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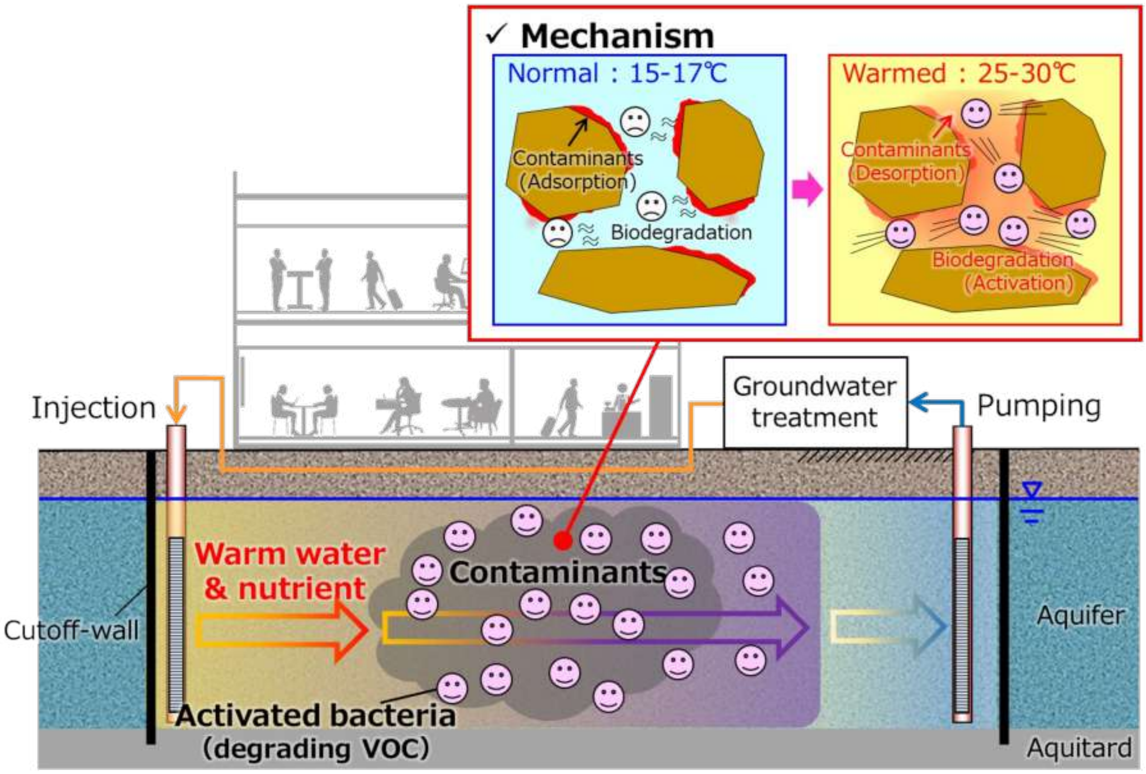
Thermally enhanced bioremediation for VOC-contaminated soil
In-situ remediation technology with low carbon dioxide (CO_2) emissions



CONTENTS

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25th Infrastructure Technology Development Award 2023

Japan Institute of Country-ology and Engineering (JICE) was established as a public interest corporation to promote construction engineering in Japan by conducting cutting-edge research and development activities.

JICE is performing the Infrastructure Technology Development Award with the Center for Coastal Development Technology (CDIT), with the support of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

This Award recognizes outstanding new technologies related to the construction industry, with the aim of increasing the motivation for research and development among technology developers and improving the level of construction technology.

In principle, the applicants' technologies should have been developed within the past five years and applied to the real sites already.

31 technologies competed for the 25th Infrastructure Technology Development Award.

As a result of examination, institutes and researchers with the following technologies were awarded 25th prizes.

The grand prize is "Thermally enhanced bioremediation for VOC-contaminated soil".

And the two excellence prizes are "Ground Thermal Utilization Technology Using Precast Piles, and "Tunnel-constructing technology by making the tunnel's outside shell precede, while using the joints which are able to respond to the behavior of groundwater".

These technologies are introduced sequentially on the following pages.

Any inquiries/ comments please contact to JICE :
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Thermally enhanced bioremediation for VOC-contaminated soil

In-situ remediation technology with low carbon dioxide (CO_2) emissions

1. Background and Opportunities for Technological Development

In Japan, an estimated 28,000 ha of land, referred to as brownfields, cannot be developed because of soil contamination (Figure-1). Brownfields often become useful for urban development if the soil contamination is remediated. However, the problem tends to increase if the contamination involves volatile organic compounds (VOC) because the contamination is deep and can widely spread. The most common remediation method for soil contamination (60% of cases) is soil excavation and removal. This method is costly and can negate redevelopment benefits. On the other hand, there is an in-situ remediation technologies called bioremediation that uses VOC-degrading bacteria. It is a low-cost method of soil remediation, but the long remediation time required is often incompatible with the redevelopment process. Consequently, the contaminated land remains underutilized.

