The 54-km-long Seikan Railway Tunnel linking the islands of Hokkaido and Honshu in Japan is the world's longest tunnel

TWENTY-THREE KILOMETERS UNDER THE SEA

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In the thirteenth century, Kublai Khan launched a fleet of ships from the Korean coast across the Sea of Japan. The ships carried battle-hardened Mongol troops—the scourge of both the European and Asian continents. Japan was their target, and no one on either side of the sea doubted that the hapless country would soon be the Great Horde's newest conquest. However, shortly after its arrival, the invading fleet was totally destroyed by a sudden storm. The fierce winds of that storm, known to the Japanese people ever since as "kamikaze" (wind of the gods), saved Japan from invasion and integration into the vast Chinese-Mongol empire.

Kamikaze has not always been the protector of the Japanese people; thousands have lost their lives in the turbulent waters that surround Japan's four main islands. The most recent disaster, which apparently provided the final momentum to the idea of a fast, safe, weatherproof passage between the islands, occurred in 1954 when the Toya-maru ferry went down in the stormy Tsugaru Strait between the islands of Honshu and Hokkaido, killing more than 1,000 passengers.

Linking the Islands

Construction of the Seikan Tunnel linking two of the four main Japanese islands was supported by the Japanese government for three reasons. First, millions of passengers and many more million tons of goods were being transported across the Tsugaru Strait by ferry each year. The ferry trip took more than four hours in good weather, and service had to be canceled in bad weather.

Second, a growing population was placing pressure on the principal island of Honshu. Adequate transportation would have to be provided if the government were going to successfully encourage people to migrate and settle in more remote and relatively unpopulated areas. The Japanese government had targeted Hokkaido as a good candidate for development because its rich natural resources could help support the country's expanding population. The government reasoned that an integrated transportation network would not only serve the people's transportation needs but also would encourage the country's regional economic development.

Third, although it was not widely discussed, Hokkaido's proximity to the Soviet Union was also a consideration in constructing the tunnel. Hokkaido is contiguous to two bodies of water that are strategically important to the Soviet Union's Pacific fleet stationed in Vladivostok. One of these bodies of water, the Tsugaru Strait, provides the Soviet Pacific fleet its only access to the Pacific Ocean. Believing that Hokkaido would be one of the first strike zones in the event of a war, the Japanese defense establishment stationed approximately one-third of its forces on the island. The existence of a tunnel, not subject to the vagaries of weather and

relatively difficult to target militarily, was indeed an attractive idea.

Constructing the Tunnel

The extreme length, volcanic activity, and environmental considerations made the design and construction of the Seikan Tunnel one of the more fascinating events in tunnel engineering history. The first task was to choose the shortest route to connect the islands. The Tsugaru Strait is narrowest at its western and eastern entrances. Preliminary investigations were undertaken along the western route because of the existence of a volcanic belt and of a valley more than 200 m (656 ft) deep along the eastern route (Figure 1).

After an extensive investigation of various tunneling excavation methods, the western route was determined to be technically feasible. Sea bottom surveys were started in 1961 and continued until 1968. Meanwhile in 1964 the project was transferred from the Japanese National Railways to the Japan Railway Construction Public Corporation; excavation and investigations started from Yoshioka on the Hokkaido side in May 1964 and from Cape Tappi on Honshu in 1966 (Figure 2).

The plans called for an inclined shaft to be excavated from each shore. From the bottom of these shafts pilot tunnels were to be constructed and run at a slightly upward angle toward the middle of the strait. Service tunnels were to be constructed off these shafts, and at intervals of 600 to 1,000 m (1,969 to 3,281 ft), cross adits would be excavated from the service tunnels so that the main tunnel could be excavated in either direction from the adits. On May 1, 1965, the working face of the 450-m (1,476-ft) inclined shaft at Cape Tappi on the Hokkaido side reached sea bottom, and a horizontal pit was excavated to allow exploratory drilling to continue parallel with tunnel excavation (Figure 3).

