

**NEW TECHNOLOGIES FOR UNDERGROUND CONSTRUCTION IN  
SOFT GROUND OF URBAN AREA**

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**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 the technologies for underground construction 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 technologies developed in Japan. It is hoped that these technologies can meet the demands to develop the underground constructions in an economic efficient way with little influence on the environment 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.

**Key words:** soft ground, site investigation, monitoring, tunneling, underground construction, soil improvement, groundwater treatment

**1. INTRODUCTION**

In Asian megacities such as Tokyo, Osaka, Shanghai and Singapore normally with soft ground, it is getting more and more popular to utilize the underground space exceeding a depth of 30m, for the purposes of subway, underpass road, underground shopping center, and water supply and sewage service system. In order to meet the demands of the deep underground space development, new technologies such as the slurry wall, soil improvement, the 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, collapses or other troubles occurred by accident and became issues during construction. Therefore, it is necessary to introduce new underground construction technologies including site investigation, on site monitoring, tunneling, soil improvement, groundwater treatment, etc.

The geo-tomography is one of a newly developed site investigation techniques, which can provide continuous and detailed investigation on site. In urban areas with the heavily congested

underground structures, new techniques of obstacle detection and monitoring technology during or after construction are necessary. The optical fiber and wireless monitoring system such as Micro Electro Mechanical Systems have been recently developed and applied into practical use. The electrical measurement of Electrochemical Response System/Electrical Flux Tracer System (ECR/EFT) is an effective way to detect leakage zones which might cause accidents in underground constructions<sup>[1]</sup>.

New technologies of tunneling are developed according to the different purposes and different construction environment in urban area. Multi-faces TBM, H&V shield, DPLEX shield, etc., are the typical tunneling technologies developed in recent decades. In addition, some new methods of underpass construction had also been developed, such as the Ultra Rapid Under Pass, the Jack culvert method. For tunnels with large section, it can be constructed by the Harmonica method which employs several assembling shields with small rectangular cross-section. Extruded Concrete Lining method is a new lining technique to construct the lining in site instead of the conventional precast segment.

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. As a new type of soil mixing wall method, the Trench cutting Re-mixing Deep wall method<sup>[2]</sup> 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 so 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 system which can work safely under large depth with high hydraulic pressure.

Technical improvement on soil improvement methods such as grout injection, cement deep mixing method and jet grout is also remarkable. The improved column performed high strength with large diameter exceeding 4m could be produced in ground by a jet grouting method using a high-pressure grouting pump. Moreover, by using a Metro Jet System<sup>[3]</sup>, a horizontal improved column could be constructed.

A new type of soil improvement methods using bio-techniques has been developed in the recent years, named as “BioGrouting”<sup>[4]</sup> and “BioSealing”<sup>[5]</sup>. The former can improve the stiffness and strength of soil mass, and the latter can clog the seepage path of ground water flow by promoting the proliferation of some kinds of bacteria in the ground. The Super Well Point method combined advantages of vacuum well point and Deep Well method, has been implemented into practical as a dewatering method in deep ground<sup>[6]</sup>.

## **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 economy and safety of construction. The essential information for design and construction, such as the soil properties and underground water, is usually obtained through boring survey, 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. Moreover, 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.

To solve these problems, some site investigation technologies have been developed. Some of them listed 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 and 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. Two boring holes are used to set the vibration source and multi-channel receiver separately. The ground between the pair of the holes can be visually in two dimensions by detecting the distribution of the resistivity and velocity.

**The acoustic tomography method**<sup>[7]</sup> using the acoustic wave with very high frequency of more than 1kHz is used to detect the distribution of *P*-wave velocity and the attenuation rate of amplitude which reflects the ground properties. Figure 1 shows one of the results 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.

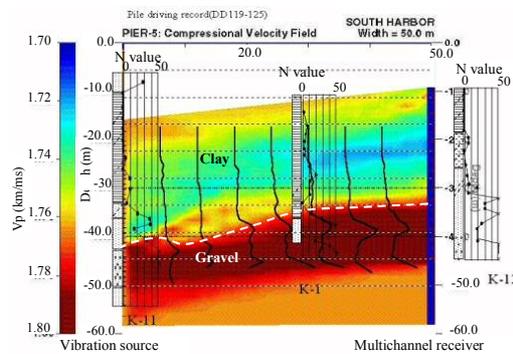


Figure 1. A velocity imaging of acoustic wave tomography.