Figure-1 Contamination sites in Japan

Japan aims to achieve carbon neutrality by 2050, creating a "virtuous cycle of economy and environment". To realize this goal and in response to the increasing environmental awareness of Japanese society, there is a growing need to reduce environmental impacts, particularly carbon dioxide (CO_2) emissions in various sectors, including the real estate sector, where a revitalization of the economic activity is expected through the redevelopment of brownfield sites using in-situ remediation technologies. To this end, a low-cost technology that can be quickly implemented to remediate contamination and reduce CO_2 emissions is essential. This need has led to the development and deployment of the present technology.

2. Contents of the Technology

The proposed technology is a low-cost, environment-friendly, in-situ remediation technology that uses indigenous VOC-degrading bacteria. It does not require large-scale soil excavation and removal (Figure-2) and has two features: 1) warm water injection to raise the soil temperature to 25°C–30°C, which is the optimum temperature for VOC biodegradation; 2) mixing of a fluorescent tracer in the injection agent with a nutrient to visualize the injection status and uniformly control the temperature and nutrient concentration in soil, even in heterogeneous ground. Figure-3 shows the results of the degradation-promoting effect of warming.

The abovementioned features possibly shorten the remediation period and improve the remediation accuracy. In addition, remediation can be performed even on sites where above-ground buildings exist and cannot be removed by excavation.

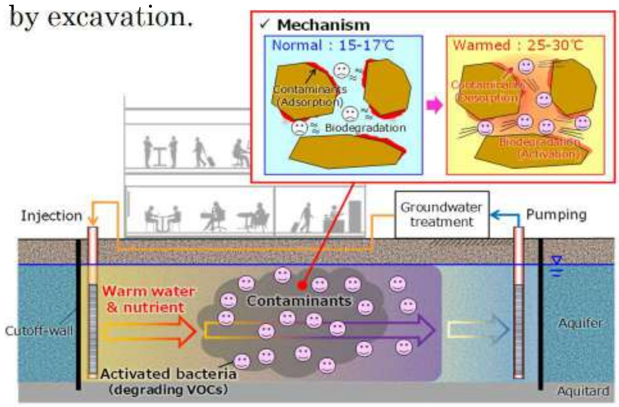


Figure-2 Overview of thermally enhanced bioremediation system

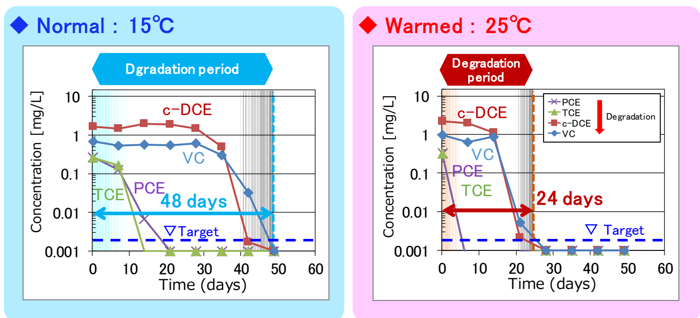


Figure-3 Promotion of warming-based decomposition (laboratory test)

3. Scope of Application of the Technology

The target contaminants were VOC. The target soil was a sandy soil layer (aquifer) with a wide VOC distribution.

4. Effects of the Technology

(1) Application to contaminated land

This technology has been applied to VOC-contaminated sites in Japan. Figure-4 provides an overview of the target sites and the implementation status. First, the soil was warmed by injecting it with warm water containing nutrients, and the groundwater was pumping up. The remediation progress was then confirmed. Real-time measurement of the nutrient concentration and the soil temperature, using a fluorescent tracer and a thermocouple, respectively, and injection control enabled the maintenance of stable nutrient concentrations and soil temperatures suitable for VOC biodegradation throughout the target area (Figure-5).

Figure-4 Contaminated site applying this technology

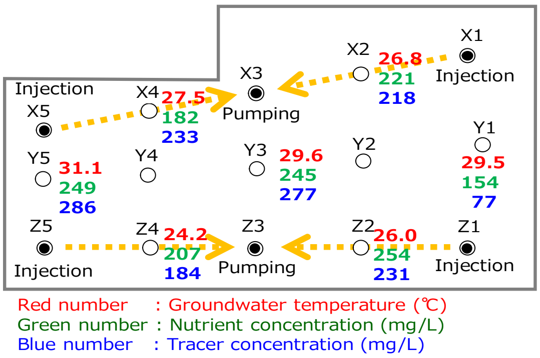


Figure-5 Temperature in ground and distribution of warmed nutrient

VOC concentration in groundwater dropped below the target value, 12 months after the remediation started, and did not increase again for 6 months (Figure-6); VOC concentration in soil was below the target value, 20 months after the remediation began.

