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NEW TECHNOLOGIES FOR SHALLOW TO DEEP UNDERGROUND CONSTRUCTION IN URBAN AREA

TADASHI HASHIMOTO
Geo-Research Institute,
4-3-2, Itachibori, Nishiku, Osaka, 550-0012, Japan

ABSTRACT

The utilization of underground space becomes a more important issue in megacities of the world in order to build more functional and advanced cities. However, because a lot of underground structures such as lifelines have already been developed in the megacities, a demand for the new underground development increases for a better efficient utilization of shallow and deep underground space. For this reason, it becomes important to establish an underground construction technology that could be applied to large depth and/or the large cross section structure constructions, with little influences on the natural environments of groundwater, the congested structures under or above the ground. Moreover, the geology of megacities in most Asian countries, particularly, consists of soft deposits such as clay, silt, sand and gravel layers with high groundwater table. Therefore, new technologies related to site investigation, design, monitoring for safety management and environmental preservation, groundwater strategy, as well as the soil improvement etc., are necessary. According to these demands, this paper collectively introduces the advanced technology developed in Japan. It is hoped that these technologies can meet the demands to develop new underground constructions in an economic efficient way with little influence on the environment safety in each megacity. The sharing of these new technologies would be useful not only for the megacities in the developed countries but also for the cities in their developing.

1. INTRODUCTION

The period of the underground space development in soft ground of Asian megacities such as Tokyo, Osaka, Singapore and Shanghai is relatively short and the depth of the utilization of underground space was not more than 10~20m about 50 years ago. Recently, it has been getting more and more popular to utilize the underground space with depth exceeded 30m, for purposes of subway, underpass road, underground shopping center, and water supply and sewage service system. In order to meet the demands of utilization of underground space with large depth, new technologies such as the slurry wall, soil improvement, groundwater strategy, and various kinds of shield tunneling are developed and have been applied into underground constructions.

However, due to the lack of experience on tunneling or excavating in troublesome ground at such a large depth, also because it is not sufficient with the general perpendicular boring and the Cone Penetration Test for geological survey, collapses or other troubles during constructions occur by accident and become social issues. Therefore, it is necessary to introduce new site investigation techniques such as geo-tomography based on seismic and acoustic waves, which can provide continuous detailed investigation on site.

In urban areas where many new projects have to be constructed among the heavily congested underground structures, new techniques of obstacle detection and treatment for the existing structures are necessary. Moreover, the monitoring technology for structure and ground during or after construction is very important too. The temperature and strain measurement method using optical fiber and wireless monitoring system such as Micro-Electro Mechanical Systems (MEMS) have been recently developed and applied into practical use [1]. The electrical measurement of Electrochemical Response System/Electrical Tracer System (ECR/EFT) is an effective way to detect leakage zones which cause a lot of accidents in underground constructions [2].

New technologies of tunneling are developed according to different purposes and different construction environment in urban area. For tunnels with large section, it can be constructed by several assembling shields or jacking tubes with small rectangular cross-section. One of the typical methods is named as Harmonica tunneling method. The Ultra Rapid Under Pass (URUP) tunneling method could bore a shield tunnel without constructing vertical shaft at start and end points [3]. There are also various closed type shields such as multi-faces shield, non-circular shield, H&V shield, and divergence tunneling method which had been developed in the past 50 years.

In order to prevent leakage from joints of diaphragm wall in the excavation construction, a hydraulic type Reinforced Concrete diaphragm wall excavator equipped with attitude control system was developed. The improved Soil Mixing Wall and the Trench cutting Re-mixing Deep wall method (TRD) [4] with Chainsaw mounted were developed as well. Moreover, the development of Cross wall beam method for soil improvement is also effective in soft clay ground as to control the deformation of the retaining wall during excavation.

A large scale drilling machine with rotating casing bits has been developed to excavate in cobble ground or for the purpose to remove underground obstacles. Pneumatic caisson method had been improved by an uninhabited and remote control which can work safely under large depth with high hydraulic pressure.

Technical improvement on soil improvement methods such as grout injection of micro cement, cement deep mixing method and jet grout is also remarkable. By a jet grouting method using a high-pressure grouting pump, an improved column with high strength and large diameter exceeding 4m could be produced in ground. Moreover, by using a Metro Jet System [5], a horizontal improved column could be constructed.

In addition, in recent years, a new bio-technology was developed by international cooperation with a core research group in Netherlands. The typical techniques are named as “BioGrouting” and “BioSealing”. The former causes the soil to be hardened, and the later can cut off the water flow inside the ground by promoting the proliferation of certain bacteria in the ground [6]. It is expected to be used in practice in nearly future. In ground water treatment, Supper Well Point method, combined the advantages of well point and deep well method, has been implemented into practice as a dewatering method, especially in the ground of fine sand which has low-permeability [7].

