D.K. Shield Method

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DK shield method, the pioneer of earth pressure balanced shield method (EPBS), was invented by Daiho Construction Co. Ltd., in 1974. This method has wider applicability for various soil conditions, and moreover, it can execute under high pressurized ground water condition, safely and economically. About 250 shield and pipe-jacking projects, from 0.96 to 8.66 m in machine diameter, have been completed under this method, as of Dec. 1987. The mechanism of DK shield method consists of three fundamental factors; 1) Changing the excavated soil into muddy soil 2) Stabilizing the cutting face by muddy soil 3) Driving control by muddy soil pressure.

The paper elaborates on the theory, advantages and special equipment of DK shield method. Furthermore, it describes some tunnelling works under this method, such as very shallow tunnel in interstratified layers of soft clay and weathered granite, the same just beneath and along the existing pipes and the pipe-jacking in 0.9 m finished inner diameter.

Introduction

To excavate the tunnel,safely maintaining the stability of cutting face in particular under unstable soil formation such as water-bearing sand,gravel,weak silt and so on was a long-chased dream of all engineers concerned with tunnelling works.

A historical analysis of development of technology on how to stabilize the cutting face indicates that firstly compressed air shield method and then slurry method,and since the earth pressure balanced method has been innovated in 1970' s in Japan, the substance with which to support the cutting face has been transformed : Air→Water→Soil

The earth pressure balanced shield is now in Japan taking place of a leader among various shield methods, as its superiority of technology and economy have well been recognized by the users. DK shield method (Muddy soil pressure balanced shield) invented by Daiho Construction Co.Ltd.,Japan has been now appreciated as the most advanced one among the earth pressure balanced shield method. We manufactured prototype in 1976, and been awarded a honorable prize by The Japan Industrial Machinery Promotion Association, due to its technical contribution to the field. DK shield machines have been utilized for not only shield tunnelling but also pipe-jacking works. About 250 shield and pipe-jacking projects, from 0.96 to 8.66m in machine diameter,have been completed under this method, as of Dec.1987.

Fundamental Mechanism of D.K. shield method

Fig.1 and Fig.2 show the typical DK pipe-jacking machine. As shown in Fig.2 ,the excavated soil taken into the kneading chamber located behind the cutter wing, blocked by the bulkhead be injected a mud-making agent and effectively and thoroughly kneaded together, thus such an admixture be turned into the "Muddy Soil" ,and filled up in the kneading chamber and screw conveyor.The excavation will be proceeded maintaining the balance between the advancing of the shield (taking the bed soil into the chamber) and the discharging of the muddy soil, while keeping the muddy soil jam-packed in the chamber and screw conveyor tightly and constantly.
In other words, the cutting face will be stablized by controlling the muddy soil pressure reflected on the earth pressure gauge embedded on the bulkhead so that the subsidence of the ground be minimized while advancing the machine.

A muddy soil pressure enough to resist the earth and water pressure from the bed soil will be created by pushing the shield by starting and intermediate jacks. In this case, a following formula be theoretically maintained:

Muddy soil pressure = static earth pressure
+water pressure

While the shield is advancing, a muddy soil pressure shall be always detected by the gauge in order to keep the above formula satisfied. A muddy soil pressure is controlled by adjusting the speeds of shield

jacks and of screw conveyor. Consequently, the bed soil is not deformed at all, and the excavated volume and discharged one are automatically equivalent. The ground water is completely blocked by the impermeability of the muddy soil.

Summarizing above, mechanism of DK shield method consists of three fundamental factors;
1)Changing the excavated soil into muddy soil
2)Stabilizing the cutting face by muddy soil
3)Driving control by muddy soil pressure.

Muddy soil and mud-making agent

A mud-making agent is an agent purporting to provide an excavated soil with impermeability and plastic fluidity and to turn the same into "muddy soil" having uniformly such substances. Clay, CMC or bentonite etc. are used normally as an agent.

Unit weight and water content of muddy soil are almost same as those of the bed soil. However, muddy soil has usually less inner friction angle than that of the bed soil, and has a plastic fluidity what we call, a nature of easier transformation and free to continuous movement. By virtue of such nature, the smoother and successive movement of muddy soil through kneading chamber→ screw conveyor→outlet of conveyor can be realized, even though it is completely jam-packed and tightly pressed in the kneading chamber and screw conveyor. Muddy soil has also an impermeability. When it is packed and pressed, it can entirely block the penetration of ground water.

