby allowing admission of the spoil into the inlet. As soon as the spoil pressure drops to the predetermined level due to admission of the spoil
25. into the chamber 48, then the operation device 52 urges the cover member 50 to close position, whereby the spoil inlet 16 is again closed.

As is apparent from the foregoing, the spoil

inlet 16 is adapted to open and close according to a change in a spoil pressure in a manner that only when the spoil inlet is opened due to the spoil pressure being raised to higher than a predeter-

5. mined level, the spoil is taken into the chamber 48 charged with the liquid and positioned behind the the diaphragm, and the spoil is discharged outside the chamber 48 through a spoil discharge pipe 56 provide in the casing member 46 in the lower por-
10. tion of the spoil chamber. Discharge of the spoil out of the chamber 48 is accomplished without changing the spoil pressure to a greater extent and hence without causing collapse of the face.

To meet the case where spoil contains gravels,

15. the chamber 48 may be a crushing chamber including a crushing means internally thereof. In this connection a rotor 60 having crushing teeth 58 must be attached by means of a key 62 to the rotary shaft
26. The wall thickness of the wall members 20 and 46
20. which constitutes the casing 49 surrounding the rotor 60 must be increased to such an extent as sufficiently resists the crushing impact. In order to provide an increased gravel-crushing effect, it is recommended to leave a distance of eccentricity e between
25. the axis of the rotary shaft 26 and the axis of

the rotor 60, as shown in Fig. 3 and to attach a liner (not shown) with crushing teeth to the inner wall of the casing 47, as the case may be.

5. In case the chamber 48 is used solely as a chamber for receiving earth from the face, the casing 49 constituting the chamber 48 need not accommodate therein the rotary shaft 26, unlike Fig. 1. In case the chamber 48 is used as a crushing chamber equipped
10. with a crushing means, it is advantageous that the rotor 60 be mounted on the rotary shaft 26, so as to be run at a higher torque. In the latter case, the crushing chamber surrounding the rotary shaft and the rotor 60 eccentrically mounted on the rotary
15. shaft preferably is formed of the casing 49. This construction is advantageous from the viewpoint of simplicity in construction of the machine itself, because a special drive source for the rotor or a special transmission means from a drive source 32 is
20. not needed.

To the effect that the chamber 48 can be usually filled with a liquid, a liquid supply pipe 66 open (as at 64) to the upper portion of the chamber 48 is provided, so as to introduce a liquid such as clean

25. water or muddy water into the chamber 48. In case spoil containing crushed gravels introduced into the

the chamber 48 is carried by the liquid in the chamber 48 to be discharged out of the chamber 48 through the spoil discharge pipe 56, such as a liquid is supplied into the chamber 48.

5. A smoothing material in the liquid state, such as an aqueous solution containing bentonite, may be supplied into part of the front portion of the diaphragm 14, so as to reduce a frictional force acting between the diaphragm and the spoil
10. whereby a resistance to the driving torque, of the cutter head 24 can be reduced. To this end, a plurality of through-holes 14a is provided in the lower portion of the diaphragm 14, and a liquid reservoir 14b is provided behind the lower portion of the
15. diaphragm, so that the smoothing material may be supplied into the liquid reservoir through a pipe 14c.

Referring now to Fig. 4, a shield body 110 of a shield tunnelling machine for a pipe jacking comprises a head portion 110a and a tail portion 110b. The head portion 110a is coupled to the tail portion 110b liquid-tightly by means of seals 111a and pivotally movably by means of four direction adjusting hydraulic jacks 111b.