2. SITE INVESTIGATION AND MONITORING

2.1 Site investigation

In the underground construction, it is very important to accurately acquire the ground information in order to ensure the safety and economy of construction. The essential information for design and construction, such as the soil properties and underground water, is usually obtained through boring survey and CPT, which, however, can only obtain the information of some individual points. The localized abnormality among these points (for instance, significant changes due to the existences of faults or caves), might be overlooked when mapping the geological cross-sectional profiles. That could be the cause of accidents during constructions. Moreover, in megacities, due to the existence of the large buildings and underground structures such as underground moles and subways, it becomes very difficult to survey the ground underneath these structures. These survey methods are also unfavorable to the deep underground space development.

To solve these problems, some site investigation technologies have been developed. Some of them listing as follows will be introduced in this section. (1) Geophysical exploration and tomography by seismic, electromagnetic and acoustic waves; (2) Investigation from tunnel face or vertical shaft by using seismic wave survey; (3) Control boring survey from the surface and horizontal boring survey from the shaft; (4) MWD (Measurement While Drilling) based on the drilling data from boring or from TBM; (5) Ground water leakage detection technologies such as ECR/EFT.

(1). Geo-tomography is suitable for geological investigation in deep and complex ground using radar waves, surface waves, electromagnetic waves, seismic waves and acoustic waves. Cross-hole Geo-tomography is a continuous cross section survey method which is similar to the medical CT-scan. Boring holes were used to set the vibration source and multi-channel receiver. The ground between the boring holes can be visually displayed in two dimensions by detecting the distribution of the resistivity and velocity of the wave. Figure 1 is a scheme of this method.

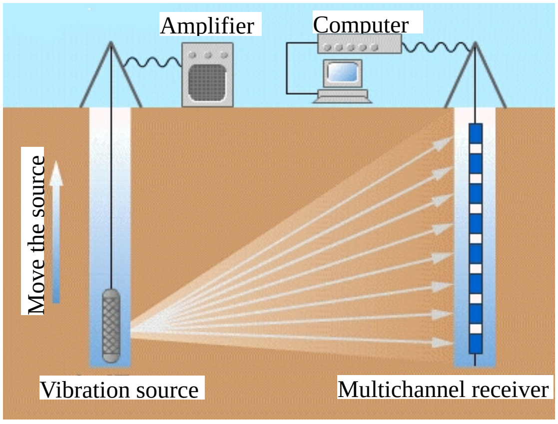

Figure 1. Configuration of cross-hole tomography.

Surface waves (Rayleigh waves) [8] are used to investigate average values of ground profile in three dimensional directions, thus large scale ground transitions can be detected. **Seismic tomography** [9] is suitable for site investigation as the *Vs* and *Vp* have distinct relationship with the stiffness of the ground. **Radar waves** are used to investigate the ground profile within a depth of a few meters. **Electromagnetic wave tomography** can detect the resistivity which is related to the density, pore water condition and particle sizes of the soil. Especially, this method is effective for investigations in tunnels with deep overburden. **The acoustic tomography method** [10] is used to detect the distribution of *P*-wave velocity and the attenuation rate of amplitude which reflects the ground properties. **Ultrasonic tomography** that uses very high frequency of more than 1 kHz is a special case of acoustic tomography. It can achieve the best accuracy comparing with the methods shown above. In addition, this method has good workability because it will not be affected by vibrations caused by traffic etc.

Figure 2 shows one of the result of the tomography that uses the acoustic wave. Based on the observed date, velocity and attenuation will be calculated and thus the ground information can be visualized. Moreover, this method can control the frequency and amplitude of the acoustic wave to make the wave to transport much further in the ground, which makes it unique to the tomography methods.

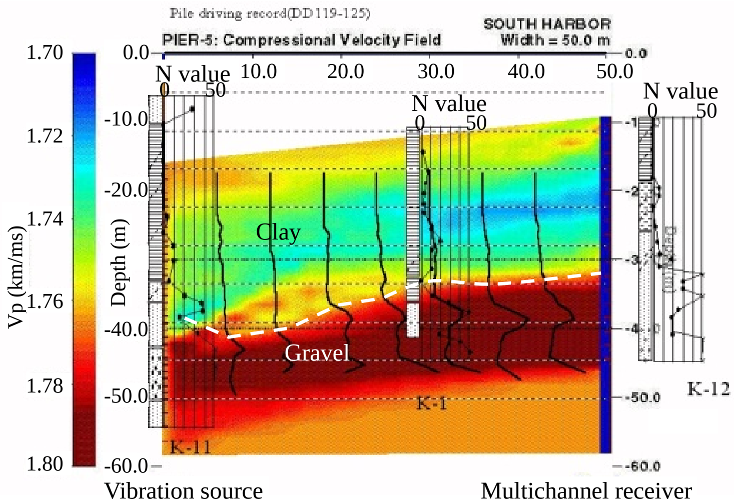

Figure 2. A velocity imaging of acoustic wave tomography [10]

(2). HSP (Horizontal Seismic Profiling)[11] is one of the effective investigation method for tunnel construction. Seismic wave was sent out from the cutting face and the reflection was recorded. Based on analysis, the location of the faults in front of the cutting face can be identified.

