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Topic
UNDERSEA TUNNEL

Title
An Overview of the Seikan Tunnel Project

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Originally published
in the Journal "Tunnelling and Underground Space Technology",
Vol. 1, Nr. 3/4, pp. 323 - 331, Year 1986.

Working Group: -

Open Session, Seminar, Workshop: **Seminar 1986, Tokyo: "The Seikan Tunnel"**

Others: **Meetings**

Abstract: The Seikan Tunnel, the survey and excavation of which were begun in 1946 and 1964, respectively, is an undersea accessway connecting the island of Honshu and Hokkaido, Japan. The main tunnel was completed in 1985. Final completion of the tunnel is scheduled for 1987. The total length of the tunnel is 53 850 m, running under the seabed; water depth reaches a maximum of 140 m at certain points. The tunnel as excavated with a minimum overburden of 100 m. This paper outlines the construction work on the Seikan Tunnel, including the background history to tunnel construction, the basic design (alignment, type of cross-section and undersea construction system chosen), the construction work (schedule and contract system for the undersea portion), the operation facilities (track, electrical facilities, drainage facilities, ventilation and fire prevention measures), and the financing.

Résumé: Le tunnel de Seikan, dont l'étape de reconnaissance et l'excavation avaient respectivement commencé en 1946 et 1964, est une voie d'accès sous la mer liant les îles de Honshu et de Hokkaido au Japon. Le tunnel principal fut fini en 1985. L'aboutissement des travaux est prévu pour 1987. La longueur totale du tunnel est de 53,85 km percé sous le fond de la mer et la profondeu de l'eau atteint un maximum de 140 m en certain points. Le tunnel fut excavé avec un terrain de couverture d'au moins 100 m. L'article donne un aper¢u des travaux de construction du tunnel de Seikan, les raisons et l'origine de la construction, la conception de base (alignement, coupe et système de construction sous la mer choisi), les opérations de construction (planning et système de contrats pour la partie sous la mer), les constructions des facilités (rail, electricité, drainage, ventilation et prévention contre le feux), ainsi qu'un aper¢u du financement.

Remarks: -

An Overview of the Seikan Tunnel Project

Shogo Matsuo

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History of the Seikan Tunnel

The possibliity of connecting Hokkaido and Honshu by means of a land route was expressed as early as the Taisho Era (1910–1925), but got no further than the paperwork stage. It was not until 1946 that a practical survey was undertaken by the railway engineering department, the Ministry of Transport. As a result of defeat (in World War II), Japan lost considerable overseas territory and had to provide living space for many returnees. Against such a background, the possible exploitation of Hokkaido attracted wide attention because of the vast tracts of uninhabited land and low population density. In addition, the Ministry of Transport was very much aware of the need to provide a stable transportation system between Honshu and Hokkaido, keenly reminiscent of the widespread damage of ferry boats caused by the bombing in 1945.

On the other hand, the Kanmon Tunnel, completed in 1943, was the world's first full-scale undersea tunnel, and might, in fact, have served as a symbol of hope and confidence to those involved in undersea tunnel construction.

From 1946 to 1949, preparatory surveys were performed mainly on desk plans. However, seismic prospecting on land and in the seabed were also carried out.

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After a brief interruption the survey was started again in 1952 and, in August 1953, the route was listed as a planned line, according to the Railway Construction Law.

On September 26, 1954, five ferryboats, including the Toya Maru, sank in the No. 15 typhoon, killing 1430 passengers. After this sea disaster it was strongly recommended that a safe transportation means be developed, one which would not be subject to the vagaries of the weather. In 1955, The Tsugaru Straits Tunnel Technological Investigation Committee was organized as a JNR Department, whose function was to expedite study and research for the technical possibilities of the Seikan Tunnel.

Thereafter, geological surveys such as dredging, geophysical exploration and seabed boring were all performed together with studies for construction methods, including grouting tests on land. In May 1961, the proposed route was listed as a study line, according to the Railway Construction Law.

In March 1964, the Japan Railway Construction Public Corporation was founded, inheriting the survey-related tasks for the Seikan Tunnel from JNR. In May 1964, the excavation of the Yoshioka Inclined Shaft in Hokkaido was started under the direct control of the Corporation. In addition, excavation started on an inclined shaft on the Honshu side in March 1966. The purpose of these inclined shafts was to facilitate carrying out geological surveys and developing construction methods for the strait tunnel. The shafts were also designed to serve as the entrance route for the main tunnel excavation work which would be carried out in the future.

As excavation of the Hokkaido side inclined shaft progressed smoothly, the bottom of the inclined shaft was reached in March, 1967, whereupon work started on the excavation of a pilot tunnel. The excavation of the Honshu side inclined shaft, however, was difficult due to geological reasons and water constantly gushing into the shaft. In February 1969, a major accident occurred in which water with a maximum inrushing rate reaching 16 T/min poured into the 1123-m-deep shaft when it was less than 100 m from the bottom.

This was the first serious mishap on the entire Seikan Tunnel project. However, after six months of recovery work consisting of grouting, etc., the situation was back to normal. In hindsight, this recovery work proved both enlightening and informative for those engaged in the construction of the undersea tunnel. In 1970, the Honshu-side inclined shaft also reached the bottom, whereupon the excavation of a pilot tunnel was also started.

A technical insight into the construction of the actual strait tunnel was obtained through the excavation of the inclined shafts and pilot tunnels. As a result, the Corporation submitted an interim report to the Ministry of Transport in 1970, in which various specifications were published, including a total estimated length of about 54 km. The report gave a high probability to constructing the straits tunnel by means of horizontal boring and grouting.

On the other hand, the demand for transportation had been increasing

Tunnelling and Underground Space Technology, Vol. 1, No. 3/4, pp. 323–331, 1986.
Printed in Great Britain.
0866–7798/86 $3.00+.00

steadily, reflecting the social and economic development of Hokkaido and the expanding trend of Japan's economy. Between 1955 and 1965, the volume of traffic between Honshu and Hokkaido Islands, which are connected by JNR Seikan Ferry, doubled for passenger traffic (from 2 020 000 persons/yr to 4 040 000 persons/yr), and rose 1.7 times for cargo transport (from 3 700 000 T/yr to 6 240 000 T/yr), indicating a continued upward curve.

In 1971, therefore, a forecast of demand was made, which estimated that the 9 360 000 persons/yr and 8 470 000 T of goods/yr transported in 1970 would climb to 9 000 000 persons/y and 17 000 000 T/yr, respectively, in 1985. However, considering the existing pier facility of the Seikan sea route, the capacity of the Seikan Ferry would be inadequate for transporting cargo of more than 10 000 000 T/yr, even if the number of trips was increased to thirty (the maximum allowed). To make matters worse, expansion of the pier facility would be difficult due to the fact that there scarcely exists any suitable location because of geographical conditions. Therefore, it was urgently required that appropriate and timely measures be taken for enlarging the Seikan route transport capacity.

