Railway Technology Today 1 *(Edited by Kanji Wako)*

Railway Construction in Japan

Yukinori Koyama

Introduction

Progress of construction technology

Japan has a relatively small proportion of lowland, consisting mainly of alluvial coastal plains. Railway construction started in the early Meiji Era (1868–1912) and since the construction technology was still immature, the first lines were built in level coastal areas. The rails were laid mostly on earth structures such as embankments and cuttings. Many railway bridges over rivers were also built at that time. Gradually, with progress in tunnelling technology, railways were constructed connecting towns and cities previously isolated by mountains.

The post-war period of rapid economic growth in the 1950s and 1960s saw problems in securing urban land for new railway construction. Moreover, the rapid spread of automobiles gave rise to severe city planning problems with more traffic congestion resulting in railway crossing accidents. To solve these problems, more urban railways were built on elevated sections.

With advances in construction technology, especially shield tunnelling, many new railways are being constructed underground. In recent years it has become completely impossible to secure new land for railway construction in big cities, although railway demand is still increasing. Furthermore, it is even getting harder to plan construction of new railways underground because there are already so many buried structures, including underground railways. Therefore, the future will see a good deal of effort in developing new technologies for using deep underground space, as well as space above existing railways.

Comparison of Shinkansen lines by structure

First, this article looks at changes in Japanese railway technology by comparing past and current Shinkansen structures (Fig. 1).

The Tokaido Shinkansen—the world's first high-speed railway—is built with a large proportion of earth structures, such as embankments. This method was chosen to shorten the work term and cut construction costs. It was possible because maintenance costs were not so high in those days and no one expected that the shinkansen would operate on the tight schedule of today (about 5 minutes headway).

The Sanyo Shinkansen, completed about 10 years later, runs mostly through mountainous districts. Consequently, more than 80% of its length is tunnels and bridges (including viaducts).

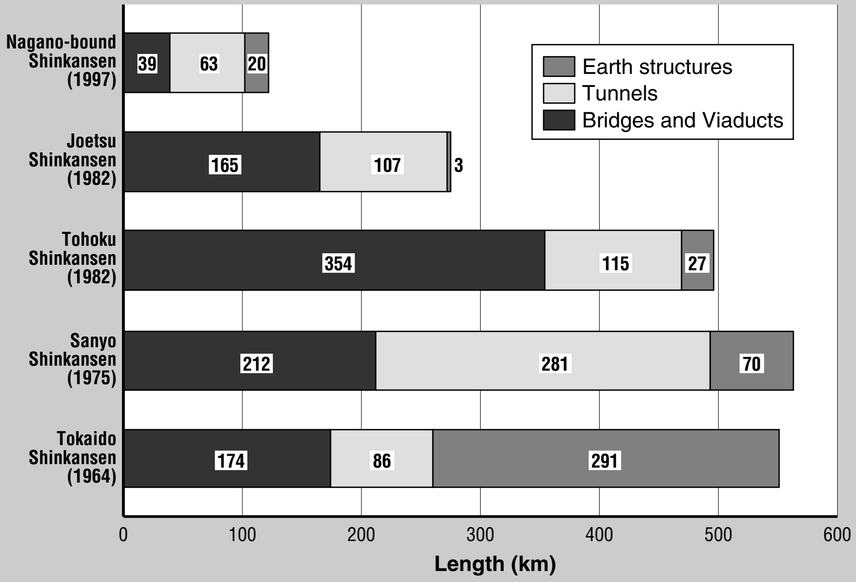
Rising track maintenance costs due to labour costs, resulted in more use of concrete slab tracks. However, since concrete slab track laid on earth structures requires strict control of track bed deformation, the Tohoku Shinkansen and Joetsu Shinkansen, both completed in 1982, have few such sections.

To minimize railway construction and maintenance costs, the Nagano-bound shinkansen, which opened on 1 October this year, uses several new techniques for laying concrete slab track on an earth structure that is not deformed under the train load.