(3). Control boring [12] is a technology that the drilling direction can be arbitrarily controlled during boring. It is quite effective on some investigation points where the working space is restricted. The boring direction can also be controlled to be horizontal when it is necessary. Moreover, this horizontal boring can be proceeded not only from ground surface but also from a pit or the cutting surface of a tunnel, which make this technique also a promising investigation method for deep ground.

(4). Rotary sounding test and Rotary percussion drilling test [12] are representative technologies in the field of MWD (Measurement While Drilling). During drilling, the data of boring machine (torque, thrust force, speed, and number of rotation) will be monitored and recorded, and then the ground properties will be evaluated by using these data. Similarly, the data of shield tunneling can be used in back-analysis to evaluate the ground properties.

(5). Groundwater leakage detection is a very important technology in the underground construction in soft soils with high water pressure because a water leakage from the diaphragm wall or impermeable improved soils is a serious problem for the construction and environment.

ECR/EFT[2] is one of the effective technologies to detect leakage. As we know, Groundwater migrating through a leak in a sealing construction, e.g. an open joint between diaphragm segments, ensures an electric flow by ion transport and creates a measurable electric field. ECR method just takes advantage of this electric field by multi-sensors, locating anomalies in leak areas in the existing natural electric potential fields. To detect even small or only potential leaks with minimum or no groundwater transport, the ion flow can be increased through the sealing structure by artificial electrical tracers (EFT method) in combination with ECR as sketched in Figure.3. The tracer follows the least resistant path from the outside of the sealing construction towards the counter pole inside. Therefore, the electrical potential field changes significantly at an opening or weak area, compared to the surrounding field of the rest of the construction. The changes in the electric potential field are measured with the ECR sensors in relation to references in the field. ECR/EFT technology is able to quickly obtain a reliable detection of potential linear or areal leaks and to perform the quality control of horizontal and vertical sealings in very complex and deep structures like metro tunnels, even before excavation. Further advantages are the non-destructive measurements from the surface, the flexible spacing of measuring grids, which can be easily adjusted according to each project and virtually no depth limit for practical investigation.

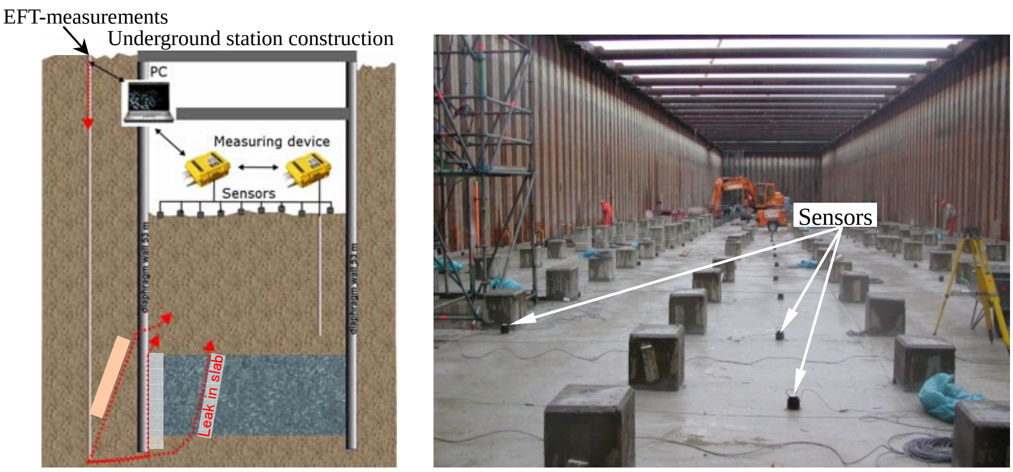

Figure 3. Schematic of leaks detection by ECR/EFT.[2]

2.2 Monitoring[13]
The underground construction in urban area in recent days becomes more and more difficult because the excavation becomes deeper and underground construction is congested with many existing structures. To ensure safety, quality of structure and the surrounding environment under the cost performance of construction, the on-site monitoring and feedback system to the design and construction based on the observation plays a very important role. Objectives of monitoring for underground construction are ground deformation, applied load and pressure, ground water pressure, displacement of structures, noise, vibration and the change of underground water table caused by construction. Required performances of monitoring for underground construction are durability, waterproof and wide range measurement for monitoring devices, wireless monitoring, real time monitoring and feedback system to the design and construction. In recent years, the following new monitoring technologies have been developed according to the above requirements. (1) Miniaturization and wireless technique (MEMS, wireless communication); (2) Optical fiber

sensor (B-OTDR, FBG, etc.); (3) Particular monitoring devices like Earth pressure meter and displacement meter for tunnel; (4) On Site Visualization system for safety management.