25. The shield body 110 comprises a diaphragm 114 remote to the rear to some extent from the front

portion 112 of the shield body across the shield body. The diaphragm 114 is provided with two openings 116 (Fig. 6) in the upper portion thereof, these openings serving as spoil inlets to be described later. A

5. bearing 118 is provided in the central portion of the diaphragm 114. The bearing 118 extends to a stationary wall 120 and is fixed thereto, the stationary wall being located behind the diaphragm 114 substantially in parallel thereto and attached to the
10. shield body 110. The bearing 118 carries a rotary shaft 126, on one end of which a spoke type cutter head 124 is mounted. The cutter head 124 allows admission of the spoil between the face and the diaphragm 114 without impeding or limiting the free passing
15. of the spoil removed from the tunnel face to the rear portion of the shield body. The other end of the rotary shaft 126 is coupled to a reduction gear 128 connected to the fixed wall 120, so that the rotary shaft may receive a drive force from a motor 130.
20. The cutter head 124 comprises three spokes 134 extending radially in three directions from a boss portion 132 fitted on one end of the rotary shaft 126 and fixed thereto. A plurality of bits 136 are attached to the front face of respective spokes,
25. as best seen in Fig. 5. A center cutter 140 is provided on a cap 138 fitted on the end of the rotary

shaft 126. Bits may be attached to the rear face of respective spokes. These spokes 134 serve as agitating blades for the spoil removed from the face.

The diaphragm 114 and the fixed wall 120 define:

5. a balancing chamber 142. The chamber 142 is usually filled with a liquid which is supplied through a supply pipe 143. The spoil which is introduced through the openings 116 into the chamber 142 are mixed with water or muddy water which is to be supplied by the supply pipe 143 into
10. the chamber 142 and discharged out of the chamber 142, along with water or muddy water, through the discharge pipe 144. to the outside. The underground water in the face ground does not move, and hence is not discharged, because the pressure of the underground water makes an equilibrium
15. with a pressure of the liquid in the chamber 142.

- Two openings 116 are positioned on the opposite sides of a support member 146 projecting upward from the bearing 118, as seen in Figs. 6 and 7. Respective openings 116 are of a sector-shape. Cover members 148 and 149 for closing
20. and opening these openings 116 are provided.

- The cover members 148 and 149 are pivotally movably carried by brackets 156 which in turn are supported on shafts 155, each of which extends between brackets 152 and 154 attached to the support member 146 and the shield
25. body 110, respectively. The shafts 155 and one edge 158 of the openings in the wall member 116 preferably be in parallel to each other, so that forces acting on the cover

members when the cover members 148 and 149 are turned to an open position by the spoil make equilibrium.

The cover members 148 and 149 are pivotally connected to piston rods 162 of operation devices 160 for cover members 5. which consist of dual hydraulic piston cylinder devices attached to the fixed wall 120, respectively. Both cover members 148 and 149 are similar in operation to each other, and the operation of one cover member 148 alone will be described for the simplicity sake.

10. A hydraulic circuit (not shown) for introducing a pressure of a predetermined level into the cylinders is connected to respective operation device 160, so as to maintain the piston in a given position within the cylinder so that the cover member 148 can usually close
15. the opening 118. So far as a pressure of spoil filled between the face and diaphragm 114 is lower than the aforesaid predetermined level, the cover member 148 consistently close the spoil inlet. On the other hand, when the spoil pressure is increased over the aforesaid predetermined
20. level, the cover member 148 is urged by the spoil to be pivotally moved about the shaft 155 to open the spoil inlet 116, thereby allowing admission of the spoil into the chamber 142. When the spoil pressure decreases to less than the aforesaid predetermined level due to the
25. spoil admitted into the chamber 142, the operation device 160 again urges the cover member 148 to a close position, thereby closing the opening 116.

