UNDERGROUND DIAPHRAGM WALL CONSTRUCTION
BY BW TECHNIQUE FOR SUPPORTING HIGH RISE BUILDING

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UNDERGROUND DIAPHRAGM WALL CONSTRUCTION BY BW TECHNIQUE FOR SUPPORTING HIGH RISE BUILDING

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SYNOPSIS

The construction technique of diaphragm wall in slurry trench has been used extensively all around the world for the past two decades. Earlier applications of diaphragm walling were most of all limited to such circumstances as when the accuracy and quality of wall was not essential, i.e., underground cut-off for seepage protection and temporary retaining wall for deep excavation. Recently, with new techniques and equipments having been developed for excavating trench, and along with many different engineering disciplines, the wall could be built with higher degree of precision; therefore, this kind of wall is capable of being accomplished into permanent structure or even as well as bearing element for supporting the building load.

It is known that quality of concrete wall rather depends upon slurry control during tremie concrete process; nevertheless, the equipment used for trenching is important both in maintaining the high degree of verticality and consequently the quality of the final product. In the present market, more than 15 types of diaphragm wall excavation machines using various arrangements of cutting processes are available, such as conventional type of clam-shell bucket or chisel, scraper bucket type Else machine and rotary driller. This report concentrates on the unique rotary drilling equipment developed by Tone Boring Co. of Japan for trench excavation in slurry with reverse circulation operation to remove cutting soil. When the

wall is designed to be incorporated into permanent structure, details of joint system, reinforcement connection and some requirements in the specification preparation are also recommended.

INTRODUCTION

In the conventional construction of a diaphragm wall, a narrow trench is first excavated by special tools with the circulation of bentonite slurry to maintain the stability of the trench throughout the entire excavation process. When a segment of the trench is completed, a concrete wall can be formed by placing precast panel or cast-in-situ reinforced concrete in the trench. It is recognized that the quality of the wall, i.e., the effective width, depth, and especially the verticality of the panel, is critically influenced by the trenching process.

Unlike other types of excavation work, the success of the diaphragm wall is determined by the adoption of an excavation system suitable to the conditions of the subsoil. For most practical civil engineering projects, the engineer tends not to specify any particular type of construction equipment during the designing stage. This is in order to allow for more competitive bidding and, presumably, to save on construction costs. Unfortunately, this is not always possible for diaphragm wall projects. There are more than 15 types of excavation systems currently available on the market. And, as a matter of fact, certain types of excavation equipment can be more efficient than others according to particular site conditions, and only certain type of equipment appears suitable when high precision is required. Therefore, the engineer may have to select the type of equipment prior to the planning of construction details.

EXCAVATION EQUIPMENT

Various cutting machines have been used for the trenching process, such as those of conventional clam shell bucket with kelly bar or wire rope, the scraper bucket type ELSE trenching machine, the percussion bit or rotary bench bit type and the rotary reverse circulation driller.

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Table 1 Excavation System & its Application

Type of Trenching Process			Clamshell		Percussion Bit	Scraper Bucket	Rotary Benching Bit	Multiple Rotary Drilling bit
			Wire Rope	Kelly Bar				
Depth of Excavation (m)		20 and less	o	o	o	o	o	o
		30 - 40	Δ	o	o	Δ	o	o
		40 - 50	Δ	o	o	×	×	o
		over 50	×	Δ	o	×	×	Δ
Thickness of Wall (cm)		80 and smaller	o	o	o	o	o	o
		80 - 100	o	o	o	Δ	o	o
		100 - 120	Δ	o	Δ	×	o	o
		over 120	×	Δ	×	×	×	×
Subsoil Condition	Cohesive Soil (SPT) (N value)	< 4	o	o	Δ	o	o	o
		4 - 10	o	o	o	o	o	o
		10 - 20	o	o	o	o	o	o
		20 - 30	o	o	o	o	o	o
		> 30	Δ	o	o	o	o	o
	Sand (N value)	< 10	o	o	o	o	o	o
		10 - 30	o	o	o	o	o	o
		30 - 50	o	o	o	o	o	o
		> 50	Δ	o	o	o	o	o
	Gravel (size in cm)	< 10	o	o	o	o	o	o
		10 - 15	o	o	o	o	o	o
		15 - 20	o	o	o	o	o	o
		20 - 30	Δ	o	o	Δ	Δ	Δ
		> 30	×	Δ	Δ	×	×	×
Rock		Soft	×	×	o	Δ	×	Δ
		Hard	×	×	o	×	×	×
Vibration and Noise			Δ	Δ	Δ	o	o	o
Disposal			o	o	o	Δ	Δ	Δ

