Should you require future details on these articles or other information on tunnelling activities in Japan, please contact:

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Challenges & Changes

TUNNELLING ACTIVITIES IN JAPAN 2000

JAPAN TUNNELLING ASSOCIATION

CONTENTS

PREFACE

Hiroshi Hagiwara

Hiroshi HAGIWARA

President
Japan Tunnelling Association

It is my great pleasure to have the opportunity to greet tunnel engineers throughout the world on this occasion of the publication of the 2000 edition of this biennial booklet of the Japan Tunnelling Association (JTA).

JTA was established in 1975, and will mark its 25th anniversary this year. Since that time, large quantities of underground space, including urban space as well as tunnels for roads, railways and waterways, have been constructed in Japan, and JTA is proud of the contribution which it has made during this period through its activities including the exchange of technical information and support of technical development. Further, as a member of the International Tunnelling Association, JTA has at the same time made endeavors for worldwide exchange of information regarding tunnel technology.

Tunnels in hard rock, soft rock and through fault zones, tunnels and underground space in soft alluvial ground in urban areas; numerous underground works of various kinds are being designed and constructed in Japan at the present time using various techniques including NATM, shield machines of various types for soft ground, TBM's for hard ground, ground freezing, immersed tunnel laying and many others.

In this last year of the present century and on entering a new millennium, representative examples have been selected from among these numerous projects to be presented in outline form in this booklet. I hope that these articles will be informative to the reader.

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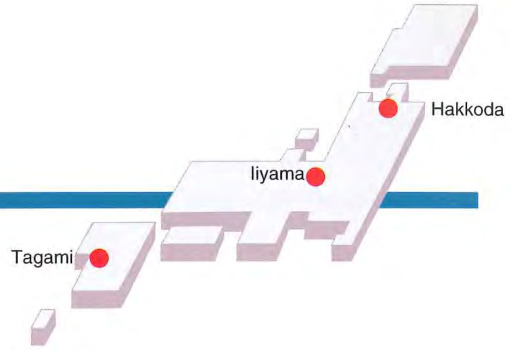
Construction Progresses on New Shinkansen Railway Lines



Shigeru KOJIMA
Senior Assistant Chief,
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Muck Transport by Belt Conveyor

The Japan Railway Construction Public Corporation is currently performing construction of a total of approximately 515km of the Tohoku, Hokuriku and Kyushu Shinkansen railway lines. This construction includes 118 tunnels which have a total length of approximately 297km.

This article will describe three of these tunnels which are being excavated by drill and blast method; Tagami Tunnel on the Kyushu Shinkansen where muck is being handled by a system in which the muck is crushed by a self-propelled crusher and transported by a continuous belt conveyor, Hakkoda Tunnel on the Tohoku Shinkansen which will be the world's longest on-land tunnel when it is completed, and Iiyama Tunnel on the Hokuriku Shinkansen which will likewise be the world's third longest.

Kyushu Shinkansen Tagami Tunnel

Tagami Tunnel, 7.0km in total length, is being driven from one end for the long distance of 5200m due to topographical restrictions.

In the field of rock tunneling, improvement in muck handling technology is a major problem. Especially in muck transport, tire mounted equipment is generally being employed to a great extent, but on a long drive the number of muck transport vehicles within the tunnel rapidly increases and much labor becomes necessary in maintaining safety measures and the operations environment.

In order to solve these problems at this tunnel, a system was developed for the handling of muck by a self-propelled crusher and a continuous belt conveyor working in combination. This is the first example of the employment of such a system in tunnel construction by drill and blast method anywhere in the world.

Using this system, muck of various sizes and shapes generated by drill and blast excavation is crushed into a maximum size of 20cm or less by the self-propelled crusher, which is parked approximately 50m behind the face, and then transported to outside of the tunnel by the continuous belt conveyor. The continuous belt conveyor is extended as the tunnel face advances, and when the maximum extension of 140m has been reached it can be further extended by inserting a new section of belt.

The technical problems which were solved in order to employ this system are as follows.

(1) Up until now, any crusher which had a capacity for muck handling equivalent to that obtainable by dump trucks was so large in size that bringing it into the tunnel was impossible, but this became possible by developing an electric powered crusher of compact size.

(2) Success was achieved in measures to protect and strengthen the equipment to withstand flying muck from blasting.

(3) By developing novel means for passing the continuous belt conveyor through travelling equipment such as the waterproofing membrane installation scaffold and the lining form, damage to the waterproofing membrane due to installation of the belt conveyor equipment was prevented and harmful effects of belt conveyor vibration on concrete after its placement were reduced to zero.

(4) Because the crusher is self-propelled, movement of the mechanism for extending the belt conveyor at the end near the face became possible.

The improvements which resulted from introduction of this system include the following items.

(1) Because dump trucks are not used, the danger of traffic accidents such as sideswipe accidents sharply decreased, and damage to the tunnel roadbed also decreased.

(2) Because the only engine driven equipment is the muck loader, all other equipment being motor driven, air pollution within the tunnel due to the emission of exhaust gas and the raising of dust by mucking vehicles was reduced, thus improving the environment within the tunnel. The noise level within the tunnel was also improved.

(3) Because dump trucks do not operate within the tunnel, following work such as surveying and concrete placement can now be performed efficiently.


Self-propelled Crusher

Tohoku Shinkansen Hakkoda Tunnel

Hakkoda Tunnel, 26.5km in length, will be the world's longest on-land tunnel when it is completed. Excavation has been commenced from both portals, and excavation in the middle contract section will be performed from an inclined adit which will be started as soon as preparations are completed. The tunnel profile has 1.0% rising gradients from both portals which meet in a summit very near the tunnel midpoint.

Except in the vicinity of the portals, the rock consists of Neocene sedimentary rock and intrusions in a large folded structure having an anticlinal axis in the vicinity of the center of the tunnel.

The construction zone is a richly natural area surrounded by natural forest, and the objective is to complete this long tunnel efficiently, in a short time, and with consideration for this surrounding environment.


Tohoku Shinkansen Hakkoda Tunnel

Hokuriku Shinkansen Iiyama Tunnel

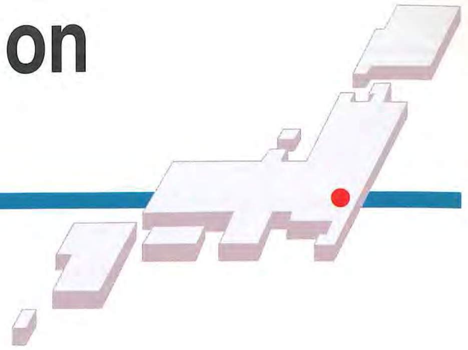
Iiyama Tunnel, 22.2km in length, will be the world's third longest on-land tunnel when it is completed.

Because the tunnel will pass through a formation of Neocene mudstone which is the same as a nearby formation which is known for its strong squeezing pressure, various investigations were performed to study the possible effect of this mudstone formation on tunnel construction. From the results of measurements of convergence and gas pressure in investigation adits at nine locations, it was judged that no squeezing which might markedly hinder excavation would be encountered on this route, and that safe and rational construction would be possible by making free use of experience obtained up to now, including the use of auxiliary construction methods and early closure of the cross section.

At the present time, work has been commenced on approximately one half of the total length of tunnel and is progressing smoothly. At one contract section, the excavation of a 765m long inclined adit has been completed and work has entered the stage of main tunnel excavation.


Hokuriku Shinkansen Iiyama Tunnel

Wide Segments Employed on New Joban Line



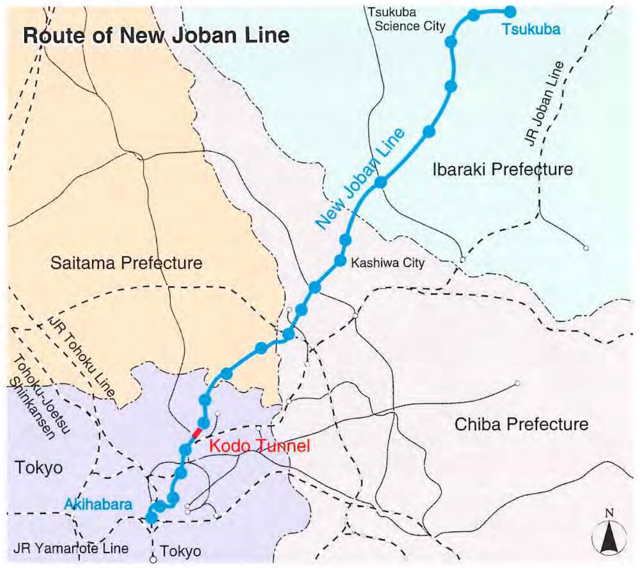
Sadao MATSUHASHI
Senior Assistant Chief,
New Joban Line Division, Construction Department,
Japan Railway Construction Public Corporation

General Outline

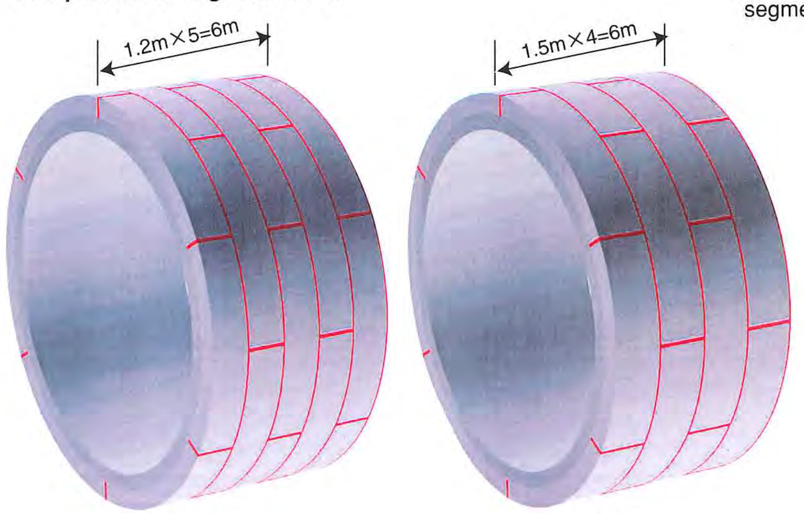
The New Joban Line, which is under construction in accordance with the July 1985 master plan for railway construction in the national capital region, is a new high speed railway line which will start at Akihabara in Tokyo, pass through Saitama and Chiba prefectures and reach Tsukuba City in Ibaraki Prefecture, a total distance of 58.3km, in 45 minutes at the highest speed of operation. Together with construction of the New Joban Line, large-scale land development is in progress along the line which will provide extensive residential land. The railway line will be operated by the Metropolitan Intercity Railway Co. and is being constructed by the Japan Railway Construction Public Corporation (JRCC) by direction of the Minister of Transport.

Described by type of structure, the line chiefly consists of underground structure within Tokyo and elevated structure in Saitama and beyond. As a whole, the line has 27km of elevated structure (46%), 7km of bridges (13%), 15km of tunnel (26%) and 9km of roadbed (15%). Construction is now in full-swing, aiming for commencement of operation in FY2005.

Route of New Joban Line



Comparison of Segment Width



1.2m Segments　　1.5m Segments

Wide Segments at Kodo Tunnel

In Pursuit of Cost Reduction

At JRCC, reduction of construction cost is an important task with the various departments cooperating to achieve overall cost reduction measures, and positive endeavors are being made to introduce new technology befitting a railway of the 21st Century.

A few specific examples are (1) development of labor saving elevated structures using arched slab and prestressed concrete U-shaped girders, (2) development of wide segments, (3) employment of economical joint structure in segments, (4) development of new type track structure and (5) development of hybrid structure elevated stations.

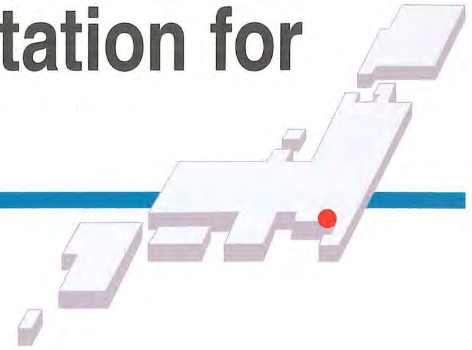
For a unit length of tunnel, wide segments, in comparison with conventional segments, have fewer joint bolts and the number of segments to be erected is less. Thus, shortening of the construction period and reduction of construction cost can be expected. Therefore, it was decided to employ 1.5m wide segments, 30cm wider than 1.2m wide conventional segments, for the first time in a railway tunnel.

Accompanying this widening of the segments from 1.2m to 1.5m (40cm thickness), structural improvements were also added; division of ring circumference into eight equal segments, and increase of rigidity of joints between segments in a ring.

Full size loading tests, which were performed to confirm the safety of the wide segments, showed that the segments possess sufficient resistance, thus confirming their safety.

The driving of Kodo Tunnel in Tokyo was completed at the end of September 1999. A total of 691 rings of wide segments of 9.6m inside diameter were erected at this double track tunnel. Erection progressed smoothly without trouble and measurements show that no particular problem has arisen in their properties.

Yokohama Underground Station for Minatomirai 21 Line

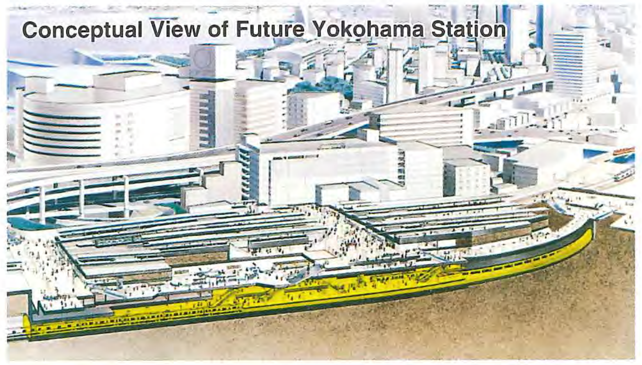


Kozo SUNAGA
Manager, Yokohama Division, Tokyo Construction Office,
East Japan Railway Company

The East Japan Railway Company is constructing an underground station beneath its Yokohama Station for Minatomirai 21 Line.

Even in Japan there are very few examples of constructing a large-scale underground station directly beneath, and in parallel with, railway tracks which are in operation. Construction is to be performed by open excavation with the existing railway tracks supported by temporary girder spans.

Conceptual View of Future Yokohama Station



The city of Yokohama, which has a population of approximately 3.3 million people, is located approximately 30km south of Tokyo. Japan's first railway line, between Shimbashi in Tokyo and Yokohama, began operation in October 1872, 128 years ago, and the first Yokohama Station was completed one year before that.

At the present time five railways, including this company, operate into Yokohama Station. Thus, this is a major terminal through which a total of approximately 3000 trains pass each day and approximately 2 million people board and alight.

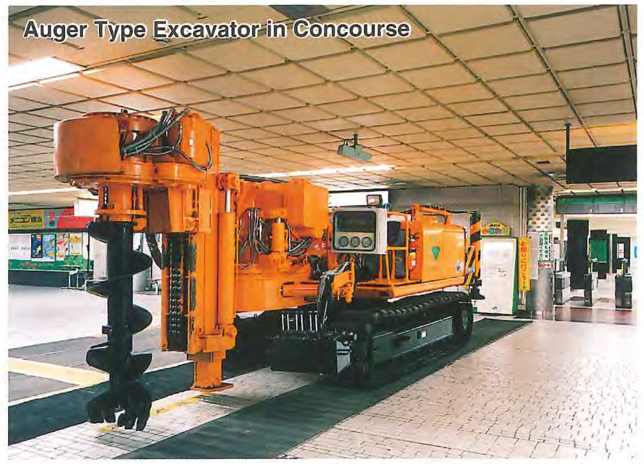
Minatomirai 21 Line (MM21) is a new, completely underground railway line which will extend approximately 4.1km from Yokohama Station to Motomachi Station. MM21 Yokohama Station, the line's initial station, is located at about the middle of the present Yokohama Station, and is to be constructed directly beneath five existing railway tracks, three tracks of this company (one track of the Tokaido Line and two tracks of the Yokosuka Line) and two tracks of the Tokyu Toyoko Line, all of which are to be temporarily supported.

The underground station structure, which will have an island platform with two tracks, is planned to have a total length of approximately 420m, a maximum width of approximately 25m, a depth of approximately 25m below track level, and a platform length of approximately 170m for eight cars. In addition, two new underground public passageways, one at each end of the existing station, are to be constructed to supplement the existing passageway located at the center of the station.

The main construction techniques which are being employed are as follows.

In order to set the piles to support the temporary concourse floor, a low clearance, auger type excavator was developed which is capable of setting piles within the approximately 2.4m ceiling height of the concourse. The holes in which to set the piles for underpinning the existing concourse are also excavated using this new low clearance, auger type excavator.