(1). MEMS (Micro Electro Mechanical Systems) are small integrated devices or systems that combine electrical and mechanical components varied in size from micrometers to millimeters, which can merge the function of computation and communication with sensing and actuation to produce a system of miniature dimensions. MEMS extend the fabrication techniques for semiconductor industry to include mechanical elements. The small size of MEMS enables high level integration of micro-machined components or structures inherently to realize multiple functions or capabilities on the same silicon chip for greater utility. MEMS sensors will offer major advantages in terms of smaller size, lower power consumption, more sensitive to input variations, cheaper cost due to mass production and less invasive than larger devices and extend the performance and lifetimes over conventional systems. A range of MEMS sensors is now available in civil applications, which can measure acceleration, inclination, temperature and pressure.

The technology of **wireless communication within ground**[1] has been practically applied. The employed electromagnetic wave frequency is less than 10 kHz and the maximum communication distance depends on the conductivity of communication medium. The maximum communication distance is about 100 m within ground and 50 m within sea water. Figure.4 shows a wireless pore water pressure transducer used in measurement of a fill dam.

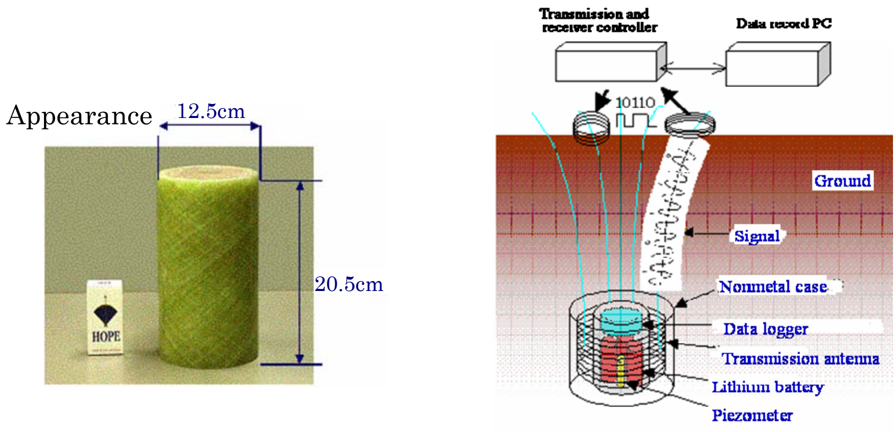

Figure 4. Wireless pore water pressure transducer.[1]

(2). Optical fiber sensor (B-OTDR)[12] applied in civil engineering has become popular recently. When an incident ray transports through an optical fiber, reflected ray will occur in the opposite direction. This is called backscatter phenomenon. By measuring the properties of backscatter ray, the strain, temperature and other information along the optical fiber can be obtained. Comparing to other measurement sensors, the optical fiber has the advantages of durability, noise resistance and long-distance transportation. Additionally, in the measuring site, power source is not necessary so that long-term measurement is possible. Figure.5 (left) shows a measuring example in tunnel using the optical fiber sensor. The internal displacement in cross section and strain in longitudinal direction were measured by the optical fiber sensor. The measured results are shown in right side.

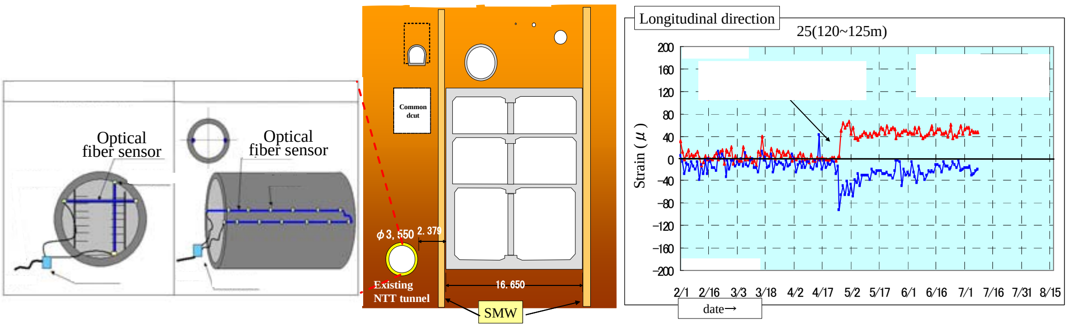

Figure 5. Installation of optical fiber sensors and Measurement results [12]

(3). A hydraulic Pad-type earth pressure meter[14] with a thin and large diaphragm for shield tunnel lining has been developed in order to measure earth pressure accurately acting on segments of shield tunnels. The observation of the earth pressure gives the information on the behavior of segmental linings in the shield tunnel.