o Suitable
Δ With difficulty
× Not applicable

Table 2 Specifications and Dimensions of BW Long Wall Drill

Model	Bit diam. (Wall width) mm	Single Excavation Length, mm	Effective Length, mm	Height of Motordrill, mm	Excavation Length, m	Number of drill bit	bit Rotation, rpm.	I.D. of Reverse Pipe mm	Power Required Kw	Weight of Motordrill kg
BWN-4055	400 450 500 550	2,500 2,550 2,600 2,650	2,100	4,300 ~ 4,320	5	7	50(50Hz)	150	15 x 2 sets (6p)	7,500
BWN-5580	550 600 650 700 750 800	2,470 2,520 2,570 2,620 2,670 2,720	1,920	4,525 ~ 4,555	50	5	35(50Hz)	150	15 x 2 sets (6p)	10,000
BWN-80120	800 900 1,100 1,000 1,200	3,600 3,700 3,800 3,900 4,000	2,800	5,505 ~ 5,555	50	5	20(50Hz)	200	15 x 2 sets (6p)	18,000

Table 1 indicates the application of these equipments in relation to different types of soil conditions and its suitability regarding the depth and width of the diaphragm wall. Besides most of those conventional trenching machines, the BW system is basically a rotary type driller equipped with a reverse circulation facility in removing cutting soil. This unique system was developed by Tone Boring Co. in Japan in 1967 and, in the past ten years, has gained popularity in the diaphragm wall industry throughout the world.

The BW long drill (Fig. 1) consists of five or seven drill bits with associated transmission, side cutters and submersible motor. Using the BW long drill, the trench is first drilled by rotary bits, followed by side cutters to finish the interior surfaces of the wall. The cutting material mixed with slurry is removed through a reverse circulation process by a suction pump built into the unit. Table 2 shows the standard specifications and dimensions of three available models of BW drills (BWN-4055, BWN-5580 and BWN-80120) which are capable of excavating trench widths of 40 to 55 cm, 55 to 80 cm and 80 to 120 cm, respectively. The standard rig for the motor drill BWN-5580 is shown in Fig. 2, control system mounted on a derrick includes switch board, hoist cable reel and monitoring instruments such as the deflection indicator, which detects the inclination of the drilling unit, and the bit resistance indicator, which shows the pressure on the cutting head for adjustment of pulling force, so that the drilling bit may remain on a true vertical line by gravity. The deflection indicator is a sensitive device with the capability of indicating

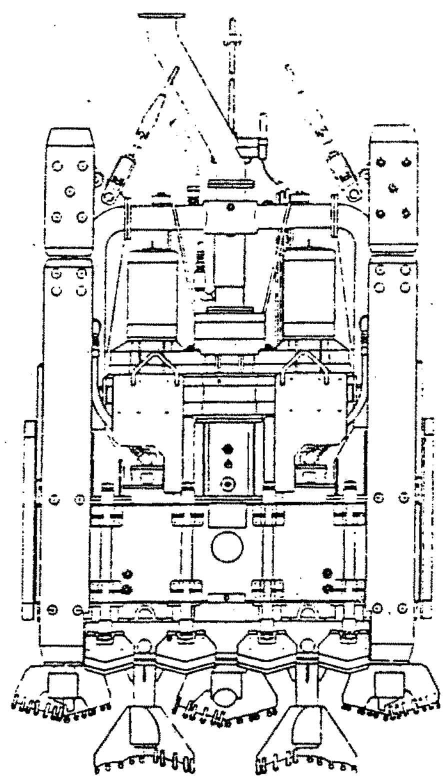


Fig. 1 BW Long Drill (BWN-5580)