Initially the tunnel was to extend more than 36.4 km (22.6 miles), 22 km (13.7 miles) of which would be approximately 240 m (787 ft) below the surface of the water. The tunnel was to be 100 m (328 ft) beneath the sea bottom and have a maximum gradient of 20/100th. However, the final design that was completed in 1971 called for a tunnel 53.83 km (33.4 miles) long with an undersea portion of 23.3 km (14.5 miles). The design was changed because of the decision to construct the tunnel for both Shinkansen (Bullet Train), which required wide tracks, and conventional trains with narrow tracks. The tunnel was therefore widened to accommodate three tracks for both rail systems, and the grades and approaches were modified downward to adjust for the speed of the Shinkansen.

Excavation of the main tunnel began in May 1972. Two additional tunnels were constructed alongside the main tunnel: the pilot tunnel to allow continuous investigation of geological and water conditions, and a service tunnel parallel to the main tunnel but 30 m (97 ft) away to transport personnel, material, and equipment. On completion of the project, the pilot and service tunnels were to be used for ventilation, drainage, and maintenance of the main tunnel.

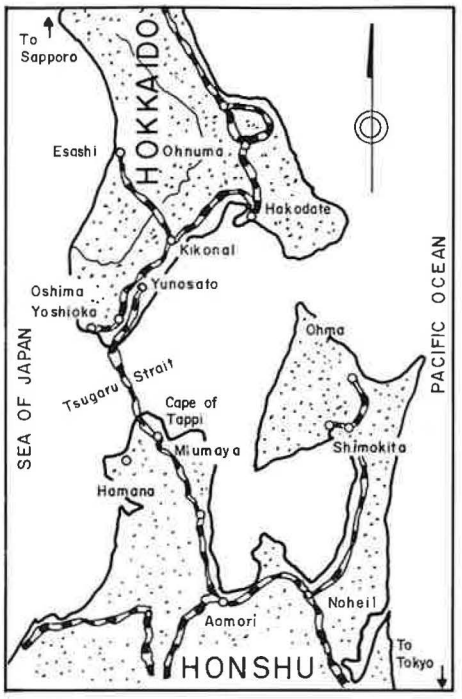


FIGURE 2 Map of Tsugaru Strait area.

Because of complicated geological conditions, progress was much slower than originally estimated. In spite of continuing precautions, in February 1969 the inclined shaft on the Honshu