**2). HSP (Horizontal Seismic Profiling)**<sup>[8]</sup> is one of the effective investigation method for tunnel construction. Seismic wave is sent out from the cutting face of tunnel and reflection is recorded. Based on the analysis, the location of the faults in front of the cutting face can be identified.

**3). Control boring** is a technology that the drilling direction can be arbitrarily controlled during boring. It is effective on some investigation points where working space is restricted. The boring direction can also be controlled to be horizontal if it is necessary<sup>[9]</sup>.

4). **Rotary sounding test and Rotary percussion drilling test**<sup>[9]</sup> 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 ground with high water pressure. **ECR/EFT**<sup>[1]</sup> is one of the effective technologies to detect leakage. Kinds of ion dissolved in groundwater induce the measurable electric field. Taking advantage of this property, ECR method can identify and locate the leakage by measuring the electric potentials. 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 (see Figure 2). 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.

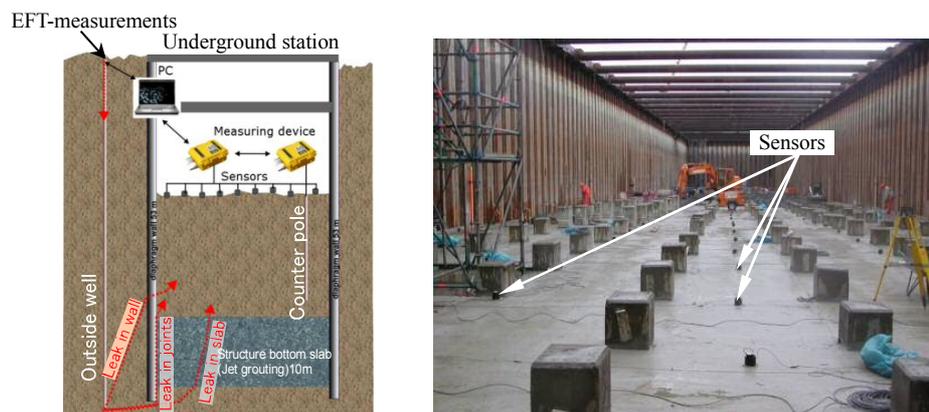


Figure 2. Scheme of leaks detection by ECR/EFT.

## 2.2 Monitoring<sup>[10]</sup>

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 observation play a very important role. The 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 the durability, waterproof and great measuring range of 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 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. A range of MEMS sensors is now available in civil applications, which can measure acceleration, inclination, temperature and pressure.

**2). Optical fiber sensor** (B-OTDR) 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. Compared with other measurement sensors, the optical fiber has the advantages of durability, noise resistance and long-distance transportation.

**3). A hydraulic pad-type earth pressure meter**<sup>[11]</sup> 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 universal displacement meter**<sup>[12]</sup> 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**<sup>[13]</sup> 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**

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. Responding to the above demands for the shield tunneling, new specified technologies, cutters, seals, backfill grouting and driving control systems for TBM and many kinds of joint systems of segment for the lining of tunnel, have been developed and led to 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. Harmonica method, URUP method, etc., make it possible to build large cross sectional underground space with less impact on the surroundings. They are the typical underpass tunneling methods. 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. This type of shield machine is basically made from a combination of multiple circular shield machines. The double or triple circular cross sections are overlapped so that it can provide more efficient useable space compared with the conventional circular tunnels next to each other. Some of the subway stations had been constructed by the multi-faces TBMs. For example, Figure 3 shows a three-faces TBM employed in a construction of station of Osaka subway in 1995<sup>[14]</sup>. It was the first application example of this kind of TBM in Japan and finally the multi-faces TBM worked successfully in this project. After that project, TBMs with three faces and four faces had been effectively employed in the construction of underground station in Tokyo.

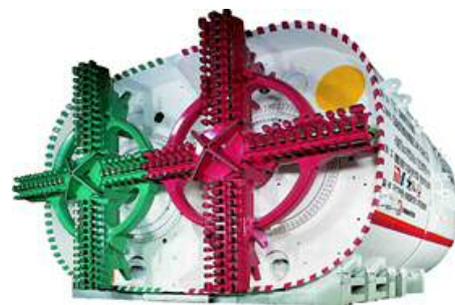


Figure 3. TBM with 3 faces used the construction of Osaka Business Park station in line-7. Figure 4. TBM with rectangular face used in Kyoto.