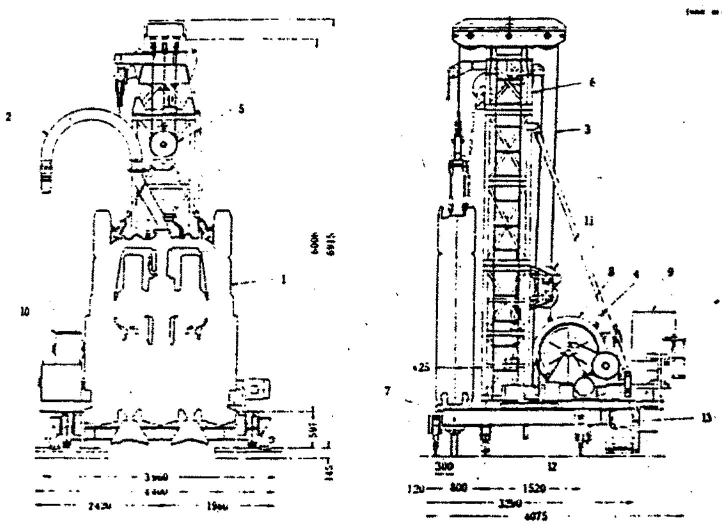


Fig. 2 Standard Rig for Motor Drill BWN-5580

1. Submersible motor drill 2. Reverse hose 3. Hoisting wire rope
4. Feed Indicator 5. Running block 6. Derrick 7. Frame
8. Hoist 9. Switch board 10. Cable reel 11. Rope guide
12. Derrick hoist 13. Baby compressor for adjustable guide

1/500 magnitude of verticality. When the drilling unit moves from the vertical position, the operator can detect the movement immediately from the deflection indicator and then operate with a built-in remote control adjustable guide to bring the drill back to vertical direction thus achieving a high degree of precision. Descending devices equipped with a vibrating mud screen and cyclone are usually used with the BW driller to intercept the coarse granular material and the fine soil, respectively. The slurry recovered by reverse circulation may be reused and recirculated into the trench after the segregation of cutting material through descending units. Fig. 3 sketches the typical lay-out of a diaphragm wall construction by the BW system.

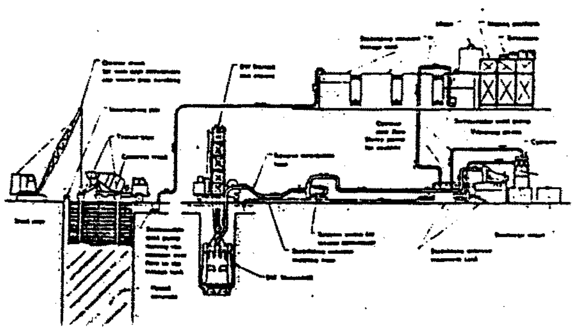


Fig. 3 BW-System Lay-out

EXCAVATION

Excavation with BW two-level drilling bits is operated at selected speed and feed load according to the hardness of the subsoil. The normal load applied on the drilling bits is generally adjusted to 2 to 3 tons. Side cutters oscillate up and down at a speed of approximately 35 runs per minute to clean off soil that is not reached by rotary bits. Drilling continuously carries down to the bottom level of the wall and then moves to the next cutting location according to the sequences shown in Fig. 4.

For an average panel length of 4 to 5 meters, three passes of cutting are usually required. In sandy silt soil such as Taipei silt, the drilling speed by BW driller is about 8 to 12 meters/hr. Prior to the procedures of placing steel cage and tremie concrete, the base of the excavation must be cleaned throughly when the panel is designed for load-bearing; otherwise, the cutting and bentonite mixture remaining on the bottom of diaphragm wall will not be completely re-compressed and hardened which may result in settlement. The cleaning of the base can be done by shifting the BW drill horizontally along the bottom of the trench and sucking out the sediment and slurry. The other factor affecting the performance of the diaphragm is the leakage of ground water through construction joints of the two adjoining panels. The leakage often occurs due to the trapping of bentonite or soil pockets across the joint (Fig. 5).

