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山岳トンネル方式の歴史と長尺先受け工*

History of so-called Rock Tunneling and Long-Distance Forepiling

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Application of so-called rock tunneling in urban areas and enlargement of tunnel faces are current challenges in the field of rock tunneling.

In urban areas in particular, careful attention should be paid to the safety of tunneling as the earth is in general covered thinly and the ground has yet to be consolidated; and there are often restrictions on adjacent and buried structures with respect to subsidence and deformation as well as strict rules as to noise and vibration.

In response to these challenges, long-distance forepiling known as the umbrella method has been applied successfully in an increasing number of cases as rock tunneling.

This paper studies the long-distance forepiling which evolved as a method supplementing tunnel excavation, with particular reference to the history of rock tunneling in Japan, and also discusses forepiling through high-pressure jet grouting.

1. HISTORY OF SO-CALLED ROCK TUNNELING

(1) Until the end of Warld War II

Tunneling means excavating a hole underground to connect two different points.

A record shows that as early as around 2200BC, a tunnel of about 1km (3,000ft) length was dug under the reign of the ancient Babylonian empire, connecting the palace and a temple. What is remarkable about this tunneling is that part of the tunnel passed below a 180m-wide tributary of the Tigris and Euphrates.[1)]

In Japan, the 1,280m Fukara tunnel in the Hakone canal was completed in 1670 and recorded as the oldest. Then in 1746 the 185m Ao-no-domon cave was completed. Both were dug only with hammer and chisel. The length they were dug each year was reported to be 256m for the former and 9m for the latter.

With the advancements in railway construction, Japan's first railway tunnel, the Ishiyagawa tunnel, having the length of 61m, was excavated in 1870 by a British engineer, followed by the Kuriko tunnel (along Route13, length: 876m) in 1880 and the old Osaka-yama tunnel (for single track railway, length: 665m). Black gunpowder was used for these tunneling works. The old Osaka-yama railway tunnel was completed exclusively by Japanese engineers.

In the construction of the Yanagase tunnel

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(length: 1,352m) which was completed in 1884, tunneling was highly mechanized and dynamite was used in tunneling works for the fist time. Then during the construction of the Sasago tunnel on the Chuo line (length: 4,656m), electric detonators were used on a large scale. It was also around this time that tunnels became longer and the "Jananese" top drift method, the mainstream at the time, was gradually giving way to the "new Austrian" bottom drift method with a view to increasing working faces to speed up contruction.

In 1906, dynamite was locally manufactured at Japan Imperial army's Iwahana Powder Factory, and the operation was later privatized.

During the 1920-to-1945 period, both "Japanese" and "new Austrian" tunneling methods as shown in Fig.1 and 2 were used. For suppurts, pine logs were put together as beams and columns, and then covered with pine sheet piles. "Branch bar strut type" was used at geologically favorable locations and "Radial beam type" use at other locations. Excavation consisted of manual digging or drilling with hand-held machines and blasting with fuse. Muck is loaded manually or dropped to lower galleries. From around 1925, machines were used for muck loading. Locomotives and wooden or steel cars were used in combination for carrying muck. Locomotives used were either catenary electric locomotives for the length where lining had bean completed or newly-imported battery locomotives for unlined length. In this type of tunneling, there could be no large working face at a given point and only small space was available in the tunnel because of support logs. As a result, it was impossible to operate large machines. Therefore, in order to accelerate working in general, it was necessary to start with excavation of pilot tunnels in which excavating and supporting could be completed in small amount time, and then expanding tunneling both horizontally and vertically, making effective use of the pilot tunnel.

In any event, Japan was scientifically and technologically separated from the rest of the world until the end of World War II. Tunneling technologies were no exception. Mechanical tunneling works, therefore, meant replacement of only part of the system with machines. As a whole, manual work played the central role.

