The World's Longest Terrestrial Railway Tunnel

Iwate-Ichinohe Tunnel on the Tohoku New Trunk Line

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Photo 1. Blasting and excavating in the Torigoe construction section; efficient working in a complex geology

Foreword

Welcome by Mt. Iwate

Riding the "Yamabiko" train on the Tohoku Shinkansen (Bullet Train) line to Morioka, my aim is to collect material for this article on the Iwate-Ichinohe Tunnel, which will be the world's longest terrestrial railway tunnel upon completion. Leaving Tokyo in mid-April, where the cherry trees had just shed their blossoms, the train proceeded north through scenery that gradually regressed back to early spring before the cherries come into bloom. As the train approached Morioka Station, the old woman sitting next to me pointed out the snow-capped magnificence of Mt. Iwate out to the west. She reminded me how lucky it was to get such a clear view of the mountain. The Kitami river was already high from the melting snow. Though the weather was still chilly, people were looking forward to their chance to enjoy the cherry and Japanese apricot trees in full bloom during the Golden Week holidays that begin in later April. Coming from further south, I was surprised that both trees bloom together, as it is commonly held that the apricot tree comes out first. But enough of these diversions; I will now describe the tunnel itself.

The Morioka-Aomori section of the Tohoku Shinkansen

The Tohoku Shinkansen is a high-speed passenger

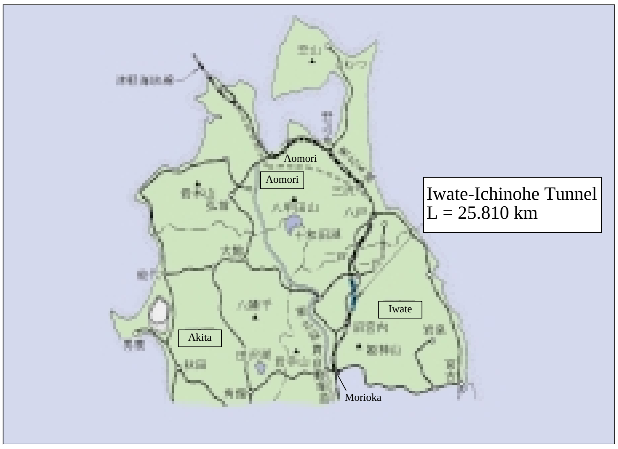

Fig. 1 Location of Iwate-Ichinohe Tunnel between Morioka and Aomori on the Tohoku Shinkansen

Name	Year opened	Country	Use	Total length (km)
Oshimizu	1982	Japan	Railway	22.2
Simplon II	1922	Italy and Switzerland	Railway	20.2
Apenin	1934	Italy	Railway	18.5
Gotthard	1980	Switzerland	Railway	16.3
Rokko	1972	Japan	Road	16.3
New Furuka	1982	Switzerland	Railway	15.4
Haruna	1982	Japan	Railway	15.4
Gotthard	1982	Switzerland	Railway	15.0
Nakayama	1982	Japan	Railway	14.9
Retzberg	1913	Switzerland	Railway	14.6

Fig. 2 List of the ten longest terrestrial tunnels; undersea tunnels such as the Seikan Tunnel are not included.

railroad with a total length of approximately 675 km and authorized under the National Shinkansen Development Law. Ultimately, it will link Tokyo with Aomori in the north, via the cities of Omiya, Utsunomiya, Sendai, and Morioka.

Tunnels form much of the section between Morioka in Iwate Prefecture and Hachinohe in Aomori Prefecture. The total distance between these two stations is 96.6 km, of which 94.5 km is currently under construction. Of this, tunnels account for 69.4 km, or 73% of the total, with open sections such as bridges, viaducts, and other earthworks totaling 25.1 km or 27%. The basic technical specifications for the railroad in this section are: a maximum train speed of 260 km/h, a minimum curve radius of 4,000 m, a steepest gradient of 2%, a track center-to-center distance of 4.3 m, and a power supply of 25 kV AC. Rapid progress is being made with construction, and the section is scheduled for opening in December 2002 in time for the 2003 Winter Asian Games.