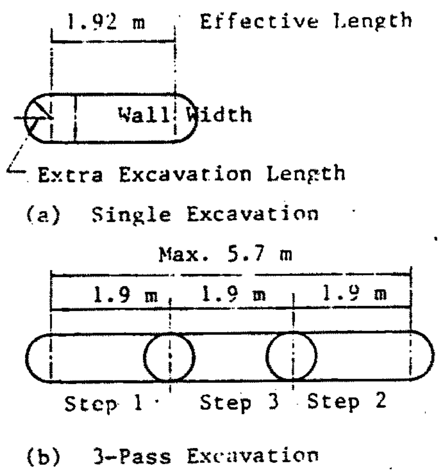


Fig. 4 Typical Panel Excavation (BWN-5580)

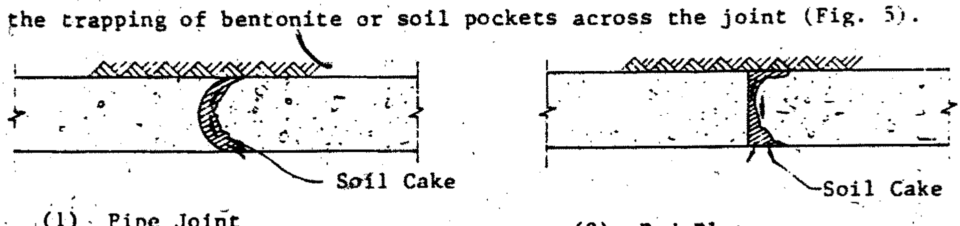


Fig. 5 Leakage of Groundwater Through Interlocking Joint

Experience shows that by using a steel tube brush (Fig. 6) to clean the joint prior to concreting improves its degree of water-tightness significantly. The vinylon sheet attached to the steel cage and covering the entire panel is used to provide a barrier for prevention of leakage of concrete through both sides of the trench.

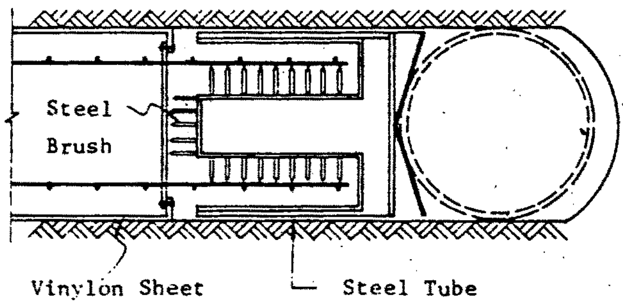


Fig. 6 Interlocking End Tube

Fig. 7 gives the detail of sheet attachment. When a defected joint is encountered, the most economic way to correct the leakage is simply to clean the joint and cover it with concrete or epoxy motar. The chemical treatment by grouting process has also proved to be an effective remedy in stopping water leakage. (Fig. 8)

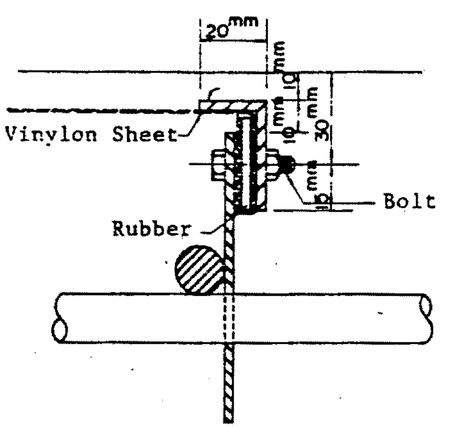


Fig. 7 End Plate and Connection of Vinylon Sheet

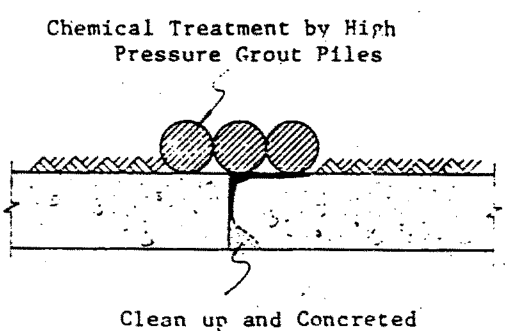


Fig. 8 Treatment of Water Leakage at Joint

control of slurry during the tremie-process will result in voids and cavities which should be avoided in diaphragm wall construction. Under normal conditions, an understrength factor of 0.8 is still recommended.