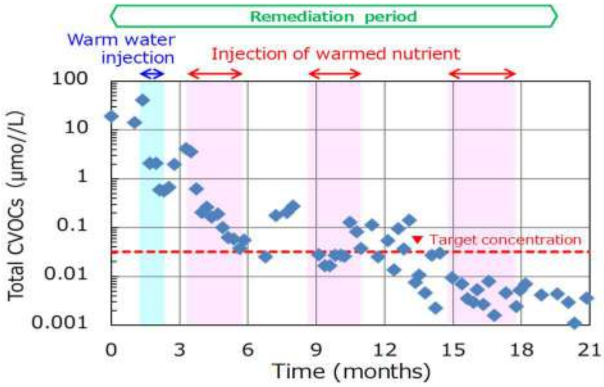


Figure-6 Change in VOC concentration over time

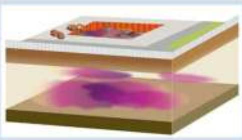
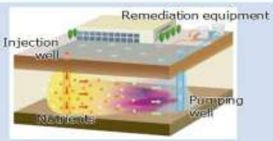
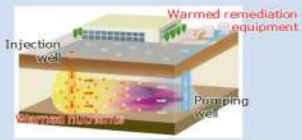
(2) Effectiveness compared to other technologies

Compared to other soil remediation technologies, the presented technology is advantageous concerning cost, time, and CO_2 emissions. Table-1 shows the remediation results for a contaminated site model. The soil volume was 12,000 m3 (40 × 30 × 10 m3), with 5-15 m depth. The technology has the following three advantages:

- remediation cost reduction to <50% and approximately 80% of the cost of excavation and conventional in-situ bioremediation.
- remediation time reduction to <50% of the time required for conventional in-situ bioremediation.
- CO_2 emission reduction to <50% and approximately 80% compared to excavation and conventional in-situ bioremediation.

Moreover, remote management is possible using digital sensors and controllers, reducing labor costs during the remediation period, and allowing the remediation to be performed while a building is in use.

Table-1 Comparison of the proposed technology with conventional technologies

Technology	Excavation and removal	Conventional in-situ bioremediation	Thermally enhanced in-situ bioremediation
Overview		 Remediation equipment, Injection well, Pumping well, Nutrients	 Warmed remediation equipment, Injection well, Pumping well, Warmed nutrients
Remediation period	0.5 year	4 - 10 years	**2 - 2.5 years**
Cost ratio※2	100	46	**37**
CO_2 emission ratio※2	100	51	**42**
Labor in operation (Workers)	–	5 - 10 people/week	**0.5 - 1 people/week**
Target soil type	Compatible with all soil types	Sandy soil (permeability coefficient 1×10⁻⁶ m/s or more)	Sandy soil (permeability coefficient 1×10⁻⁶ m/s or more)

*1 Estimated results of suppositional case (in JAPAN). Contaminated ground volume 12,000 m³ [Area 1,200 m² (40 × 30 m), Depth 5-15 m]
*2 Displayed as unit treatment price and CO_2 emissions per m³ of contaminated soil

5. Social Significance and Development Potential of the Technology

(1) Social Significance

Many cases in Western countries have promoted brownfield redevelopment as "redevelopment that solves urban problems and leads to revitalization," consequently creating a virtuous cycle for the local economy. This remediation technology allows rehabilitation to proceed while utilizing the land and buildings on site. Therefore, soil remediation can be carried out flexibly in accordance with the redevelopment project. Utilizing this advantage can contribute to promoting brownfield redevelopment.

(2) Development Potential

There are many soil-contaminated sites in countries other than Japan. For example, it is estimated that there are 250,000 sites in the EU that require remediation, and 500,000 to 600,000 brownfield sites in the United States. In particular, VOC-contaminated soil has become a social problem in many countries. Therefore, this technology can be expanded overseas by working with local environmental consultants.

The groundwater circulation system applied in this technology can be repurposed as a geothermal heat utilization system for utilizing geothermal heat as a heat source for air conditioning in buildings after remediation is completed.

6. Track Record of Application of the Technology

The new bioremediation technology described in this paper has been applied to three VOC-contaminated soil sites in Japan between 2017 and 2022.

This new technology is inexpensive, can be implemented rapidly, has fewer land use restrictions, and is expected to reduce CO_2 emissions. An optimal growth temperature can be established, and nutrients can be supplied to microorganisms capable of degrading VOC, even in heterogeneous ground. Concerning cost, remediation time, and impact on CO_2 emissions, this technology is advantageous when compared to conventional remediation technologies.

In the future, we aim to apply this technology to remediate brownfields, which are difficult to remediate using conventional technologies, and contribute to urban development by revitalizing brownfields.