The Universal displacement meter [15] was developed to measure the internal displacement of tunnel in cross sectional direction. Connecting rods are installed in polygonal shape inside tunnel lining with the inclinometer and displacement meter.

(4). On Site Visualization system for safety management[16] can be used so that each worker can easily identify the level of safety according to the change of instruments' emission color due to stress and deformation. A new deformation sensor is developed for monitoring of infrastructures. This sensor is composed of a deformation detection part and a data visualization part. The detection part is similar to common sensor which can measure strain, deformation and so on. The data visualization part is made up of a specially designed switch that can convert measured displacement into different color of LED lamp correspondingly.

3. TUNNELING AND UNDERGROUD CONSTRUCTION

Among the recent demands for development of the shield tunneling technology are the long distance driving, high speed driving, deep tunneling, large cross section, multi-faces TBM, noncircular TBM, high durability of tunnel structure and cost efficiency. To realize the above demands for the shield tunneling, new specified technologies such as cutters, seals, backfill grouting and driving control systems for TBM and many kinds of joint systems of segmental joints for the lining of tunnel have been developed as examples to lead the practice. Moreover, due to various demands for specialized utilizations of underground space, various shapes of bored tunnel such as rectangular, horse shoe shape, elliptic and multi-circular face are used in construction. And also, in the limited traffic condition and surrounding condition for the underground construction such as construction and tunneling beneath facilities; some particular tunneling methods and jacking methods have been developed. Applying harmonica method, URAP method and etc. it is possible to build large cross sectional underground space using TBMs and they have became the typical underpass tunneling methods using TBM. There is also alternative method which is a kind of box culvert jacking method that is frequently employed for underpass in a shallow ground.

3.1 Shield tunnel

Multi-faces TBM has been developed in recent years for the construction of the underground station of the railway and tunnels adjacent to other structures. Figure.6 shows a three faces TBM employed in a construction of station of Osaka subway in line-7[17]. Then, TBMs with three faces and four faces had been effectively employed in the construction of underground station in Tokyo.

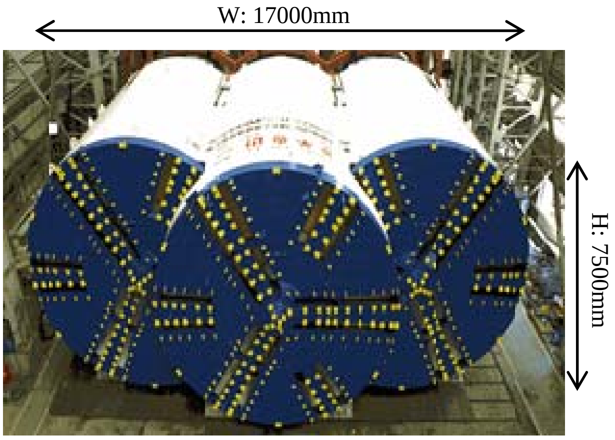

Figure 6. TBM with 3 faces used in Osaka.

Noncircular face TBM used in practice is sorted into three types with different shape of faces, rectangular, elliptic and horse shoe shapes. More than 15 rectangular shield tunnels have been constructed for waterway, underpass, underground railway and multiple services in Japan. The elliptic shape of TBM was used in Tokyo Metro, No.13 line between two stations. The reason for using this is that a vertical alignment is very restricted by existing structures. On the extension project of the East-West line of Kyoto Subway, a large cross sectional rectangular shield method is used to construct the tunnel as shown in Figure.7. The sectional area of this shield is $60m^2$ with a long side span of 9.9m.

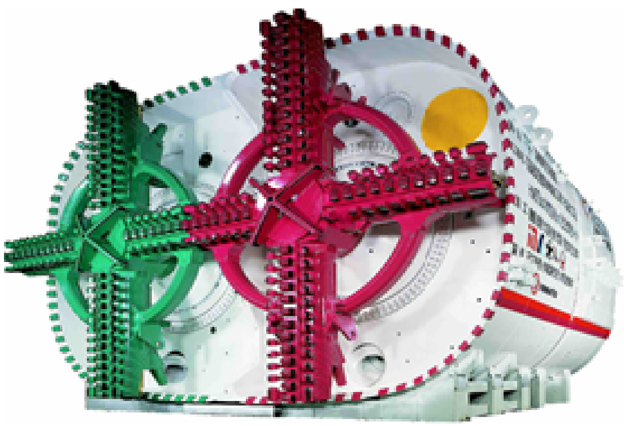

Figure 7. TBM with rectangular face used in Kyoto.

A feasibility study of horseshoe shape shield tunnel with large cross-section of about 190m^2 and the largest width of 19m was carried out for Hirakata Tunnel of New Meishin Expressway [18]. Concerning the excavation work of the horseshoe type of cross section, one of the cutting methods called DPLEX is recommended in this project. Cutter frames which were linked to the tips of multiple shafts are turned in parallel link motion by turning each crank shaft in the same direction [19].