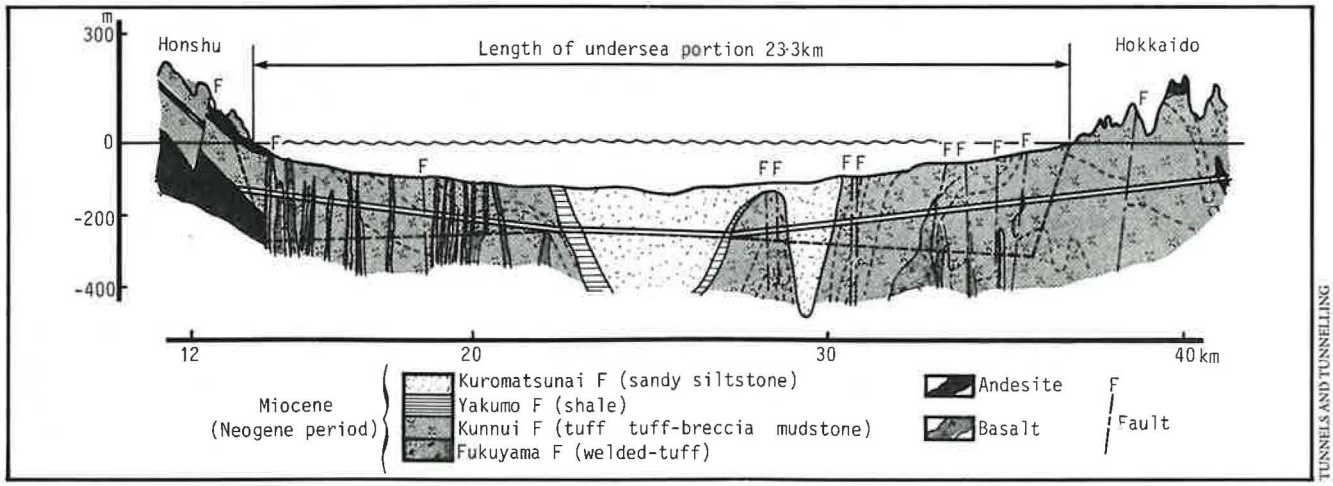
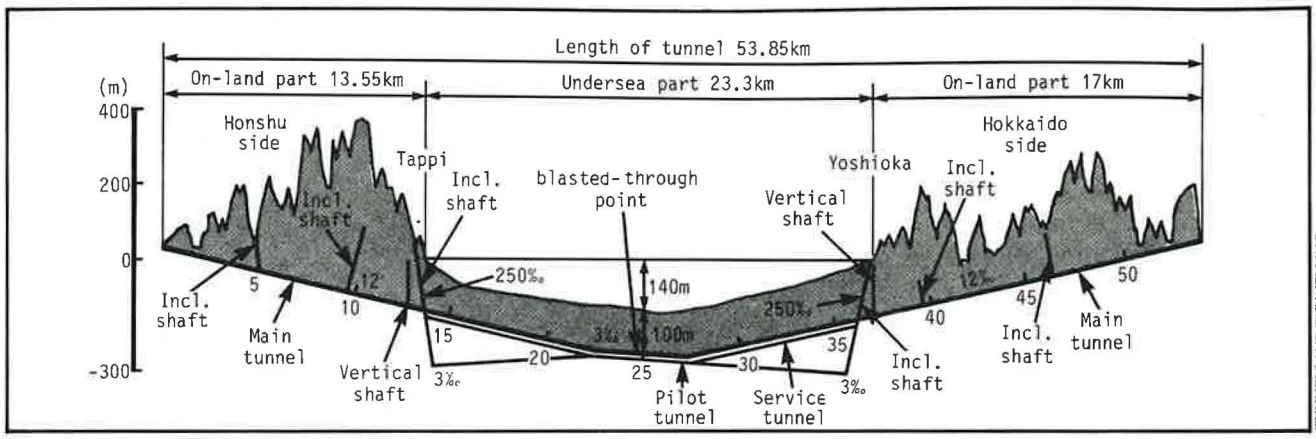


FIGURE 1 Geological profile of Seikan Tunnel.



TUNNELS AND TUNNELLING

FIGURE 3 Profile of tunnel.

side encountered an abnormal inrush of water with only 100 m (322 ft) left to be bored. This caused the collapse of a 150-m (483-ft) section of the shaft. It was seven months before the flooding problem was solved, and the inclined shaft on the Honshu side did not reach bottom until January 1970.