In September 1971, the decision was made to start work on the main Seikan tunnel, in view of the prevailing conditions. The cross-section and gradient of the main tunnel were designed to be capable of accomodating Shinkansen, reflecting the overall trend of developing a high-speed railway network throughout Japan, due to the success of Tokaido Shinkansen.

In November 1971, a ground-breaking ceremony was held to celebrate the start of construction work proper on the Seikan Tunnel. Unfortunately, the work did not progress as smoothly as had been anticipated initially. Accidents involving inflows of abnormally large volumes of water occurred, together with squeezing ground, unconsolidated ground, etc. In the case of a water inrushing accident that occurred in the Yoshioka service tunnel in May 1976, the service and main tunnel were flooded to lengths of about 3000 and 1500 m, respectively, with inflow rates sometimes as high as 70 T/min. However, these setbacks were overcome by advanced technology, and excavation steadily progressed toward completion.

In January 1983, with the symbolic switch-pressing by Prime Minister Nakasone, the pilot tunnel was completed, connecting Hokkaido with Honshu for the very first time in history. In March 1985, the main tunnel also was completed, when Mr Tokuo Yamashita, Minister of Transport, symbolically pressed the button (see Table 1).

The construction work on the connecting lines between the conventional railway and the Seikan Tunnel has progressed smoothly since it was started in 1982, and they will be completed in 1987, together with the Seikan Tunnel. However, the social and economic environment surrounding the Seikan Tunnel today is considerably different from that which prevailed at the start of construction. The popularity of road transport, for one thing, has grown, while aviation routes have grown ever more extensive. The result of these two factors alone has been a depressed demand for railway transportation between Honshu and Hokkaido. Moreover, the financial climate of the nation as a whole, and JNR in particular, has recently turned negative, resulting in

Table 1. Chronological table showing the history of the development of the Seikan Tunnel.

Apr. 24, 1946	Geological investigation began on both Honshu and Hokkaido sides by Japanese National Railways (JNR).
Mar. 23, 1964	Japan Railway Construction Public Corporation was established, taking over investigation work from JNR.
May 08, 1964	Excavation of the inclined shaft on the Hokkaido side began (under direct control).
Mar. 21, 1966	Excavation of the inclined shaft on the Honshu side began (under direct control).
Mar. 04, 1967	The inclined shaft on the Hokkaido side (length of 1210 m) reached its bottom and excavation of the pilot tunnel began (under direct control).
Jan. 17, 1970	The inclined shaft on the Honshu side (length of 1315 m) reached its bottom and excavation of the pilot tunnel began (under direct control).
Sep. 28, 1971	Main tunnel construction began.
Jan. 27, 1983	The pilot tunnel was holed through.
Mar. 10, 1985	The main tunnel was holed through.

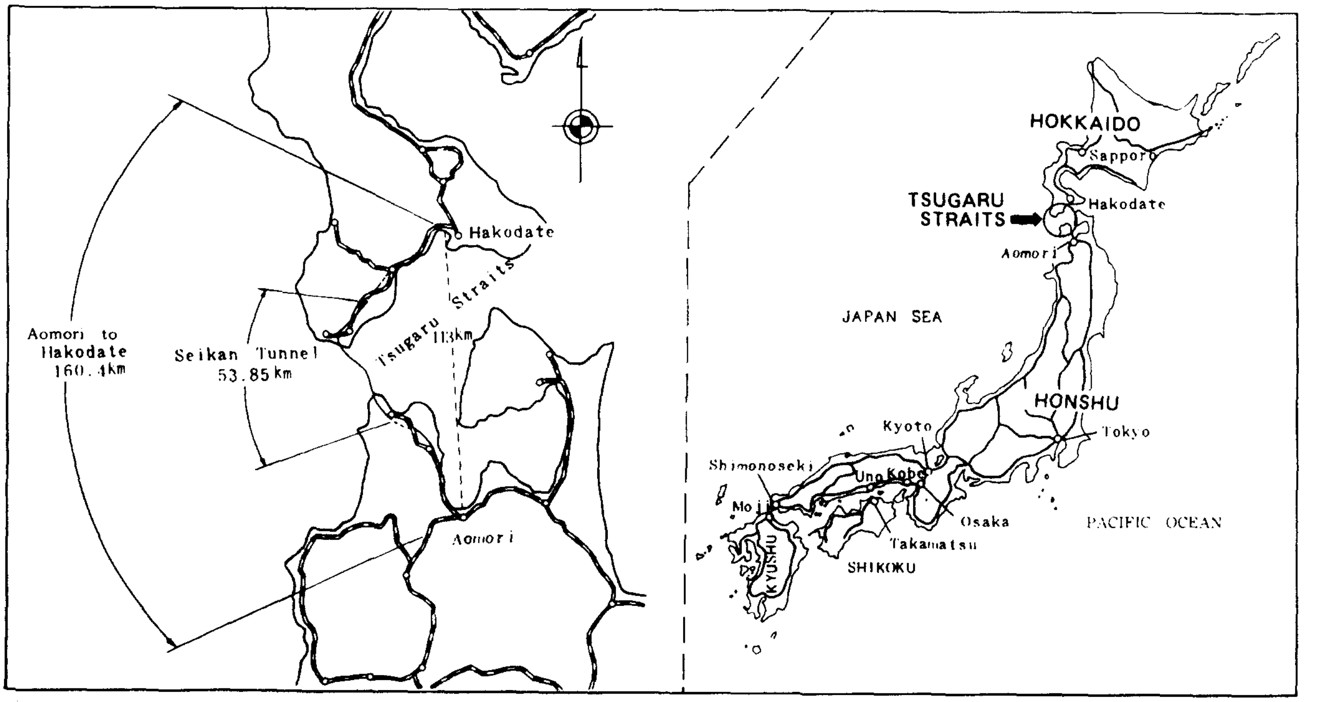

Figure 1. Location map for the Seikan Tunnel, connecting the islands of Honshu and Hokkaido (Japan).