Incidentally, The development of this technology was supported by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

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Ground Thermal Utilization Technology Using Precast Piles

Chinetsu Tornado Method

1. Background and Opportunities for Technological Development

Technologies (borehole methods and foundation pile utilization methods) that utilize geothermal heat, which is a renewable energy, are examples of measures for reducing CO_2 emissions and saving energy in the field of construction.

With the borehole method, the work of constructing boreholes to install the ground heat exchanger pipes takes a great deal of time and incurs tremendous costs, and the small size of the boreholes makes the pipes prone to thermal interference with each other, causing the problem of decreasing the heat extraction efficiency.

With the foundation pile utilization method, there were concerns that attaching ground heat exchanger pipes to the piles could have an impact on the characteristics of the pile bodies (cross section defects and the decrease in bearing capacity of the piles). In addition, ground heat exchanger pipes were exposed from the pile heads following pile construction, creating the possibility of a decline in construction efficiency during excavation work and damage to the ground heat exchanger pipes (Figure-1).

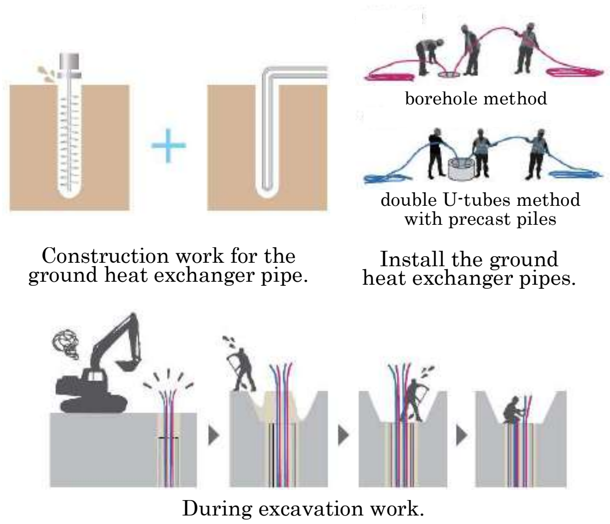

Figure-1 Issues with conventional construction methods

2. Contents of the Technology

This technology is a construction method that enables double spiral ground heat exchanger pipes (Photo-1) to be installed in the ground in parallel with pile construction work. Forming the ground heat exchanger pipe in a double spiral shape allows the ground heat exchanger pipe to extend and contract, so that the ground heat exchanger pipe, which is in a contracted state beforehand, can be installed in the hollow part of the piles, and then extended like a spring during pile construction, making it possible to more precisely install the ground heat exchanger pipe to a prescribed depth and position.

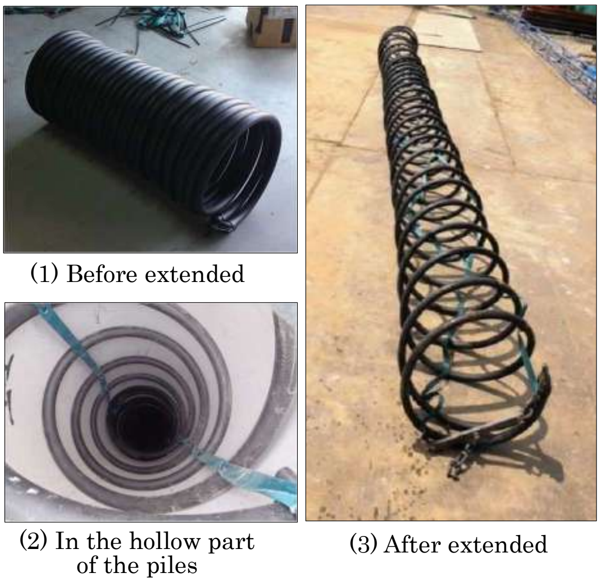

Photo-1 Double spiral ground heat exchanger pipes

As a pile hole is used, construction work for the ground heat exchanger pipe is not necessary like it would be in the borehole method, nor are dedicated workers, making it possible to save on both energy and personnel. In addition, because all the ground heat exchanger pipes are installed in the hollow part of the piles, concerns that ground heat exchanger pipes sticking out from the piles may be damaged during excavation work are also eliminated.

There are concerns about a decline in pile performance with regard to the ground thermal utilization technology for precast piles. With this technology, however, because the ground heat exchanger pipes are installed in the hollow part of the piles, there is no deterioration of friction resistance in the areas surrounding the piles, and there is no cross section defect in the pile bodies, which would affect the bearing capacity.

With regard to heat extraction performance, as well, the heat extraction efficiency has been improved over conventional technologies (Photo-2) by forming the ground heat exchanger pipes into double spirals, evenly maintaining the space between the pipes with a belt, and minimizing the thermal interference between the pipes by placing them in the vicinity of the inner wall of the piles.