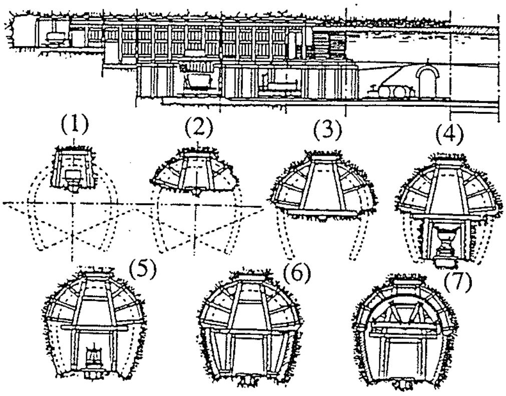

Fig.1 "Japanese" top drift method and Branch bar strut type timbering.[2]

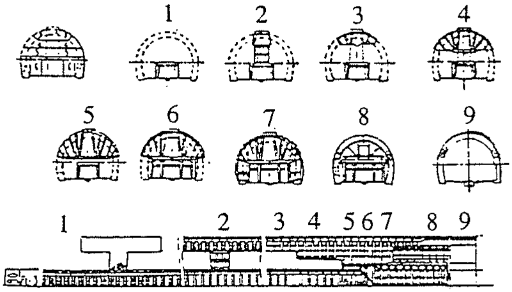

Fig.2 "New Austrian" bottom drift method and Radial beam type timbering..[2]

(2) After the end of World War II

During the reconstruction period following the end of World War II, electric power development was a key player in the development of tunneling technology. Such a move was triggered by the establishment of the Electric Power Development CO., Ltd. (EPDC) in 1952 and by the start of construction of the Sakuma dam in the same year. In the excavation of the 5,062m-long Ohara tunnel which was constructed as national railway replacement work necessitated by dam construction, full-face tunneling instead of conventional pilot drift method was adopted for the first time, and the use of US-made tunneling machines helpted substantially shorten the construction period. Then in 1962, the double-track type Hokuriku tunnel (length: 13,850m) was completed through full-face excavation, which resulted in US-style steel support being fully accepted in Japan.

Mechanical excavation methods using no blasting were introduced from overseas, and tunneling through TBM was put on a trial use nationwide as from 1965 in the hope of increased safety and labor saving in the tunneling works, possibility of rapid excavation, and increased cave stability owing to the use of no blasting. As no total systems were yet completed, however, which paid full attention to support, the method did not prevail as expected and rapidly declined around 1975. Later TBM which took support and ground protection into consideration was devised and actively adopted in sewer tunnels and water tunnels for small-scale hydroelectric power generation from around 1983. Partial face cutting machines developed from mining cuchines and drift boring machines were first adopted in the civil engineering field when bottom drift excavation was conducted in the Shiroyama tunnel on the national railway's Kagoshima main line in 1969. They were originally designed for soft rock, but those for semi-hard and hard rock have recently been developed. Mechanical excavation methods provide ever increasing excavating speed and total cost matching that for blasting methods as long as they are used under proper ground conditions. There are even cases in which they are adopted at the sacrifice of tunnleling efficiency under certain environment.

As for supporting, what we call NATM which treats the earth as a support member and excavates tunnels through observation and measurement was imported from Europe around 1967, and was gradually adopted as from around 1975, backed by rock mechanics knowledge -

In 1986, it was designated as a standard rock tunneling method in the standard tunneling specifications prepared by the Japan Society of Civil Engineers (JSCE), and has been enhanced rapidly with the support of the development of supplementary methods.

Rock tunneling required as a prerequisite that working face be freestanding. Some supplementary means were necessary where the earth is not fully freestanding such as unsolidified ground or fractured zones. With an incresae of tunnels adopting rock tunneling method in unbam areas in particular, more effective new auxiliary methods have been introduced and developed, which seem to be making rock tunneling possible even under difficult coudition. Of all such methods, forepiling has been making a remarkable progress.

2. LONG-DISTANCE FOREPILING

(1) History of forepiling

Forepiling was referred to as supplementary method A when definition of supplementary methods were discussed and opinions were about to be standardized. Rock bolts, round pipes, reinforcing bars were used as materials. Steel spiles included in the meterials were rooted in the short-distance forepiles adopted in the age of US-style steel support. "Steel crown bars" adopted in the U.S.A. as "longitudinal members" are also in this category in a broader sense of the word.[3]

Then injection-type forepiling using materials such as urethane and cement milk for injection was developed and adopted as a supplementary method securing tunnel safety under severe conditions. At the 7th Rock Tunneling Technology Symposium organized in 1987 by the Japan Tunneling Association (JTA), S. Nagatomo[4] showed, using a displacement diagram associated with West Germany's tunnel construction on a new trunk line, that when the earth is relatively weak, displacement of surrounding ground starts ahead of the face and reaches a substantial level