The cover member is adapted to open and close the

- opening 116 according to a change in a spoil pressure, and only when the cover member is pivotally moved to an open position as a result of increase of the spoil pressure, so that the spoil is taken into the spoil chamber
5. 142 positioned behind the diaphragm 114, and the spoil is transported by a liquid rearward of the shield body through the discharge pipe 144. Discharge of the spoil is achieved without greatly changing the spoil pressure by the diaphragm 114 and the cover member 148, and hence
10. removal of the spoil from the face is achieved without causing collapse of the tunnel face. The cover members 148 and 149 open and close sequentially from the cover member positioned on the upstream side, as viewed in the direction of rotation of the cutter head 124.
15. Operation of the spokes 134 will be referred to below. The cover members 148 and 149 are positioned on the left and right sides of the support member 146, as described with reference to Fig. 6. Assuming that the cutter head 124 is rotated counterclockwise, as viewed
20. from the rear end of the shield body 110, the spoil is rotated in the same direction as the cutter head. The spoil is thus moved onto the right-side cover member 148 in Fig. 6 and then comes to the left-side cover member 149. Movement of only a spoke 134 will be referred
25. to for the simplicity sake. The qualitative relationship of the movement of one spoke 134 verses the spoil pressure is shown in Fig. 8. When the spoke 134 comes to the diaphragm 114 (a point A in Fig. 8) beyond the left-side

cover member 149, the spoil is turned toward the right-side cover member 148 by the spoke 134 as same is held between the face and the diaphragm 114. For this duration, coupled with the spoil removed from the face and the

5. shield body 110 moving forward of the shield, the pressure P of the spoil is raised degree by degree from a level P_1 to a level P_2 . When the spoil comes to the right-side cover member 148 (a point B in Fig. 8), if the spoil pressure is higher than the predetermined level present

10. by the operation device 160, the right-side cover member 148 is moved to an open position by the spoil, and the spoil is admitted into the chamber 142. As a result, the spoil pressure is lowered to a level P_3 . If the spoil pressure by no means is lowered to less than the

15. predetermined level, the cover member 148 is maintained in the open position. Thereafter, as the spoke 134 is rotated along the right-side cover member 148, the spoil pressure P is gradually increased to a level P_4 . When the spoke 134 moves over the support member 146 (a point C

20. in Fig. 8) the left-side cover member 149 is in turn turned to an open position by the spoil pressure, whereby the spoil is discharged through the spoil inlet into the chamber 142. As a result, the spoil pressure P is again lowered to a level P_5 . Thereafter, the spoil pressure is

25. raised to a level P_6 as the spoke 134 is rotated, and the spoil is discharged into the chamber 142. Consequently,

the spoil pressure is lowered to the level P_1 , and the left-side cover member 149 resumes a close position.

By the provision of two cover members 148 and 149, a change of the spoil pressure is lessened and distribution of the spoil pressure becomes uniform, as compared with the case where the spoil is discharged by a single cover member, because the pressure raised by one cover member 148 is lowered by the other cover member 149.

The muck admitted into the chamber 142 by the left-side cover member 149 turned to the open position by the movement of the spoke 134 is transported from above toward the diaphragm 114, as seen in Fig. 7. A bit or a scraper 166 is attached to the lower edge of the opening in the diaphragm 114, so that the spoil removed from the face by the cutter head 124 is again cut into pieces by the scraper 166, namely, the spoil is subjected to the secondary cutting. The spoil contains gravel of a relatively large size is cut into pieces by the scraper, for the smooth discharge to the outside of the shield. A bit or a scraper 168 (Fig. 5) attached to the edge of the right-side opening 158 acts in like manner as described above, when the cutter head 124 is rotated clockwise.

Fig. 9 shows another embodiment in which four openings are provided in the diaphragm 114 and cover members 148 for these openings are provided, respectively. In this embodiment, the whole area of the diaphragm 114 is adapted to open and close by the cover members 148. Since

- 17 -

respective cover members 148 are maintained in the close positions when the spoil pressure is short of the level predetermined by the operation device 160 attached to the cover members, respectively, a force is permitted

5. to act on the face through the medium of the spoil so as to prevent collapse of the face. In this embodiment, a scraper 166 and a scraper 168 contribute to the secondary cutting of the spoil and introduction of the spoil into the spoil inlets or openings, as in the former example.

10. One scraper 166 operates when the cutter head 124 is rotated counterclockwise, and the other scraper 168 operates when the cutter head 124 is rotated clockwise.