**Noncircular face TBM** used in practice is sorted into three types with different shape of faces, such as rectangular, elliptic and horseshoe 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 line-13 between two stations. The reason for using this kind of TBM 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 was used to construct the tunnel (shown in Figure 4). By employment of the rectangle shield with a sectional area of  $60\text{m}^2$ , the amount of muck, that is, excavated soil, was reduced by 20 %. Besides, a feasibility study of horseshoe shape shield tunnel with large cross-section of about  $190\text{m}^2$  and the largest width of 19m was carried out for Hirakata Tunnel of New Meishin Expressway<sup>[15]</sup>. Concerning the excavation work of the horseshoe type of cross section, one of the cutting methods called DPLEX (Developing Parallel Link Excavation) was recommended in this project. Cutter frames linked to the tips of multiple shafts with eccentricity were turned in parallel link motion by turning each crank shaft in the same direction.

**URUP method**<sup>[16]</sup> named from Ultra Rapid Under Pass method is employed to construct the underground road, the underpass beneath railway, road and utilities without open cut and launching and arriving shafts. This method contains a special EPB which can drive from the surface to the underground directly and come out to the surface again at the arrival. Therefore, the construction period could be shortened comparatively. Throughout the whole driving stage, little ground settlement control is possible as same as a normal EPB. Figure 5 shows the procedure of construction by URUP method.

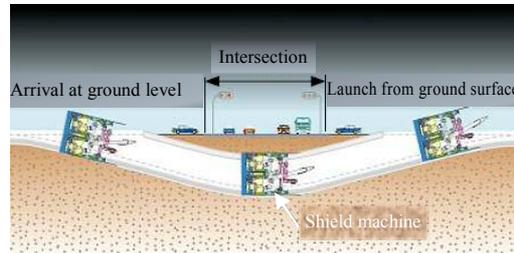


Figure 5. URUP method.

**H&V type shield**<sup>[17]</sup> can be separated into two individual ones along the driving which makes it possible to drive spiral line with each of tunnels in pare (see Figure 6). 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 one, and the connecting pins 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.

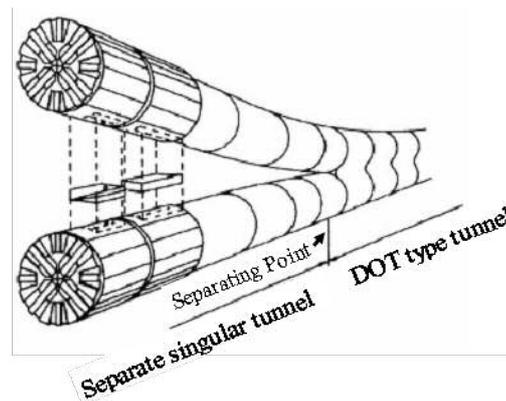


Figure 6. H&V shield and Up-down shield.

**Multi-directional Shield Tunneling method**<sup>[18]</sup>, that is possible to drive at any directional change such as vertical to horizontal, horizontal to horizontal and horizontal to vertical using a single machine, has been developed to eliminate access shafts at turning points. Excavation is executed by a TBM continuously from the ground surface first in the vertical shaft then in horizontal for the adit (see Figure 7). 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 underground structures where no vertical shaft can be driven for rotating the shield machine.

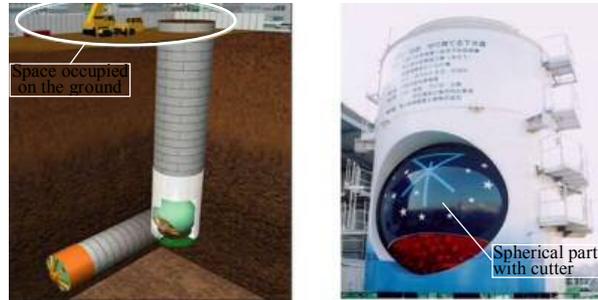


Figure 7. Multi-directional Shield Tunneling Method.

**ECL Method** (the Extruded Concrete Lining)<sup>[18]</sup> is applicable to the construction of high quality linings with concrete by cast-in-place method at the shield tail instead of precast segment. Flowing concrete is extruded to the tail of shield machine by a pressure equivalent to the combined force of water and earth pressure simultaneously with the shield advancement. The biggest advantage is that the linings can be closely contacted to the ground so that the ground settlement or ground loosening can be minimized. The extruded concrete ensures the water-tightness at the tail of shield. The thrust force of shield jacks is supported by the friction between concrete lining and internal frameworks.