Auger Type Excavator in Concourse



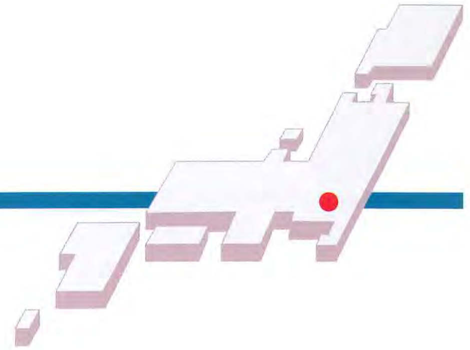
A total of approximately 280 girder spans ranging in length from 8m to 11m, which will be supported by piers made of H-shapes, will be used for temporary track support, and all of these girder spans will be set in place by a railway crane owned by this company, placing one span per night.

Diaphragm walls of 0.8m thickness will be constructed to a depth of approximately 30m to the foundation bed, and in order to work within a narrow space, a compact model diaphragm wall excavator which has two vertically revolving excavator drums was developed. Also, the permanent structure foundations will be constructed as 2.6m diameter caisson type piles, and for this purpose a low clearance, caisson type pile excavator was developed and is planned to be used.

Because the operation of placing girder spans for temporary support of the existing tracks can only be performed during the short hours between the last train (about 1:00 a.m.) and the first train (about 4:00 a.m.), a long construction period is necessary. Under the banner of "Safety First," construction work is being advanced toward the goal of first train operation in the year 2004.

Excavated Space beneath Ten Existing Tracks

Tokyo Metropolitan Subway Loop Line



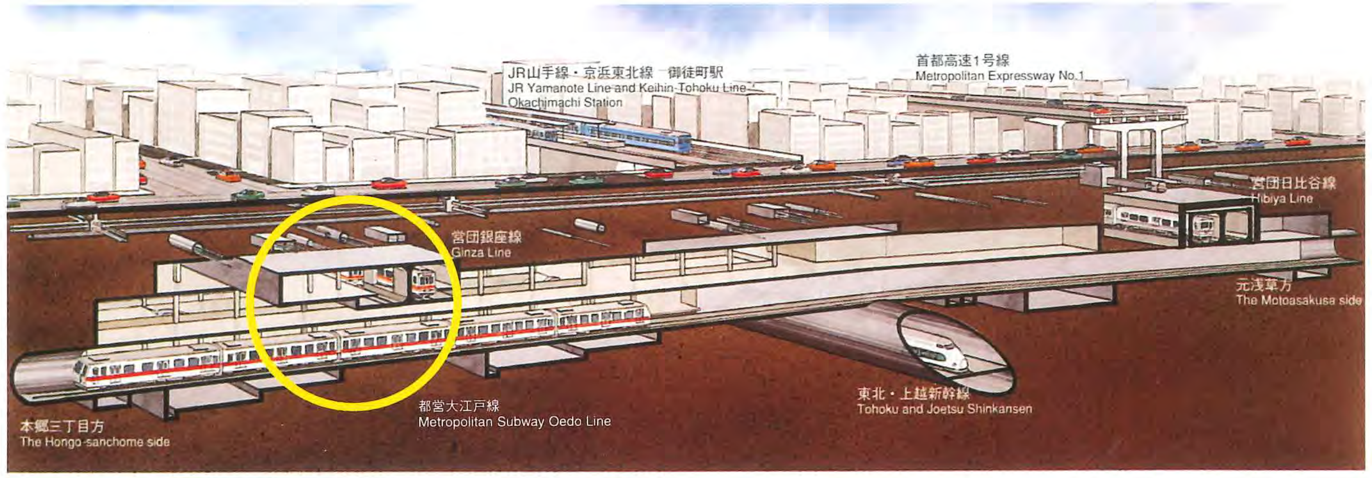
Hitoshi NIIHARI
Construction Headquarters,
Tokyo Metropolitan Subway Construction Corporation

Metropolitan Subway Oedo Line, 43km in total length, consists of an approximately 14km long radial line which is already in operation and an approximately 29km long loop line which is presently under construction. On this line, subway cars of reduced size and a linear motor drive system were adopted to decrease the tunnel size and thus reduce construction cost by decreasing right-of-way expense and work quantities.

The loop line has two special characteristics. The first is the fact that it crosses or closely approaches existing urban facilities at numerous locations within the central part of Tokyo. These include crossings and close approaches with radial railway lines at 41 locations, crossings and close approaches with expressways at 12 locations and crossings with rivers at 10 locations. The second special characteristic is the fact that construction work is being performed in congested streets in bustling quarters which are busy even throughout the night, under severe restrictions regarding hours of work and operating space, and at the same time protecting numerous urban infrastructure facilities of various size which are buried underground. Station structures are being constructed by cut and cover method, except for Roppongi and Iidabashi stations which are being constructed by shield driving method, and running tunnels between stations are all being constructed by shield driving method.

All shield driven tunnel construction is being performed by closed type shield machines. At two stations, the station structures were designed to be constructed by shield machines having multiple circular faces; Roppongi Station which has two levels of single track station structure constructed by a shield machine having four circular cutter faces (reported in the 1998 edition of *Tunnelling Activities in Japan*), and Iidabashi Station which has a double track station structure constructed by a shield machine having three circular cutter faces (1996 edition). In the running tunnels between stations, a total of 49 single face shield machines for single track (5300mm outside diameter of lining) are being employed on the two directions, and three single face shield machines for double track (8500 and 8800mm outside diameter of lining). The total length of tunnel to be constructed by shield driving is 41km.

Because the shield driven circular tunnel has a cross section of reduced size, at curves having radii between 100m and 160m, the required internal width of tunnel was secured by reducing segment thickness while maintaining a constant outside diameter of tunnel, and a secondary lining, which has been placed up until now, will be placed only when necessary. The segmental lining which is being employed as a standard is of the type which is generally used in Japan; flat reinforced concrete segments having a straight bolt connection structure using metal bolt boxes. In addition to these standard type segments, other new types of segmental lining are being employed experimentally on approximately 11km of this loop line, 30% of the total length to be constructed, in an attempt at cost reduction. One of these is tongue and groove joint type segments which have tongues and grooves on their circumferential edges which fit together to form the tunnel lining. Another is honeycomb segments, each of which has an identical hexagonal configuration.



At Ueno-hirokoji Station, a typical example of the cut and cover construction being performed, the station structure not only crosses under Ueno-hirokoji Station on the existing Ginza Line of the Teito Rapid Transit Authority but also crosses or closely approaches the elevated structure of East Japan Railway's Okachimachi Station, the shield driven tunnel of that company's Tohoku and Joetsu Shinkansen railway lines, the existing Hibiya line of the Teito Rapid Transit Authority and the elevated structure of Metropolitan Expressway No.1. This station has the following special characteristics.

(1) In consideration of convenience of transfer to and from other transportation lines, the station structure is large in scale, 460m long in comparison with the standard length of 160m, and has a complex structure.

(2) Being adjacent to an amusement quarter, a large amount of vehicular and pedestrian traffic continues both day and night.

(3) The Ginza Line, which must be underpinned, is now 70 years old since its construction.

In passing under the Ginza Line, a method of underpinning was adopted in which the Ginza Line is temporarily supported by steel underpinning girders and then permanently supported by the Oedo Line structure after that structure has been completed. The width of the Ginza Line where it was underpinned is approximately 26m, and the minimum distance between the two structures is approximately 2.1m. The structure of the Ginza Line consists of a four span rigid structure box which has an unsymmetrical cross section formed of a side platform station section and a concourse section on one side only which has a footing level 1.5m above that of the station section.

Because of the difficulty of installing steel underpinning girders which are very long but do not deflect beyond the allowable limit, and the double footing level of the structure to be underpinned, it was decided to underpin the structure in two spans with separate underpinning girders for the station section and the concourse section. The underpinning piles were made to support both the load from the Ginza Line structure and the load from the street surface above. Because these underpinning piles had to be installed within the area of the street intersection, they were installed from the ground surface by a reverse circulation boring method which can be performed within a small operating area. Also, because the middle row of underpinning piles was installed so as to penetrate through the concourse section of the Ginza Line station which was in operation, openings were broken through the upper and lower slabs of the structure and casings were inserted so that the boring slurry would not flow into the station.

Kobe Municipal Subway Kaigan Line

Masumi ISHII
Director, Kaigan Line Construction Department, Transportation Bureau, City of Kobe

The Kobe Municipal Subway presently has 22.7km of line in operation; the Seishin-Yamate Line. Now, a new 8.1km line, the Kaigan Line, is under construction in the southern area of Chuo, Hyogo and Nagata wards, which were stricken by the Hyogoken-Nanbu Earthquake. This basic transportation facility is intended to promote the development of this inner-city area, and is expected to play an important central role in post-earthquake restoration.

New Seismic Design

Although subways were said to be strong against earthquakes, some subway structures suffered great damage from the Hyogoken-Nanbu Earthquake (M7.2), a near-source earthquake. On the Kobe Municipal Subway too, the center pillars of rigid frame box structures suffered great damage. Taking a lesson from this damage, the already completed designs of the rigid frame box structures for stations on the Kaigan Line were modified by performing seismic design assuming a large-scale earthquake equal to the Hyogoken-Nanbu Earthquake.

Allowable stress design was performed for a medium-scale earthquake which may occur several times during the lifetime of the structures, and the seismic safety of this design with respect to a large-scale earthquake was checked by limit state design with non-linear analysis. As a result, the quantity of reinforcing steel increased by approximately 30% compared to the previous design.

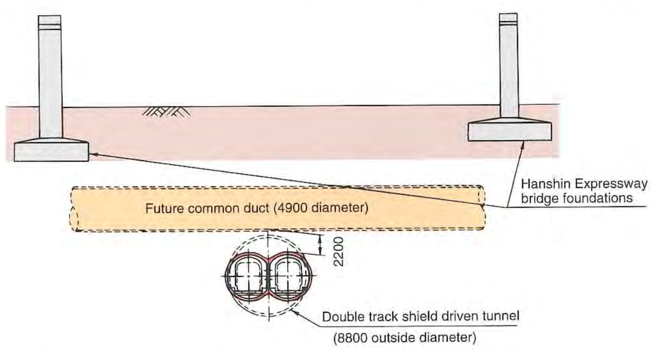
No great damage occurred to tunnels driven by conventional circular face shield machines, even those in the area of most severe earthquake intensity. However, tunnels which are driven by multi-circular face shield machines (RC segmental lining) have center pillars, and it was thought that they would show earthquake behavior similar to that of rigid frame box structures. Consequently, as a result of seismic design, the material of these center pillars was changed from reinforced concrete to ductile cast iron which has superior shear resistance.

Adoption of Multi-circular (DOT) Tunnelling Method

Tunneling by multi-circular face shield machine was adopted between Shin-nagata and Komagabayashi to secure separation from the bridge foundations of the Hanshin Expressway and to avoid as much as possible infringement on private land along Goinoike Street, which has a narrow width of 12m. In order to secure separation (approximately 2m) from a common duct which is planned for construction above Kaigan Line, a shield driven tunnel of double track circular cross section could not be adopted.

Cross Section at Crossing under Hanshin Expressway

(unit: mm)

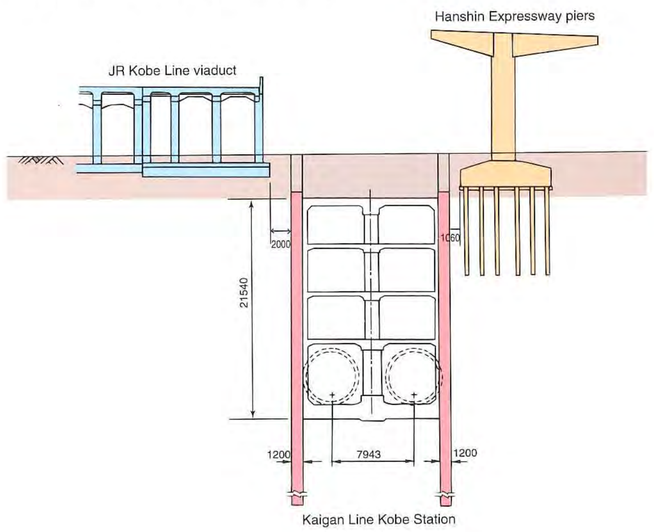


Construction near Important Structures

Kobe Station on the Kaigan Line is being constructed by cut-and-cover method in the space between the JR Kobe Line (continuous rigid frame viaduct of 2 to 5 spans) and the Hanshin Expressway Kobe-Nishinomiya Route (steel non-composite I beam continuous viaduct of 2 to 3 spans). Because of the proximity to these important structures, deformation of the earth retaining walls and ground displacement accompanying excavation must be held to an absolute minimum. Highly rigid reinforced concrete diaphragm wall of 1.2m thickness was adopted and is being utilized as a part of the side walls of the station structure in order to secure even a small additional distance from these adjacent structures.

Cross Section at Kobe Station

(unit: mm)



Large Cross Section Tunnel Being Constructed under Built-up Area

Shoji ISHIKAWA
Supervisor, Hiroshima National Highways Office, Ministry of Construction

Yasumiyama Tunnel is an approximately 1700m long highway tunnel which is under construction in a built-up area of the city of Kure in Hiroshima Prefecture. Excavation was begun at the west portal in September 1997. For the first 80m from the portal the depth of cover was less than the tunnel's excavation width of approximately 15m, and the geology in this section consisted of unconsolidated embankment, fill and talus deposits. Further, houses, concrete retaining walls and a principal thoroughfare with buried utilities (water and gas pipes) were located on the ground surface above the line of tunnel. Also, the tunnel has a large cross section with an inside area of 85m² and a flatness ratio of 0.57.

The methods which were adopted to control surface settlement at this tunnel were upper heading excavation with a center diaphragm, and long, injection type forepiling.

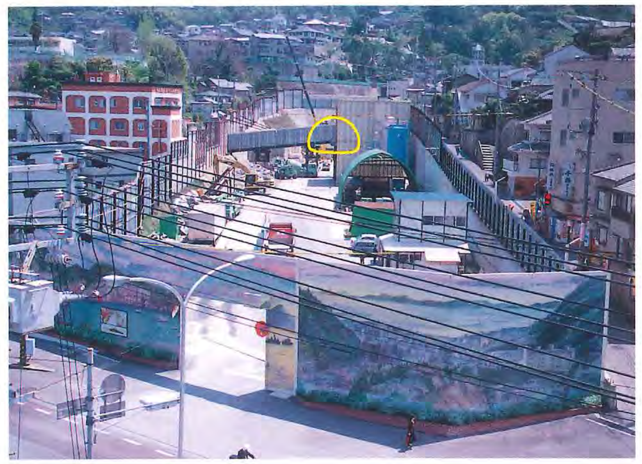
In upper heading excavation with a center diaphragm, the upper heading is excavated by dividing it into two headings. As the first heading is excavated a temporary support diaphragm is placed and later removed after excavation of the other heading. Because each heading is structurally closed during excavation, this method is especially effective in preventing deformation of the tunnel and stabilizing the excavation face.

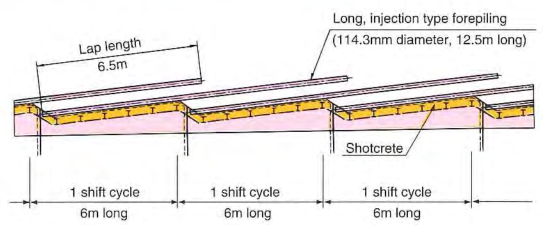
In long, injection type forepiling, long steel pipes of 76.3 to 114.3mm diameter (114.3mm at this tunnel) are driven along the periphery of the tunnel and chemical grout is injected through these pipes. In this way, surface settlement is restrained by the rigidity of the steel pipes and the effect of ground improvement. The length of pipe generally used is 12.5m, but because the initial plan was to use this forepiling together with center diaphragm excavation, the length to be driven and the shift length were decided as 6.5m and 3m, respectively, based on ease of operation and past experience.

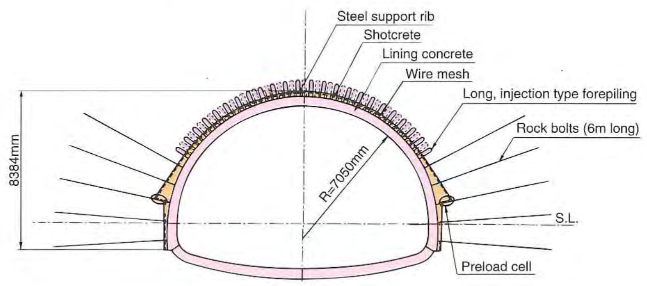
However, in actual construction, upper heading excavation with a center diaphragm was performed for a length of only 9m, between the points 14m and 23m from the portal. In the design stage, such excavation was planned for up to 226m from the portal, but because the face became stable, the method of excavation was changed to simple upper heading excavation followed by bench excavation, and emphasis was placed on selecting the optimum method of preventing surface settlement. The length of pipe to be driven for the injection type forepiling was changed to 12.5m, the most generally used length. The minimum lap length is normally 3.5m, but for extra safety a length of 6.5m (6m shift length) was secured to restrain preceding settlement and crown settlement at the face. Further, preload cells were used at the feet of the steel support ribs to restrain settlement by introducing upward preload into the steel support ribs by filling and pressurizing a special grout material into the gaps between the feet of the support ribs and the ground.