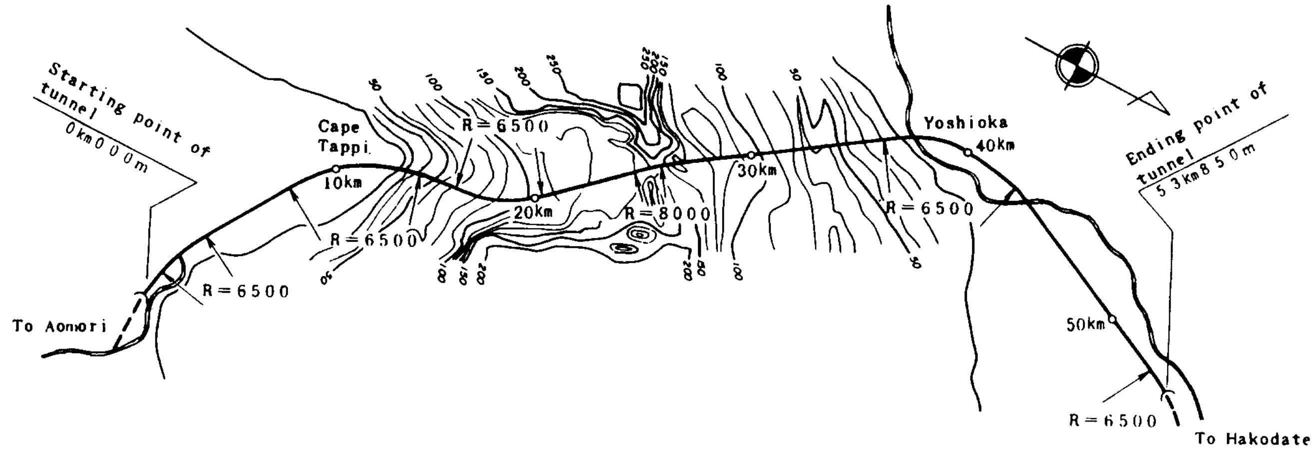

Figure 2. Plan of the Seikan Tunnel.

the suspension of the extension of the Shinkansen route northwards from Morioka. The plan for the Shinkansen to eventually pass through the Seikan Tunnel will be delayed once the tunnel is completed.

Under these circumstances, the Seikan Tunnel will be operated by the conventional railways for the time being. The operation of a car train to supplement road functions will also be studied.

Basic Design

The basic design of the Seikan Tunnel is described below. Figure 1 shows the location of the 53.85-km tunnel.

Alignment

Overburden. The most fundamental and important matter for planning any undersea tunnel is what overburden should be incorporated, since this decision directly affects the safety, difficulty and economical performance of the work.

The smaller the overburden, the shorter the tunnel length and the lower the water pressure becomes. However, there is increased risk of a complete collapse, which, should it reach the seabed, would make recovery completely impossible.

Before specifying the overbuden for the Seikan Tunnel, comprehensive studies and investigations were performed, including the laws and regulations concerning the excavation of undersea coal mines, as proven by long experience, trial calculation of seepage water volume, pumping costs, etc.

According to Clause 384 of the Safety Rules of Coal Mines, the excavation of various undersea positions is clearly prohibited, among which are the following positions concerning the Seikan Tunnel:

(1) Position at which the thickness of the tertiary is less than 10 m, provided that the thickness of the quarternary deposits under the seabed is 30 m or above.

(2) Position at which the thickness of the tertiary is less than 60 m, provided that the thickness of the quarternary deposits under the seabed is less than 5 m.

(3) Position less than 100 m from the exposed head of coal layer in the seabed, along the relevant rock layer.

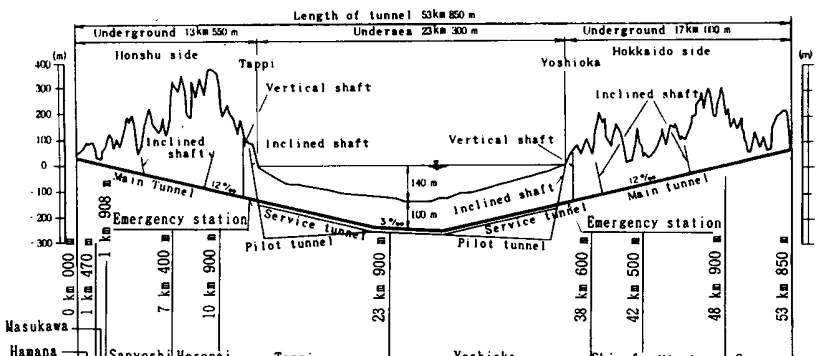

Figure 3. Profile of the Seikan Tunnel.

The Seikan Tunnel contains mainly tertiary sedimentary rocks. As no quartenary deposits are generally observed along the route, the foregoing rule (2) could apply in the case of a necessary overburden thicker than 60 m. According to another geological survey on the seabed, conducted afterwards, there are weathered strata in a range of about 30 m underneath the seabed, in which water permeability is greater. Furthermore, the relationship between overburden and the rate of inrushing water was calculated using several models. Based on these results, the minimum overburden was specified as 100 m.

Minimum curve radius. Standard minimum curve radii are 2500 m for Tokaido Shinkansen; 4000 m for Sanyo Shinkansen and subsequent Shinkansen; and 600 m for the conventional lines (class 2 tracks). In the Seikan Tunnel, a double-gauge line system will be employed, in which the conventional line and Shinkansen will commonly use one rail. If the cant is specified for Shinkansen, the cant becomes excessively large for the conventional train and vice-versa. Therefore, the minimum radius for the Seikan Tunnel should allow the setting of cant within allowable range for both Shinkansen and the conventional line.

More explicitly, the planned train speed of Shinkansen was assumed at 250 km/h and deficiency of cant was set up at less than 30 mm, in consideration of passenger comfort. Thereby, actual cant was determined. At that time, the actual cant of the conventional line should remain within an over-cant of 60 mm against a train speed of 70 km/h for the conventional line. As a minimum curve radius satisfying the above, a radius R=6500 m was specified.