Embankments

Embankments made by heaping and compacting soil are inexpensive and quick to construct and have long been used in Japan. A typical embankment has a quadrilateral cross section (Fig. 2). Since soil cannot be heaped squarely, sloping embankments on both sides provide structural stability, meaning that the embankment requires more space than

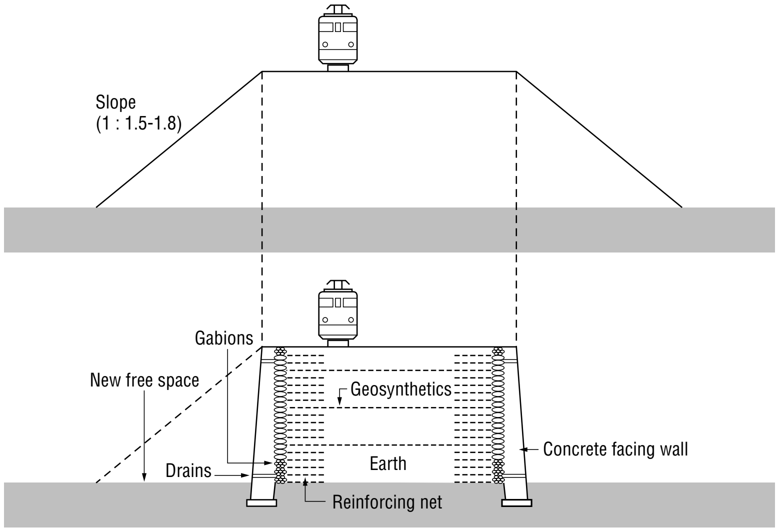
Figure 1 Changes in Shinkansen Structures



the track actually needs. In addition, soil embankments are easily affected by heavy rain and earthquakes, which are a serious and common problem in Japan. Consequently, concrete structures were introduced in the last 10 years to provide more stability, but still did not solve the wasted space problem.

Recently, sloped embankments have been disappearing to be replaced by geosynthetic-reinforced embankments with vertical concrete retaining walls. In this method, soil is heaped in layers with high-polymer geosynthetic sheets and the entire structure is stabilized by vertical concrete retaining walls, thus eliminating the wasted space of typical sloped embankments. Furthermore, no foundation work (pile driving, etc.) is required even on soft ground and the concrete walls are not undermined by rain. Consequently, this new method is very economical and has outstanding stability—these embankments even withstood the Great Hanshin Earthquake that hit Kobe in January 1995.

Figure 2 Typical (top) and Geosynthetic-Reinforced Embankments (bottom)



Viaducts

Rigid-frame, reinforced concrete (RC), beam and slab viaducts are common in Japan. They are monolithic structures with a rigid frame of columns and beams and a slab serving as the railway track. This type of viaduct is the most economical and has high resistance to earthquakes.

Many shinkansen were built using rigid-frame viaducts to cut construction costs and work terms. In fact, such viaducts account for 700 out of the total 2000 km of shinkansen tracks.

Figure 3 shows the procedure for constructing a rigid-frame viaduct. After the foundation is completed, the superstructure is built using the scaffold shoring support method. The columns, beams, and slab are erected in that order. First, temporary scaffold shoring is erected. Then, reinforcing bars and timber forms are set up. Finally, the columns, beams, and slab are poured by the cast-in-place method.

Bridges

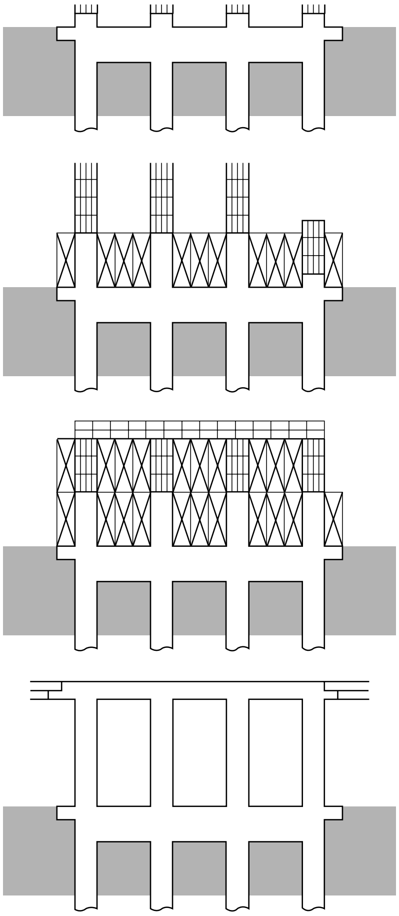
Concrete railway bridge

Short-span railway bridges (up to 25 m) are built using RC beams supported on pillars (columns, etc.) at both ends. The scaffold shoring method described above

Typical embankment collapsed during Great Hanshin Earthquake *(RTRI)*

Geosynthetic-reinforced embankment with vertical concrete facing wall undamaged by Great Hanshin Earthquake *(RTRI)*