Through the use of these measures, it was possible to drive safely through this section without any damage to the buried utilities which had been the subject of concern. The final amount of settlement was 49.7mm in a depth of cover of approximately 14m. From this, it is judged that the combination of preload cells and long, injection type forepiling with a driven length of 12.5m and a shift length of 6m had been optimum for this ground.

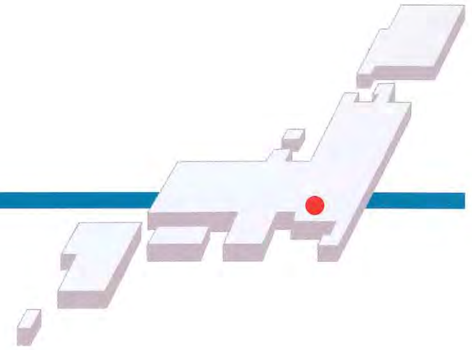
Excavation at the east portal was begun in June 1999, and the opening of Yasumiyama Tunnel to traffic is scheduled for spring of 2002.







Present Status of Tunnels on New Tomei Meishin Expressway



Katsushi MIURA
Deputy Director General,
Expressway Research Institute,
Japan Highway Public Corporation


Route Map

The New Tomei Meishin Expressway is a high speed highway facility having six lanes throughout its total length of 502km which was planned for the purpose of forming a new transportation backbone for Japan in the 21st Century connecting Tokyo and Kobe and supplementing the existing Tomei and Meishin expressways. Work is now in progress on an initial 370km long section.

The tunnels on the New Tomei Meishin Expressway have a large, flattened cross section of approximately 190m^2 excavation area and an excavation width of approximately 18m. The total number of tunnels presently planned is 167, having a total length of 224km. There is no previous example of the construction of a large number of tunnels of such large scale as this anywhere in the world. Thus, there are diverse problems of a technical nature, including problems in design such as cross sectional configuration and support structure, and problems in construction such as how to excavate a large group of tunnels safely and efficiently.

The Japan Highway Public Corporation has investigated these technical problems through numerical analysis and comparison with past construction experience and is obtaining verification through test construction. The problems which are receiving the greatest emphasis are the development of efficient excavation methods and rational support structures.

Development of Efficient Excavation Methods

In comparison with conventional two lane tunnels, the tunnels on the New Tomei Meishin Expressway have a large, flattened cross section which is approximately 2.5 times as large in area of excavation cross section and has an excavation height exceeding 10m. Thus, stability of the crown and the ability of the face to stand by itself during excavation are major problems. Because of this, to employ as a standard a method in which a large cross section is excavated as a whole, such as the method of full face excavation with a bench which is the standard method for conventional two lane tunnels, is considered to be difficult from the standpoints of safety and stability of the tunnel and efficiency of construction. Thus, for the tunnels on the New Tomei Meishin Expressway, it is necessary to investigate and develop safe and efficient excavation methods which are different from conventional methods.

The TBM Pilot and Enlargement Excavation Method, in which a pilot heading is excavated efficiently in advance utilizing the TBM capability for high speed excavation, is expected to provide various beneficial effects including drainage into the pilot and stability of the face.

In the test construction at Shimizu No.3 Tunnel (Neocene sandstone and mudstone), which is being performed as a test of the TBM Pilot and Enlargement Excavation Method in rock which ranges in hardness from medium hard to soft, the enlargement excavation is now almost completed except for sections at portals. Here, the anticipated effects of the pilot heading have been verified for the most part. Especially, efficient excavation was achieved due to improvement in face stability and the extension of the length of advance per excavation cycle which this made possible. In the upper heading, a maximum advance on the order of 110m in one month was recorded. Now, similar verification is being looked for at tunnels having different rock. At Ritto Tunnel (granite), test construction is being performed in hard rock. The TBM Pilot and Enlargement Excavation Method is expected to be adopted as a standard method based on the results of verification obtained through this test construction.

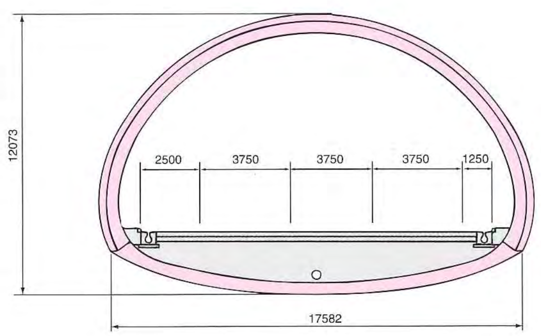
Excavation methods which do not use a TBM will be employed at tunnels which are relatively short in length, and when employment of a TBM would be economically disadvantageous.

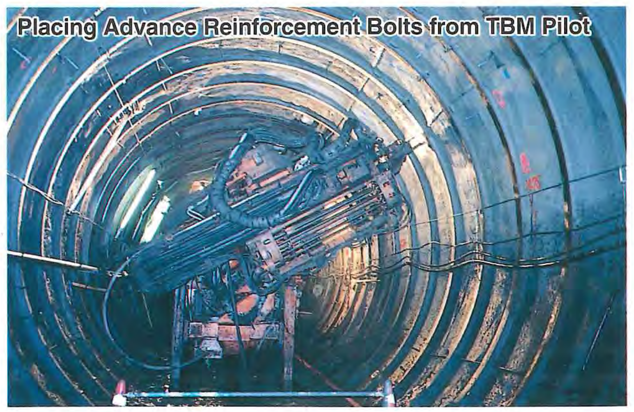
Because the upper heading corresponds in area to the cross section of a two lane tunnel, excavation by upper heading and bench, in which the upper heading is excavated as a whole, is being considered for application where the rock is comparatively good and stable. However, because the arch is fairly flat in comparison to that of a two lane tunnel, selection of the method of excavation must be made with thorough consideration to stability of the tunnel.

On the other hand, where the rock lacks stability, auxiliary methods will be employed, but there are cases in which dividing the upper heading excavation is more advantageous than making extensive use of large-scale auxiliary methods. For such cases, consideration is being given to use of the Center Pilot and Enlargement Excavation Method, in which a pilot heading is driven within the upper heading, and the Upper Heading Center Diaphragm Method, in which the upper heading is divided into left and right headings with a center diaphragm between them for temporary support. Both of these methods compare unfavorably with the upper heading and bench method in terms of ease of construction, but they are advantageous for excavation through rock of poor quality.

These methods are presently being employed in test construction at Shizuoka No.2 Tunnel (Paleogene sandstone and mudstone) to verify their advantageousness and ease of execution depending on ground conditions.

Standard Cross Section (unit: mm)




Placing Advance Reinforcement Bolts from TBM Pilot


Side Pilots at Portal


Lining Concrete Placing Operation

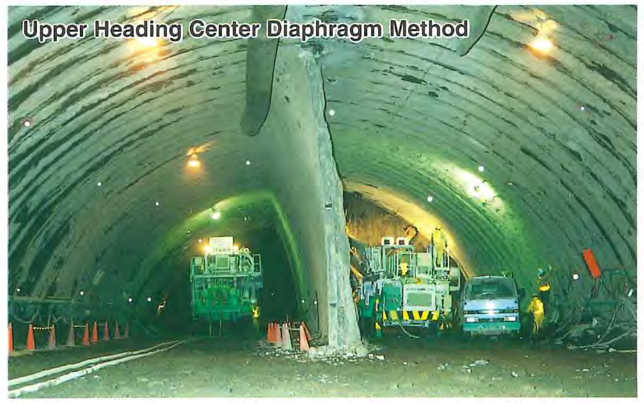
Development of Rational Support Structures

Together with excavation methods, the development of support structures for the New Tomei Meishin Expressway tunnels is also an important problem. The initial design of the support structure for the New Tomei Meishin Expressway tunnels was determined on the basis of FEM analysis and experience obtained in three lane tunnels such as those on the renovated Tomei Expressway, and resulted in an unprecedented scale and quantity of support. Thus, there are various problems when using conventional material specifications; lose of ease of construction, decrease in speed of operations, how to secure quality, and others. Because of this, the Japan Highway Public Corporation is aiming to develop rational support structures which have superior qualities of stability, ease of construction and economy through the development of new material specifications.

To this end, a thinner and lighter support structure and more efficient construction are being sought through the development of high strength shotcrete, the adoption of fiber reinforced shotcrete, and the development of steel arch supports of higher standard and lining concrete of greater strength.

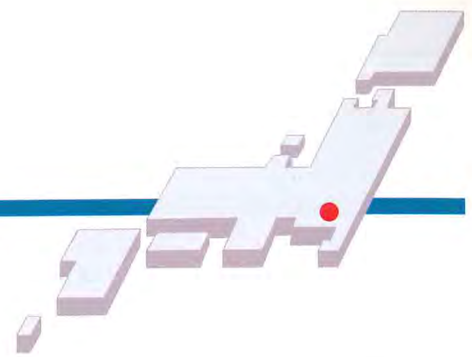
Other Problems

In the present test construction, investigation and development is centered on standard excavation methods for general conditions of topography and geology, but numerous other problems remain for solution in the future. Examples are special ground conditions where the geologic conditions are extremely bad or the depth of cover is extremely shallow, or suburban areas which entail construction in close proximity to existing structures. Individual study has already been commenced concerning special tunnels such as these, and it is planned to develop techniques for their safe and efficient excavation.


Upper Heading Center Diaphragm Method


Center Pilot and Enlargement Excavation Method

Double-Tier Tunnel for Inter-City Expressway



Mikio FUJIMURA — Project Manager, Oume-Naka Project Management Section, Hachioji Construction Office, Tokyo Construction Bureau, Japan Highway Public Corporation

Route Map

The Metropolitan Inter-City Expressway is an approximately 300km long loop highway exclusively for motor vehicles which is planned to circle the center of Tokyo at a distance of 40 to 60km. The 19.8km long section from Tsurugashima Junction on the Kan-etsu Expressway to Oume Interchange is already open to traffic, and other sections of the project are also being advanced successively. Completion of this inter-city expressway is expected to produce numerous benefits including relief of traffic congestion in the Metropolitan area and improvement of the environment.

Oume Tunnel, which forms a part of this inter-city expressway, is planned to be 2095m long, the 1093m long central section of which is to be constructed by non-cut-and-cover method and the remainder by cut-and-cover method.

The special characteristics of the non-cut-and-cover section are as follows.

(1) The tunnel has a large cross section of double-tier structure which has an excavation height of approximately 18m and a large excavation cross section of 240m^2.

(2) The ground consists of unconsolidated gravel containing cobbles with clay mixed in.

(3) The tunnel is located at the top of an alluvial fan, and the groundwater level is high.

(4) The depth of cover is shallow, approximately 8m, and a city street is located directly above with numerous buried lifeline facilities.

A study was performed concerning non-cut-and-cover methods by which this double-tier highway tunnel, the first in Japan, having the above special characteristics could be constructed safely and economically with the minimum possible effect on the surrounding houses, buildings and buried utilities. From this study it was decided to employ NATM excavation with multiple benches and to place the lining of the upper half before excavating the lower half.

The special characteristics of this method are as follows.

(1) The upper half is excavated by two benches, and then the middle slab and secondary lining of the upper half are placed before excavation of the lower half.

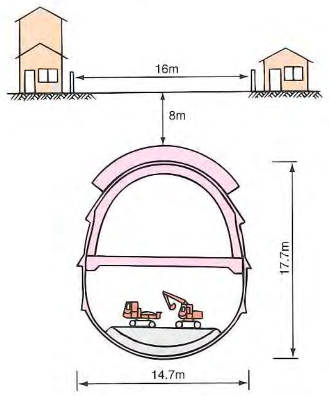
(2) By constructing the upper half structure in advance, the amount of stress release which occurs during excavation of the lower half is reduced and face stability is secured.

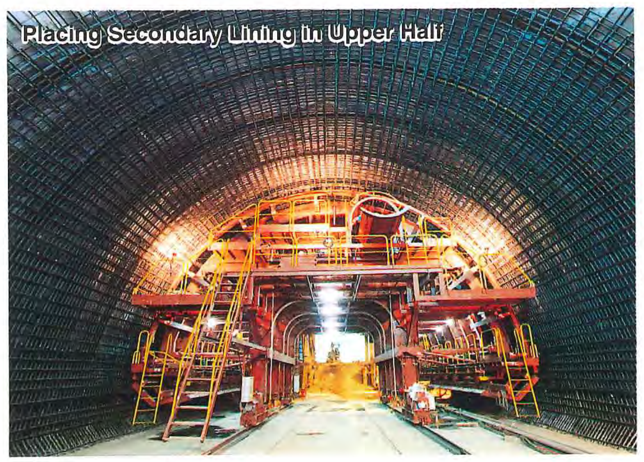
(3) The lower half is excavated down to the invert by two more benches, the secondary lining of the invert is placed, and then the secondary lining of the side walls is placed.

(4) When executing the lower half, the method of execution and the quantity of reinforcing steel to be placed in the secondary lining are determined by evaluating the rigidity of the middle slab and secondary lining of the upper half in the longitudinal and crosswise directions.

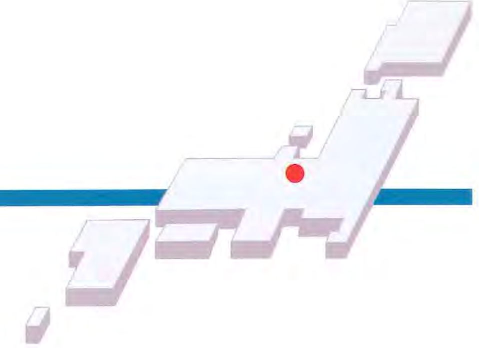
As of December 1999, work was being performed in the upper half, and careful monitoring and observational construction management are being used to achieve secure construction.

Because most of the urban tunnels in Japan are constructed through unconsolidated ground and any effect of construction extends to the ground surface due to the shallow depth of cover, the principal method of excavation in practice is shield driving. NATM construction of a double-tier structure in unconsolidated ground with a shallow depth of cover such as at Oume tunnel can be thought of as a new method for the construction of urban tunnels.





Large Diameter TBM at Hida Tunnel



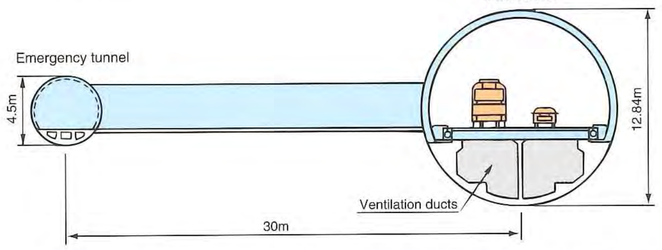
Takaaki YAMADA — Head of Kiyomi Construction Office, Nagoya Construction Bureau, Japan Highway Public Corporation

Hida Tunnel is a long tunnel to be constructed on an expressway which will connect the city of Nagoya on the Pacific Ocean side of Japan and the city of Toyama on the Japan Sea side at the approximate center of the country. Having a total length of approximately 10.7km, this will be the second longest highway tunnel in Japan. The tunnel will consist of a main tunnel which will carry facing traffic and an emergency tunnel. The profile gradient is 2% upward from the Toyama end toward the Nagoya end.

Because this tunnel is located in the center of the Hida mountain region, the depth of cover reaches a maximum of 1000m. The rock which is believed to exist at the formation level of the tunnel chiefly consists of granite, rhyolite and gneiss. The geological conditions are relatively good; the greatest part of the rock being estimated as medium to hard with unconfined compressive strength in the range of 80MPa to 360MPa.

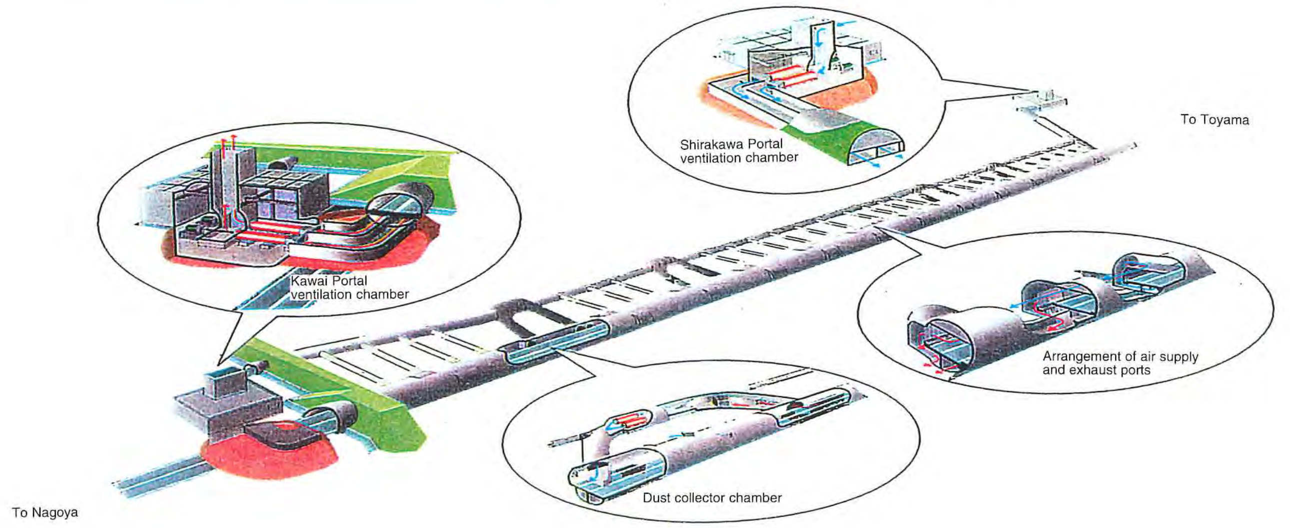
Because this is an area of high snowfall, it would be difficult to secure a construction road to the portal at the Nagoya end of the tunnel during the winter due to the danger of snowslides. For that reason, as well as the fact that the profile gradient is in one direction only, excavation of the tunnel from one end only is the most efficient.