Density and quantity of mud-making agent will be varied, depending upon the soil conditions. Composition of fine particle contained in clayey soil can be easily deformed and disorganized. On the other hand, rather coarse particles of sandy soil needs powerful force to deform and disorganize its structure by dismantling inner friction between particles. Therefore, how much content of fine particles in the bed soil will be an important factor to decide the density and quantity of mud-making agent. For example, clayey soil consist of fine particles would become muddy soil by only kneading it by kneading blades, without injection of mud-making agent.

Advantages of DK shield method

a)Wider applicability for various soil conditions

DK Method has wider applicability against various type of layers such as sand, gravel, silt, clay,volcanic ash soil or interstratifications thereof, by turning the excavated soil into the muddy soil, applying suitable type of the mud-making agent in adequate quantity and density.

b)Simple disposal of the spoil

Discharged soil be removed usually by belt-conveyor and trolley or through sludge pump out to the surface and onto dump truck without treatment, thus, spacious spoil processing plant like slurry separation plant is not required. Under special condition, however, soil consolidating process might be necessary.

c)Minimum subsidence of the ground

As the bed soil be supported by the muddy soil, affection to the ground surface by excavation will be almost nil, keeping the deformation of the bed soil at the minimum.

d)Negligible auxiliary works

Auxiliary works like ground improvement will usually not be required except for the area around starting and arriving shafts, under very important super-structures or when encountered an obstacle. Compressed air method is in principle not necessary.

e)Small surface plant area

A required area for surface plant necessary for the works will be smaller than that of slurry shield, therefore, DK Method be suitable for the construction in busy urban district.

Machine Elements of DK shield machine

a)Cutter wings

DK shield machines which we have used,have no face cutter disc but only bar-type cutter head, leaving the cutter head completely open to the front. In fact, this structure reflects 100 percent the theory of DK shield method :supporting the soil by the soil ("Muddy Soil").

The reason why our machine is equipped with bar-type cutter head is that a cutter disc prevents the accurate driving control by muddy soil pressure. As Fig.3 shows, in case a earth pressure balanced shield has a cutter disc, a pressure (P) coming from the bed soil is not accurately transfered to the soil pressure in the chamber (PO) which is measured by earth pressure gauge, because PO is pressurized only through narrow slit of the cutter disc and excavated soil in the chamber is not fluid.

b)Kneading blades

Kneading blades are equipped with back side

of cutter wings and are imperative to produce the Muddy Soil as explained above. They also prevent the stick of muddy soil on the plate in the chamber. Its design is determined, taking into consideration the soil condition, shield diameter and so forth.

c)Excavating bits

D.K. shield machine has, other than teeth bits(Fig.4) commonly used in other type of machine, roof bit, shell bit and fish-tail bit, which we have developed.

Roof bit(Fig.5) is used for excavation of sandy or clayey layers. It can excavate in both clockwise and counterclockwise cutting direction. In case of teeth bit (Fig.4), two bits are embeded for both cutting direction, that tends to cause the stick of soil on the cutter wing between these two bits. In this situation, it requires bigger thrust force to dig into the bed soil. In order to solve this problem, roof bit has been developed and its effectiveness has been proved under various soil conditions.

Shell bit is used for excavation of gravel layer, featured like shell with ultra hard tips embeded at the edge, so that it is competent against a hard shock from gravels. (Fig. 6)

Fish-tail bit embeded in center shaft portion functions to dig deeply the center of the cutting face earlier than other type of bits, thus making easier the excavation. This idea was originated from the way of rock tunnelling where the explosives are used first at the center of the proposed tunnel.

Job site report under DK shield method

(Case 1) O.D. 1080mm pipe-jacking

Location:	Tokyo,Japan
Machine dia.:	1080mm (Fig.7)
I.D. of pipe:	900mm
Length:	252m(divided into 6 spans)
Overburden:	4.0～5,1m
Ground water:	G.L.-0.5m
Soil condition:	Silty sand (Fig.8)

Because the job site is lacated on the most crowded area in Tokyo, the space for starting shaft and equipment on the surface is very limited, and moreover, near the tunnel various utility pipes including high-voltage cables are installed in the ground. DK pipe-jacking method overcame the above difficulties and completed this project successfully without auxiliary method like chemical grouting except starting and arriving area. Subsidence of the ground was less than 2mm. To remove the discharged soil to the surface effectively, sludge pump was used. (Fig.9)

(Case 2) O.D. 2120mm pipe-jacking

Location:	Toyama pre.,Japan
Machine dia.:	2120mm (Fig.10)
I.D. of pipe:	1800mm
Length:	380m
Overburden:	7.5m
Ground water:	G.L.-1.3m
Soil condition:	Sand (Fig.11)

This project was the long distance jacking (L=380m) and the tunnel was just below the water supply pipes (O.D. 700mm). By continuous injection of granular-type lubricant agent from DK pipe-jacking machine, the thrust force for jacking was relatively small than expected. Furthermore, due to the reliable supporting system of cutting face by DK method, the existing water supply pipe was not deformed at all.