URUP method [3] named from Ultra Rapid Under Pass method is employed to construct the underground road, the underpass beneath railway, road and utilities without necessary of open cut or launching and arriving shafts. This method contains a special EPB which can drive from the surface into ground and come out to the surface at the arrival point directly. Through the whole driving stage, small settlement control is possible as same as a normal EPB.

H&V type shield [20] can be separated into two individual ones during the boring which make it possible to drive spiral line with each other tunnels. The principle of H&V shield is to connect two circular shields which can be controlled independently using detachable connecting mechanism. The launch of such type of shield is nothing special with the ordinary shield, and the connecting pin or bolts can be detached inside the machine when the drive need to be split apart. By adopting cross articulation jacks, the rolling of the machine can be controlled and the spiral driving becomes possible.

Multi-directional Shield Tunneling Method[19] make it possible to change driving direction of shield in any pattern, such as vertical to horizontal, horizontal to horizontal and horizontal to vertical using a single machine. By this method the access shafts at turning point can be eliminated. Excavation can be executed by a TBM continuously from the ground surface, firstly in the vertical then change into horizontal to drill the adit. This method performs the functions of caissons or diaphragm walls required by conventional methods of driving a vertical shaft, so it contributes to easier construction, shorter construction period and reduced cost. This method is highly effective in underground spaces below congested intersections or space occupied by buried structures where no vertical shaft can be driven for rotating the shield machine.

In **Harmonica Tunneling Method** [21], mini rectangular EPB type of TBM is used to excavate the ground along the designed alignment in sequence. Finally a box tunnel with large cross section is formed by connecting the neighboring small box tunnels. The concept is that the tunnel section is equally divided into smaller portions in a grid pattern, which are separately and repeatedly excavated one by one by the TBM. Adopting such ideas, this method can deal with excavation as long as 400m and curved alignment is also allowed.

3.2 Open Cut Method

Diaphragm Wall plays a very important role for safe and high quality construction by open cut method. To reduce leakage through the joints, new technologies as for the wall construction such as TRD Method, Self-pose controlled SMW (GST etc.) and a new type hydraulic RC diaphragm wall excavator equipped with attitude control system have been developed in Japan.

In these methods, **TRD method** (Trench cutting & Re-mixing Deep wall method) is one of the most innovative methods of the diaphragm wall. The machine for TRD method has a chainsaw style cutter which can penetrate into the ground. The trench is formed by moving the machine to the direction of the wall axis and cutting the ground at the same time. The excavated soil and cement slurry injected from the bottom of the cutter is mixed by the chain mechanism in the whole trench to provide temporary support to the ground. Reinforced steel H columns are sequentially inserted into the soil/cement slurry in the trench before it getting harden to complete the wall structure [4].

GST method (Geo-drilling Survey-control Technology)[22] can measure the real-time inclination of the borehole by the inclinometer which is installed at the auger shaft. The boring machine is able to modify the direction of boring mechanically under the controlling of computer system, so the value of inclination and displacement of the auger shaft would be controlled in an acceptable range during the construction.

3.3 Caisson

The Remote controlled Pneumatic Caisson method [23] has been developed originally in Japan in the 1990s. As unmanned remote controlled excavators with cameras were equipped in the work space which was filled by highly compressed air, it is possible to excavate in deep ground in environment of high pore water pressure with considerable safety.

3.4 Rotary all casing boring machine

Rotary all casing boring machine is equipped with the cutter bits made of super hard chip at the front end of cutting edge of the casing. This machine can provide very powerful torque so that it can get rid of the obstructions such as reinforced concrete or the blocks of rock underground by breaking, cutting them with the cutters and removing them with the hammer grab, while rotating and pressing the casing into the ground.

4. SOIL IMPROVEMENT AND GROUND WATER TREATMENT

4.1 Soil Improvement

Soil improvement methods for the underground construction could be classified into the following categories based on the improving mechanism. (1) Jet grouting (CJG, Supper Jet, MJS, PJG, Cross Jet, DJM, etc.); (2) Cement mixing in deep ground (Soil mixing wall, CDM, SDM etc.); (3) Injection grouting (Chemical grouting, Permeability grouting, Dry cement grouting etc.); (4) Bio-improvement (BioSealing, BioGrouting).

(1). JGP (Jet Grouting Pile) [24] adopts high pressure to jet cement milk into soil to form cement column. Although by the traditional JGP method, columns with small diameter of about 1m, and also the inconsistent columns in hard and dense ground can be constructed, it may be not so competent in cases that stable and waterproof seal is required at launching and receiving shaft and tunnel face with intervention etc. New types of JGP involving CJG(Column Jet-Grout Method), Supper Jet, MJS(Metro Jet System), PJG(Pendulous Jet Grout), Cross Jet, DJM(Dry-Jet-Mixing), etc. with extremely high pressure pumped up to 40MPa have been developed.