Judging from the above conditions, excavation by TBM is considered to be the most suitable method of excavation for this tunnel, and both the emergency tunnel and the main tunnel are planned to be excavated by TBM from the portal at the Toyama end.

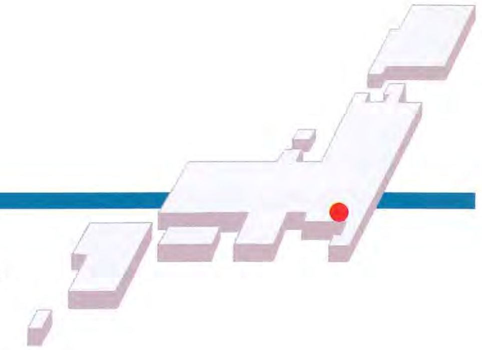


Excavation of the emergency tunnel was commenced at the beginning of 1998 using a 4.5m diameter TBM. Because the main tunnel will have two traffic lanes which will carry facing expressway traffic, a large TBM having an excavation cross section of 12.84m diameter will be used. For tunnel ventilation, it is planned to adopt a system which does not require a ventilation shaft by utilizing the lower half of the circular cross section excavated by the TBM as ventilation ducts to function as a substitute for a ventilation shaft and providing electrostatic dust collection. Adoption of this system will enable saving the cost of construction of a ventilation shaft and an underground ventilation chamber. The TBM for the main tunnel is to be erected within the main tunnel, and commencement of excavation is planned in the year 2000.

Because rock burst, large volume water inflows and poor ground conditions at fault zones are foreseen from the geological characteristics, preparations are being made for the confirmation of geological conditions and predrainage of groundwater by pilot boring, the use of liners in sections of poor ground conditions, and the provision of a system for performing forepiling from the TBM for the main tunnel. Also, a continuous belt conveyor system has been adopted for muck transport to achieve high speed TBM driving.



Metropolitan Expressway Central Circular Shinjuku Route

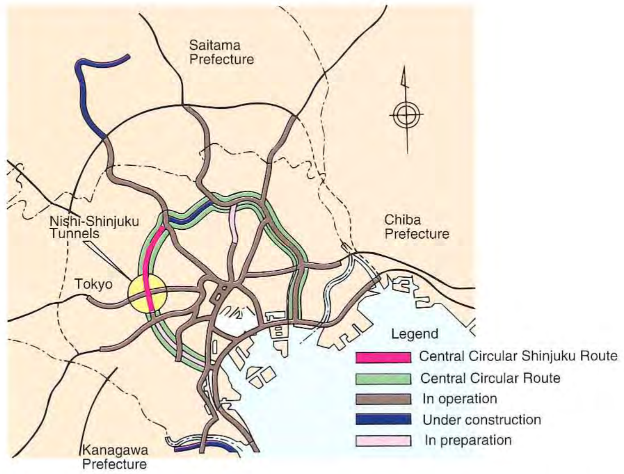


Naoyuki ODAGIRI — Manager, First Design Division, First Construction Department, Tokyo Construction Bureau, Metropolitan Expressway Public Corporation

Hiroshi DOBASHI — Assistant Manager

Metropolitan Expressway System

The Metropolitan Expressway system forms a network in which approximately 263.4km of expressways are now open to traffic as major arteries of the Metropolitan area performing an important role as indispensable social capital supporting civic life and economic activity. The Central Circular Route is a part of an expressway which is planned to circle the urban center at a distance of approximately 8km in order to achieve an efficient transportation network in the Metropolitan area without concentration of inter-city traffic into the urban center. The eastern section of this line, which forms approximately 40% of its total length of approximately 46km, is already completed and open to traffic as expressway. Also, the approximately 7.1km long northern section and the approximately 11km long western section are under construction at the present time.



Metropolitan Expressway Central Circular Shinjuku Route

The Metropolitan Expressway Central Circular Shinjuku Route, which constitutes the western section of this line and is located along Tokyo Loop Road No.6 (also called Yamate-dori), is being constructed as a tunnel structure for most of its length in consideration of the environmental conditions and preservation of the good urban environment along the line through effective three-dimensional utilization of limited urban space above and below the ground surface.

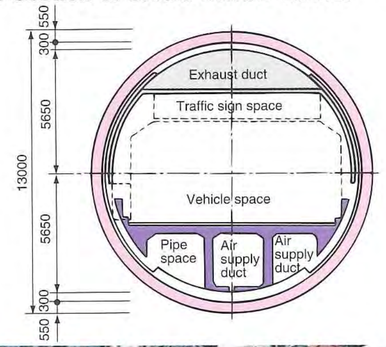
Because this line is planned beneath an arterial street for effective use of urban space, methods of construction must be studied which are suited to the conditions of the street including its alignment. Also, the presence of a congested array of existing lifeline facilities buried beneath the street presents numerous problems for construction. Further, consideration is required concerning construction near other structures such as adjacent buildings, and crossings with subways and expressways. When constructing a tunnel under prescribed conditions, careful study is required in selecting the method of construction (cut-and-cover method, non-cut-and-cover method, or a special method) which is appropriate to each construction site. In particular, the method must be selected through adequate study of factors such as groundwater conditions, ground conditions and environmental conditions along the street. Further, selection of a method which will be economical based on comprehensive judgement from the viewpoint of cost is also an important question.

Against this background, the construction of over 70% of the approximately 11km total length of tunnel on the Central Circular Shinjuku Route is being advanced by non-cut-and-cover methods centered on shield driving.

Nishi-Shinjuku Shield Driven Tunnels

Located where the Central Circular Shinjuku Route crosses under National Highway Route 20 and Metropolitan Expressway Route No.4, the Nishi-Shinjuku Tunnels are twin tunnels which are planned to be constructed by shield driving.

Cross Section of Shield Driven Tunnel (unit: mm)




Reversing Shaft


Launching and Arrival Shaft

These twin tunnels, one for each direction of traffic, are approximately 600m long and have a large outside diameter of 13.0m. The two tunnels are to be excavated by one shield machine which will be launched from a launching and arrival shaft, turned 180° at a reversing shaft, and then driven back to the launching and arrival shaft.

Because this section is surrounded by numerous important structures located in close proximity, to minimize any effect on the surrounding ground, a slurry type shield machine was selected following comprehensive consideration of various factors including actual performance in the construction of large diameter tunnels. The shield machine has an outside diameter of 13.23m, a length of 13.12m and a weight of approximately 28,000kN. The outside diameter of this machine is the fourth largest in the world, and for a highway tunnel it ranks next to those of Tokyo Wan Aqua-Line. Also, because the tunnel alignment has a curve of 204m minimum radius, the shield machine is equipped with an articulation mechanism, thus making it the world's largest shield machine to have an articulation mechanism (as of March 1999).

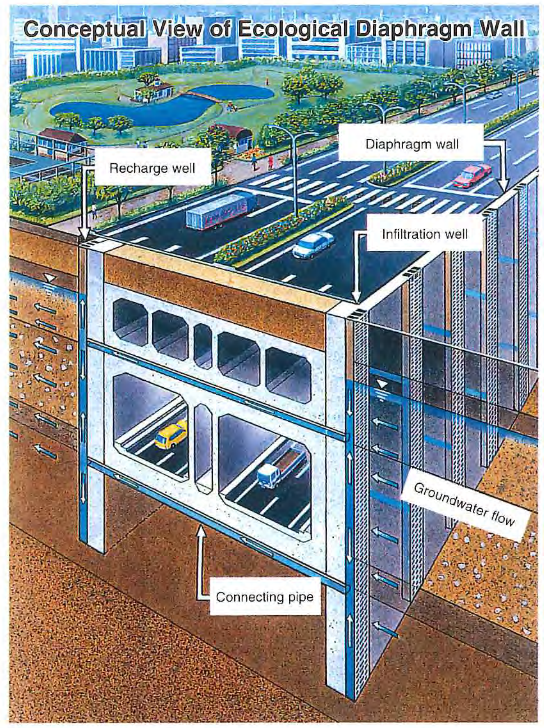
Ecological Diaphragm Wall

In general, when constructing a large-scale underground structure by cut-and-cover method, diaphragm walls are employed to support the excavation because of their high rigidity, water cutoff effectiveness and capability of being constructed with a low level of noise and vibration. However, in some cases, problems arise such as temporary change in groundwater level during construction and obstruction of groundwater flow by the structure itself following completion. Now, to solve the problem of such effects on the groundwater environment, a new type of diaphragm wall, which gives consideration to the groundwater environment by making possible "water cutoff during construction and water transmission after completion," is being employed in one section of this project.

With this new diaphragm wall, wells (infiltration wells and recharge wells) which are capable of both water cutoff and water transmission are formed within the diaphragm wall, and then the excavation is performed. Following this, the wells installed on the upstream and downstream sides are joined by connecting pipes at suitable locations for transmission of groundwater by a roundabout path which enables long-term, stable water flow.

In developing Ecological Diaphragm Wall, structural safety was secured through study of design methods by investigation and analysis, and constructability and water transmissivity were confirmed by test construction. Having secured the anticipated results, this new diaphragm wall was employed practically at the construction site.

Conceptual View of Ecological Diaphragm Wall



Development of New Technology

At Ohashi Junction (tentative name) located at the southern end of the Central Circular Shinjuku Route, connections are provided to Metropolitan Expressway Route No.3 together with diverging and merging sections on the main expressway. Also, because of site conditions such as the close proximity of substantial surface structures and important underground structures, and the character of this site as the intersection of arterial streets carrying heavy traffic, any idea of cut-and-cover construction had to be abandoned. However, construction by an existing non-cut-and-cover method would be difficult due to the conditions of varying cross section on the connections, cross section widening at diverging and merging sections and on sharp curves, and construction of sharp curves having a minimum radius of 60m. Accordingly, it is planned to employ at the applicable locations the MMST Method which the Metropolitan Expressway Public Corporation has developed. Details of the MMST Method were reported in the 1998 edition of *Tunnelling Activities in Japan.*

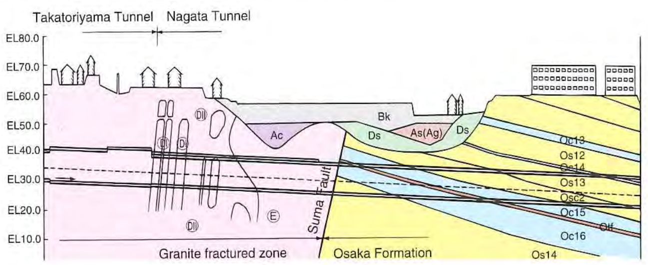
Excavation in Fractured Zone and Unconsolidated Ground

Yoshihito MORI
Assistant Manager, Design Division,
First Kobe Construction Department,
Hanshin Expressway Public Corporation

Hanshin Expressway Kobe-Yamate Route, located in the western part of the city of Kobe, was planned as an expressway to connect the newly urbanized northwest Kobe area with the city center. Takatoriyama Tunnel and Nagata Tunnel form a single continuous tunnel of 2km length which is being constructed by NATM. Both tunnels consist of two tunnels, northbound and southbound, which are separated by a distance of 20m. Each of these two tunnels has a 2-lane cross section the excavation area of which is approximately 110m^2 in the standard cross section, approximately 140m^2 in the emergency parking cross section, and approximately 190m^2 in the enlarged cross sections for merging and diverging.

The geology of Takatoriyama Tunnel in its mountain section consists of conglomerate and semi-hard rock which is mainly Rokko granite, and in its urban section, granite which has undergone advanced weathering and a fractured zone which has been affected by the Suma Fault. The geology of Nagata Tunnel, which is in the urban area for its full length, changes at the Suma Fault from rock base to the Quaternary Osaka Formation, later Pleistocene terrace strata and alluvial strata. The Osaka Formation, which consists of alternating layers of gravelly soil, sandy soil and cohesive soil, has a low degree of consolidation and both the gravelly and sandy soil layers are aquifers which store large quantities of groundwater. The Suma Fault forms an impervious barrier between the granite fractured zone and the Osaka Formation, making the groundwater discontinuous.

Geology in Vicinity of Suma Fault



For any tunnel construction in urban areas, thorough study must be given to the effect of construction on the surrounding environment. In the mountain section of Takatoriyama Tunnel, mechanical excavation by hard rock excavating machine MM-130R was employed in consideration of the effect on housing in the vicinity of the tunnel portal. In the urban section of Takatoriyama Tunnel, because of the densely built-up condition of the area and the shallow depth of cover, the standard method being employed is excavation by upper heading and bench cut with long, injection type forepiling used in the upper heading to minimize any effect of construction on the ground surface. Where it is thought that the feet of support ribs may settle following excavation, the standard method of excavation by upper heading and bench cut is modified to include side pilots. Further, in a section near the fault where a deposit of lake sediment in an old valley lies above the tunnel with a minimum separation of approximately 4m, there is a danger of blowout to the ground surface due to contact with the old valley or the flow of lake sediment into the tunnel. Here, the use of long, injection type forepiling, in which the pipes are driven diagonally into the ground, was changed to the use of a pipe roof which is driven parallel to the tunnel axis.


Pipe Roof in Takatoriyama Tunnel

At Nagata Tunnel, water bearing unconsolidated ground will be excavated at a shallow depth of cover beneath a densely built-up area. Consequently, to secure safety and minimize any effect on the ground surface, various auxiliary construction methods, including long, injection type forepiling, preload cells, support rib foot strengthening, face strengthening and side wall strengthening, were tested for effectiveness in a test section of tunnel and a standard combination of auxiliary construction methods was determined. After the test section, the work is being advanced using the most safe and rational auxiliary methods, adjusting these methods according to the geology at the face, the condition of water inflow and the results of measurement of surface settlement and other related factors.


Long, Injection Type Forepiling in Nagata Tunnel

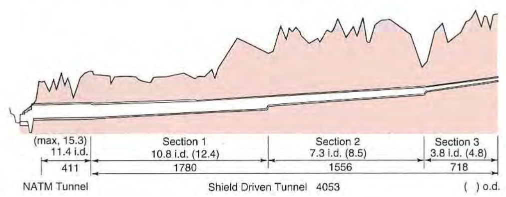
Otsu Discharge Channel Tunnel

Minoru WADA
Deputy Director (Engineering),
Biwa Lake Construction Work Office,
Ministry of Construction

The 4.7km long Otsu Discharge Channel, a tunnel which is under construction in the city of Otsu in Shiga Prefecture to relieve chronic flood damage caused by eight rivers which flow through the center of that city, was designed to have a total capacity of 290m^3/s, equivalent to the runoff from a 100 year rainfall. Due to the varying topographical and geological conditions along the line, the channel consists of an open channel section, a box culvert section, a section of tunnel to be constructed by NATM, a section of tunnel to be constructed by shield driving (depth of cover ranging from 20 to 50m), and the diversion works at each river. In order to save construction costs for the manufacture of shield machines and the construction of additional launching shafts, the section to be constructed by shield driving was divided into three sections, each of uniform diameter.

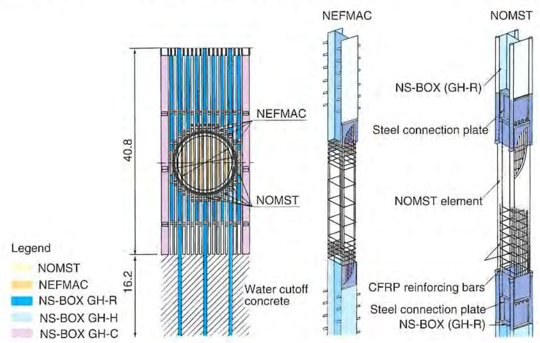
Profile of Otsu Discharge Channel Tunnel

(unit: m)



Details of Structure at Tunnel Openings

(unit: m)



Adoption of NEFMAC

Because the shield machine must pass through the steel diaphragm walls (1.8m thick) of the vertical shaft (18m square and 34m deep) at the Sanda River Diversion Works which was constructed using NS-BOX (New Steel BOX structure for diaphragm wall), the material of these walls at the position of the tunnel openings had to be a type of material which could be cut through by the shield machine. The initial plan was to use NOMST (NOvel Material Shield-cuttable Tunnel wall system), precast concrete elements which are reinforced by carbon fiber reinforced plastic, for the full area of these tunnel openings and connect it to the NS-BOX above and below the openings. However, it was decided to change eight of the 17 NOMST elements in each of the two openings to NEFMAC (NEw Fiber composite MAterial for reinforcing Concrete), a material which is composed of carbon fiber, has a high tensile strength and forms a unified mass with cast-in-place concrete. This change, which was based on Value Engineering after contract signing, was intended to achieve reduction in costs for factory precasting and transport, and construction time reduction through the saving of space and labor, including simplification of the connections with NS-BOX.