3. Scope of Application of the Technology

This technology can be applied to precast piles, such as precast concrete and steel piles, having an outer diameter of 600 mm or greater. The maximum depth of installation when a ground heat exchanger pipe is in the extended state is 30 meters (the pipe length is approx. 200 meters).

4. Effects of the Technology

As this technology does not require processing or joining work of ground heat exchanger pipes at construction sites (Figure-2), adding only several minutes to the amount of time normally taken for construction work on each pile joint, it does not have an impact on the number of working days normally needed for the construction of piles.

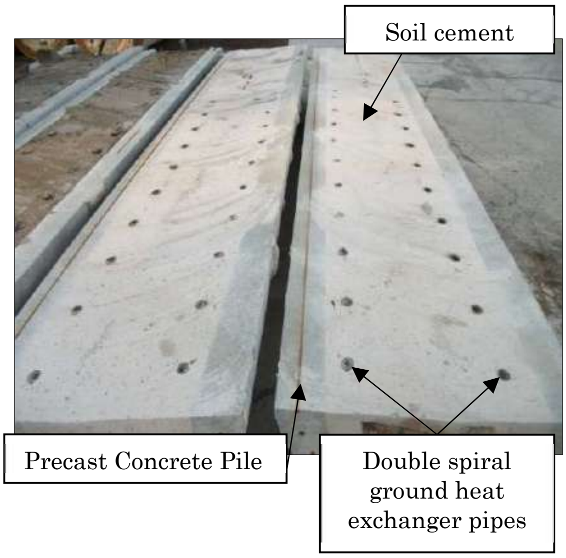

Photo-2 Digging up the piles after construction, cut in half lengthwise

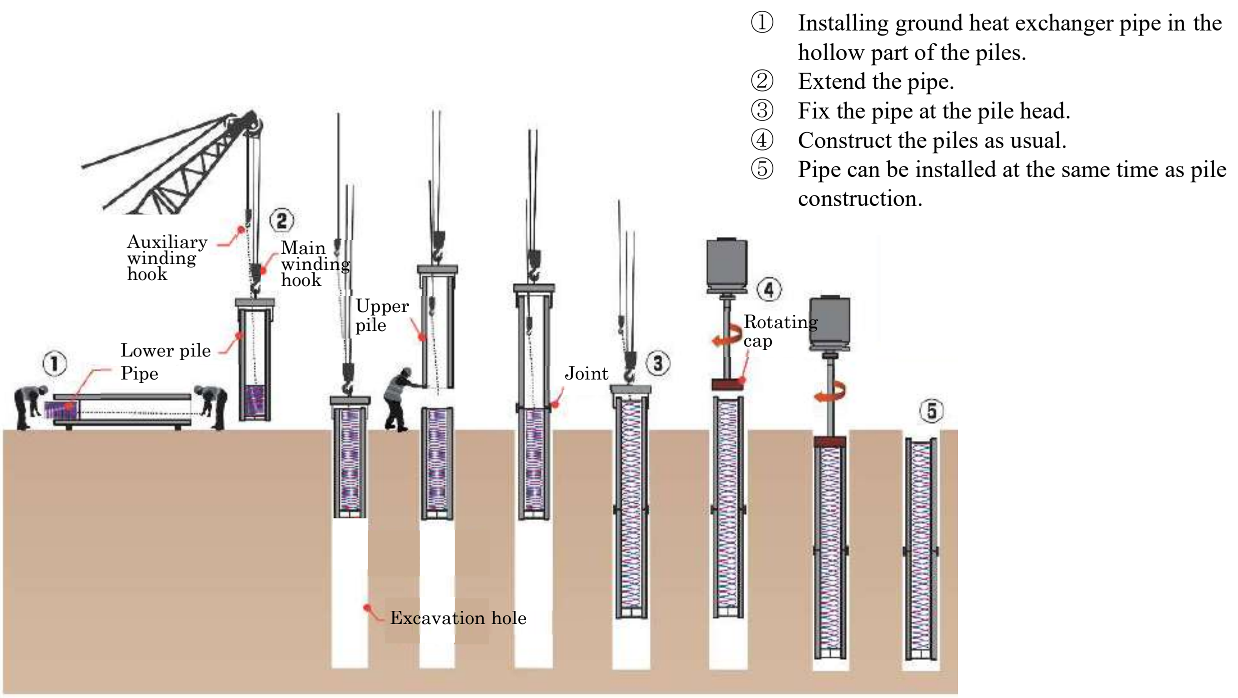

Figure-2 Construction procedure

Consequently, even if this ground thermal utilization technology using precast piles is employed, it will be possible to reduce costs (excavation and installation costs) associated with the installation of ground heat exchanger pipes, and additionally, the construction period is expected to be shortened (Figure-3).