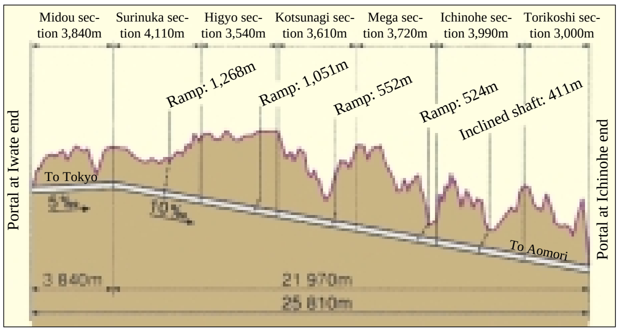

Fig. 3 Longitudinal section of tunnel showing construction sections

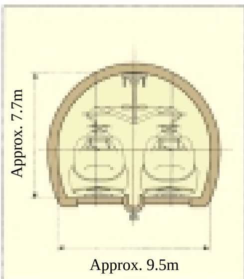

Fig. 4 Typical tunnel section

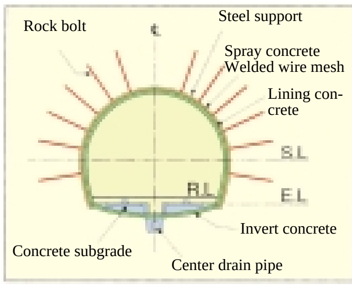

Fig. 5 Standard NATM support arrangement

Iwate-Ichinohe Tunnel

The Iwate-Ichinohe Tunnel is located near the midpoint of the section in northern Iwate Prefecture (Figure 1). The 25.81 km long tunnel will be the world's longest terrestrial railway tunnel upon completion (Figure 2). Following survey work that began in 1988, full-scale construction commenced in 1991. To reduce construction costs and tunneling time, the tunnel has been divided into seven sections. In order from the portal at the Tokyo end, these are known as: Midou, Surinuka, Higyo, Kotsunagi, Mega, Ichinohe, and Torigoe. Ramps or inclined shafts were built to provide access to the intermediate five sections (Figure 3). Such access is essential in the construction of such a long tunnel. The standard cross-sectional dimensions of the tunnel are approximately 7.7 m and 9.5 m in internal height and width, respectively (Figure 4). The tunnel has an uphill gradient of 0.5% from the portal on the Tokyo side up to a high point between the Midou and Surinuka sections. There is then a downhill gradient of 1% down to the portal at the Aomori end.

Topography and geology

Topographically, the tunnel passes through hilly ter-

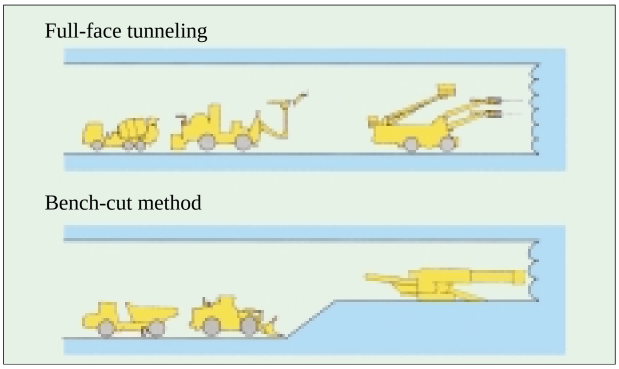

Fig. 6 NATM tunneling systems

rain bounded by the Kitakami Mountains to the east and the Ou Mountains, including Mt. Nanashigure and Mt. Nishidake, to the east. Near the portal at the Tokyo end, the Higyo construction section (in Ichinohe Town in Nakayama District) marks the watershed that divides the Mabuchi river, flowing north, from the Kitakami river that flows south.

The geology around the tunnel site is classified roughly into three types. A section measuring about 17 km from the southern portal is characterized by argillite, granodiorite, hornfels, and chert in Mesozoic and Paleozoic strata. An intermediate section of approximately 5 km long is ground vulnerable to swelling consisting of crushed volcanic tuff of the Yotsueki stratum of the Neogene period. This potentially swelling ground is the chief source of difficulties with the tunneling work, and the measures used to counter the difficulties are described later. The final section at the Aomori end, measuring about 4 km in length, is dominated by argillite in the Mesozoic and Paleozoic strata, and volcanic tuff in the Yotsueki stratum as well as mudstone and andesite of the Monnosawa stratum of the Neogene period. The geology of the site is complex and many faults cross the tunnel path.