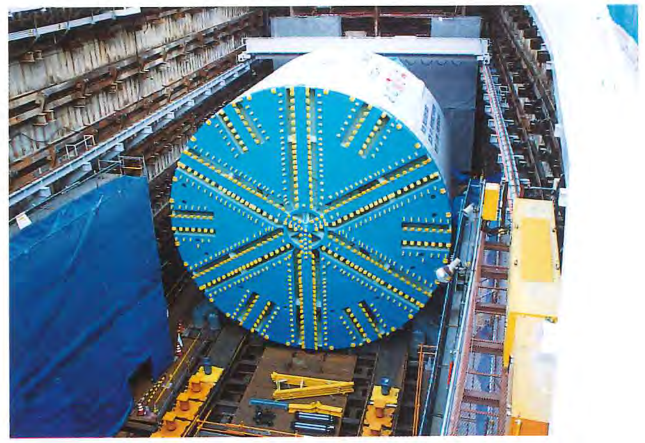
Automatic Segment Erection

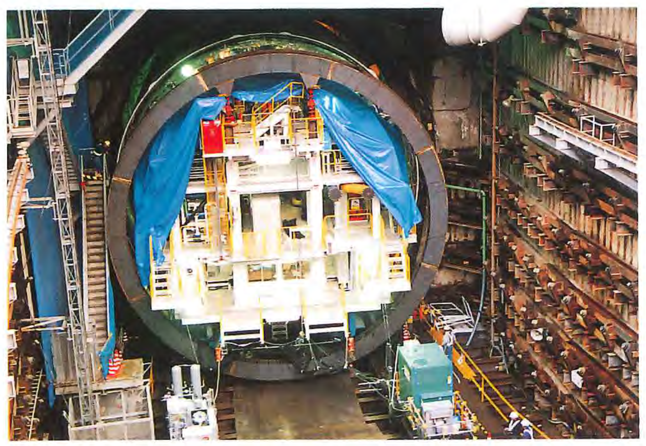
Shield Driving Section 1 consists of a 1780m long section of tunnel having an inside diameter of 10.8m driven by a shield machine having an outside diameter of 12.64m. The erection of the segmental lining in this section is being performed speedily (70 minutes per ring), with high precision and also with a high degree of safety by automatic segment erection devices in each of the three steps of segment movement, supply, and positioning and bolting. The steps are as follows.

Step 1: Segments are moved one by one from the segment carriers to a stock conveyor, the segments for one lining ring being stocked by 10 repetitions of this action.

Step 2: The segment erector receives the nuts for one segment from the nut supply device and one segment (3895.6mm x 550mm x 1200mm) from the segment supply device, and moves to the prescribed erection position.

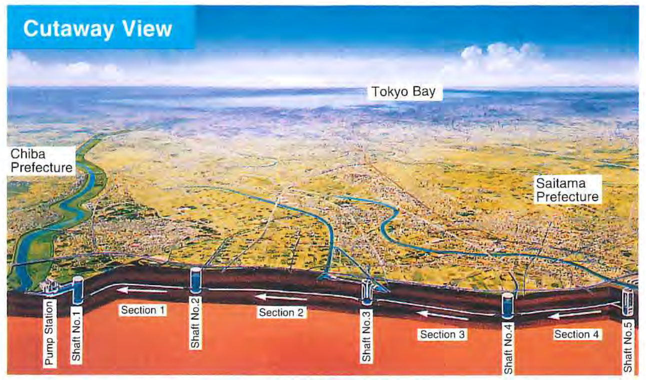
Step 3: Through the use of sensors, the segment erector determines the erection position of each segment, presses the segment to compress the seals, and tightens the bolts between segments and lining rings.





Metropolitan Area Outer Discharge Channel

Hirokazu MIYAO — Director, Edo River Work Office, Kanto Regional Construction Bureau, Ministry of Construction



The Metropolitan Area Outer Discharge Channel is Japan's first genuine "underground river" which is under construction in the eastern part of Saitama Prefecture, approximately 30km north of the capital city of Tokyo. Being constructed as a part of a comprehensive emergency flood control plan for the Naka/Ayase River Basin which suffers chronic inundation, this discharge channel will connect the small and medium rivers of this area to Edo River by underground tunnel to discharge the flood water into that river, which flows into Tokyo Bay. Through this project, damage due to flood inundation in this river basin will be reduced, thus making possible the provision of a good housing environment in the outskirts of the Metropolitan Area. The principal facilities consist of two 70m deep shafts which serve as bases for tunnel driving and will become water intakes after completion, the 6.3km long, 10.6m inside diameter tunnel which is being driven at a depth of 60m below the ground surface by large diameter slurry type shield machines, a pump station of 200m^3/s total capacity powered by gas turbine engines, and a surge tank between the tunnel and the pump station. Construction was commenced in 1992. Four shafts and approximately 3.0km of tunnel have been completed. As of 1999, construction work was approximately 45% complete and was being continued energetically toward completion in the year 2001.

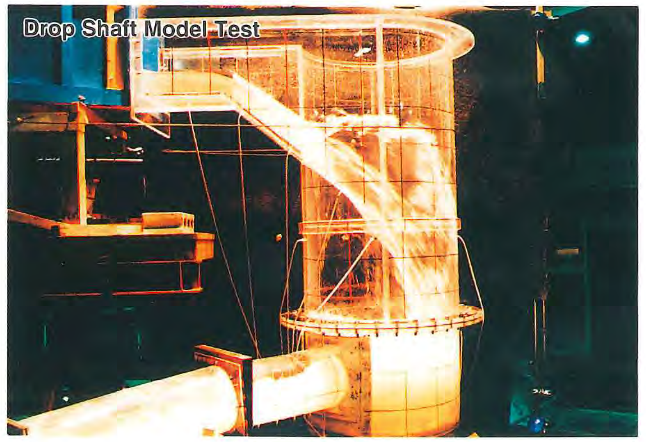
Plan of Tunnel Facilities

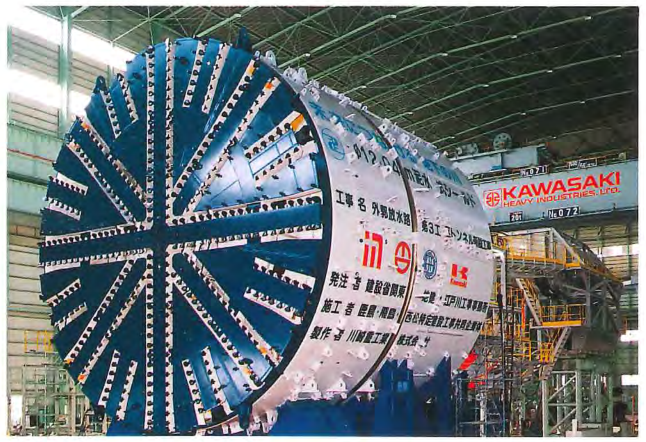
The tunnel was driven through stable diluvial soil having N-values exceeding 50 at a depth of 60m where the segmental lining will be subjected to external water pressure of 0.6MPa due to groundwater, and internal water pressure due to floodwater flow. Because of this, concrete was specified to have a strength of 47MPa, and due to the necessity for positive sealing of segment joints, hydrophilic seal material was provided in two lines, near the inside and outside faces. If the discharge pumps suddenly stop in an emergency, surging will occur in the channel. In order to prevent this from affecting the facility adversely, a large-scale surge tank was located just before the pump station. Regarding the form of flow into the shafts, in order to ease the impact of inflowing floodwater on the bottom slab of the shafts due to the 60m height of drop from the intake, the shafts themselves were designed as large diameter drop shaft structures to make the inflowing floodwater fall gently along the shaft wall. The form of structure was determined through model tests at the Public Works Research Institute of the Ministry of Construction.

Construction

All tunnel driving operations from excavation through segment erection were performed automatically. Each ring of the segmental lining is 1.2m wide and is composed of nine segments, each of which weighs 80kN. Excavation is proceeding at a speed of approximately 6m per day. All excavated soil material is being processed to reduce its water content by high pressure filter presses and is being utilized as material for the construction of high standard river levee. Because the minimum radius of curvature of tunnel alignment is 250m and the shield machines are 12m long, in order to minimize overcutting, an articulated design, which will follow the tunnel curve as closely as possible, was adopted for the first time in a large diameter shield machine. Also, in one contract section, long distance driving of over 2.5km was made possible by exchanging cutter bits at an intermediate point.

Because the object of this project is an "underground river" at great depth below the ground surface, almost no land was purchased, and no facilities for crossing waterways and roads were required. Because of this, it was possible to realize in a short time the result of concentrated investment of project funds.





Area Saving Shaft System for Sewer Reconstruction

Makoto AKIBA — Director of Design Section, Chubu Construction Office, Bureau of Sewerage, Tokyo Metropolitan Government

The sewerage system of the inner area of Tokyo is in transition from the age of initial construction to an age of reconstruction. However, planning for the reconstruction of main sewer lines by shield driving is confronted with difficulty in securing land for the location of launching shafts due to the scarcity of vacant land of suitable area in highly built-up urban areas.

The "Area Saving Shaft System" is being employed on a sewer reconstruction project to solve the problems of aging of old sewer pipes in the area around Akihabara Station and eliminate flooding in a part of that area. This project consists of constructing one sewer line of 2200mm finished inside diameter and two sewer lines of 1500mm finished inside diameter from a single shaft by slurry type shield machines. Because the area of land which could be leased was limited to only 600m^2, one third of the standard area, it was necessary to greatly reduce the space for shield operation. Furthermore, because the period of lease was restricted to the period of five years until a redevelopment project is to begin, two of the sewer lines were constructed simultaneously to shorten overall construction time.

Elements of "Area Saving Shaft System"

(1) Solid Clay Collection System

Cutters which can be extended and retracted are provided to cut out soil material at the tunnel face in a solid form. In this way the quantity of secondary treatment is reduced and the equipment for secondary treatment can be reduced in scale.

(2) Small Concentrator Cyclones

Instead of filter presses, which are large and take space, small concentrator cyclones are provided to concentrate secondary treatment material into highly concentrated slurry having a specific gravity on the order of 1.5, instead of drying it into cake form.

(3) Continuous Slurry Modification System

The highly concentrated slurry is treated with modifying agent to transform it into material which can be transported by dump truck. By employing this system a stock pit for curing becomes unnecessary.

(4) Spiral Conveyor

Being able to convey material both vertically and horizontally, a spiral conveyor makes direct loading into dump trucks possible even in a small space.

(5) Real Time Face Stability Control System

The slurry plant which is usually located on the ground surface is replaced by this new system which is installed on the support equipment train within the tunnel.

(6) Segment Stock System

A segment stock system designed for installation within the shaft is employed to reduce the area taken for stocking segments. This system was installed along the wall of the circular launching shaft which has an inside diameter of 12.0m.

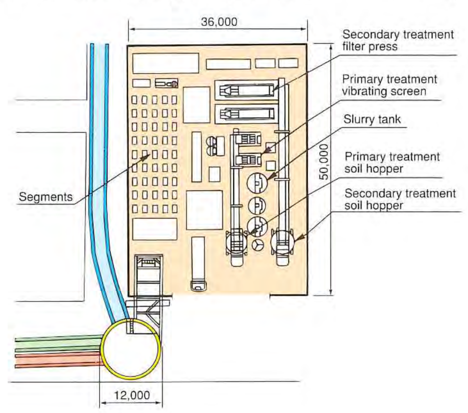
Effectiveness of "Area Saving Shaft System"

(1) By employing the above slurry treatment equipment and segment stock system, it was possible to reduce the area of the launching shaft site to one-third of that which has been required previously and use this small site effectively.

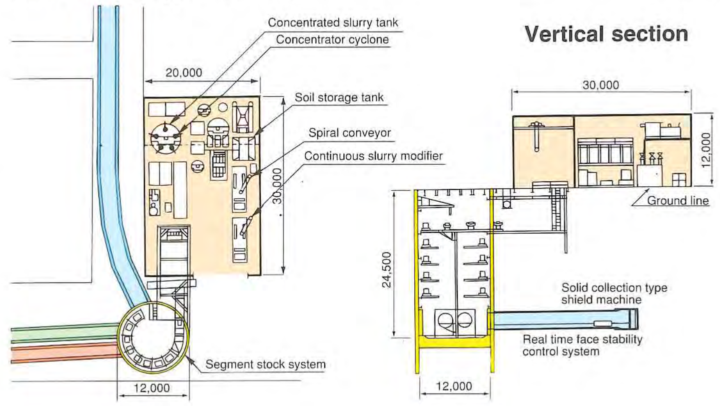
(2) Due to this reduction of launching shaft site area and the employment of solid collection, the costs of land lease, soundproof house enclosure and waste material disposal could be reduced, thus achieving a reduction in total construction cost.

(3) By employing the Solid Clay Collection System, one of the elements of the Area Saving Shaft System, the quantity of primary treatment material (ordinary material) was increased, thus reducing the quantity of industrial waste "sludge" from secondary treatment, and contributing to the policy of recycling excavated soil material.

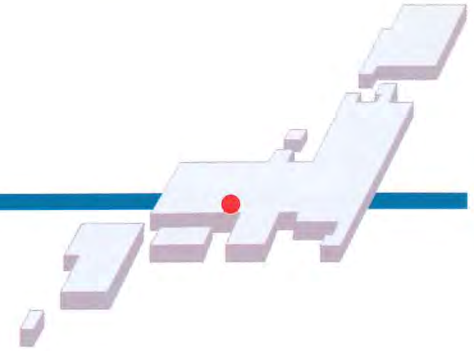
Conventional Type (1800m^2) (unit: mm)



Area Saving Type (600m^2) (unit: mm)



Long Distance, T-Branch and High-Speed Automated Shield Machines

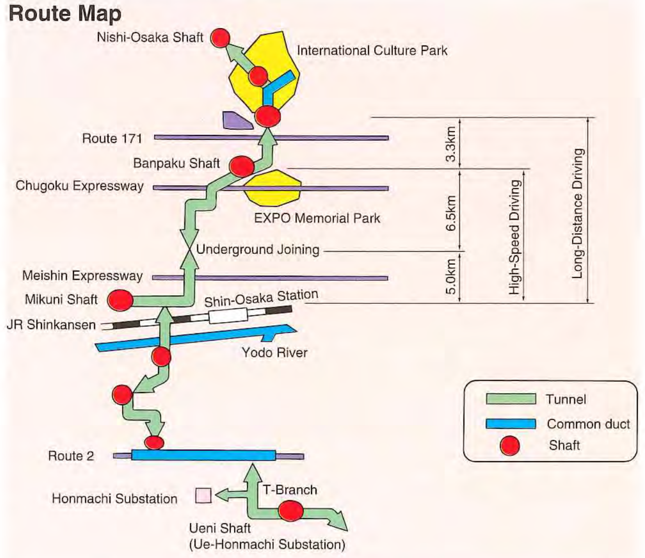


Hiroyasu INOGUCHI — Manager, Underground Lines Engineering Team, Central Transmission and Substation Construction Office, The Kansai Electric Power Co., Inc.

Mugio NAIDE — Manager, Underground Lines Civil Engineering Section

The Kansai Electric Power Co., Inc. is in the process of constructing high voltage transmission lines to supply 500kV electricity to the central area of the city of Osaka. This article will introduce two parts of this major project in which the transmission lines are to be placed in underground tunnels. One is extra long-distance tunnel driving which is presently in progress by slurry shield machines, and the other is the simultaneous driving of three tunnels which was performed from Ue-Honmachi Substation.

Route Map



Extra Long-Distance Shield Driving

The approximately 14.8km long section of tunnel between Gakuen Shaft and Mikuni Shaft is divided into three contract sections, but each of these contract sections requires long-distance driving which greatly exceeds approximately 2km, the driving distance which until now has been considered to be the limit. Especially, the approximately 11.5km (5.0km + 6.5km) section between Banpaku Shaft and Mikuni Shaft is planned as an extra long-distance drive by two shield machines (5750mm o.d.) which will join within the ground where they meet. The tunnel is planned to have a segmental lining only throughout its full length.

a) Long-Distance Shield Driving Technology

For this extra long-distance driving of as much as 6.5km, the following technology was developed and incorporated in the shield machines.

(1) Through research and development work to improve the durability of cutter bits for long-distance driving, new cutter bits were developed which are approximately 1.5 times the size of previous cutter bits and have approximately 1.7 times the hardness. This was achieved by improving the method of cooling after uniting the chip and base metal of which the bits are composed, and by improving the mixture and particle diameter of the material of the chips.