CJG [25] method can constructs cylindrical body of 1.0~2.0m diameter by using the high pressure water jet, the compress air and the stabilizer. In this method ground was cut by the compressed air accompanied with high pressure water jetting from a monitor attached to the front of the triple tube rod, and filled with the stabilizer from the bottom of the rod while pulling and rotating the rod. The CJG is suitable for soil improvement in depth of 25m or in the ground such as gravel layer, where the traditional Jet Grout method is difficult to be used.

Super Jet [26] improves the ground by using two kinds of fluids including compressed air and the stabilizer. This method jets a large amount of slurry with a very high pressure from the tip of the rod. As a result, larger diameter columns can be produced within short period and the cost can be reduced. The standard specification can generate columns in 5m diameter with strength as 6 times stronger than those produced by normal JGP and the spoil can be reduced by 40%.

MJS[5] inherits the merit of an ordinary high pressure injection mixing method. In addition, the pressure meter device and the porous pipe are newly developed to overcome the drawbacks of the traditional high pressure injection mixing method. The most excellent feature of this method is the excretion mechanism of the sludge. As a result, all-direction construction from the horizontal to the perpendicular plane became possible.

PJG (Pendulous Jet Grout)[27] can construct the columns at an arbitrary angle like semi-column by using a hexagonal rod according to the improvement purpose. It serves to shorten the construction period and saves the stabilizers by reducing the sectional area of the column.

Cross Jet[28] is a method that controls the range of the improvement by intersecting the supper high pressure jet, and makes a uniform column of 2.5m diameter. Cross jet constructs the column of a constant improvement diameter regardless of the type of soil and the hardness of the ground, which is not possible for conventional methods.

(2). CDM(Cement deep mixing)[29] is a ground improvement method which mixes cement slurry with soft soil in situ to attain a required strength. This method can deal with grounds in large areas and at a depth reaching about 30m, with lower cost than other alternatives. In order to alleviate the ground deformation, the improved type of CDM was developed which equipped screw flights around the upper part of the mixing rod to remove soil from the ground as the augers being installed.

SDM (Super Deep Mixing) method [30] is a combined type of soil improvement method which uses the mechanical mixing together with a high injection pressure, and it results in a large diameter improved body. In addition, by removing the soil by a special auger screw ground movement during construction can be reduced.

(3). The penetrating grouting method [31] was developed for strengthening soft soils based on the double-pipe double packer method. This method can maintain the stable improvement effect for a long term by injecting grouting material with low injection pressure, which is the basis of penetration, using a way to penetrate the grout between the soil particles without destroying the soil structures as much as possible. The largest diameter of the improvement body is about 4m in a sandy ground.

(4). BioSealing [2] is a natural method which can reduce permeability of soil on site. Water leaks in retaining structures can be easily and efficiently prevented. In addition, natural water retaining layers like peat and clay layers can also be sealed. Compared with traditional repair methods, BioSealing does not require injection at the exact location of the leakage. The injection position should only be located in the area where the groundwater flow is directed towards the leakage. The main application areas of BioSealing are excavations, tunnels, wells and salty seepage and leaking of dams. To initiate the BioSealing process, nutrolase are injected into the ground and be transported to the leak with the groundwater flow. The nutrolase mainly stimulates the microbiological activity in the soil at the leakage as shown in Figure.8. Because the flow at the leakage location is highest, a continuous replacement of nutrients occurs, thus a higher concentration of nutrients. This results in the formation of bioslime and mineral deposition in the leakage, so as to block the soil particles.

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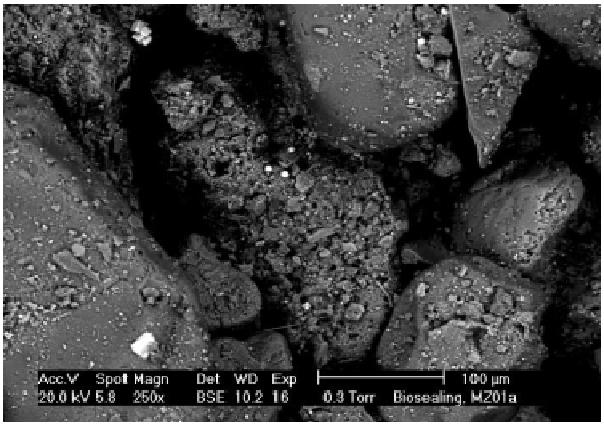

Figure 8. Micro-scope image of BioSealed sample.