Tunneling method

Many tunneling methods are in common use, and a suitable one is generally chosen according to geology, tunnel dimensions, and other factors. The New Austrian Tunneling Method (NATM) was adopted in this case. As shown in Figure 5, this method makes the most of the ground's bearing capacity through the use of a combination of rock bolts, shotcrete, and steel supports. The choice between blasting-excavating or mechanical excavation depends on ground conditions. Blasting-excavating entails drilling holes in the rock and detonating

Photo 2. Movable form placed at the Tokyo portal of the Midou section

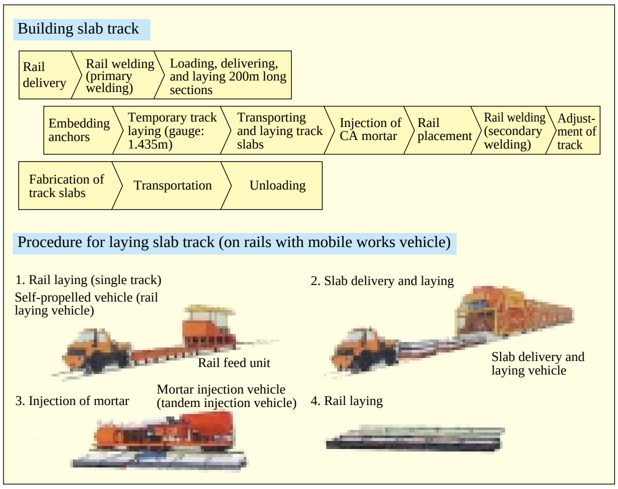

Fig. 7 Procedure for laying track for the Morioka-Hachinohe section of the Tohoku Shinkansen

explosives inserted in the holes. Mechanical excavation makes use of tunneling machines such as free-cross-section excavating machines. Further, there is a choice between full-face tunneling and the bench-cut method; the former is suitable for good ground, while the latter is the standard form of NATM and it achieves tunnel closing at a relatively early stage. The choice of these methods, also, depends on the ground conditions (Figure 6). After mucking out, primary shotcrete is first cast, steel supports are erected, the secondary shotcrete placed, rock bolts installed, and finally primary lining is completed. After that, the lining concrete is cast using a movable form (called centering).

First day of site tour

After alighting from the Shinkansen, I visited the Morioka Branch of Japan Railway Construction Public Corp., where I was briefed on the project. From there, I headed north up National Highway No. 4 toward the construction site. A milestone along the way indicates a

Photo 3. Laying track slabs; teamwork is the key

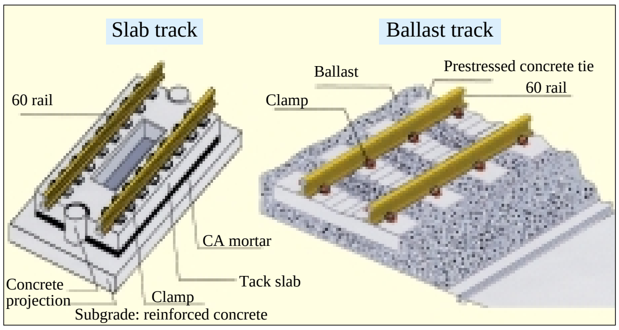

Fig. 8 Slab track and ballasted track

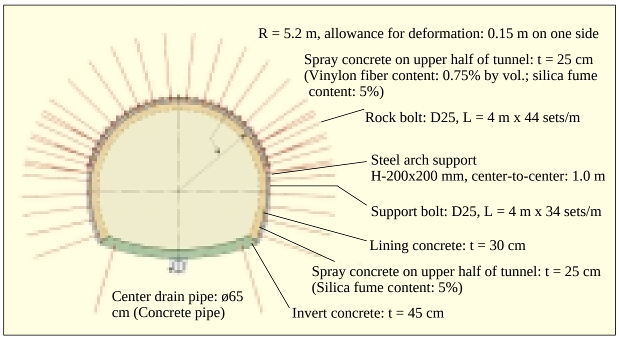

Fig. 9 Different support arrangement used for Mega section; the difference from Figure 5 is quite obvious

distance of 570 km from Tokyo; given that the distance by Shinkansen is 540 km, there is no great difference between road and rail. However, the train took only about 2 and a half hours to reach Morioka from Tokyo, and I could only imagine how long it would take to drive. This well illuminates the advantage of rail over road.