Figure 3 Construction of Rigid Frame Viaduct using Scaffold Shoring Method

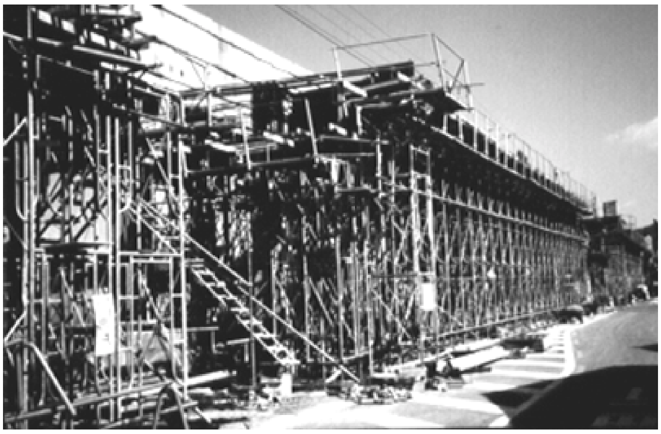


is used to erect the RC beams. Medium-span bridges (20 to 50 m), are built using prestressed concrete (PC) beams instead of RC. In this case, both scaffold shoring and crane erection methods are used. In the crane erection method, prefabricated girders are erected on-site using a crane. Long spans (over 50 m), use rigid-frame PC bridges with a monolithic structure of columns and beams, or cable-stayed PC bridges. The cantilever method is usually used to build long-span PC bridges.

Figure 4 shows the cantilever procedure. The girders are erected in 3 to 5 m sections. First, movable erection vehicles are assembled on each side of the central bridge tower. Next, timber forms, reinforcing bars, and PC tendons and strands are assembled. Then, the concrete is poured and the PC tendons and strands are tensioned. The vehicles then move outward on both sides to build the next sections. The procedure is repeated. This method makes it possible to construct a long-span girder bridge using relatively simple equipment.

Steel bridges

Steel railway bridges can roughly be divided into plate girder bridges (bridges with rails above the girders are called deck plate girder bridges and those with rails under the girders are called through



Scaffold shoring for rigid frame viaduct *(RTRI)*

Completed viaduct *(RTRI)*

Figure 4 Cable-Stayed PC Bridge Construction using Cantilever Method

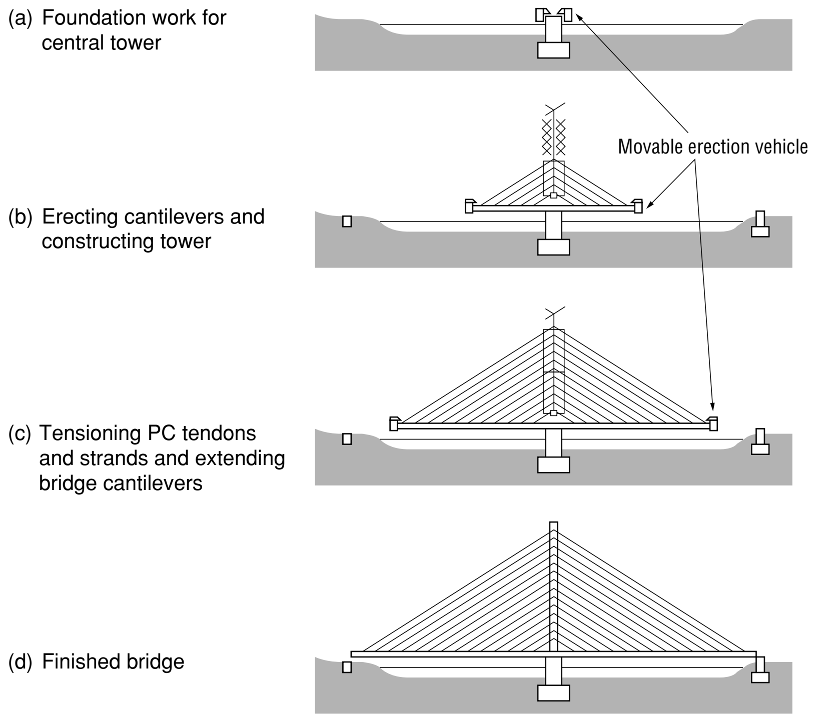


plate girder bridges) and through-truss bridges with rails under a steel frame. Normally, these steel railway bridges are fabricated at factories. The steel is marked, cut, and welded or joined by high-strength bolts into a bridge, which is then erected on-site.