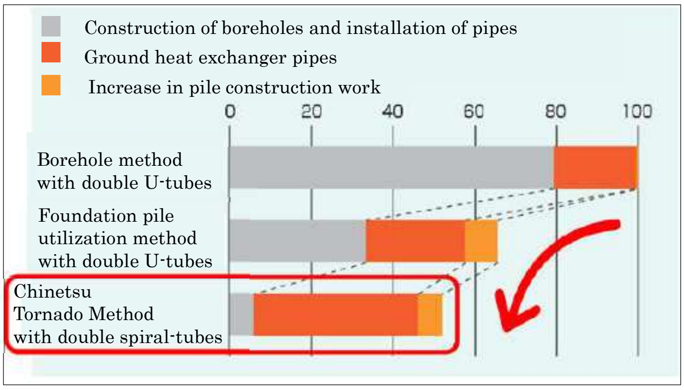

Figure-3 Comparison example of construction costs

Compared with conventional borehole methods that use double U-tubes, this technology makes it possible to collect the amount of ground heat by up to twice by maintaining a uniform spacing between ground heat exchanger pipes and by positioning the pipes in the vicinity of the inner wall of the piles (Figure-4).

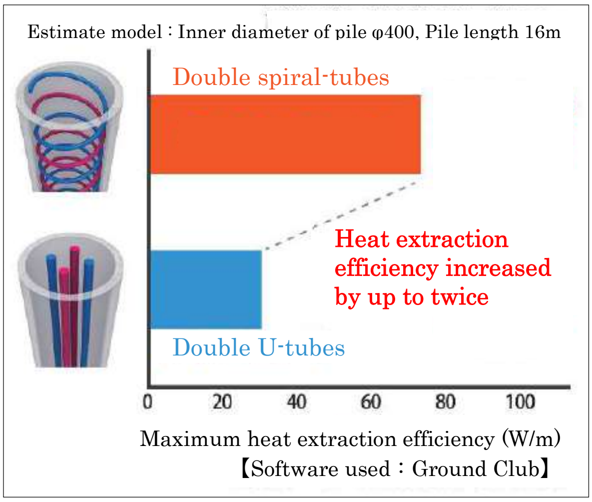

Figure-4 Comparison of heat extraction efficiency

5. Social Significance and Development Potential of the Technology

Since many buildings are supported by pile foundations, it is expected that if ground thermal utilization technology using precast piles can lower risks compared with conventional methods, and makes it possible to carry out construction work at a lower cost, the spread of ground thermal utilization can be realized. And in turn, this technology can play a key role in achieving ZEB for buildings, as well as contributing to the realization of a decarbonized society. Furthermore, as pile foundations are used not only in Japan but also in many other countries around the world, it is believed that this technology is likely to spread globally.

6. Track Record of Application of the Technology

- (Provisional name) N40E8 New construction work on company office building from October 1, 2020 to February 1, 2021
- Two other examples

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Tunnel-constructing technology by making the tunnel's outside shell precede, while using the joints which are able to respond to the behavior of groundwater

Tunneling technology nicknamed "SAKUSAKU JAWS"

1. Background and Opportunities for Technological Development

Demand for trenchless tunnel excavation technology that is able to develop underground spaces even if there are special restrictions on the ground surface has been growing especially in the development of urban areas in recent years. This method provides a wide range of applications such as underground lifelines, subways and underground malls, and utilization of underground areas as a safety measure against floods and earthquakes. They need to be designed in sizes and shapes that suit the purpose.

Among trenchless tunneling methods, the outer shell-proceeding type has been used especially for tunnels with a large cross-section in the category of the shield method, but with such conventional technology, it is known that there are various problems such as the low degree of freedom in terms of cross-section shape and difficulty in responding to high water pressure. Therefore, we have developed an outer shell-proceeding type method that is able to construct underground spaces with large cross-sections and to design the cross-sections more freely, as well as to cope with high-pressure groundwater even during construction.

This paper presents an overview of this method and examples of its application in the field.

2. Contents of the Technology

This is a trenchless tunnel-construction technology in which the outer shell structure (Figures-1) is formed in advance of excavation using the propulsion method. In other words, this approach is to make the outer shell first for constructing a large cross-section tunnel. Because the cross-section of each steel element is small, it is possible not only to minimize the impact on the surrounding ground during construction, but also to ensure the safety for a project even in urban areas.

In many cases, high groundwater pressure often acts on large cross section tunnels, therefore we have developed a unique joint (JAWS joint, Figure- 2), which is applicable to deep underground. In addition, this joint, which is adjustable in length, can be used and applied to any cross-section tunnel shape, rectangular or circular, and to horseshoe-shaped tunnels, which are known to have structural advantages. The joint thus developed increases the rigidity of a structure, making it possible to use the outer shell structure as the main body.