TRANSFER OF LOAD

As mentioned previously, the diaphragm is capable of being incorporated into the entire structural system in carrying permanent load. To transfer the load safely to the diaphragm wall either from column; shear wall or from beam, and base slab, the reinforcement required should be cast together with the steel cage of the main panel in advance. Fig. 10 demonstrates the required additional reinforcement for diaphragm wall elements in carrying vertical loads. In the meantime, a special interlocking joint must be used to provide structural continuity in resisting lateral loads. All three types of elements shown in Fig. 11 have been used. For type A & B elements, two type A elements are installed first and then type B element is inserted into the space between. This process requires high accuracy, especially the plumbness of the type A panel. For type C panels the installation can be done in continuous order in one direction.

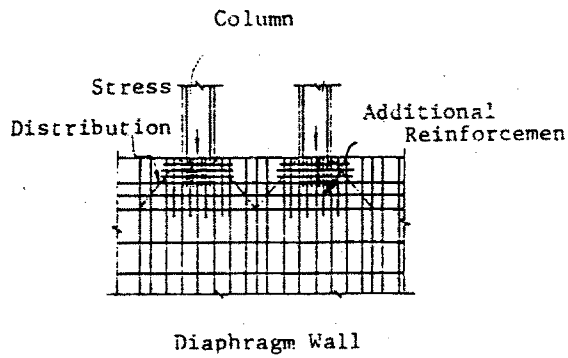


Fig. 10 Additional Reinforcement for Transfer of Vertical Load

The transfer of shear and moment from the floor slab and beams to the diaphragm wall can be accomplished by means of bent-out steel bars embedded into each connecting member with sufficient overlapping. Fig. 12 provides a typical example of connection from diaphragm wall to slab and beams. Since the dowels must be cast in the wall with recess formed by polylon plate or bands of wood, the most difficult action is probably the positioning of the steel cage so that force from connecting members can be properly transferred to the diaphragm

STRUCTURAL ELEMENT CONSIDERATION

The application of casting reinforced concrete foundation element in slurry to support building load has become an acceptable practice. Nevertheless, some doubt remains as to whether the slurry may contaminate the concrete and also serve as a lubricant between concrete and soil, decreasing the concrete's strength and reducing its skin resistance. However, it must be recognized that a thin layer of bentonite cake is bound to develop at the interface between soil and concrete (Fig. 9).

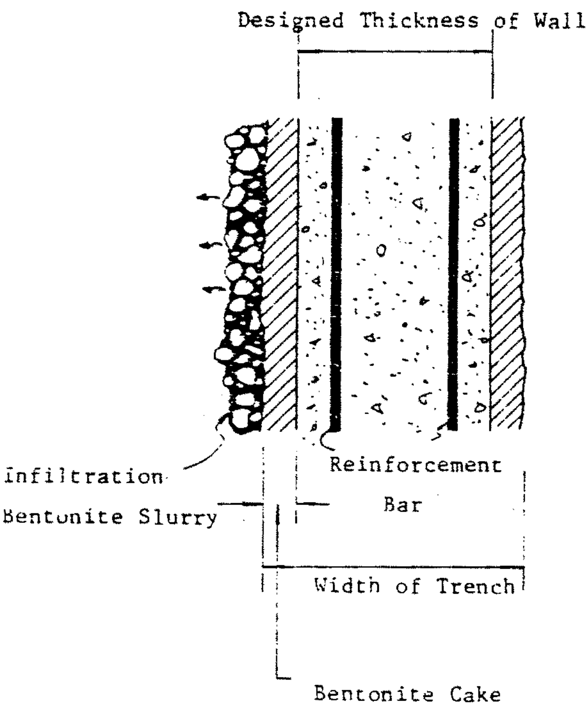
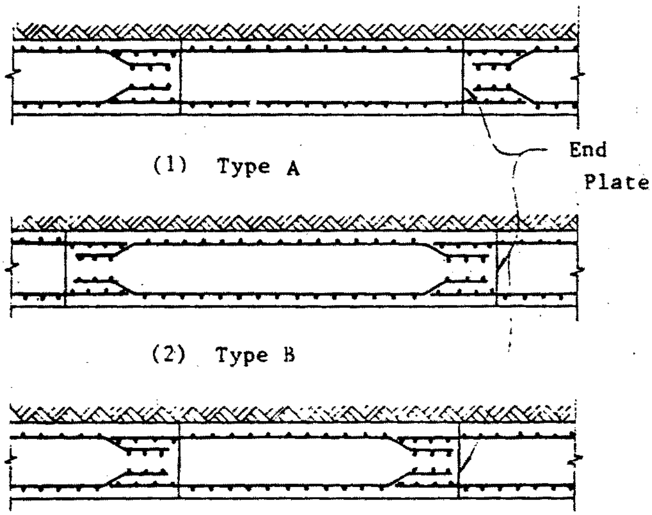