(Case 3) Very shallow tunnel by DK shield

Location:	Fukuoka pre.,Japan
Machine dia.:	4430mm (Fig. 12)
Length:	523m
Overburden:	3.7～4.5m
Ground water:	G.L. -1.1～ -2.1m
Soil condition:	Clay, Weathered granite (Fig. 13)

The soil condition of this project varies from soft layers such as clay and sand to weathered granite which compressive strength is about 60 kg/cm². Moreover, the minimum overburden is 3.7m that is less than machine diameter. Although its complex and difficult condition, DK shield machine completed the tunnel without problem.

Conclusion

On planning shield tunnelling and pipe-jacking works, the engineer should select the most suitable shield method taking various conditions, especially geological condition, into consideration.

There are several types of earth pressure balanced shield method and each has its own characteristics. Among them, as explained in this paper, DK shield method is based on the simple theory and it has been comfirmed through actual execution amounting to 250 projects. We are now believing that this method is the most sophisticated earth pressure balanced shield method.

To our regret, in this paper, we only explained fundamental theory and essence of this method, and outlined three cases of its execution. Concerning further know-how and job site reports, we would like to present on other opportunities.

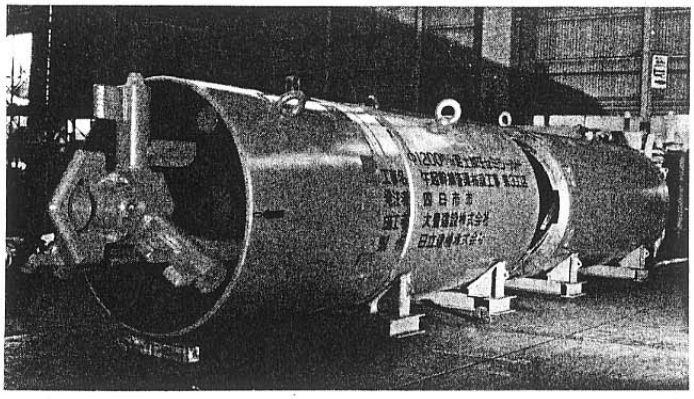


Fig.1 DK pipe-jacking machine (O.D. 1 200 mm)