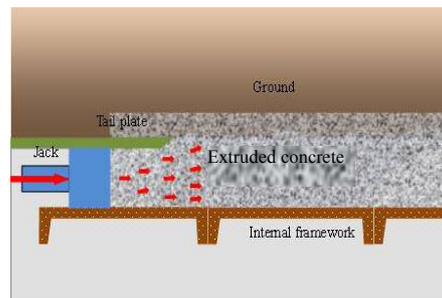


Figure 8. ECL method.

### 3.2 Jacking Culvert Method<sup>[19]</sup>

Jacking Culvert Method (SFT, Harmonica method, etc.) is an efficient method in underpass construction. For example, the SFT method (Simple and Face-Less method of construction of tunnel) thrusts the box culvert from the launching shaft to the arrival shaft under the protection of a box roof. The box roof is consisted of small box tubes which were jacked previously into the ground coinciding with the outer edge of the cross-section of the culvert. Steel FC-plate (friction cut plate) was attached on the surface of the box roof and was jacked into ground together. Then, the FC-plate is separated from the box roof and fixed in place before jacking the culvert, so that the resistance of jacking the culvert can be minimized. Moreover, the culvert is thrust simultaneously at tail of the box roof which containing the soil sealed inside. So there is no necessary of excavation at the tunnel face. The application of SFT method provides higher safety for underpass construction under shallow overload.



Figure 9. SFT method.

In **Harmonica Tunneling Method**<sup>[20]</sup>, mini rectangular EPB type TBM is used to excavate the ground along the designed alignment in sequence and the final box tunnel is formed by connecting the neighboring small box tunnels (as shown in Figure 10). The concept is that the tunnel section is equally divided into smaller portions in a checkered pattern similar to each other, 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.

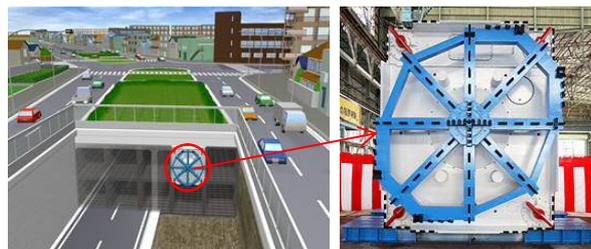


Figure 10. Harmonica Tunneling Method.

### 3.2 Open Cut Method

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

In these methods, **TRD method**<sup>[21]</sup> (Trench cutting & Re-mixing Deep wall method) is a most innovative method of the diaphragm wall. The machine for TRD method has a chainsaw style cutter which can penetrate into the ground (see Figure 11). The trench is formed by moving the machine along 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 then inserted into the trench in sequence before the soil/cement slurry has hardened to complete the wall structure.

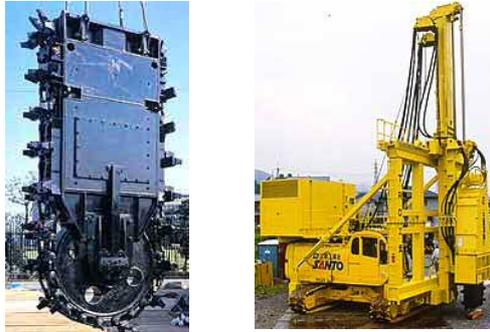


Figure 11. TRD method machine.

**GST method** (Geo-drilling Survey-control Technology method)<sup>[21]</sup> can measure the real-time inclination of the borehole by the inclinometer which is installed at the auger shaft. Furthermore, the boring machine is able to modify the attitude of the boring mechanically under the control of computer system, so the value of inclination and displacement of the auger shaft would be kept in an acceptable range during the construction. Figure 12 shows the comparison of piles drilled by conventional method and GST method.

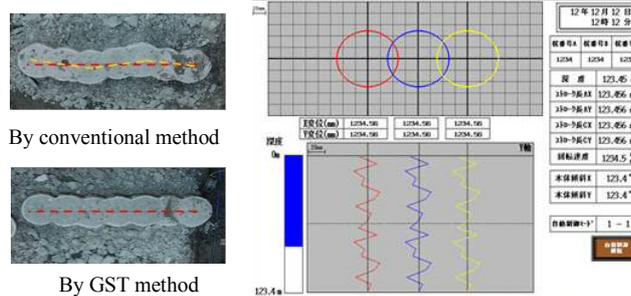


Figure 12. Verticality control system of GST method.