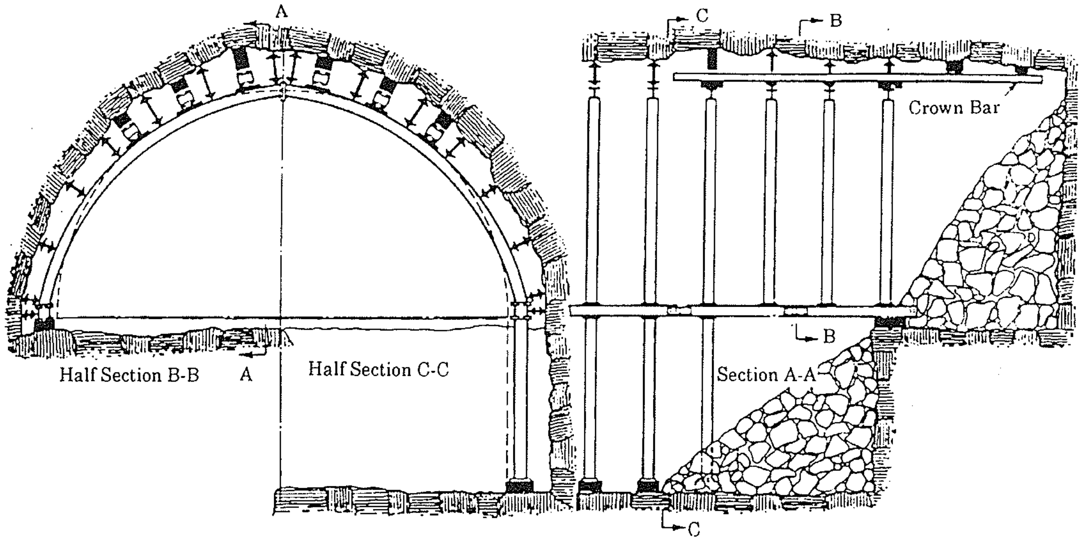

Fig.3 Crown bars mounted on the steel ribs support the new roof by cantilever action. [3]

at excavating time, and pointed out measures should be taken ahead of the face. Of forepiling methods, long-distance forepiling methods with the length of 10 to 15m have been developed as those guaranteeing more reliable forepiling, and producing good results as what we call the umbrella method.

Nakata, M and others[5] indicated reduction of earth stress changes and control of stress relief caused by excavating ahead of the face as benefits of long-distance forepiling.

Many more studies have been made as to displacement and stress distribution ahead of the face, and it is suggested that the long-distance forepiling is effective when it is necessary to prevent subsidence of ground surface and loosening of ground where the earth strength is low.

In the world of rock tunneling, enlargement of tunnel faces and response to urbanization are today's major challenges. It is hoped that even bad ground conditions and bad environmental conditions would be coquered with the use of supplementary methods. There have been an increasing number of successful projects such as the construction of the southern part of Maiko tunnel on the Honshu-Shikoku Highway where the injection-type forepiling (Trevi tube method), a long-distance forepiling method, was adopted, and the Hodogaya tunnel on the Yokohama Shindo highway where high-pressure jet grout forepiling (Rodin jet method) was used.

(2) Long-distance forepiling in corporating high-pressure jet grout betterment

Of long-distance forepiling methods incorporating high-pressure jet grout betterments, one makes forepiles through jet grout while pulling off jetting tools after excavation has reached the predetermined depth, and the other entrains steel pipe with rod either to excavate and perform jetting and make betterments as drilling progresses.

The "water jet" technology has long been available which uses breaking strength of jet of water or the like under high pressure, as an application to crushing. There is a record that it was used for placer mining in California, US in 1852. In 1916, the former Soviet Union conducted experiments for applying it to coal mining and put it into practical use in 1939 as the hydraulic mining.[6]

Then with progress in high-pressure water generators and pressure hoses, and in response to the requirements of the times, water jet has been applied to various methods in mining[7] and construction[8] industries.

Studies of water jet application to precise cutting of solid materials were started in the 1960s, inspired by the idea of rain wash for aircraft radar dome. Studies are now being continued for more efficient implementation.[9]

The long-distance forepiling incorporating high-pressure jet grout betterment applies construction systems for the jet grout and column jet methods referred to in the Underground Construction Using Water Jet, and makes forepiles by bettering ground with hardening materials through several hundred kgf/cm^2-pressure jet. While conventional forepiling had structures centering on beams, these types are of higher grade, constituting structures more like shells. In the future, it is hoped that implementation of more rational and efficient methods for control and hadling of slurry discharged from jetting will make this method more effective.

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