Maximum gradient ratio. Because the Seikan Tunnel includes very long sections in one-way inclination, the gradient ratio to be specified was studied on

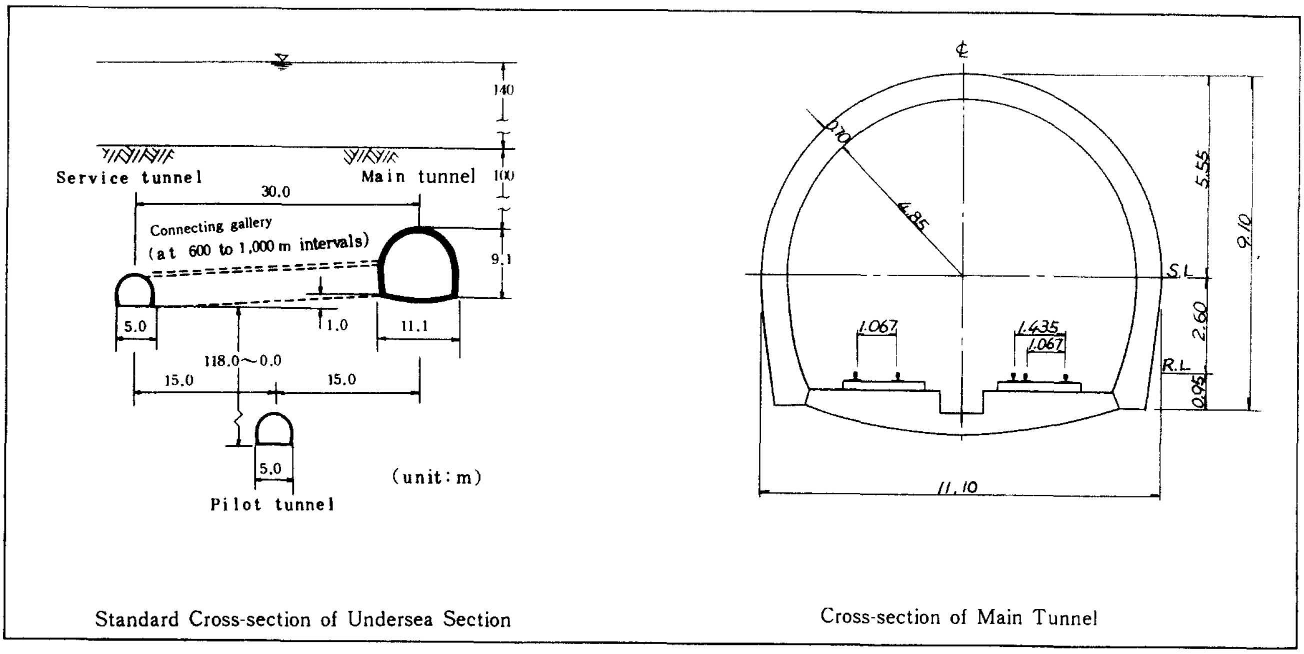

Figure 4. At left: standard cross-section of an undersea section of the Seikan Tunnel. At right: cross-section of the main tunnel.

the assumption of various operating conditions. As a result, a maximum permissible gradient ratio of 12‰ was specified assuming that, when a Shinkansen train (12-car train) fails, one unit is cut off, and is activated on the slope and self-propels itself up to the long slope to the land surface. For the central undersea part, a gradient ratio of 3‰ was applied in consideration of the natural flow-down of seepage water.

According to the railway structure rules of the Tokaido Shinkansen, a maximum gradient ratio of 15‰ is specified. For the Sanyo and subsequent Shinkansen, 15‰ is specified, together with a mean gradient of 12‰ in 10 km or smaller lengths.

Briefly, the specifications of the tunnel were determined at a minimum overburden of 100 m in the undersea part, a minimum curve radius of 6500 m, and a maximum gradient ratio of 12‰. Other precautions for route selection included an undersea part of as short a length as possible, passage underneath the shallow belt of saddle structure, and detouring of dyke swarm in the Honshu side and faults parallel to the routes. As a result, a total length of 53.85 km (including an undersea length of 23.3 km) was obtained. The plan and profile of the Seikan Tunnel are shown in Figs 2 and 3, respectively.

Type of Cross-Section

The type of cross-section to be used for the Seikan Tunnel could be either two single-track types or one double-track type, in view of tunnel construction and operation after completion.

The following conclusions were drawn from the viewpoint of construction.

- The one double-track type of cross-section requires smaller quantities of excavated material, lining concrete, grouting, etc., than do two single-track types.
- When subsoil grouting is applied to two single-track types, each tunnel must be very carefully worked. Safety and efficiency could be improved in order to construct one double-track type, even with a slightly larger cross-section.
- With a Shinkansen cross-section, full-face excavation is not applicable in the geological conditions of the Seikan Tunnel, even if a single-track section is involved. Therefore, the merits of single-track section becomes less impressive.
- The double-track type of cross-section requires less construction work and permits a smaller quantity of seepage water, resulting in construction costs being cheaper by an estimated 10%.

With a view toward the operation after completion the following results were obtained:

(1) When a train enters a long tunnel, the double-track type of cross-section is subjected to less air resistance.

(2) When a Shinkansen train and a conventional freight train pass each other on a double-track type, the Shinkansen train causes wind pressure to be exerted on the freight train. According to experiments, however, it was revealed that the wind pressure has no great effect on the stability of the freight train.

(3) When maintenance work is carried out on a double-track type, train speed in the adjacent track is often restricted.

(4) The double-track type of cross-section brings about greater temperature rise in the tunnel because of train operation. Ventilating conditions for the single-track type are also more advantageous. However, forced ventilation can be employed with the double-track type of cross-section.

(5) With the double-track type, recovery work after a train accident can be performed more easily.

After evaluation of the foregoing studies on both construction and operation, the cross-section of the Seikan Tunnel was specified to be the double-track Shinkansen type.

Undersea Construction System

For the construction of the undersea part of the Seikan tunnel, a pilot tunnel and a service tunnel were excavated in addition to the main tunnel (Fig. 4).

The pilot tunnel was excavated in advance of the main tunnel and service tunnel. The pilot tunnel was bored at a gradient of 3‰ from the bottom of an inclined shaft towards the center of the undersea part, at which point it connects with the service tunnel, parallel to the main tunnel. Major objectives in excavating the pilot tunnel were to conduct a detailed survey of the geological conditions and seepage water, and to develop technology which would permit the service and main tunnels to be constructed by excavating the pilot tunnel first. The pilot tunnel will be used for drainage and ventilation purposes once the main tunnel has entered operation.

The service tunnel was excavated parallel to and alongside the main tunnel. It also served the purpose of shortening the total construction period, by having the connecting gallery excavated towards the main tunnel at about 600-m intervals and by increasing the cutting faces for excavation of main tunnel. The service tunnel will be used for drainage, ventilation and maintenance work, once the main tunnel has entered operation.

Advance boring was always performed prior to excavation of the pilot and service tunnels in order to glean information on the nature of the front ground, as well as on seepage water conditions. Based on these conditions, grouting was performed before excavation and the shotcrete early lining was applied thereafter.

Construction

Overview of the Construction Process

The entire construction area for the Seikan Tunnel was divided into nine work sections. Four work sections were situated onland at the Honshu side: Hamana Work Section (1470 m); Masukawa Work Section (438 m); Sanyoshi Work Section (5492 m); and Horonai Work Section (3500 m). Two work sections were on the undersea portion: Tappi Work Section (13 000 m) and Yoshioka Work Section (14 700 m). Three work sections were on the land at the Hokkaido side: Shirafu Work Section (3900 m); Mitake Work Section (6400 m); and Sengen Work Section (4950 m).