### 3.3 Other construction methods

#### 1). Caisson

The Remote controlled Pneumatic Caisson method<sup>[22]</sup> was developed originally in Japan in 1990s. As unmanned remote controlled excavators with cameras were equipped in the work space under high air pressure, it is possible to excavate with considerable safety into deep ground with high pore water pressure. Figure 13 is a scheme of the Remote controlled Pneumatic Caisson

#### 2). Rotary all casing boring machine

Rotary all casing boring machine is equipped with the cutter bits which have super hard chips at the front end of cutting edge of the casing (see Figure 14). This machine has 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.

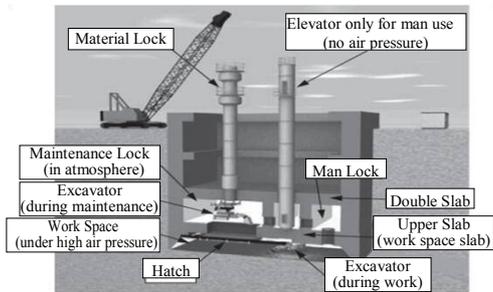


Figure 13. The Remote controlled Pneumatic Caisson.



Figure 14. Rotary all casing boring machine.

## 4. SOIL IMPROVEMENT AND GROUND WATER TREATMENT

### 4.1 Soil Improvement

Soil improvement methods for the underground construction could be grouped into the following categories based on the improving mechanism. 1). Jet Grouting Pile (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)**<sup>[23]</sup> adopts high pressure to jet cement milk into soil to form cement column in the ground. Because routine type of JGP usually forms inconsistent columns with small diameter of about 1m in hard and dense ground, it may be not so competent in cases that stable and waterproof seal is required, for example at the launching and receiving shaft or the tunnel face with intervention, etc. New types of JGP method with extremely high pressure pumped up to 40MPa have been developed, involving CJG(Column Jet-Grout method), Supper Jet, MJS(Metro Jet System), PJG(Pendulous Jet Grout), Cross Jet, DJM(Dry-Jet-Mixing), etc.

**CJG**<sup>[24]</sup> constructs a cylindrical body of 1.0~2.0m diameter by using the high pressure water jet, the compressed air and stabilizer. In this method, the ground is cut by the air accompanied with high pressure water jetting from a monitor attached to the front of the triple tube rod. The stabilizer is injected simultaneously from the bottom of the rotating and rising rod. The CJG is suitable for soil improvement in depth of over 25m or in gravel layer where it is difficult for the previous Jet Grout method.

**Super Jet**<sup>[25]</sup> improves the ground by using two kinds of jetting flows including the compressed air and the stabilizer. The slurry is jet with a very high pressure and a large amount from the tip of the rod. As a result, this method can construct larger diameter columns, and the construction period and the cost can be reduced. Column with 5m diameter can be constructed by the standard specification. The strength of columns is 6 times stronger than those produced by normal JGP and the spoil is reduced by 40%.

**MJS** 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 limitations of the traditional high pressure injection mixing method. The most excellent feature of this method is the sludge system, which makes it possible to construct in all direction from the horizontal to the vertical direction.

**PJG** (Pendulous Jet Grout)<sup>[26]</sup> can control the direction of jetting flow by using a hexagonal rod to construct columns with the cross section of not only circle shape but also sector shape of arbitrary angle according to the improvement purpose. This method provides merits shortening the construction period and saving the stabilizers by reducing the sectional area of the column. Figure 16 shows a scheme of PJG method.

**Cross Jet**<sup>[27]</sup> is a method that controls the range of improvement by intersecting the super high pressure jet, and makes a uniform column of 2.5m diameter (as shown in Figure 15). 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.

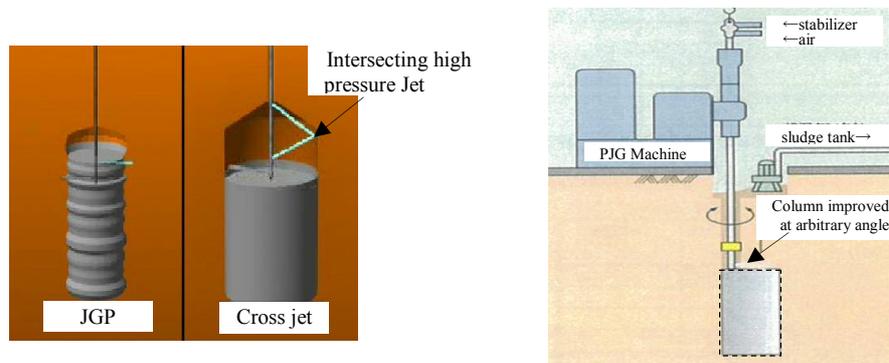


Figure 15 Comparison of ordinary JGP and Cross Jet. Figure 16. Improvement mechanism of PJG.