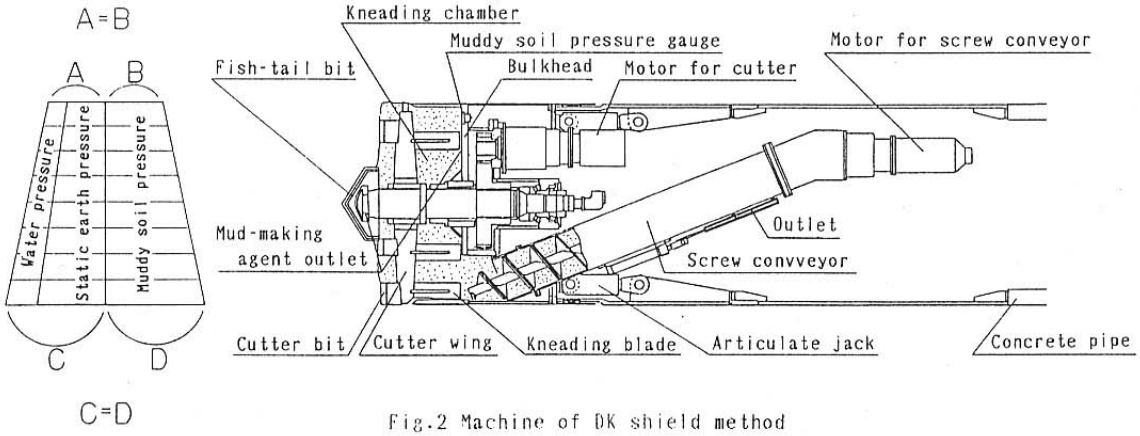


Fig.2 Machine of DK shield method

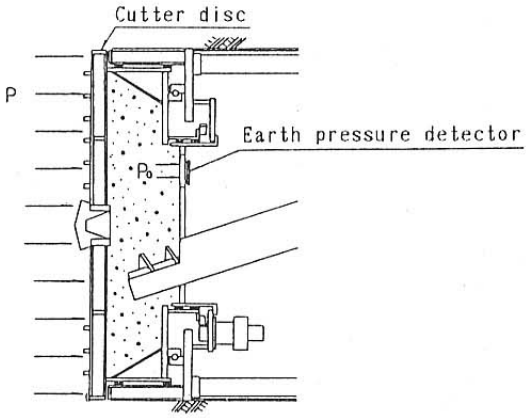


Fig.3 Influence given by cutter disc against earth pressure measurement

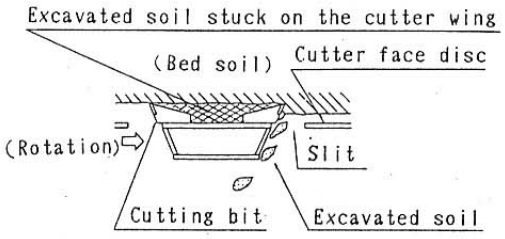


Fig.4 Teeth bit

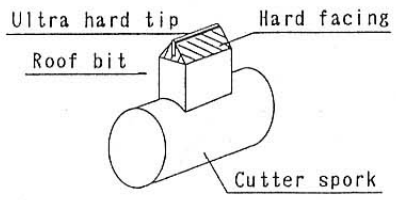
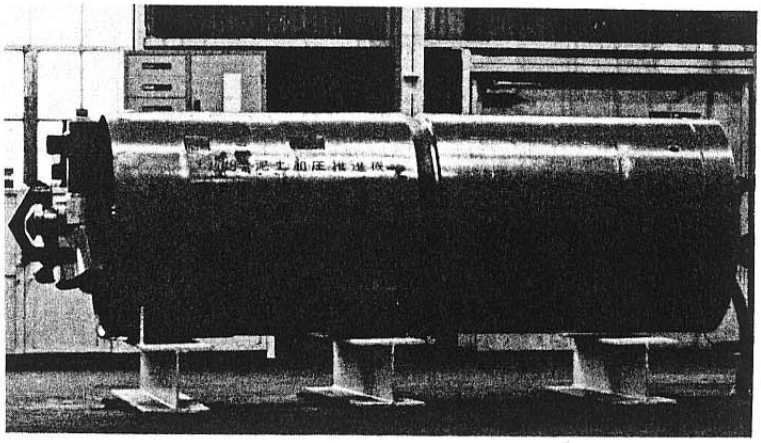


Fig.5 Roof bit

Fig.6 Shell bit embeded on DK pipe-jacking machine



O.D.	1080 mm
Length	3400 mm
Articulate jack	35t×30mm×4sets
Cutter torque	Max. 3.3 t•m
Cutter rotation	4.4 r.p.m.
Screw dia.	250 mm
Screw rotation	Max. 7.6 r.p.m.

Fig.7 DK pipe-jacking machine (Case 1)

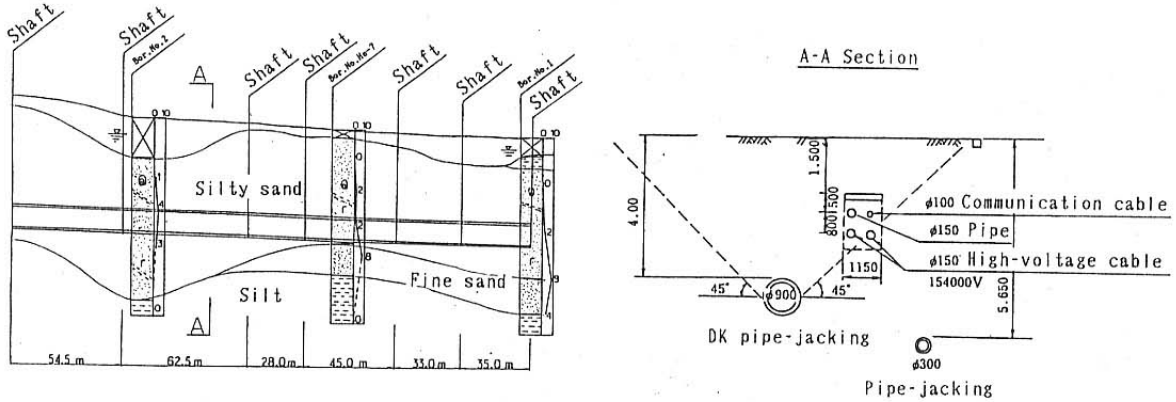


Fig.8 Geological profile and cross section (Case 1)