(2) The shield machines are equipped with automatic cutter bit exchange devices. When wear of the original bits (long-distance cutter bits) due to excavation has reached the allowable limit, spare bits which were originally installed behind the cutter face are pushed out to in front of the cutter face by hydraulic jack mechanism for use in the subsequent excavation.

(3) To prevent lose of watertightness at the tail seal because of damage due to long-distance driving, a tail seal was adopted which has four stages and uses solidified urethane seal brushes made by filling urethane foam into conventional wire seal brushes.

b) High-Speed Operation Technology

Because high-speed operation with an average monthly advance of 280m is required in the long-distance driving section due to tightness of the construction schedule, the following technology for speedup of operations was adopted.

(1) Thrust jacks were adopted which are capable of acting at an average speed of 60mm/min and a maximum speed of 90mm/min.

(2) To maintain the rate of cutter penetration per revolution of the cutter head at about the same rate as before, the speed of revolution was set at a rated speed of 1.3 to 1.35rpm.

(3) By employing a type of segment joint connection which can be completed quickly and a high-speed automatic erection system, the time to erect one ring of lining was reduced to 20 to 25 minutes.

The tunnels being driven by the shield machines which incorporate this technology for long-distance, high-speed driving are showing smooth progress at the present time, and these two machines, which are of equal diameter, are scheduled to join within the ground in autumn of the year 2000.

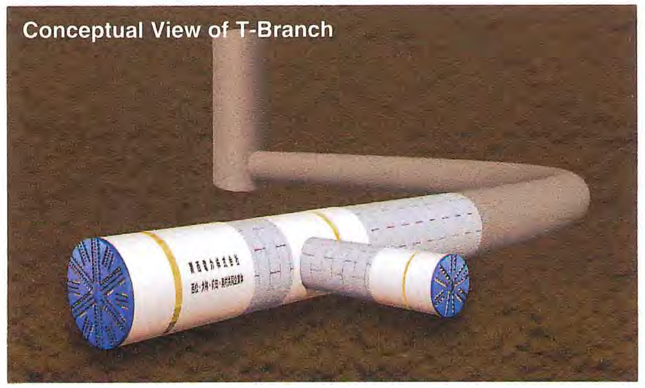
Shield Machine for Long-Distance Driving

T-Branch and High-Speed Automated Shield Machines

Two shield driven tunnels were launched from the shaft at Ue-Honmachi Substation. One was driven by the world's first "T-Branch" shield machine, a "parent" machine which is designed to launch in a perpendicular direction from itself a "child" machine which was built into it in advance. The other was driven by a high-speed automated shield machine which incorporated new technology of various kinds for automation and speedup of operations to rationalize construction and improve safety.

a) T-Branch Shield Machine

The "T-Branch" shield machine is a method by which a branch shield machine can be launched mechanically within the ground at any desired branch point by building the branch (child) machine into the parent machine in advance. This new technology makes unnecessary the ground improvement work which has been deemed to be necessary up until now, enables reduction of cost and shortening of construction time, and is highly safe. The 17.49m long shield machine (7260mm o.d.) is divided into front, middle and rear sections. The middle section has a double skin plate and the child machine (4240mm o.d.) is launched by sliding the skin plate to open the launching opening. After launching the child machine, two independent systems of slurry circulation equipment and segment transport equipment were provided, thus realizing simultaneous driving of two shield machines.



Conceptual View of T-Branch

T-Branch Shield Machine

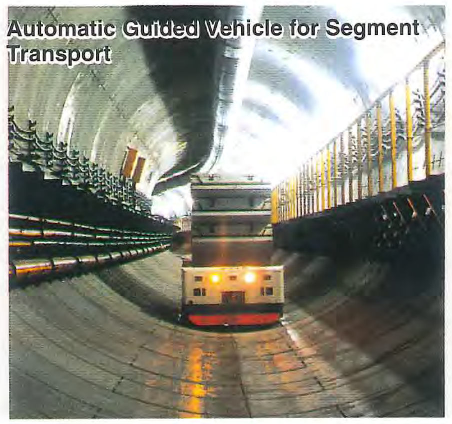
b) High-Speed Automated Shield Machine

The other shield machine which was launched from the shaft at Ue-Honmachi Substation was a high-speed automated shield machine (7.79m long, 6360mm o.d.) which incorporated the following equipment to secure rationalization of operations and improved safety.

(1) Improvement in the safety of operations within the tunnel and reduction of labor were achieved by fully automating the supply of segments to the erector and the erection of these segments.

(2) Reduction in segment erection time and simplification of operations were achieved by adopting reinforced concrete segments which use Cotter Joints and Quick Joints instead of conventional bolted joint segments.

(3) For the transport of materials within the tunnel, Automatic Guided Vehicles (AGV) were employed which operate on pneumatic tires instead of a track. In this way, track laying operations and track material transport vehicles became unnecessary, contributing to the relief of congestion.



Automatic Guided Vehicle for Segment Transport

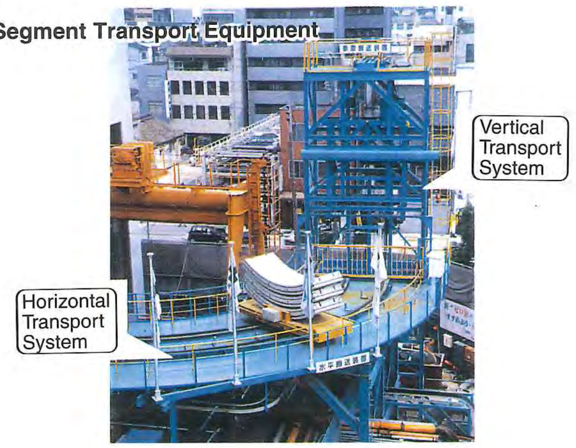
c) Simultaneous Driving of Three Tunnels

Because several construction projects, including building construction, were being performed within a narrow land area at the site of the shaft, the slurry treatment plant was designed as a three level vertically stacked plant and provided with treatment equipment which would enable the simultaneous driving of three shield machines after launching of the branch machine of the T-Branch machine.

(1) The segment stock yard had a separate level for use by each of the tunnels being driven. Material transport from the second level to the shaft was performed by a horizontal transport system.

(2) Because of simultaneous driving of three tunnels, the movement of materials down the shaft to the tunnels was performed using a vertical transport system which moved up and down within a guide frame to prevent contact between suspended loads within the shaft.

Segment Transport Equipment



Japan's Largest Pumped Storage Hydropower Station

Yoshifumi NISHIWAKI
General Manager,
Kannagawa Hydro Power Plant Construction Office,
The Tokyo Electric Power Co., Inc.

Kannagawa Hydropower Station is a pure pumped storage type hydropower station, Japan's largest, to have a maximum output of 2700MW (six 450MW units) which The Tokyo Electric Power Co., Inc. is presently constructing at a site northwest of Tokyo, with July 2004 as the target for commencement of operation.

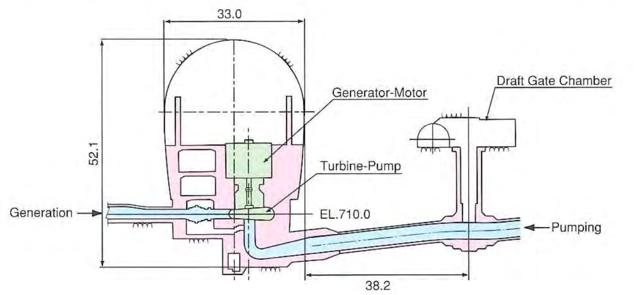
Two large-scale underground caverns (underground power houses) are planned to be constructed at a depth of approximately 500m, each having its own waterway. The excavation volumes of the two caverns are 223,000m^3 (No.1) and 156,000m^3 (No.2), respectively, and the waterways each consist of a headrace (approximately 2400m long), penstocks (approximately 1400m long) and a tailrace (approximately 2100m long).

The geology at the site is ancient rock of 200 to 300 million years ago called the Chichibu Mesozoic and Paleozoic Formations which have a nearly east-west zonal structure. This rock, which is hard and dense, is mixed rock consisting of sandstone, chert and limestone gravel and blocks mixed into a chiefly pelitic matrix. The geologic structure is homoclinal having an east-west strike and a dip of 50° to the south. At the power house caverns, the maximum and minimum values of initial rock stress are 12.3MPa and 4.7MPa, respectively, and the coefficient of lateral stress is 0.39.

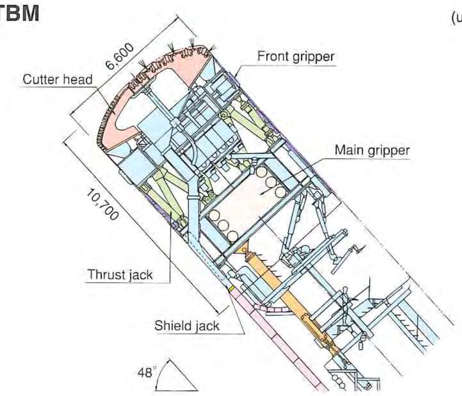
The No.1 power house cavern has a 33m wide, 52m high horseshoe-shaped cross section, and is 216m long. Cavern excavation is by bench cut, and an observational construction management system has been introduced by which operations such as predictive analysis and selection of the optimum support pattern for each bench can be performed by real time computer processing of monitored data concerning behavior of the surrounding rock mass before and after excavation of each bench.

The penstocks are steel lined underground waterways having a diameter which changes from 8.2m to 2.3m. The 48° steeply inclined section (approximately 1000m long) of these penstocks will be excavated upward from the power house end in a single stage by a 6.6m diameter full face TBM. At Kazunogawa Pumped Storage Hydropower Station, the penstocks were excavated in two stages by pilot and reaming TBM's, first driving a pilot upward from below using a small 2.7m diameter TBM and then performing an enlargement excavation in the downward direction from above using a 7.0m diameter finished cross section TBM. At this project, excavation in one stage by a full face TBM has been adopted to excavate the required finished cross section by one continuous drive from below to reduce excavation cost by improving the speed of inclined shaft excavation.

Construction was commenced in May 1997, and as of December 1999, excavation of the arch of the No.1 power house cavern has been completed and the bench cut excavation of the cavern body is in progress. Also, penstock excavation by TBM was begun in November 1999, with the excavation of one penstock to be completed in approximately 1.5 years.



Cross Section of Power House (unit: m)



Full Face TBM (unit: mm)

CAES-G/T Pilot Plant

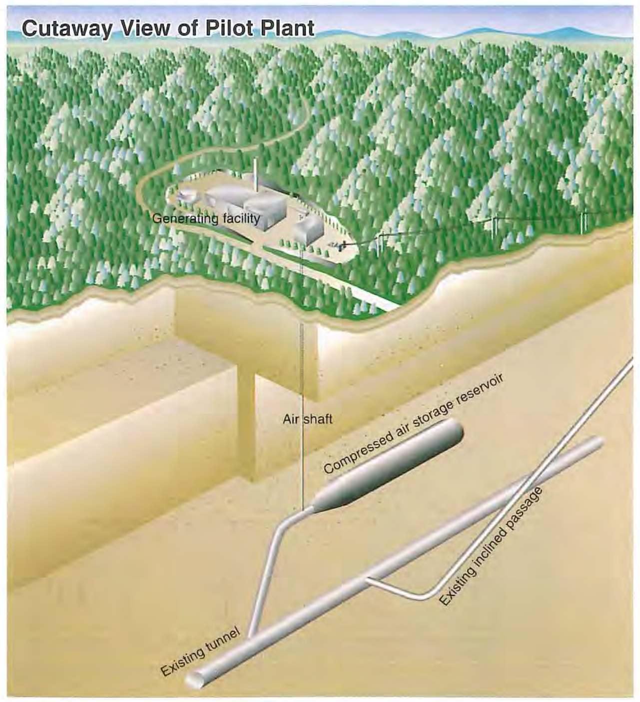
Shigenori KURODA
Director of Investigation Department,
Energy Storage Engineering Development Center,
New Energy Foundation

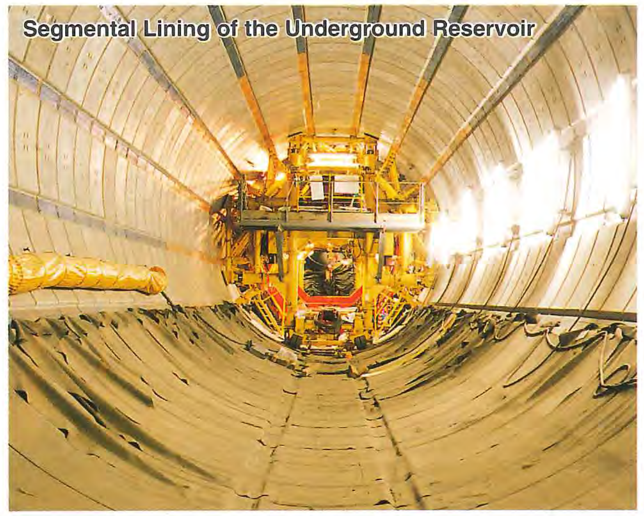
The Compressed Air Energy Storage Gas Turbine Power System (CAES-G/T) is coming up as a new method of electric power load leveling to accommodate concentrations of electric power demand in certain seasons and hours of the day. CAES-G/T is a hybrid system of thermal power generation in which the high pressure air which, together with fuel, is essential to gas turbine power generation is produced and stored in an underground cavern utilizing surplus electric power during off-peak hours and then supplied to the gas turbine for power generation during daytime peak hours.

The utilization of caverns in rock at a great depth underground is conceivable for the storage facilities to supply this high pressure air in large quantities for power generation combustion at periods of peak demand. However, there are numerous problems which must be solved regarding location, geologic investigation, design, construction execution, and operation management. In a cavern in a fissured rock mass within a complex geological structure, is it possible to secure with confidence the capability to resist repeated application of air pressure in the range of 40 to 80 atmospheres and the airtightness to retain the stored air without leakage? Can the basic conditions as an underground storage facility be maintained over a long period? What should be required in design and construction execution to satisfy these basic conditions? Can the construction of large-scale caverns at great depth underground be executed economically? What will be the effect on the surrounding environment? What are the operating characteristics of the CAES-G/T System and what measures should be taken to achieve high efficiency?

The New Energy Foundation, on commission from the Ministry of International Trade and Industry, is performing technical development investigations to overcome the above problems surrounding this globally unprecedented rock cavern type CAES-G/T and demonstrate the locational feasibility and practicality of the project. Based on the results of investigations, tests, design and analyses regarding CAES-G/T, a 2000kW capacity pilot plant has been under construction since January 1998 at the abandoned Sunagawa Colliery at Kami-Sunagawa on the island of Hokkaido. Utilizing existing passages which had been abandoned, a compressed air storage facility is being newly excavated in hard rock at a depth of approximately 450m (elevation −250m). The generating facility is located on the ground surface directly above, and these two facilities are connected by means of a 100mm diameter air shaft for the free passage of high pressure air.

The underground compressed air storage facility, constructed by excavating a 7.4m diameter cavern in a rock mass of sandy mudstone, consists of a cylindrical storage reservoir (6m inside diameter, 57m length, 1600m^3 capacity), a concrete end block and a concrete plug. Pressure within the storage reservoir is resisted completely by the surrounding rock mass, and the required airtightness is secured by lining the interior surface of the storage reservoir with a 3mm thick airtight rubber sheet. As a buffer zone between the rock mass and the airtight rubber sheet, a lining structure has been adopted here which consists of a reinforced concrete jointed segmental lining having 16 segments per ring and backfill concrete, a structure which will permit free cavern deformation.





Demonstration testing of the pilot plant is scheduled for the year 2001. Cycles of operation for filling compressed air into the underground storage reservoir, holding and generation operation by releasing high pressure air from underground will be performed to confirm the function and operating characteristics of CAES-G/T, and to evaluate the soundness of the pressure resistance and airtightness functions of the underground storage facility by monitoring the behavior of the storage reservoir with special attention to the quantity of air leakage, air storage temperature, and the stress-deformation behavior of the jointed segmental lining structure and the surrounding rock mass.

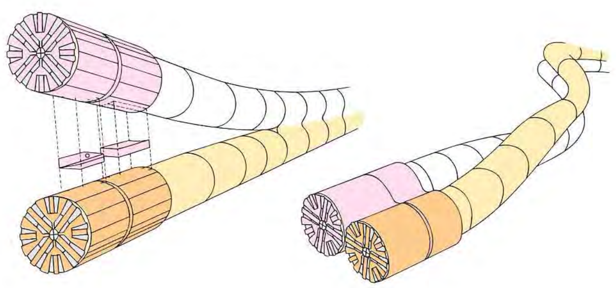
Innovations in Technology

H & V Shield Tunneling

The H & V Shield, a shield machine for constructing a tunnel which has a double circular cross section, incorporates special vertical direction articulation mechanisms which enable free control of the machine's attitude and direction. Further, by means of these articulation mechanisms, a double circular cross section of horizontal orientation can be gradually twisted into a vertical orientation and vice-versa. Also, by separating the two parts of the shield machine, a tunnel can be constructed which forks from a double circular cross section into two tunnels of circular cross section.