The other structure is the same as that of the preceding embodiment.

CLAIMS

1. A method of tunnelling, using a shield-type tunnelling-machine which comprises cutting means at a leading end thereof, a working space between said cutting means and
5. a transverse wall, and a balancing chamber rearwardly of said transverse wall, the method comprising the steps of:-
 - operating the cutting means to detach spoil from a working face and introduce it into the working space;
 10. introducing a liquid to the balancing chamber to maintain therein a first predetermined pressure; advancing the machine, whilst operating the cutting means, to apply to the spoil in the working chamber a second predetermined pressure which is higher than an active
 15. earth pressure in the face ground but lower than a passive earth pressure in the face ground; allowing spoil to pass through said transverse wall from the working chamber to the balancing chamber when the pressure of spoil in the working chamber exceeds said
 20. second predetermined pressure; and transferring a mixture of spoil and said liquid out of the balancing chamber for disposal whilst maintaining said first predetermined pressure in the balancing chamber.
2. A method as claimed in claim 1, wherein transfer
25. of spoil from the working space to the balancing chamber is effected via a port normally closed by a member which is displaced when the spoil pressure



in the working space exceeds said second predetermined pressure.

- 3. A shield tunnelling method as claimed in claim 2, further comprising the step of secondarily cutting said
- 5. spoil into pieces in the balancing chamber.
- 4. A shield tunnelling method as claimed in claim 2, further comprising the step of crushing large pieces of the spoil into smaller pieces within the balancing chamber.
- 10. 5. A shield tunnelling machine comprising:
 - a drive shaft rotatably carried by a transverse wall provided in the front portion of a shield body which can be thrust forward;
 - a cutter head attached to the end of the drive shaft
 - 15. and allowing the passage of spoil therethrough and defining a working space between the cutter and the transverse wall; a balancing chamber defined behind the transverse wall
 - a spoil inlet provided in the transverse wall;
 - 20. a cover member adapted to open and close the spoil inlet;
 - an operating means adapted to exert on the cover member predetermined second pressure higher than an active earth pressure in the face ground but lower
 - 25. than a passive earth pressure, thereby displacing said cover member to close said spoil inlet, and adapted to displace said cover member to open said 'spoil inlet when the pressure acting on said diaphragm



and said cover member by the spoil admitted into the shield body is raised above the predetermined level;

means for supplying a liquid into said balancing chamber, so that said chamber is usually filled with

5. the liquid; and

means for transporting liquid containing spoil out of the balancing chamber.

6. A shield tunnelling machine as claimed in claim 5, further comprising; a rotor for crushing gravel contained in the spoil, the rotor being mounted on the rotary shaft at the rear of the transverse wall; and the spoil inlet being provided in the upper portion of the transverse wall.

7. A shield tunnelling machine as claimed in claim 5, said cutter head being of a spoke type.

8. A shield tunnelling machine as claimed in claim 5, wherein the transverse wall is provided with two or more spoil inlets, and the spoil inlets are adapted to open sequentially by action of said spoil.

9. A shield tunnelling machine as claimed in claim 5, wherein the transverse wall is provided with a pair of spoil inlets, and one of said pair of spoil inlets is opened by the spoil according to a direction of rotation of the cutter head during rotation thereof.

10. A shield tunnelling machine as claimed in claim 5, wherein the transverse wall consists of two or more movable cover members, and the cover members are sequentially opened by the spoil during rotation of the cutter head.



- 21 -

11. A shield tunnelling machine as claimed in claim 5, and further comprising means for supplying a lubricating material in the liquid state to the working space to reduce the frictional force acting between the spoil and the transverse
5. wall.
12. A shield tunnelling machine as claimed in claim 5, 6, 7 or 9, wherein the transverse wall includes a scraper attached to the edge of the spoil inlet.
13. A tunnelling method substantially as hereinbefore
10. described with reference to and as illustrated in the accompanying drawings.
14. A tunnelling machine substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.
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