Tunnel Opens

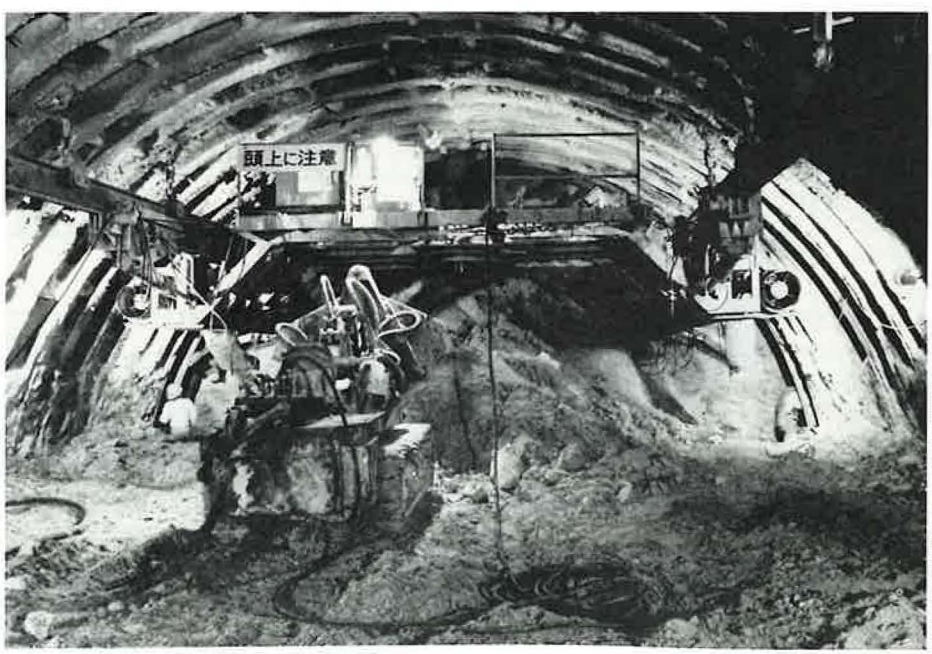
Twenty-four years after the beginning of its construction, the Seikan Tunnel opened to rail service in 1988, and the undersea passage between Honshu and Hokkaido was completed on March 13, 1988. Billed as the world's longest, the tunnel is about 100 meters (322 ft) beneath the sea bottom at its midpoint.

Lessons Learned

The lessons learned and the data compiled will be valuable for years to come. For example, the total amount of excavated muck reached almost 10 million m^3 (10.9 million yd^3). Because environmental considerations were carefully noted from the beginning of excavation, the muck was dumped at designated places for purposes of safety and environmental protection. Excavated muck was also used for sea reclamation. Muddy water pumped out of the tunnel was purified by clarifiers before being discharged into the sea to prevent sea contamination.

Obviously, one of the most valuable aspects of the experience gained from designing and building this tunnel is that many of the lessons learned can be applied to similar projects. For example, Japanese engineers are presently advising the banking consortium that is funding a large part of the Eurotunnel—the tunnel that will connect Great Britain and France. Other projects still in the planning stages that may benefit from the Japanese experience are the Bosporus Strait project and the proposed tunnel under the Strait of Gibraltar.

The Seikan Tunnel project has had its share of criticism. Some critics charge that the technology transfer is the only good that will ever come of the project. Still others charge that the tunnel is an idea whose time has come—and gone. They point out that when construction of the tunnel was first begun, rail travel was the principal mode of transportation, but since the 1970s, airplanes have been the preferred mode of transportation. Also, approximately 76 percent of the freight transported between the islands is carried by independent ferry



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Excavation operations at tunnel face during construction.

companies. This figure is not expected to decrease significantly, further cutting into any profit that might be realized.

Operating Costs

The project was financed by 90 percent loan capital and 10 percent government grant. Because of the privatization of the Japanese National Railways, this debt has been passed on to a residual settlement corporation, which means that ultimately it will be paid by the taxpayer.

Operating costs during the first year that the tunnel was open were estimated to be about $63 million (current exchange rates). Revenue is expected to be about $38 million. The shortfall will be covered by a fixed subsidy of approximately $25 million per year from a fund set up by the government. Although the new Hokkaido Railway Company inherited the Seikan Tunnel debt free, it is unlikely that it will make an operating profit. The subsidy is granted in perpetuity in an effort to give the company a strong incentive to hold down costs and increase revenues. The financial picture for the tunnel is less than encouraging at this point, but the economic prospects for the once-isolated island of Hokkaido are more optimistic since completion of the tunnel, and the Japanese government's hopes for the development of a strong regional economy may yet be realized.

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Cross section and longitudinal grade of Seikan Tunnel are designed for operation of both Shinkansen (Bullet Train) and conventional trains.

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Parallel to main tunnel are smaller pilot and service tunnels used for ventilation, drainage, and maintenance.