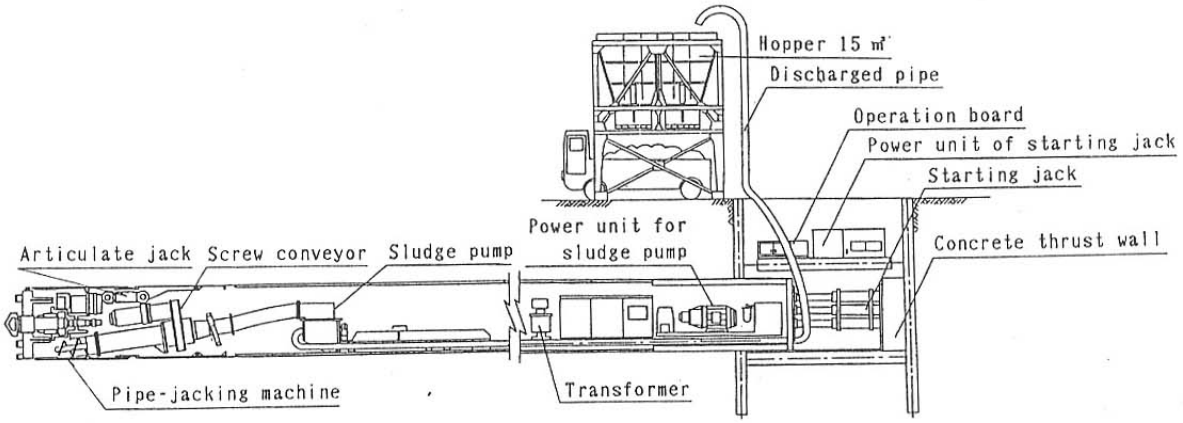
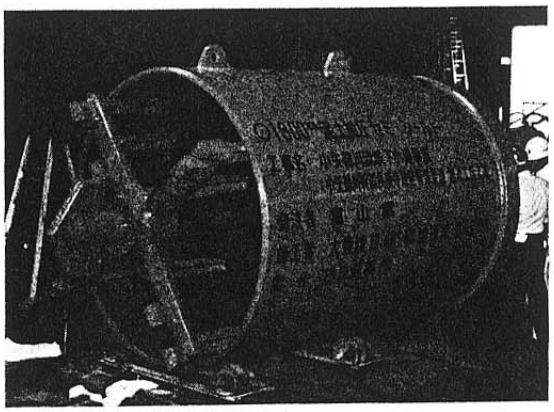


Fig.9 Soil removal system (Case 1)



O.D.	2148 mm
Length	2530 mm
Cutter torque	Max. 17.6 t·m
Cutter rotation	2.7 r.p.m.
Screw dia.	470 mm
Screw rotation	9 r.p.m.

Fig.10 DK pipe-jacking machine (Case 2)