Fig. 9

Bentonite Cake Trapped at the Interface between Soil and Concrete Wall

It is therefore recommended that a certain reduction in effective wall thickness and a proper decrease in the concrete strength be calculated during design of the diaphragm wall, in order to compensate for the imperfections during construction. From experience, a reduction of 2.5 cm applied to both sides should be adequate. As far as the strength of concrete is concerned, there is no solid evidence on how the concrete affected by the tremie process; anyhow, the improper



(3) Type C

Fig. 11
Types of Continuous Concrete Panel
(1) Female Panel
(2) Male Panel
(3) Combined Panel

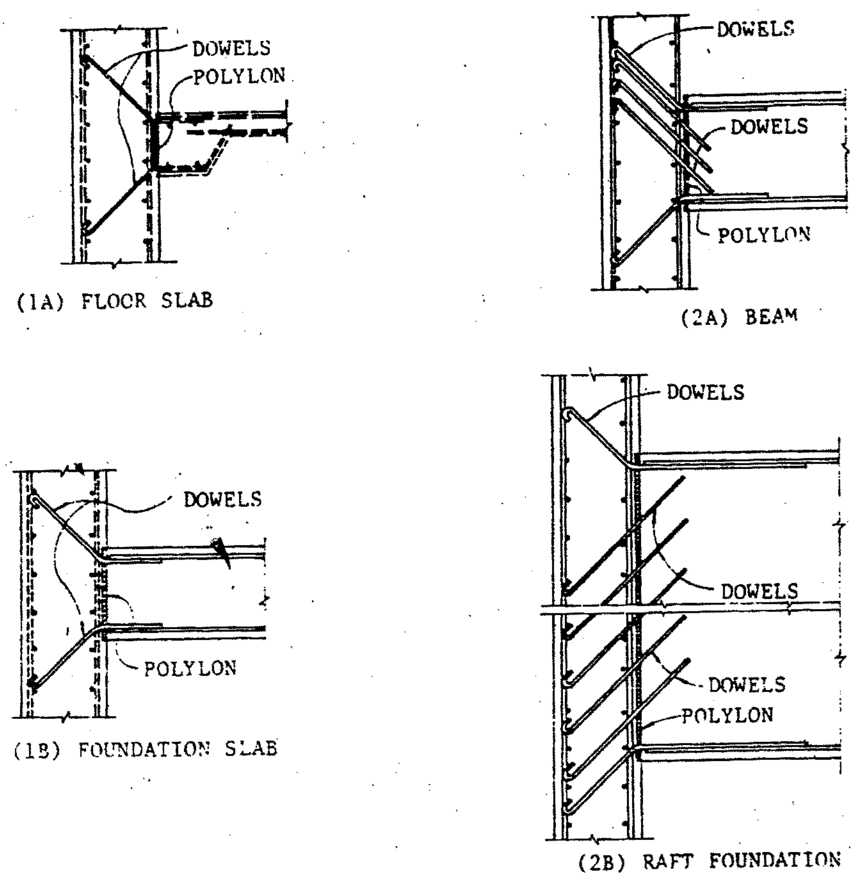


Fig. 12 Connection of Reinforcement Bars to Permanent Structure

wall without creating additional eccentric forces. This means that a high degree of accuracy in depth and verticality of trench is absolutely necessary.

CONCLUSION

There are many excavation techniques which can be used for the slurry diaphragm construction. The full theory and application has not yet been developed. As previously mentioned, for most diaphragm projects, little can be gained by not identifying the method of excavation. It is important to study the subsoil conditions and to select most efficient and suitable type of equipment which the owner, engineer and contractor can all benefit from and appreciate. Especially when the diaphragm wall is considered to be a part of the permanent structural wall, and the plumbness, minimum width and depth are critical structural requirements, the excavating equipment considered most appropriate for the site conditions and with regard to depth shall be selected. BW long wall drill equipped with high sensitive deflection indicator and verticality adjustment device is one of the excavation machines which gives promising result for such purpose.

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