In the Hamana and Sanyoshi Work Sections (on the Honshu side) the side drift method was mainly applied; in the Masukawa Work Section, the cut-and-cover method was adopted; and in the Horonai Work Section, upper half-heading and core-cut methods were mainly used. On the Hokkaido side, the side drift method was mainly applied.

In the undersea portion at the Tappi Work Section, the bottom heading method was for 4535 m in all; the side drift method for 3584 m; and upper half-heading for 4781 m. In the Yoshioka Work Section, the bottom heading method was adopted for 4334 m; the side drift method, for 7313 m; upper half-heading, for 1920 m, the circular short bench cut method, for 587 m; and the circular short bench with spring line drifts method, for 446 m.

Table 2 shows extended construction of individual methods for each work section.

Work Schedule

Construction took approx. 21 yr from the start of work on the inclined shaft in the Yoshioka Work Section (Hokkaido) in May 1964, until the final laying of concrete at the bottom of the main tunnel in August 1985. Figure 5 shows the actual work schedule for the project.

Work System and Contract System of Undersea Work Section

Because the Seikan Tunnel was a large-scale construction project and it took a long time to complete due to many undersea geological factors, e.g. seepage water, the construction system adopted was considerably different from that for a normal tunnel.

Inclined shafts and pilot tunnels were executed directly by the Japan Railway Construction Public Corporation, because the pilot tunnel is always supposed to lead other tunnels and involves considerable risk. It is also unsuitable for contract, due to the technical development needed mainly for the construction of the main tunnel.

Service and main tunnels were put out to contract. However, several points, described below, were studied for the contract system.

First, discussions were held on which type of contract should apply in this construction—normal contract of the cost-plus contract. The following factors were considered:

(1) It is difficult to calculate actual cost when using the cost-plus type of contract.

(2) The builder's effort will be reduced and, as a result, the cost will be increased in the cost-plus contract.

(3) If various imprecise factors, such as fault-fractured zone, gushing water, etc., are omitted, construction on this project is the same as normal tunnel construction. Therefore, the normal contract is applicable if special conditions are additionally included in the contract.

As a result of these considerations, the normal contract was adopted for this construction project.

Several plans were offered to contractors: (1) a plan in which only one company was involved in the contract; (2) a plan for a new company to be created by a group of companies for carrying out undersea excavation; and (3) a plan for JV to be organized by two to four companies in each work section of undersea portion in Honshu and Hok-

Table 2. Cumulative length of excavation (in meters) for each work section and method used on construction of the Seikan Tunnel.

Work section	Land on Honshu side				Undersea portion		Land on Hokkaido side		
Method	**Hamana**	**Masukawa**	**Sanyoshi**	**Horonai**	**Tappi**	**Yoshioka**	**Shirafu**	**Mitake**	**Sengen**
Bottom heading method			289	951	4535	4335	59	310	
Side drift method	1401		5203	182	3684	7413	3010	6090	3297
Upper half heading method					4781	1920	831		1478
Upper half heading and core cut method				2367		587			
Circular short bench method						587			
Circular short bench with spring line drift						446			
Cut and cover method	69	438							175
Total	1470	438	5492	3500	13 000	14 700	3900	6400	4950

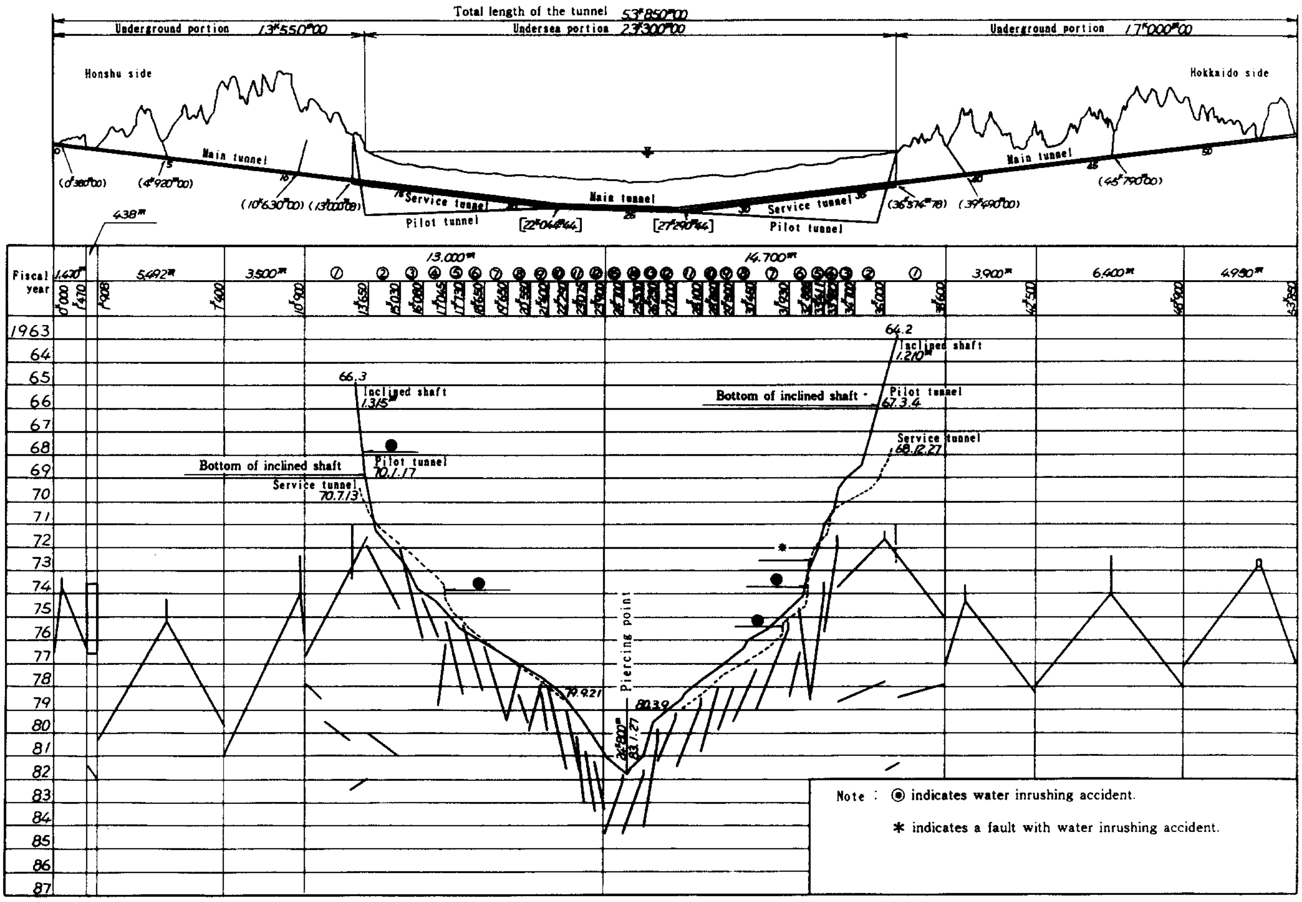

Figure 5. Timeline showing actual progress on the Seikan Tunnel.

kaido, etc. These plans were compared and studied from the viewpoint of their reliability, construction capabilities, exploitation of technology, spreading of risk, etc. The JV plan organized by three companies in each work section was eventually adopted.