The outer shell structure to be formed in advance is constructed by repeating the following steps: (1) first, rectangular steel elements of 1.0 to 1.5 m per side equipped with groundwater-responding joints are connected and placed underground by a propulsion method.

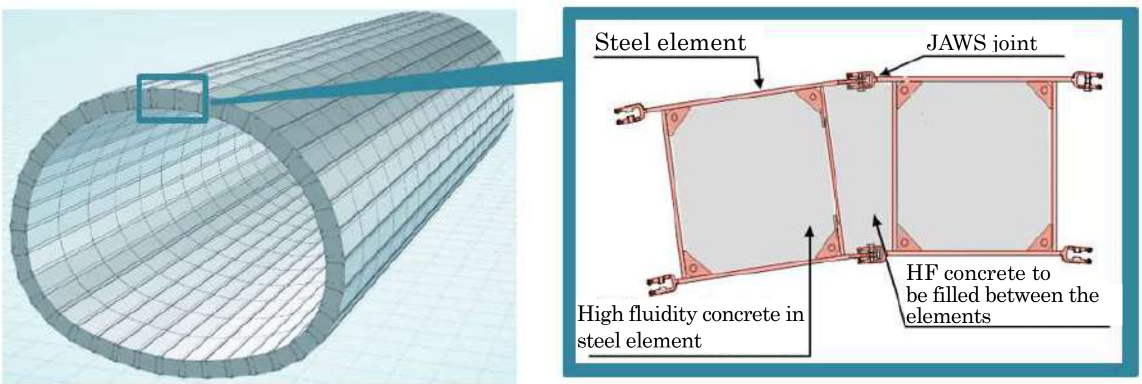

Figure-1 Structural diagram of the outer shell

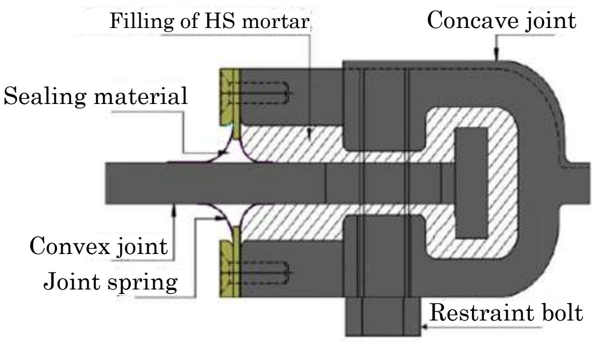

Figure-2 Structural diagram of JAWS joint (when mated)

(2) Then, the soil between the elements is removed, mortar is filled into the joints, and the concrete is placed into the elements.

(3) After the outer shell structure is formed, a backhoe or other heavy construction equipment is used to excavate the earth from the inside of the tunnel, and the inner surface is finished to complete a large-section tunnel.

The construction procedure for this method is shown in Figure-3.

3. Scope of Application of the Technology

This tunneling method is designed to be used at construction sites with a trenchless tunnel where there are strict limitations on construction on the ground surface.

Even under conditions where an arrival shaft cannot be placed due to ground surface restrictions, this method can be applied because the internal mechanism (driving unit) of the propulsion machine can be recovered from the launching shaft side using a dedicated extraction device.

The application criteria for this technology are as follows:

- Application: Construction of underground spaces, such as large cross-section tunnels, etc.
- Cross-section shape: Circular, rectangular, horseshoe, etc.
- Construction depth: Up to about 35 m below GL
- Construction length: 50 to 100 m (depending on soil conditions)

4. Effects of the Technology

Thanks to groundwater pressure-responding joints, this method is able to eliminate improvement work for the ground surrounding the excavation cross-section along the railroad line, even at groundwater table or deeper levels, not having to resort to chemical injection.