In the past, subway station structures have generally been constructed by cut and cover excavation. However, this method is accompanied by many problems and restrictions such as the necessity to move tangled systems of buried utility structures and the complications of construction in areas bustling with people both day and night. The shield machine used here is a 4 face shield machine having cutter faces of 6560mm diameter on the left and right and 1720mm diameter at the top and bottom in the center. The left and right sides of the machine have independent articulation mechanisms, a structure which enables easy attitude control.

A 2400mm inside diameter trunk sewer and a 2000mm inside diameter branch sewer are to be constructed simultaneously by a vertically oriented two-face shield machine having cutters of 3290mm and 2890mm diameter, and separate on the way into their different routes. Because the shield machine can separate within the ground, the construction of an intermediate shaft has become unnecessary. (Shield Tunneling Association of Japan)

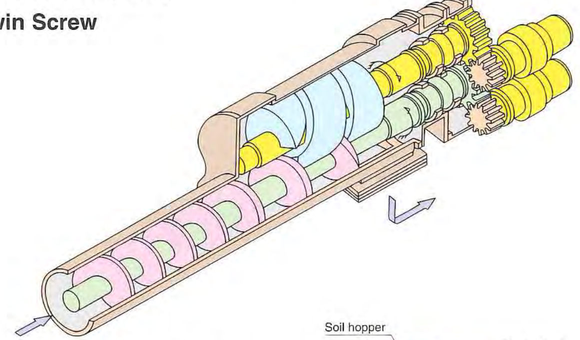


Twin Screw Shield Machine

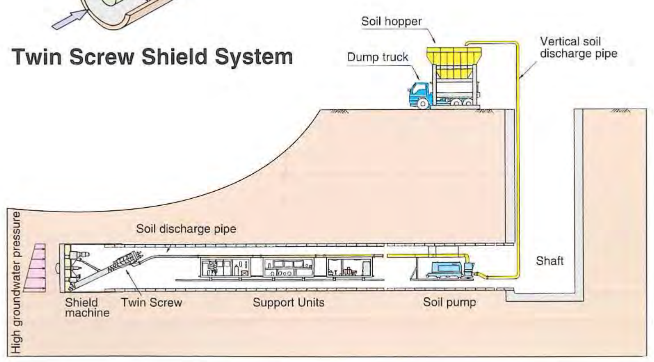
The construction of underground space in urban areas is now performed principally by the method of shield driving using shield machines which are divided by type into slurry type and earth pressure balanced (EPB) type. A cost comparison of these two types shows the EPB type to be the more advantageous because construction can be performed even with a surface site of small area due to the small scale of the equipment. However, with the EPB type there is a problem that at great depth the water pressure acting on the face becomes high, and with the conventional type of screw conveyor which is used in the discharge of excavated soil material, the soil material blows out and control of face pressure becomes impossible.

The Twin Screw is a new discharge mechanism which solves this disadvantage and makes possible an EPB type of shield machine which can operate at great depth. The Twin Screw is composed of two screw conveyor screws, their casing and a drive motor. One of the screws has a conventional thin spiral and the other has a thickened spiral which fits into the spaces of the thin spiral of the first screw with a suitable clearance. By designing the two screws so as to fit together by having spirals of mutually opposite direction, a watertight mechanism is formed, and by rotating these screws in the mutually opposite direction, soil material is forced to move along the screw and can be discharged continuously. Because this device has no continuously open space within itself, the soil material is forcibly moved through closed space formed by the thick spiral screw and mechanically discharged. Thus, even under conditions of high water pressure at the tunnel face, blowout of soil material is prevented, and stable control of face pressure without pulsation and control of the quantity of excavated soil by controlling the speed of screw revolution have became possible. (Taisei Corporation and Ishikawajima-Harima Heavy Industries Co., Ltd.)

Twin Screw



Twin Screw Shield System



"Kuroon" Shield Machine

The "Kuroon" shield machine, an epoch-making new type of shield machine for driving extra-long tunnels, is designed for easy exchange of cutter bits which have been warn down by excavation. The machine is equipped with a spherical head which can be turned to bring the cutter face around to inside the tunnel to enable safe, certain and speedy cutter bit exchange and cutter face repair.

The special characteristics of the "Kuroon" shield machine include (1) when the exchange of cutter bits becomes necessary, it can be performed anytime, anywhere and any number of times; (2) because the bit exchange operation can be performed within the tunnel, it can be performed with an extremely high degree of safety and certainty; (3) because of the ease with which the operation can be performed, the number of days required is substantially reduced; and (4) because ground improvement is unnecessary, the economic advantage is great.

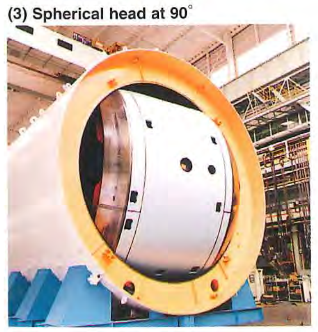
In structure, the cutter spokes are adjustable in length so that they can be contracted, and the excavation mechanism as a whole, including the cutter spokes, can be retracted so as to fit within the spherical head.

As an example of actual use in construction, "Kuroon" is being employed in the driving of the Nippa-Suehiro Trunk Sewer for the Yokohama Bureau of Sewerage. The outside diameter of the shield machine is 9450mm, and the total length of tunnel to be driven is 4435m. The soil through which the tunnel is being driven consists of mudstone having considerable inclusions of sand. Bit exchange has been performed once, after driving 2570m, and the time required was 40 days. Driving is still in progress at the time of writing, with completion of driving scheduled for March 2000.
(Shield Tunneling Association of Japan)

(1) Cutter spokes are contracted

(2) Spherical head begins to turn

(3) Spherical head at 90°



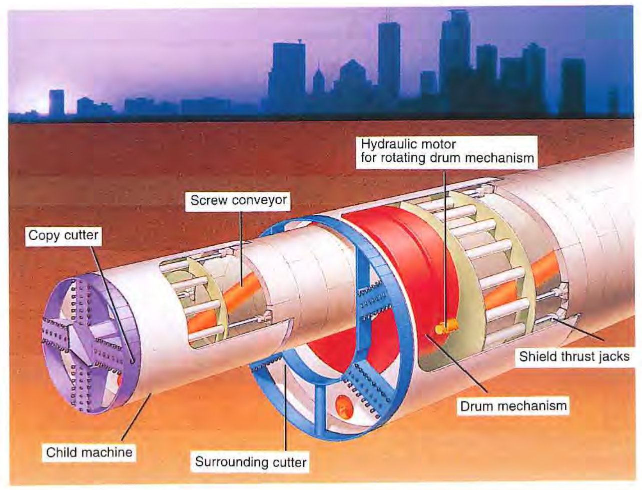
(4) Spherical head completes turn (180°)

"Flex" Parent-Child Shield Machine

A "parent-child shield machine" is a type of shield machine which enables a reduction in tunnel diameter within the ground at any desired point during tunnel driving. In the past, the practice has been to drive a tunnel of unchanging diameter from the launching shaft to the arrival shaft, but on a long distance drive, to keep the same diameter throughout is not necessarily rational. By employing a parent-child shield machine, a shaft at the point of diameter change can be omitted and fewer shield machines need to be manufactured, thus reducing cost. Up to the present, parent-child shield machines have had a form in which the parent and child machines were connected at the center, but the "Flex" parent-child shield machine has further developed the capability of the parent-child concept by enabling the connection to be made at any position in the cross section, such as at the top or bottom of the tunnel.

The child machine is initially located in the center of the parent machine and the cutters on the child machine also serve as cutters for the parent machine. To excavate the full cross section of the parent machine, a surrounding cutter is provided outside of the child machine's cutter head. The child machine is mounted eccentrically in a drum mechanism which itself is mounted eccentrically in the parent machine and a U-shaped opening is provided in the surrounding cutter. Thus, by rotating the drum mechanism, the child machine can be moved from its center position to a peripheral position. After rotating the drum, necessary equipment, such as that for discharging excavated soil material, and the tail plate are installed on the child machine and it is then launched from the parent machine. Because these operations can be performed without the use of a crane, they can be completed safely and in a short time.

The "Flex" parent-child shield machine promotes the economy of shield driving works, which are ever increasing in length and depth, and application of the machine's special feature of making connection possible at any position will expand its range of utilization for sewer, railway, electric power, communications and gas distribution facilities.
(Taisei Corporation and Ishikawajima-Harima Heavy Industries Co., Ltd.)

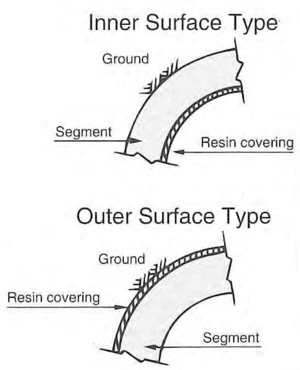


Innovations in Technology

HD Lining

HD Lining (High Durability Tunnel Lining) is a new type of tunnel lining material of high quality produced by applying a covering of synthetic resin to the lining segments which form the primary lining of a shield driven tunnel, thus heightening their durability and enabling the omission of a secondary lining even under severe conditions. HD Lining was employed for the first time in the Kitsune River Improvement Project in the city of Kobe, which was performed as an urban river flood protection measure, and is presently being employed at two other project sites.

HD Lining has several special characteristics. By enabling the omission of a secondary lining, HD Lining makes possible a substantial reduction of construction time and total construction cost. Also, by improving water impermeability and durability against acid, chemicals and abrasion, the lining is maintenance free. Further, by improving inner surface smoothness, flow capacity is improved. In addition, because the synthetic resin covering is applied under strict factory quality control, a product of high quality is obtained. Furthermore, according to the environment of use, desired quality and cost, a selection can be made between "inner surface type" and "outer surface type," each of which is further divided into "panel type" and "spray coat type." The "inner surface type" is suited to sewer and underground river applications where durability, inner surface smoothness and resistance to abrasion are required, and the "outer surface type" is suited to applications such as subway tunnels and conduits for electric power, gas and communications lines where water impermeability and durability are required. (Kajima Corporation, C.I.Kasei Co., Ltd., Ishikawajima Construction Materials Co., Ltd. and GEOSTR Corporation)



Honeycomb Segments

Honeycomb Segments are reinforced concrete segments of hexagonal configuration which were newly developed to achieve rapid tunnel driving by performing excavation and segment erection simultaneously. These segments are called "Honeycomb Segments" because the pattern of joints following erection resembles the honeycomb of bees. Because the inner surface of the segments is smooth, they are suited to the omission of a secondary lining. Also, because every segment has an identical configuration, they are suited to automatic erection.

In order for the Honeycomb Segments to be applicable to the soft ground of the plains where many Japanese cities are located, they were designed with a structure in which the joints which come together in wedge form are firmly connected by long bolts at the segment ends. Also, numerous full-scale loading tests and analyses were performed to grasp the mechanism of stress transmission in these wedge form joints, and original design techniques and methods of manufacture and execution were established. Further, the configuration of segments is being altered to enable easy execution of curves by tapering one half of the hexagonal shape.

Honeycomb Segments were used for the first time in 1995 in a 4.1m outside diameter electric power transmission tunnel for Tokyo Electric Power Co., Inc. which included curves of 200m radius at four locations and omitted a secondary lining. Up to 1999, Honeycomb Segments have been employed in five tunnels including electric power transmission, subway and sewer applications. On one of these projects, a 4.68m outside diameter electric power transmission tunnel which was constructed for Chubu Electric Power Co., Inc. in 1999, success was achieved in simultaneous excavation and segment erection by automating all driving operations from thrust jack operation to attitude control, and segment handling operations from supply to erection. (Okumura Corporation and Ishikawajima Construction Materials Co., Ltd.)

Ring Lock Segments

In recent years tunnel projects for underground storm water storage facilities and storm sewers are being actively advanced as a measure against urban flooding. In these projects, the tunnel lining structure is often designed with only a primary lining for reasons of economy such as reduction of excavation diameter. Because of this, the segmental primary lining is required to resist both external load due to soil and water pressure and internal water pressure at times of flooding. Ring Lock Segments were developed as "a rational reinforced concrete segmental lining which is capable of resisting external soil and water pressure and internal water pressure."

Structural verification of these segments by full-scale (5100mm diameter) loading tests has been completed and they are expected to be employed in the construction of a 3800mm outside diameter storm sewer trunk in which a secondary lining has been omitted.

The special characteristics of these segments are as follows.

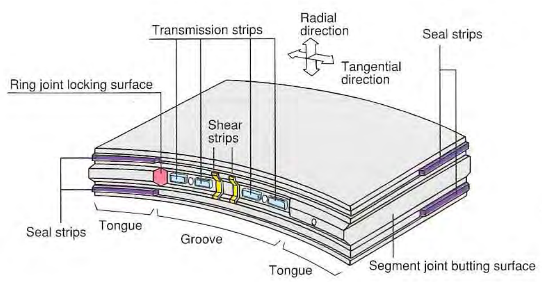
(1) The tongues and grooves which are provided on the segments in both the radial and tangential directions resist external load and internal water pressure.

(2) The cost of segment manufacture can be reduced by simplifying connection members. Also, the form of connection can be selected freely to meet an objective such as securing a smooth inner surface, or automation of segment erection.

(3) Structural members are made entirely of reinforced concrete with no exposure of steel parts. Durability and corrosion protection equal to a reinforced concrete lining can be secured without performing any special anticorrosion treatment.

(4) Having a high capacity for following ground displacement as a result of the buffer material on the contact surfaces of the tongue and groove joints, the completed tunnel possesses superior seismic quality. (Ring Lock Segment Research Association)

Basic Shape of Ring Lock Segments



Cone Connector Segments

Cone Connector Segments (one-pass joints) are a new type of segmental lining which, being intended for omitting a secondary lining, is based on one-pass lining execution suited to automatic erection and makes possible a perfectly smooth inner surface. The joint connectors on these segments are located on the edges of the concrete segments in both the joints between segments in a ring and those between rings.

Structural verification of these segments by element testing and demonstration construction (30 rings of 2750mm outside diameter) have been completed, and in 1999 they were employed in the construction of a sewer trunk (548 rings of 6600mm outside diameter) in which a secondary lining was omitted.

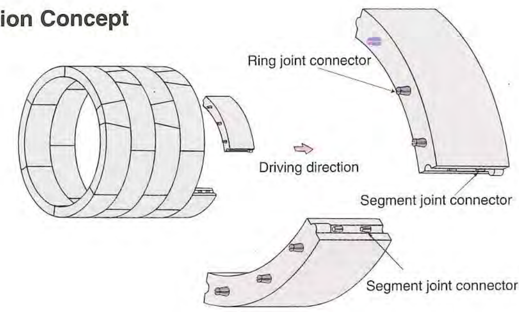
The special characteristics of these segments are as follows.

(1) Because joint connections are completed merely by sliding segments in the axial direction of the tunnel, and furthermore, because it is unnecessary to perform the additional tightening of bolts after completion of erection which has been performed on conventional bolted joints, erection time can be reduced.

(2) Because the metal joint connectors are located on the edges of the segments, the tunnel has a smooth inner surface when segment erection is completed, and a secondary lining can be omitted depending on the purpose of tunnel use.

(3) Because conventional joint bolts are not needed, the operation of bolt supply during segment erection is unnecessary, making this type of segment suited to automatic erection. (Japan RC Segment Industrial Association)

Erection Concept



Innovations in Technology

SRC Segments

Steel and Reinforced Concrete (SRC) Segments are a new type of segmental tunnel lining in which composite SRC structure, widely used in both building and civil engineering structures, has been adopted in order to realize a relatively thin segmental lining for large diameter shield driven tunnels. SRC Segments were employed for the first time in 1996 in the construction of a section of 6000mm outside diameter sewer trunk.

The special characteristics of these segments are as follows.

(1) Higher strength and thinner structure can be achieved without any loss of corrosion resistance which is a characteristic of concrete segments.

(2) By anchoring the joint connectors directly to the ends of the structural steel members, the strength and stiffness of the joints can be increased to the same level as those of the segments themselves.

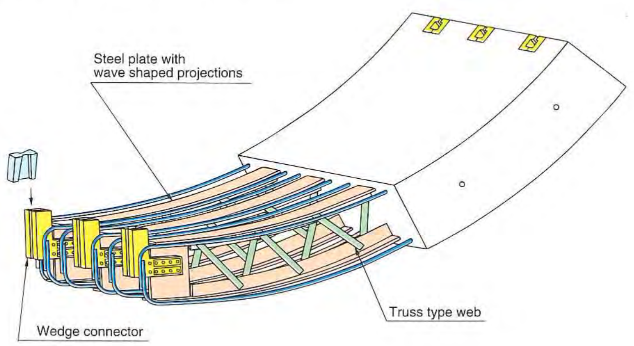
(3) Because of the unified steel structure of the segments and joints, this structure is highly adaptive to tensile stress due to internal water pressure.

(4) A secondary lining can be omitted similarly to ordinary concrete segments.

(5) Various types of joint connectors can be combined with the steel frame of the segments. Especially, if wedge connectors are used, automatic erection is easy.