At the Midou construction site, the placement of lining concrete using the movable form had been completed, as shown in Photo 2, and the invert concrete was being cast. At first I was surprised to find that the ventilation system was much simpler than that for a road tunnel, but on second thoughts this seems reasonable as the Shinkansen trains are electric. Carbon dioxide emissions from the trains are only one-eighth and one-fifth of those from automobiles and airplanes, respectively.

A ramp had been built to gain access to the Surinuka section, and the section was being constructed with two faces (with excavation advancing from each end). Excavation from the Aomori side had been completed, so I went down the ramp to the face at the Tokyo end. The ramp totals 1,233 m in length and has passing places at intervals of about 100 m to allow heavy dump trucks (25-ton capacity) to pass each other. The ramp varies from 5.6 m to 9.4 m in width and has a gradient of 10%, reduced to 3% at passing places.

Tunnel construction in this section is by full-face blasting and excavation with auxiliary benches. The drainage system is critical to tunneling work, and the ramp is used to prepare for unexpected water seepage. Two 8-inch-dia drain pipes run alongside the tunnel walls. A larger ventilation system than normally used allows excavation of the two faces concurrently.

My last visit on the first day was to the Kotsunagi section. Here, civil engineering work had already been completed and the track was being laid. I was briefed on the work by Mr. Tokuda, Manager of Ninohe Railway Track Construction Office. Shinkansen track is laid by the process shown in Figure 7. Rail in transportable lengths is welded into 200 m sections for laying as temporary track. Using this track, concrete slabs (ties) are moved into place and laid (Photo 3). The position and height of these slabs are controlled and adjusted to the millimeter. After injecting cement asphalt (CA) mortar into the clearance between the slabs and the concrete subgrade, rail is moved in and laid on the slabs before welding into long lengths. This work makes use of many traditional engineering techniques, such as improved injection methods for CA mortar. Most of the Morioka-Hachinohe section, with the exception of a length near Hachinohe Station where ballasted track is adopted, is laid with slab track (Figure 8).

Second day of site tour

Before visiting the Torigoe section, I had a brief look at the Jumonji River Bridge. This is a 180 m prestressed concrete bridge linking the Nagase and Ninohe tunnels. The view from the top of a bridge pier under construction is far better than from a dark tunnel.

At the tunnel site, excavation was advancing toward the planned breakthrough in summer 2000. In this end section of the tunnel, the geology is complex: there are irregular deposits of andesite, siltstone, volcanic tuff, argillite, and tuff breccia broken up by faults and fracture zones. Machine excavation was used for the first 70 m from the portal and full-face blasting and excavating with auxiliary benches thereafter (Photo 1).

Addressing the challenges

Civil engineering work on the tunnel was nearing completion at the time of my visit. Mr. Nomiya, the manager of the construction site, noted that tunneling work had faced problems due to the vulnerable swelling ground mentioned earlier. In the Ichinohe section, prior to excavating the main tunnel, an inclined shaft and another tunnel of the same diameter as the main tunnel were excavated between 1988 and 1991 to investigate ground behavior during tunneling work. The results of this investigation were used in developing the design of the tunnel plans for excavation. In the section known as Mega, the rock demonstrated a tendency to weaken, and this falling ground strength caused additional deformation of the tunnel, tunnel face collapses, cracking of shotcrete, and deformation of steel supports. To solve these difficulties, the measures indicated in Figure 9 were taken: the size of the H-section steel was increased (to H-200 mm) and the number of rock bolts was increased to 44; the bolt support arrangement was modified; supports using long face bolts were added; and steel fiber-reinforced concrete was used for the lining.

As regards concerns that these measures would lead to rising construction costs, the works manager was confident that the public corporation carrying out the work would be reviewing productivity and work rates, and that costs would be held to an appropriate level.

Expectations

The Hakkoda Tunnel through Mt. Hakkoda is planned for the section of line between Hachinohe and Shin Aomori Stations. This tunnel will have a total length of 26.455 km, surpassing the Iwate-Ichinohe Tunnel. I look forward to on-site reports from this construction site when work gets under way.