The general rule is that only those companies designated by the Japan Railway Construction Public Corporation can compete for the contract when the contractor is being selected. The Public Corporation did not issue a contract to tender all at once for the entire work on the undersea sections. Rather, the contracts divided work on the overall project into several parts, to be completed in one-and-a-half to two years, depending on the bidder's estimate.

It was not considered ethical to ask for cost competition for only the individual sections of the work, and to then offer the rest of the work to the successful bidder. It was also possible that the initial partial work might be knocked down in terms of unreasonable prices. Therefore, the Public Corporation selected two JVs in each work section, and required each of them to submit a written estimate listing the unit prices for individual works if the total work period was estimated at seven years. These estimates were studied, and the suitable contractors were then selected. The contract for the partial work was then made with the selected companies as a negotiated contract.

Every time the contract for partial work was renewed, the unit price was corrected, depending on the fluctuation of prices and the development of technology, but always on the basis of the initially estimated prices.

Before the submission of the written estimates, the Public Corporation offered the following terms to reduce the contractors' risk, in consideration of the unusual working conditions, i.e. construction of a long undersea tunnel:

(1) The Public Corporation will bear all the expenses of facilities for drainage and ventilation.

(2) The Public Corporation will supply the necessary quantity of electric power and water for construction.

(3) The Public Corporation will accept as its responsibility the need to provide failsafe facilities such as emergency communication facilities and washout-proofing facilities against water inrushing accidents, etc.

(4) All necessary locomotives with storage batteries, rectifiers and spare storage batteries are to be lent by The Public Corporation.

(5) The Public Corporation will pay for any major damages to contractors' machines caused by water inflow accidents.

In conclusion, the contracts were made with JVs, which were organized by three companies each in the Tappi and the Yoshioka Work Sections.

Operation Facilities

Track and Electrical Facilities

The Seikan Tunnel initially will enter operation as a conventional line. Figure 6 shows the layout of tracks and trolley wires at the start of the conventional line service and Shinkansen service. The rail gauge was 1067 mm and trolley wires were set up mainly for the trains used on the conventional line, once they began operating.

The feeding voltage was 20 000 V, which, again corresponded to the conventional line. However, track slabs and types of trolley wires are not easily changed over for Shinkansen usage. Therefore, three-rail slab and trolley wires with large diameter were applied from the beginning.

For the Shinkansen service, another rail corresponding to the standard gauge, i.e. rail gauge 1435 mm, was prepared at the central passage side for both conventional line and Shinkansen use. The trolley wires will move approximately between the centers of the Shinkansen car and the conventional car. The feeding voltage was increased to 25 000 V to cope with the Shinkansen requirements. However, since the feeding voltage for the conventional line was 20 000 V, trains for the conventional line should be improved somewhat in order to cope with both voltages.

Drainage Facilities

The rate at which water leaks into the

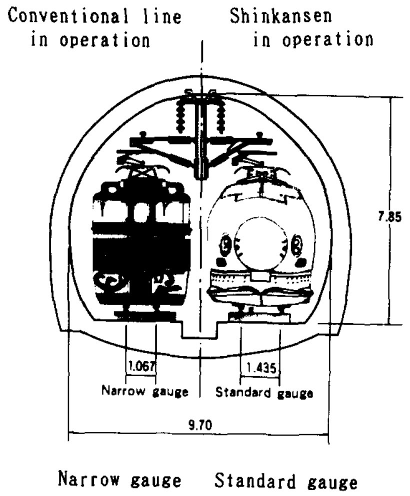

Figure 6. Track and trolley in operation (unit of measurement: m).

Seikan Tunnel was about 40 T/min. Because the tunnel sloped downwards toward the seabed from both entrances, a natural-gravity-flow drainage method, similar to that used in mountain tunnels, could not be adopted. As a result, the permanent forced-pump drainage method had to be applied. Figure 7 shows the seepage water flow and layout of pumps.

Pump stations on the Honshu side were located at those parts of the pilot and service tunnels which came into contact with each inclined shaft. On the Hokkaido side, pumps were located in the pilot tunnel. In this way, two pump stations were set up on the Honshu side, because the rate of seepage water on land at the Honshu side was extremely high. Therefore, a pump room (P1) with small head was installed in the service tunnel for reasons of economy and interim drainage purposes. The Public Corporation considered that the increased cost for the facilities would be sufficiently covered by the savings in electric power charge.

Water seepage into the tunnel flows down the drainages in the service and pilot tunnels, is led to each pump statin, and is then forced through the inclined shaft by the pump before being drained to the outside of the shaft.

The pump station (P3) in the pilot tunnel at the Hokkaido side has sufficient draining capacity even if the pump station (P1) in the service tunnel at Honshu side is damaged and all seepage water comes into P3. Furthermore, in order to prevent long-term power failure, a double supply route of electricity was set up for each pump station, and emergency engine generators are provided at regular intervals by the entrances to the inclined shafts, together with the power-receiving facilities from the electric power company. Nevertheless, when an accident or mishap renders drainage difficult, water will be stored in the pilot tunnel by means of the water flow changeover facilities and the emergency floodgate, thus ensuring the time required for restoration.

Ventilation

Because the Seikan Tunnel is a very long tunnel, sufficient wind rate will not be obtained by natural ventilation alone, resulting in the following problems:

(1) Heat generated by the running trains will raise temperatures inside the tunnel.

(2) Noxious gas exhaust from the maintenance cars, etc., will remain in the atmosphere.

(3) Increases in humidity will have adverse effects on instruments and their insulation, with the resultant fog rendering signposts practically invisible.

In order to solve these problems, longitudinal forced ventilation was applied in all cases. Figure 8 shows the facilities used and ventilation route chosen.