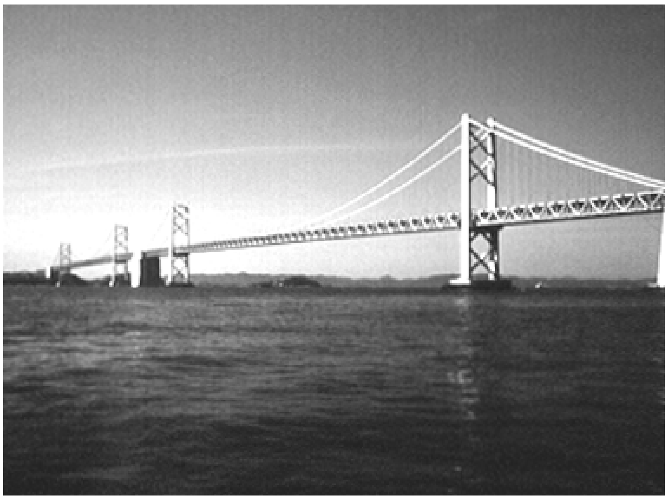
Recent advances in materials, design, and fabrication technologies have made it possible to erect huge railway bridges. A typical example is the chain of combined railway and road bridges between Honshu and Shikoku (opened in 1988) crossing the Seto Inland Sea. The 9.4-km section spanning the strait consists of three suspension bridges, two cable-stayed bridges, and one truss bridge. These incorporate the latest construction technology and are among the world's longest bridges.

Mountain Tunnels

Japanese railways nationwide pass through some 3800 mountain tunnels totalling 2100 km in length, including the Seikan Tunnel (the world's longest tunnel) completed in 1988. The New Austrian Tunnelling Method (NATM), composed of the following three stages, is used most widely today to construct mountain tunnels.

1. Excavating—blasting with dynamite or by machine digging with natural ground above kept intact
2. Supporting—steel supports installed in tunnel, concrete sprayed onto wall, and rock-bolts driven through concrete into tunnel rock
3. Lining—NATM creates tunnel support by pouring concrete into forms, re-

Constructing cable-stayed bridge *(RTRI)*

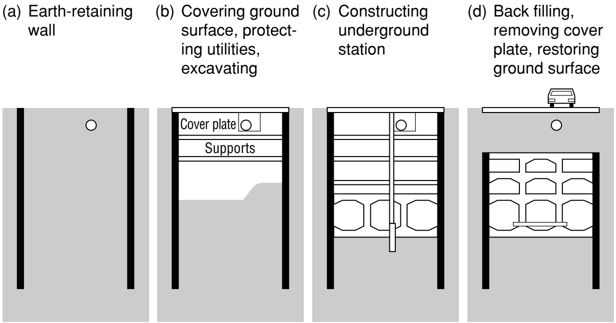


Chain of bridges joining Honshu and Shikoku over Seto Inland Sea—upper deck for motorway and lower deck for railway *(Honshu-Shikoku Bridge Authority)*

Plate girder bridge *(RTRI)*

Through truss bridge *(RTRI)*

Figure 5 Tunnel Construction using Cut-and-Cover Method



placing the conventional steel and pile supports. This has become the standard method since it was first used for the Nakayama Tunnel on the Joetsu Shinkansen (completed in 1982).

Recently, the tunnel excavation has become increasingly automated and some tunnels have been constructed using shield tunnelling machines.

Subways

For some time after the construction of the first tunnel, subways were built using exclusively the cut-and-cover method. In this method, the ground is cut to the tunnel depth, so it can only be used for relatively shallow tunnels and where there are no existing structures on or under the ground. However, the shield method, which permits deep tunnels to be dug horizontally, is widely used today.

Cut-and-cover method

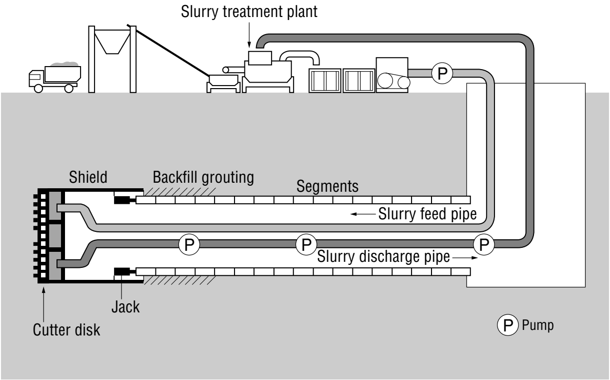
Complex underground stations are chiefly constructed using the cut-and-cover method (Fig. 5).

First, an earth-retaining structure of steel piles, concrete, etc., is constructed from ground level, then the open cut is covered so as not to interfere with the above ground traffic. Next, the ground is excavated to the required depth using suitable supports and taking care not to damage underground utilities, such as water supply, sewage, and gas pipes. After the station is built, the above space is back-filled to restore the ground surface.