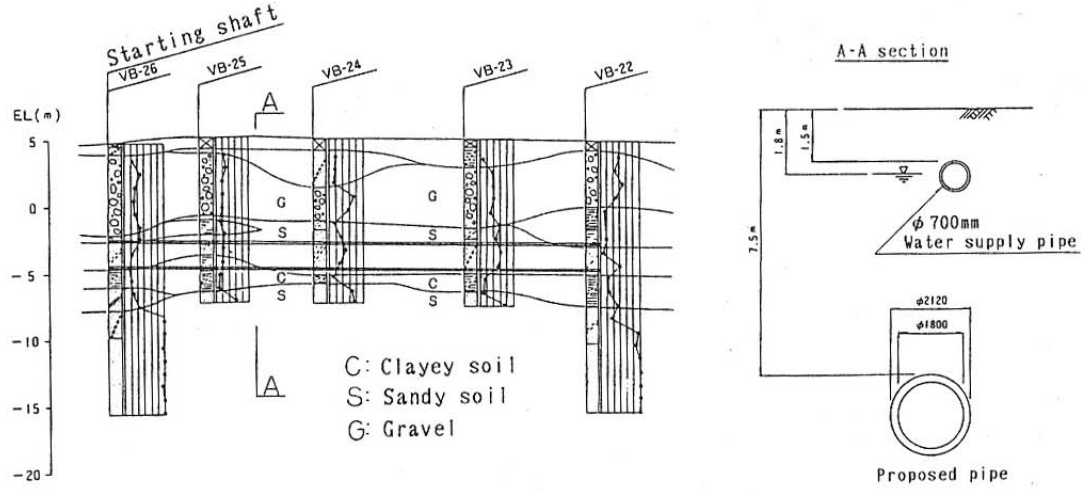
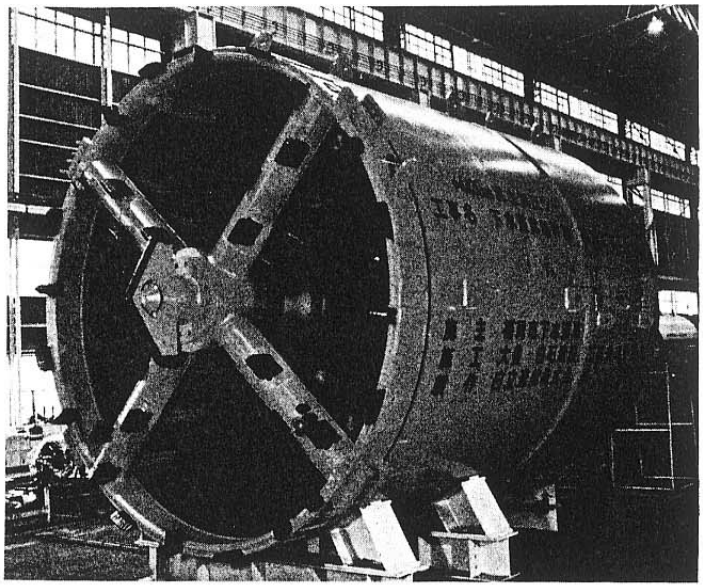


Fig.11 Geological profile and cross section (Case 2)



O.D.	4430 mm
Length	4840 mm
Shield jack	100t×18
Articulate jack	60t×100mm×12sets
Cutter torque	Max. 176.0 t·m
Cutter rotation	Max. 1.36 r.p.m.
Screw dia.	570 mm
Screw rotation	Max. 14 r.p.m.

Fig.12 DK shield machine (Case 3)

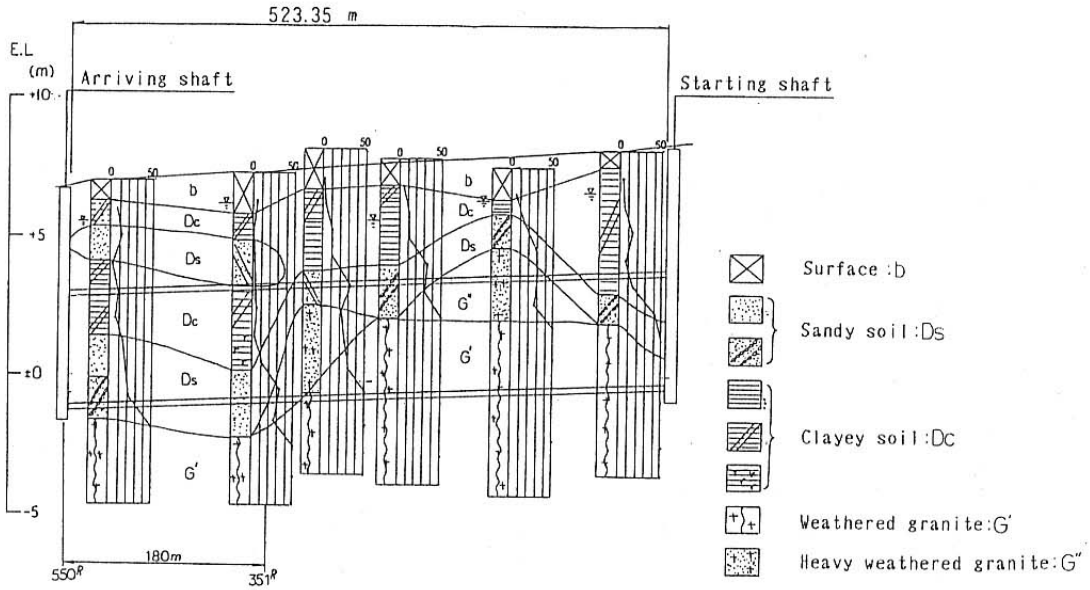


Fig.13 Geological profile (Case 3)