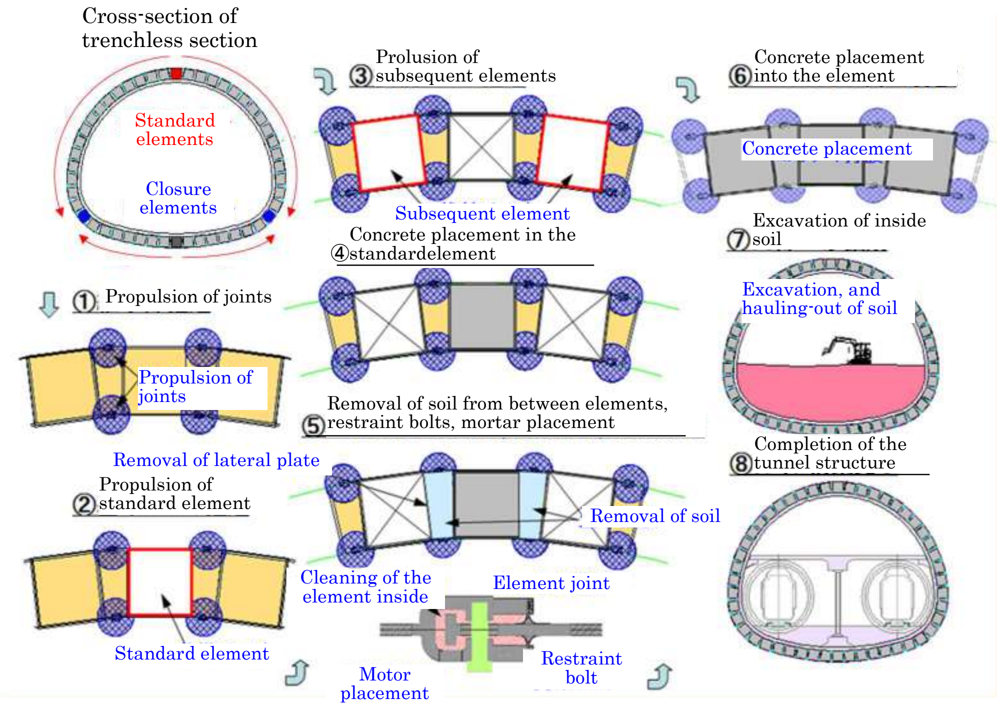

Figure-3 Diagram of construction steps

Furthermore, the outer shell structure, now given a greater strength, can be used as part of the tunnel main structure, and because the internal structures no longer need to be provided, the time needed for construction is shortened drastically.

In addition, since the impact on the surrounding ground can be minimized,becase each constructuon section is small.

5. Social Significance snd Development Potential of the Technology

Compared to conventional methods, the new approach for trenchless tunneling has proven to be applicable to any cross-section shape other than rectangular or circular, thus making construction of longer tunnels possible. Therefore, we believe that the outer shell-preceding type tunneling method can be recommended as a reliable solution to various facilities and projects for a wider range of application than ever before, including large lifeline facilities.

6. Track Record of Application of the Technology

This construction method was applied to a large horseshoe-shaped tunnel (approx. 35 m long) with a 224 m2 (14 m high x 19 m wide) inner space in order to construct a new platform at the New Tsunashima Station on the Sotetsu-Tokyu Line (Figure-4).

The new Tsunashima Station is an underground station with an island-type platform that is approximately 35 m deep at its deepest point and 14 to 25 m wide, and out of its total length of 240 m, a 35 m section on the Hiyoshi side was selected for trenchless construction.

The above ground portion of this trenchless section was densely packed solid with hospitals and commercial buildings, which limited the use of the area. Therefore, with regard to excavation of underground spaces, it was necessary to overcome high water pressure of up to 0.35 MPa and other difficult construction conditions by adopting a special horseshoe-shaped cross-section. To solve this issue, we have selected this unique method with specially designed joints that are

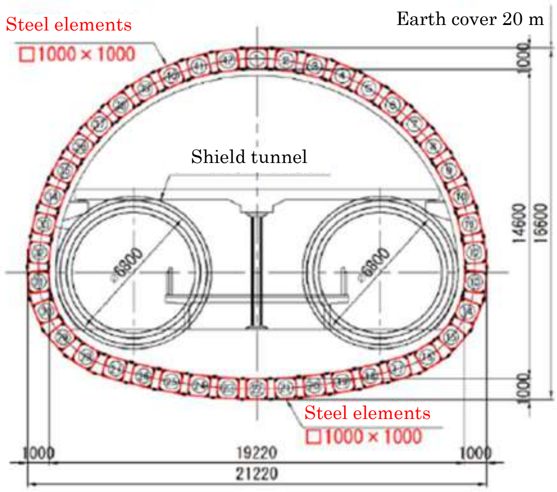

Figure-4 Cross-section of horseshoe-shaped tunnel

able to deal with the behavior of groundwater, which has less impact on the surrounding environment than the conventional trenchless tunneling method.

The tunnel in the trenchless section tunnel, forming a cavity after excavation, is shown in Photo-1.

Photo-1 Construction of the tunnel by element propulsion

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Infrastructure Development Institute-Japan (IDI) is a general incorporated association operating under the guidance of Ministry of Land, Infrastructure, Transport and Tourism of Japanese Government.

IDI provides consulting services to facilitate international assistance to developing countries, to promote international exchange of information and human resources, and to support globalization of project implementation systems targeting both developed and developing countries in the field of infrastructure.

IDI has been publishing a free quarterly journal called "IDI Quarterly" since1996 to introduce information related to public works and construction technologies developed in Japan, to foreign countries. We have distributed the journal to administration officials in more than 90 countries around the world via e-mail.

It will be highly appreciated if you could send us your opinions, impressions, etc. regarding the articles. We also welcome your specific requests regrading technologies you would like to see on following Quarterly issues.