Shield method

In the shield method, a shield (steel shell) with a cutter at the front is used to tunnel through the ground. The excavated ground is prevented from collapsing by the pressure of slurry, etc., pumped back to the work face. Segment concrete blocks prefabricated elsewhere are assembled automatically inside the shield behind the work face to finish the tunnel (Fig. 6). Shield tunelling permits fast, relatively safe construction work, and neither interferes with traffic above ground nor adversely affects nearby underground

Figure 6 Tunnel Construction using Shield Tunneling Machine (Pressurized Slurry Shield Type)



Erecting prefabricated segments behind shield in Tokyo's new Subway Line No. 7 of Teito Rapid Transit Authority *(M. Shimizu)* structures.

In recent years, since shallow underground space in big cities is almost fully used, more subway stations are being constructed deeper underground, using the shield method.

Seikan Tunnel

With a length of 53.8 km, the Seikan Tunnel connecting Honshu and Hokkaido is the world's longest tunnel (Fig. 7). Construction started in 1971 and was completed in 1988. Because of the exceptional length, pilot and service tunnels were also dug. The pilot tunnel was used mainly for geological surveys, and the service tunnel alongside the main tunnel was used as a passage for construction workers and for removal of excavated rock.

The main tunnel diameter is 9.6 m to allow passage of shinkansen in the future. The submarine section is 23.3-km long and the deepest point is 240 m beneath sea level. Construction proceeded with great difficulty because of the presence of huge volumes of water and high earth pressures. These difficulties were overcome by developing several new technologies, including grouting by injecting a high-pressure sodium silicate-cement mixture to stop the water, shotcreting by spraying concrete immediately after excavation to stabilize the bedrock, and long-distance horizontal boring. ■

Figure 7 Longitudinal Cross Section of Seikan Tunnel

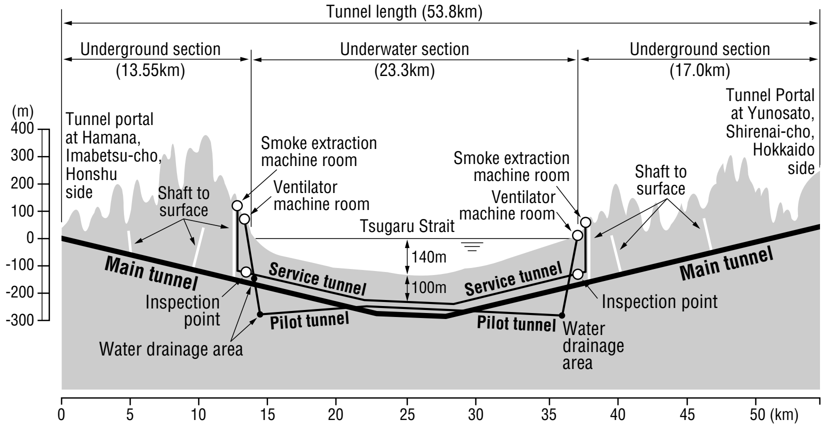
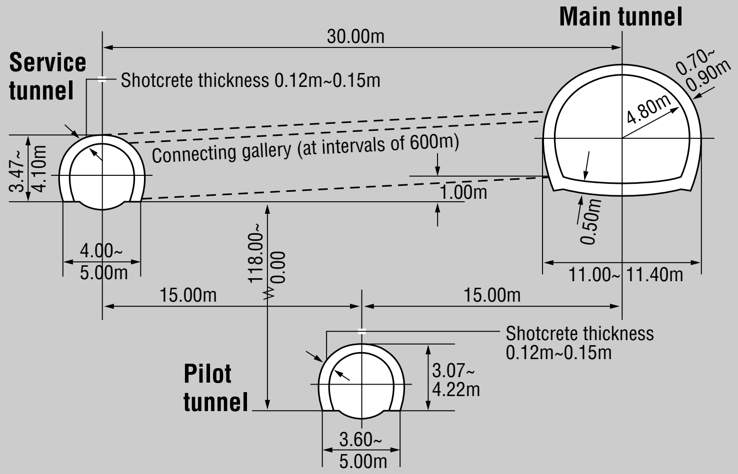


Figure 8 Seikan Tunnel between Honshu and Hokkaido showing main, service and pilot tunnels



Yukinori Koyama

Mr Yukinori Koyama is General Manager of the Structure Technology Development Division at the Railway Technical Research Institute (RTRI). He joined JNR in 1971 after graduating from the University of Tokyo in Engineering, and transferred to RTRI in 1987.

Kanji Wako

Mr Kanji Wako is Director in Charge of Research and Development at RTRI. He joined JNR in 1961 after graduating in engineering from Tohoku University. He is the supervising editor for this new series on Railway Technology Today.