Air is taken from the intake of both inclined shafts at both the Honshu and Hokkaido sides by an air intake fan. After passing through the pilot tunnel, this air is led to the main tunnel at center of underground portion, where it is exhausted through both outlets of the main tunnel.

The air rate was calculated using unsteady-state calculation for heat balance while considering heating value per train, train schedule, underground temperature, atmospheric temperature, thermal conductivity of concrete or base rock, and temperature decrease caused by seepage water. Results of the calculations showed that if wind velocity in the main tunnel stabilizes at around 1 m/s, the heat generated by trains will no longer be a major problem, even when heavy usage is made of the tunnel by trains.

The aforementioned ventilation air flows toward the land from the center of undersea portion even in service tunnels. However, the air pressure in the service tunnels is maintained at a level slightly

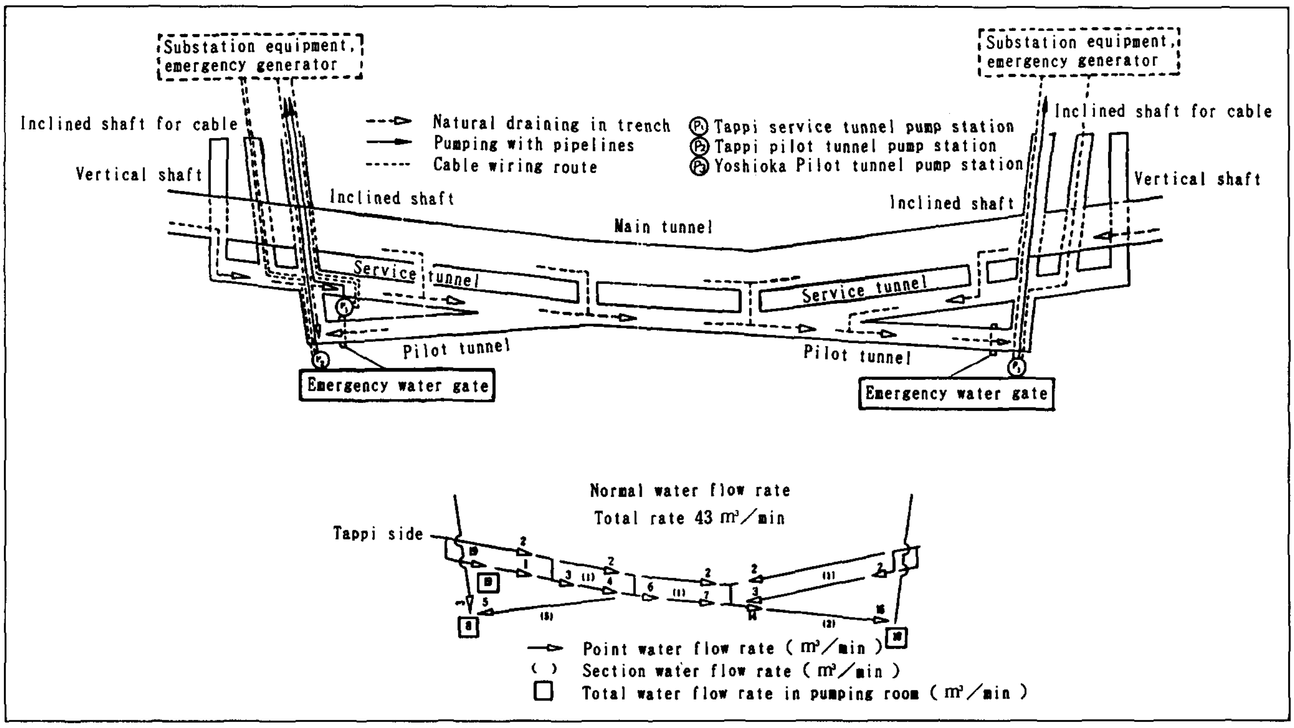

Figure 7. Drainage system for the Seikan Tunnel.

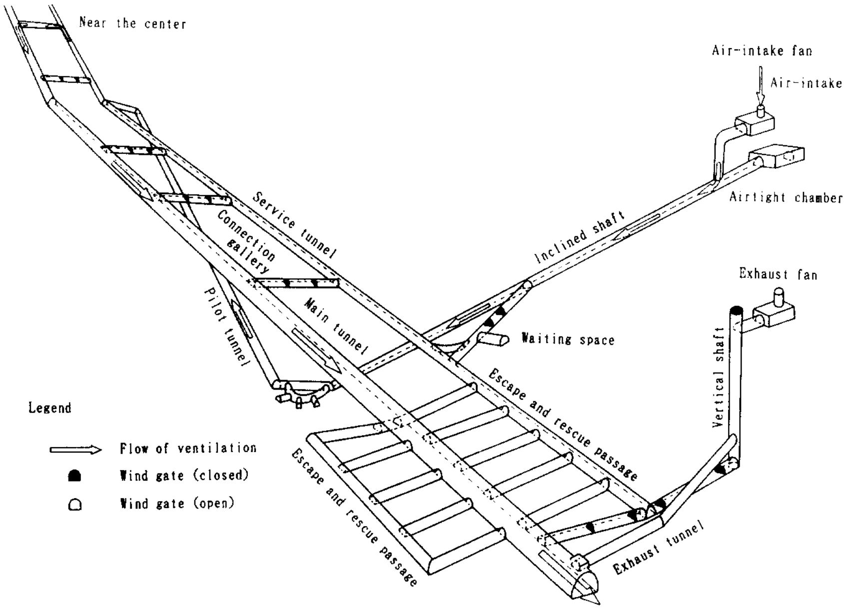

Figure 8. Ventilation system in ordinary operation (Yoshioka Emergency Station).

higher than that which prevails in the main tunnel. As a result, smoke will be prevented from entering the service tunnels, which will be used as escape routes in addition to providing access for rescue parties in the event of a train fire.

Facilities for Fire Prevention

On November 6, 1972, a fire occurred on a train while passing through Hokuriku Tunnel, one of the longest conventional railway tunnels in Japan (length=13.87 km). Thirty people died and many were injured as a result. After a study was conducted on the cause of the accident, JNR reached the conclusion that once the fire was discovered, the passengers would have had the greatest chance of survival if the train had continued travelling to the other end of the tunnel, whereupon the passengers could then escape to safety.

The Seikan Tunnel, however, is exceptionally long—53.85 km. The train may not be able to reach the other end of the tunnel, but might, in fact, have to stop inside the tunnel, depending on its position at the time fire is discovered. Bearing this in mind, The Public Corporation decided to install special areas (emergency stations) to where trains in distress could make their way, enabling passengers to escape to safety and the necessary rescue and fire-fighting operations to be performed.