(Japan RC Segment Industrial Association)

Details of Segment Structure



Utilization of Excavated Soil

The soil material which is generated in large quantities by slurry type shield driving generally has a high moisture content and, according to the Japanese "Waste Management and Public Cleansing Law" is classified as inorganic sludge which is to be disposed of as industrial waste. However, in the construction of the Saitama Railway Line north of Tokyo, this construction sludge is being processed as described below for regenerative utilization to promote recycling and reduce construction cost.

(1) Employing high pressure, thin layer filter presses (in which the spacing of filter plates is reduced to 2/3 and the pressure applied is three times that of conventional filter presses), the moisture content of the secondary treatment soil is reduced and high strength cake is formed.

(2) Because lumps of cohesive soil of the size of sand become mixed into the sand fraction which is subjected to primary treatment only, thereby increasing the moisture content of that fraction, a "crush-pump" to break up these lumps was newly developed to promote the dissolving of cohesive soil into the return slurry, thus reducing the moisture content of the primary treatment soil and suppressing the amount of improvement agent used in secondary treatment.

(3) By mixing a small amount of a newly developed neutral inorganic improvement agent into the soil during secondary treatment, improved soil material is produced which has the required strength, has a pH in the neutral range of 5.8 to 8.6, contains no harmful substances, and is free of any possible organic contamination.

The system for improving excavated soil material was constructed by adding this equipment for soil improvement to the conventional slurry treatment line.

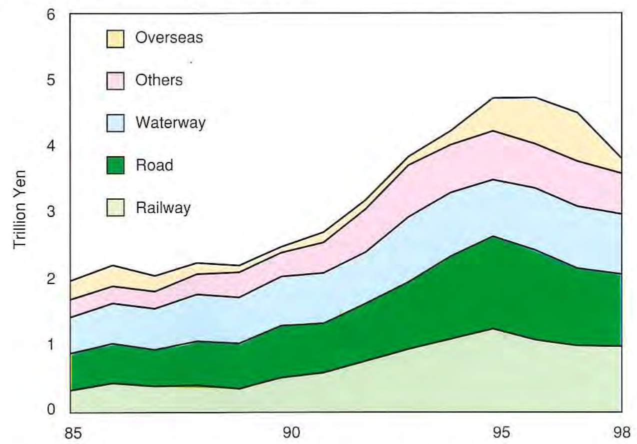
Also, the improved soil material is being used effectively as fill material in applications such as land grading.

(Japan Railway Construction Public Corporation)

General Aspects of Tunnelling in Japan

Trend of Construction Investment in Tunnels and Underground Space

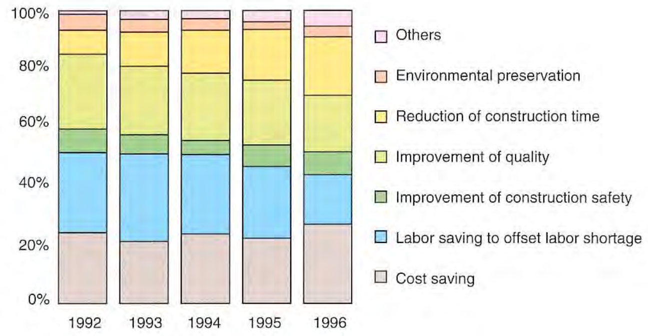
The total amount of construction investment in tunnels and underground space in Japan has been declining continuously since 1995 as a result of the Government's restraint of public infrastructure construction projects. However, the amount of such domestic investment has recently come to level off from this decline as a result of emphasis being placed on public infrastructure construction as a government financial measure for business recovery. On the other hand, the amount of construction overseas by Japanese contractors continues to decline. The following chart shows the year by year variation in the total amount of tunnel and underground space construction works, divided according to purpose, under contract by the Japanese construction industry.



Because the amount of work under contract in a particular year includes works which were contracted in previous years and were still under construction in that year, the amounts shown by the chart are not strictly the amount of works contracted in a single year, but they can be considered as an index which shows the general tendency of change in amount invested.

Trend in Technical Development Regarding the Construction of Tunnels and Underground Space

In response to the above mentioned restraint of investment in public infrastructure, tunneling engineers have been faced with the necessity of achieving compatible levels of quality and safety together with cost saving in the design and construction of tunnels and underground space. The following chart shows the year by year variation in the proportions of investment in technical development for various objectives. The proportions for cost saving, labor saving to offset labor shortage, and quality improvement each account for over 20%.



Tunnel Lining Fall Accidents and Follow-up

A series of incidents occurred during 1999 in which sections of concrete fell from the linings of railway tunnels. On June 27, a 1960N section of concrete fell from the lining of Fukuoka Tunnel on the Sanyo Shinkansen Line, directly hitting a moving train. On October 9, 2214N of concrete fell from the wall of the nearby Kitakyushu Tunnel of the same Sanyo Shinkansen Line. Further, on November 28, a 19,600N section of concrete fell from the roof of the Rebunhama Tunnel on the Muroran Line of Hokkaido Railway Company, derailing a freight train which collided with it.

In response to this situation, the cause of these concrete falls is being sought through detailed investigations being performed under the leadership of the Ministry of Transport concerning external factors such as ground pressure, water pressure, train vibration and air pressure variation, various internal factors related to materials and construction, and deterioration promoting factors such as age and water seepage. The results of these investigations are to be presented in the near future.

In the light of this series of accidents, emergency inspections were performed on railway and road tunnels throughout the country. These inspections were performed chiefly by visual and percussion tests, and preventative measures were taken where problems were discovered.

Meanwhile, in order to prevent future recurrence of accidents such as these, committees have been formed in the Ministry of Construction, Ministry of Transport, Railway Technical Research Institute, Japan Society of Civil Engineers and other relevant organizations for the study of inspection and maintenance techniques and construction techniques, and the preparation of manuals and guidelines.

Deep Subterranean Space Utilization

Based on the May 1998 report of the Provisional Investigation Committee for Deep Subterranean Utilization, a proposed "Law Providing Special Measures Concerning Public Utilization of Deep Subterranean Space" (provisional title) has been prepared and will be submitted to the Diet shortly. The objective of this proposed law is to provide the legal framework for promoting the smooth achievement of, and assuring the rational utilization of deep subterranean space for, certain projects of benefit to the public by providing special measures concerning the requisite conditions, legal formalities and other matters pertinent thereto.

Within JTA, working groups have been advancing technical studies concerning deep subterranean utilization since four years ago, and a meeting for an interim report to JTA members is planned to be held when the new law has been approved.

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Senken Kogyo Co.,Ltd.
2-2-13,1-Bancho,Aoba-ku,Sendai 980-0811
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Shimizu Corporation
Seavans South,1-2-3,Shibaura,Minato-ku,Tokyo 105-8007
TEL:3-5411-0566,FAX:3-5441-0515,E-mail:koga@civil.shimz.co.jp.

Shiraishi Corporation
1-14,Kandaiwamoto-cho,Chiyoda-ku,Tokyo 101-8588
TEL:3-3253-9111,FAX:3-3253-4566

Sumitomo Construction Co.,Ltd.
13-4,Araki-cho,Shinjuku-ku,Tokyo 160-8577
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Taihei Kogyo Co.,Ltd.
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Takenaka Civil Engineering & Construction Co.,Ltd.
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TEL:3-3542-6321,FAX:3-3248-6545

Tekken Corporation
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TEL:3-3221-2131,FAX:3-3265-3776

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Tobishima Corporation
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TEL:3-3562-6111,FAX:3-3561-5745

Tokura Construction Co.,Ltd.
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Totetsu Kogyo Co.,Ltd.
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TEL:3-5261-5224,FAX:3-3268-4258

Toyo Construction Co.,Ltd.
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1-4-35,Maizuru-machi,Oita-shi 870-0044
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TEL:11-892-7266,FAX:11-892-7344,E-mail:nsn7266@seagreen.ocn.ne.jp

Seiken Co.,Ltd.
1-12-14,Koishikawa,Bunkyo-ku,Tokyo 112-0002
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Sanshin Corporation
1-2-7 Koraku,Bunkyo-ku,Tokyo 112-0004 TEL:3-3816-2151,FAX:3-3816-2178,E-mail:sales@sanshin-corp.co.jp,http:www.sanshin.corp.co.jp/

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1-16-14,Shibuya,Shibuya-ku,Tokyo 150-0002
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3-3-7,Iidabashi,Chiyoda-ku,Tokyo 102-0072
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1-20-4,Nihonbashi-kakigaracho,Chuo-ku,Tokyo 103-0014
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1-8-29,Nishimiyahara,Yodogawa-ku,Osaka 532-0004
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3-5-28,Hakataekiminami,Hakata-ku,Fukuoka 812-0016
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2-4-8,Watanabedori,Chuo-ku,Fukuoka 810-0004
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Fuji Research Institute Corporation
Takebashi Square,2-3,Kandanishiki-cho,Chiyoda-ku,Tokyo 101-8443
TEL:3-5281-5418,FAX:3-5281-5414,E-mail:j_itoh@star.fuji-ric.co.jp

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5-4-5,Akasaka,Minato-ku,Tokyo 107-0052
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Shibuya Chikatetsu Bldg.6F,1-16-14,Shibuya,Shibuya-ku,Tokyo 150-0002
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1-7-5,Sekido,Tama-shi,Tokyo 206-8550
TEL:42-372-0111,FAX:42-356-6081,E-mail:eigyou@ss.pacific.co.jp

Quest Engineer Co.,Ltd.
3-7-1 Ekinishihonmachi,Kanazawa,Ishikawa 920-0025
TEL:76-264-7871,FAX:76-264-7877

Shingijutsu Keikaku Co.,Ltd.
6-1-12,Minami-Ohi,Shinagawa-ku,Tokyo 140-0013
TEL:3-3766-3211,FAX:3-3765-9700,E-mail:shingi@pop17.odn.ne.jp

Structure Engineering Center,Japan,Inc.
3-1,Suido-cho,Shinjuku-ku,Tokyo 162-0811
TEL:3-3266-0381,FAX:3-3266-0386

Suncoh Consultants Co.,Ltd.
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Tonichi Engineering Consultants,Inc.
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TEL:3-3374-3555,FAX:3-3374-3550

Toyo-Giken Consulting Civil Engineers Inc.
1-14-11,Shinkitano,Yodogawa-ku,Osaka-shi 532-0025
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TEL:3-3591-6491,FAX:3-3591-2145,E-mail:cmt.sales@atlascopco.co.jp

Bridgestone Corporation
3-5-15,Nihonbashi,Chuo-ku,Tokyo 103-0027
TEL:3-5202-6873,FAX:3-5202-6874,E-mail:kashiw-t@bridgestone.co.jp

C.I.Kasei Co., Ltd.
1-18-1,Kyobashi,Chuo-ku,Tokyo 104-8321
TEL:3-3535-4547,FAX:3-3535-4600

Denki Kagaku Kogyo
1-4-1,Yurakucho,Chiyoda-ku,Tokyo 100-8455
TEL:3-3507-5358,FAX:3-3507-5085

Elkem Japan K.K.
Nikko Sanno Bldg.#401,2-5-3,Akasaka,Minato-ku,Tokyo 107-0052
TEL:3-3584-7712,FAX:3-3584-0437,E-mail:akitomo.tamai@elkem.no

Fuji Bussan K.K.
Kojun Bldg.,6-8-7,Ginza,Chuo-ku,Tokyo 104-0061
TEL:3-3571-4101,FAX:3-3571-4109,E-mail:sales@fuji-bussan.co.jp

Fujimi Koken Co., Ltd.
3-11-18,Iidabashi,Chiyoda-ku,Tokyo 102-0072
TEL:3-3264-4825,FAX:3-3264-4832,E-mail:f-koken@magical.egg.or.jp

Fujimori Sangyo Co., Ltd.
1-2-17,Higashi-Shinbashi,Minato-ku,Tokyo 105-0021
TEL:3-3574-9571,FAX:3-3574-9705,E-mail:iwatsuki@fujimori.co.jp

Furukawa Rock Drill Sales Co., Ltd.
2-6-1,Marunouchi,Chiyoda-ku,Tokyo 100-0005
TEL:3-3211-7887,FAX:3-3211-2033

Hitachi Zosen Corporation
1-1-1,Hitotsubashi Chiyoda-ku,Tokyo 100-8121
TEL:3-3217-8483,FAX:3-3217-8544,E-mail:asaik@omtky.tky.hitachizosen.co.jp

Hokuetsu Metal Co., Ltd.
3-3-1,Zao,Nagaoka-shi,Niigata 940-0028
TEL:258-24-5111,FAX:258-21-2000

Ishikawajima-Harima Heavy Industries Co., Ltd.
Shin-Otemachi Bldg.,2-2-1,Otemachi,Chiyoda-ku,Tokyo100-8182
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Ishikawajima Construction Material Co., Ltd.
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TEL:3-5221-7221,FAX:3-5221-7297,E-mail:webmaster@ikk.co.jp

JAPEX Corporation
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TEL:3-3506-9061,FAX:3-3580-8244

Japan RC Segment Industrial Association
Takano Bldg.,2-22-6,Hachiobori,Chuo-ku,Tokyo 104-0032
TEL:3-3553-1344,FAX:3-3553-1344

KATECS Co., Ltd.
1-3-3,Kami-Maezu,Naka-ku,Nagoya 460-8331
TEL:52-331-8821,FAX:52-332-0164,E-mail:construction@katecs.co.jp

Kawasaki Heavy Industries, Ltd.
World Trade Center Bldg,2-4-1,Hamamatsucho,Minato-ku,Tokyo 105-6116
TEL:3-3435-2556,FAX:3-3436-3039

KFC Ltd. Tokyo head office
2-5-10,Shiba,Minato-ku,Tokyo 105-0014
TEL:3-3798-8511,FAX:3-3798-8516

Komatsu Ltd.
2-3-6,Akasaka,Minato-ku,Tokyo 107-8414,TEL:3-5561-2725,FAX:3-5561-2905,
E-mail:Webmaster.um@komatsu.co.jp,http://www.komatsu.co.jp

Kotobuki Eng. & Mfg. Co., Ltd.
Ohhashi Gyoen Station Bldg.1-8-1,Shinjuku,Shinjuku-ku,Tokyo 160-0022
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Kubota Corporation
3-1-3,Nihonbashi-Muromachi,Chuo-ku,Tokyo 103-8310
TEL:3-3245-3560,FAX:3-3245-3565

Maruya Industry Co., Ltd.
5-5-6,Ebie,Fukushima-ku,Osaka 553-0001
TEL:6-6453-0521,FAX:6-6453-0525,E-mail:maruya@pearl.ocn.ne.jp

Mazda Earth Technologies Co., Ltd.
2-1-26,Niho,Minami-ku,Hiroshima 734-0026
TEL:82-287-5815,FAX:82-287-5808,E-mail:tanabe.h@metmazda.co.jp

Mitsubishi Heavy Industries, Ltd.
2-5-1,Marunouchi,Chiyoda-ku,Tokyo 100-8315
TEL:3-3212-9685,FAX:3-3212-9853,E-mail:Q10416@hq.mhi.co.jp

Mitsui Miike Machinery Co., Ltd.
Mitsui No.2 Bldg.,2-1-1,Nihonbashi-Muromachi,Chuo-ku,Tokyo 103-0022
TEL:3-3270-2006,FAX:3-3-3245-0203,E-mail:koken@mail.mitsuimiike.co.jp

Nihon Koki Co., Ltd.
Fuji Bldg.,2-11-1,Shiba-daimon,Minato-ku,Tokyo 105-0012
TEL:3-3431-9331,FAX:3-3431-1634,E-mail:futatuki-sac@kyb.co.jp

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Mc-Nakanobu Bldg.,4-1-20,Futaba,Shinagawa-ku,Tokyo 142-0043
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3-16-26,Roppongi,Minato-ku,Tokyo 106-0032
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TEL:3-3216-1981,FAX:3-3216-1910,E-mail:y-fujimoto@psgate,psc.co.jp

Seiwa Kiko Co., Ltd.
Shinjuku TK Bldg.,2-16-9,Kabuki-cho,Shinjuku-ku,Tokyo 160-0021
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Taiku Machinery Co., Ltd.
3-6-5,Haginaka,Ota-ku,Tokyo 144-0047
TEL:3-3741-3131,FAX:3-3741-6457

Toho Chikakoki Co., Ltd.
1-2-2,Uchisaiwai-cho,Chiyoda-ku,Tokyo 100-0011
TEL:3-3591-8301,FAX:3-3591-8310,E-mail:thdrillt@blue.ocn.ne.jp

Tokai Rubber Industries, Ltd.
3-1,Higashi, Komaki-shi,Aichi 485-8550
TEL:568-77-2121,FAX:568-72-4537,http.//www.tokai.co.jp/index.shtml

Toyo Industry Co., Ltd.
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Toyoko Elmes Co.,Ltd.
2-19 Kanda-Sudacho,Chiyoda-ku,Tokyo 101-0041
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Tsuzuki Concrete Industrial Corporation
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