**2). CDM** (Cement deep mixing)<sup>[28]</sup> is a ground improvement method which mixes cement slurry with soft soil in situ to attain a certain 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 when the augers are installed.

**SDM** method (Super Deep Mixing)<sup>[29]</sup> is a hybrid type of soil improvement which uses the mechanical mixing together with a high injection pressure. A large diameter body can be constructed by this method. In addition, the ground movement during construction can be reduced by removing the soil using the special auger screw.

**3). The permeability grouting** method<sup>[30]</sup> was developed for strengthening soft soils based on the double-pipe double packer method. This method can maintain the stability improvement effect for a long term. Grout is injected into ground with low injection pressure, which is the basis of penetration, to make the grout penetrate the gap between the soil particles so as to avoid destroying the soil structures as much as possible. The largest diameter of the improvement body is about 4m in a sandy ground.

4). **Bio-improvement** is new type of soil improvement method including BioSealing and BioGrouting etc. **BioSealing**<sup>[5]</sup> is a natural method that enables soil permeability to be influenced on site. Groundwater leaks in retaining structures are easily and efficiently prevented by using this method. In addition, natural water retaining layers like peat and clay layers can be sealed. Compared with traditional leakage repair methods, BioSealing does not require injection at the exact location of the leak. The injection position should be situated in the area where the groundwater flow is directing towards the leak. The main application areas of BioSealing are excavations, tunnels, wells and salty seepage and leaking of dams. To initiate the BioSealing process, nutrient will be injected into the ground and transported to the leak with the groundwater flow. The nutrient mainly stimulates the microbiological activity in the soil at the leak (as shown in Figure 17). Because the flow at the leak is the highest, a continuous replacement of nutrients occurs, then causing a higher concentration of nutrients. This results in the formation of bioslime and mineral deposition in the leak, so as to block the soil particles.

**BioGrouting**<sup>[4]</sup> 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. For 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 18 shows a series of experiments of BioGrouting.

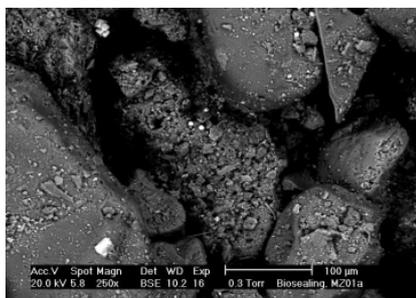


Figure 17. Micro-scope image of BioSealed sample.

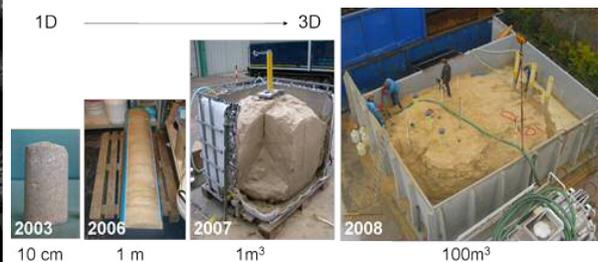


Figure 18. Development of improvement soil by BioGrouting.

## 4.2 Groundwater treatment and groundwater flow preservation

### 1). Super Well Point Technology<sup>[6]</sup>

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.

## **2). Groundwater flow preservation method<sup>[31]</sup>**

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.

## **5. SUMMARY**

This paper introduces some new technologies for underground constructions in urban area, including the site investigation and monitoring, tunneling and other underground constructions, soil improvement method, groundwater treatment and groundwater flow preservation. These new technologies developed taking the advantage of the progress of electronic technology, modern electrical signal and control technology, and also bio-technology, etc. And the technologies provide more functions, more wide usage and more safety for construction. In sequence, the underground space can be utilized efficiently, economically and in eco-friendly way. By using these technologies effectively, it is possible to contribute not only to meet the demands of development of new underground constructions in each megacity but also for the cities in their developing way by sharing these new technologies.

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