As shown in Fig. 9, the emergency stations were set up around the inclined shafts of the undersea portion at both the Honshu and Hokkaido sides, thus effectively dividing the Seikan Tunnel into three parts. The length of tunnel between the emergency stations was consequently shortened to approx. 23 km, which is almost equal to the longest railway tunnel on the existing line (Daishimizu Tunnel, Joetsu Shinkansen). In these emergency stations fire prevention facilities were provided, and the escape and rescue environments were similar to those outside the tunnel. As a result, the same standard of safety as in tunnels on existing lines could be guaranteed.

In Fig. 10, an emergency station with escape and rescue routes is shown. Emergency stations consist of escape and rescue passages located at both sides of the main tunnel and connecting passages joining the main tunnel and the escape and rescue passages at 40-m intervals. The main tunnel is provided with platforms to assist the passengers in dismounting from the burning train, as well as water-spraying nozzles for firefighting purposes. Furthermore, each emergency station and escape-and-rescue passage is provided with a communication and announcing system to guide passengers to safety, plus an industrial television (ITV) camera to check and monitor how the escape is progressing.

To assist passengers escaping from the burning train, it is absolutely essential that smoke be exhausted from the area. This is performed by means of a smoke exhaust fan installed at the entrances to the vertical shaft, in the immediate vicinity of the emergency stations. At the same time, the air intake fan used for ventilation purposes under normal conditions will continue to operate. Ventilation air flow is sent directly to the emergency station by opening the wind gate located in the shortcut route leading from the inclined shaft to the emergency station.

This ventilation route ensures that ventilated air always flows in the opposite direction to that in which passengers are escaping. Therefore, passengers will never be overwhelmed by smoke (see Fig. 10). The escape-and-rescue route leading from the emergency station to the inclined shaft outlet is provided with a waiting area capable of accomodating all the passengers on one train. A medical relief station will also set up here.

It is of the utmost importance that any

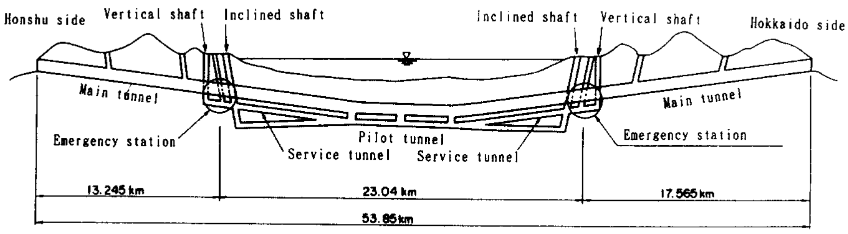

Figure 9. Location of emergency stations in the Seikan Tunnel.

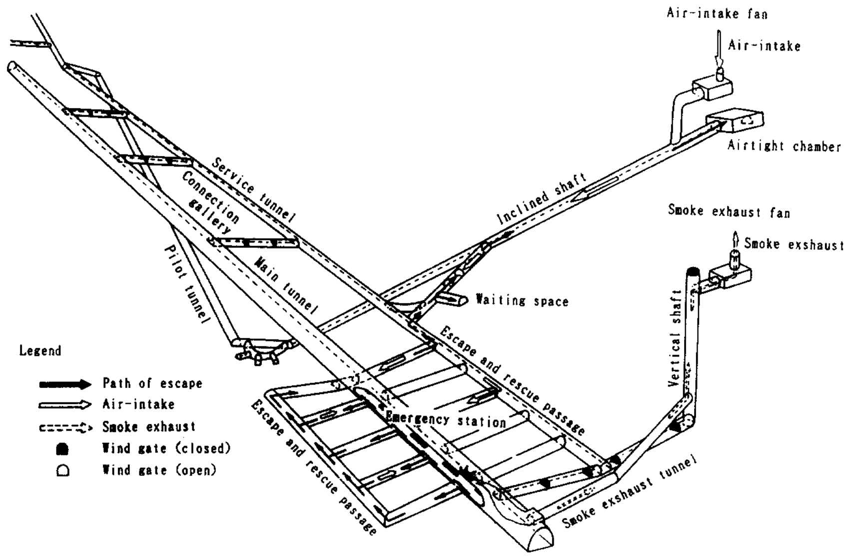

Figure 10. Ventilation in emergency operation. The example above shows a southbound train brought to a stop at Yoshioka Emergency Station.

train fire in the tunnel be detected as soon as possible. This will be a decisive factor not only in checking the spread of fire, but also in guaranteeing the train's continued operation and passengers' successful escape. For this reason, thermal fire alarms operated by infrared rays will be set up at the entrance and the exit of the Seikan Tunnel and also inside this tunnel, in order to detect any train fire in its earliest stages. These facilities will monitor the surface temperature of the train from both sides. However, because these facilities are not as effective for so-called smoke fires on trains, smoke alarms are also provided as auxiliary facilities.

Financing

The cost for the construction of the Seikan Tunnel was Y689 billion in total, including the investigation costs of Y13.7 billion, which were spent by 1971 (the year in which main construction was started), and connecting line costs of Y151 billion.

The greatest proportion of the funds were onerous funds related to the government (governmental financial funds); these exceeded 50% of the total amount. The Japan Railway Construction Public Corporation itself raised onerous funds by issuing bonds, which amounted to just under 30% of the total.

As is obvious from the above, most of the construction funds were onerous funds. The redemption amount exceeds Y1000 billion if the interest during the construction period is included. However, the quantity of both freight and passengers transported by rail between Honshu and Hokkaido has been decreasing recently due to more diversified traffic facilities. Accordingly, it would be impossible to cover all outstanding expenses from passenger receipts or railway management itself even if the demand for railway transportation increases upon the completion of the Seikan Tunnel. This problem is presently under study. However, because the Seikan Tunnel belongs to the nation as a whole and will play a crucial role in integrating the country, developing local areas, stabilizing transport facilities, and providing a main arterial route throughout the nation, the govenment will bear the construction expenses.

Postscript

It took more than 20 yr and more than Y500 billion to complete the Seikan Tunnel. Because the tunnel is expected to be used for Shinkansen and car trains, followed by conventional line planned for 1988, we are confident that the tunnel will prove a major advantage, not only for the development of Japan's industry and economy, but also for upgrading the welfare of the people of Japan.

The human and material resources committed to construction of the tunnel amounted to 12 million man-days, 850 000 T of cement, and 170 000 T of steel material. As one of the people engaged in the construction of the tunnel, I sincerely hope that the priceless technologies and experience gained from the project will be reflected in the future development of scientific technology on an international scale. □