BioGrouting[32] is a new ground improvement method based on induced precipitation of calcium carbonate crystals microbiologically. It is an in-situ cementation process to strengthen the soil using calcium carbonate or silicate crystals, depending on the type of the soil. To strengthen sand-soils microbial induced calcite precipitation is used. In this process a lab-culture of soil-bacteria is injected into the ground together with a solution of urea and calcium. These bacteria convert urea into carbonate, which will precipitate with the calcium forming calcite. The calcite crystals precipitate on the sand grains and will form “bridges” between the grains causing cementation, and thus the strength and stiffness of the soil mass will increase. The strength of calcite-precipitated sand is adjustable between 250kPa and 30MPa, without causing a decrease in the porosity. One of the remaining issues is that the remaining ammonium chloride will be extracted during the BioGrouting process. Figure.9 shows a series of tests on BioGrouting done in the past

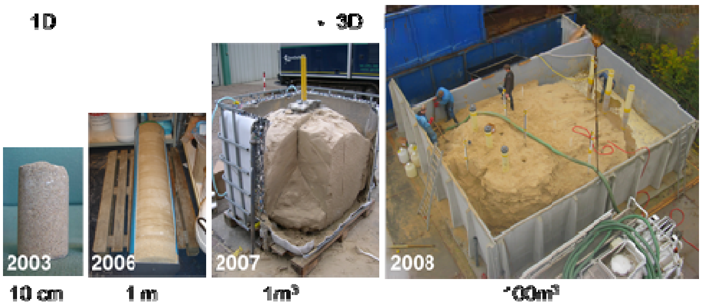

Figure 9. Development of improvement soil by BioGrouting.

4.2 Groundwater treatment and groundwater flow preservation

Super Well Point Technology[7]
All ordinary methods of drainage, such as Well Point (forced drainage), Deep Well (gravity drainage), and Vacuum Deep Well (gravity drainage + forced drainage), have their drawbacks. However, a new method named Super Well Point method (SWP) highly improved from the vacuum deep well method has eliminated these drawbacks. It enables to forcibly drain keeping vacuum in the well due to a specially designed double-pipe strainer. SWP allows us to drain at the great deep point of the well. Discharge volume capability of SWP is increased by 1.2 to 10 times comparing with normal deep well method. SWP enables faster groundwater level drawdown within a wider area.

Groundwater flow preservation method[33]
When the aquifer is intercepted by an earth retaining wall or a long linear underground structure such as the tunnel, the groundwater flow will be obstructed, and consequently the groundwater table rises on the upstream side, and falls on the downstream side. As a result, the groundwater infiltrates to the basement on the upstream side, and uplift acts on the underground structure. Moreover, the liquefaction resistance decreases owing to the rising of the groundwater level. On the other hand, the drawdown of groundwater table occurs on the downstream side, and it causes the dried-up of the well and the settlement of the ground. Therefore, groundwater flow preservation countermeasures which consist of intakes, water conduction pipes and recharge facilities are necessary. Nowadays, a common method is to make a way for groundwater flow through the underground constructions freely in order to minimize the influence of the nature groundwater flow from upstream to downstream. Figure.10 shows the conceptual diagram of the groundwater flow preservation countermeasures.

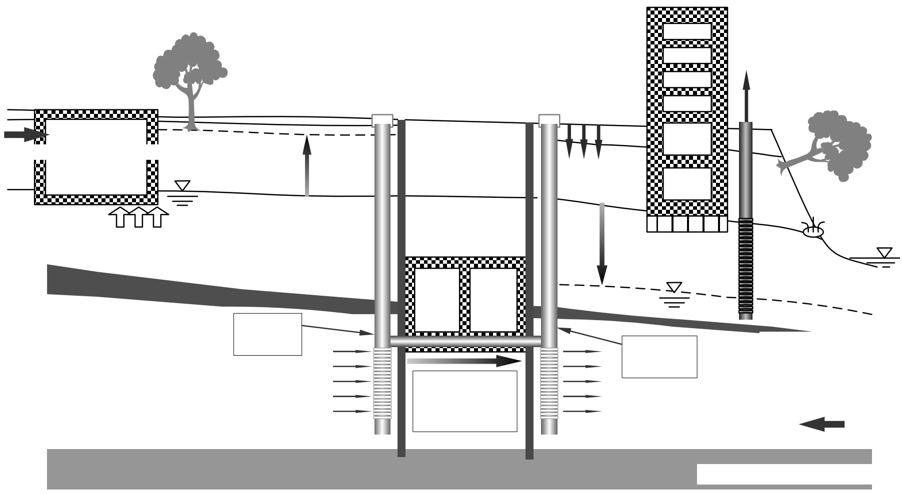

Figure 10. Conceptual diagram of a groundwater flow preservation measure

5. SUMMARY

This paper introduces some new technologies for underground constructions in urban area, including the site investigation and monitoring, tunneling and underground construction, soil improvement, groundwater treatment and groundwater flow preservation. By using these technologies effectively, it is possible to contribute not only to the safety, the economy and the quality securing, but also to the mitigation of the adverse influence to the environment during and after constructions. And it is believed that it is more than a challenge for us while encountering the troubles with development of underground construction.

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