AROUND THE WORLD WITH CONCRETE

Grout And Shotcrete Put Derailed Japanese Railway Tunnel Back On Track

By Ashraf M. Ghaly, PE, Ph.D.

Cost overrun is nothing new in the construction industry. We hear all the time about projects that cost two, three, or even four times the original estimate. However, we rarely hear about projects that cost ten times the original estimate. This was, however, the case with the longest railway tunnel in the world, the Seikan Tunnel in Japan. It was not lack of good planning or incompetence in the design. Many unforeseen circumstances and extremely difficult soil conditions resulted in this huge cost overrun. Furthermore, the actual construction time of the tunnel took twice as long as it was initially expected, which also contributed to increasing the cost. The construction of this tunnel and the significant cost overrun gave the Japanese National Railways a wild ride for the money!

Seikan tunnel lies beneath the Tsugaru Strait between the islands of Honshu and Hokkaido (Figure 1). The irony is that, although it is one of the most well designed and safe tunnels in the world, at present it is hardly used. Only about fifteen trains a day in each direction pass through this 34 miles long tunnel. Many of the travelers the tunnel intended to serve took to the skies while the construction of the tunnel dragged for over seventeen years between 1971 and 1988.

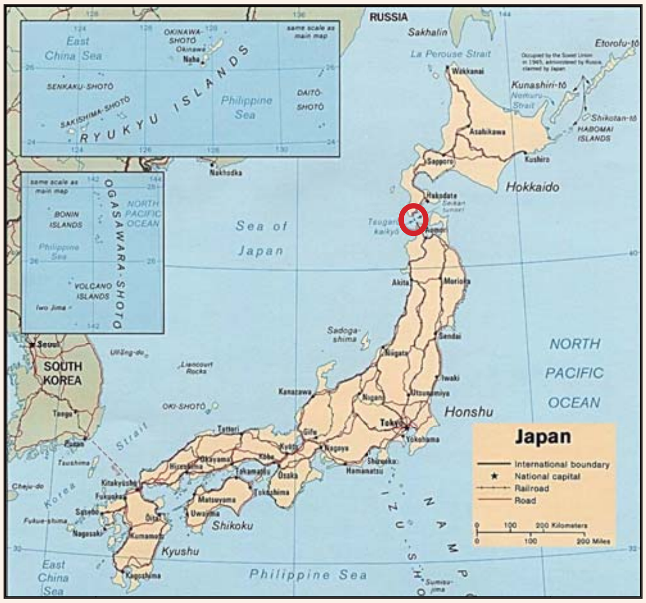

Fig. 1. Circle shows location of Seikan Tunnel.

The tunnel is only one segment in a much greater scheme that was never realized to its fullest extent. In 1936, Japanese engineers envisioned a railway line that links all the islands of Japan, including the farthest northern island of Sakhalin, then goes further north to Korea that was a Japanese colony at the time.

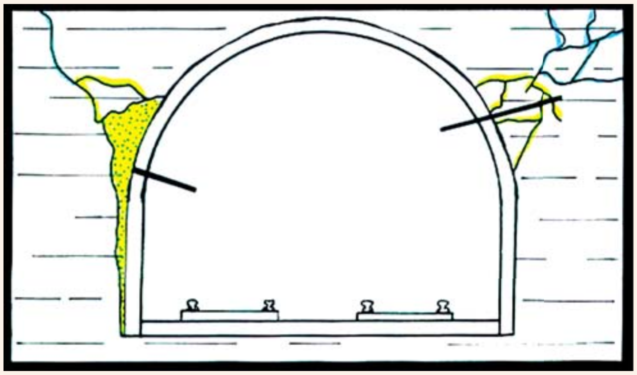

Fig. 2. Illustration of void filling and pressure crack injection.

The island of Sakhalin fell to the Soviet Union in World War II, and Korea gained independence, and the grandiose scheme of a mega railway line died. A modified plan was devised to link the four major islands of the Japanese archipelago.

The loss of five ferries during a typhoon in 1954 was the event that triggered an investigation into the feasibility of building a tunnel in the Tsugaru Strait, which is prone to extreme weather and violent currents that close it for over 80 days a year. The Tsugaru Strait is 15 miles wide at its narrowest point. Initial survey of the rock in the area revealed that they are geologically young. These rocks were created by volcanic action and are full of faults and fissures. Moreover, these rocks are unstable and porous, thus allowing large volume of water flow. This type of rock is considered to be the worst to drill a tunnel through.

Treacherous sea conditions in the strait made surveying the rock formation extremely difficult. This had the adverse effect of obtaining less information than what the Japanese National Railways engineers hoped for.

In 1964, the first shaft of the tunnel was drilled on the Hokkaido side. A second inclined shaft was drilled on the Honshu side two years later. These two shafts were exclusively used to gather more information about the nature of rocks where the tunnel was to be constructed, develop a suitable drilling technique, and ultimately serve as entrances to the main tunnel.

The additional information gathered from the surveying work confirmed that it was not possible to drill in such weak, porous, and unstable rock. It was necessary to stabilize the rock before drilling could begin. Grouting was the technique of choice where small holes were drilled into the rock ahead of the advancing mechanical excavators. These holes were then filled with cement and a gelling agent (grout) under very high pressure (Figure 2). The grout mixture penetrated the small fissures in the rock under the applied high pressure. As these pockets of grout solidified, a network of grout-impregnated rock was formed, which allowed the advancement of the excavators (Figure 3). Without this arrangement, the advancement of the excavators seemed to be impossible as the water seeped through the porous rock and flooded the tunnel. Conventional mining techniques of breaking up the rock with explosives before clearing it with mechanical excavators were generally used due to the weak nature of the rock deposit, which did not require the use of tunnel boring machines.

After the detonation of every charge, the walls were sprayed with shotcrete for primary stabilization then lined with steel H-section supports and a layer of 2 to 3 feet thick

Continued on page 22

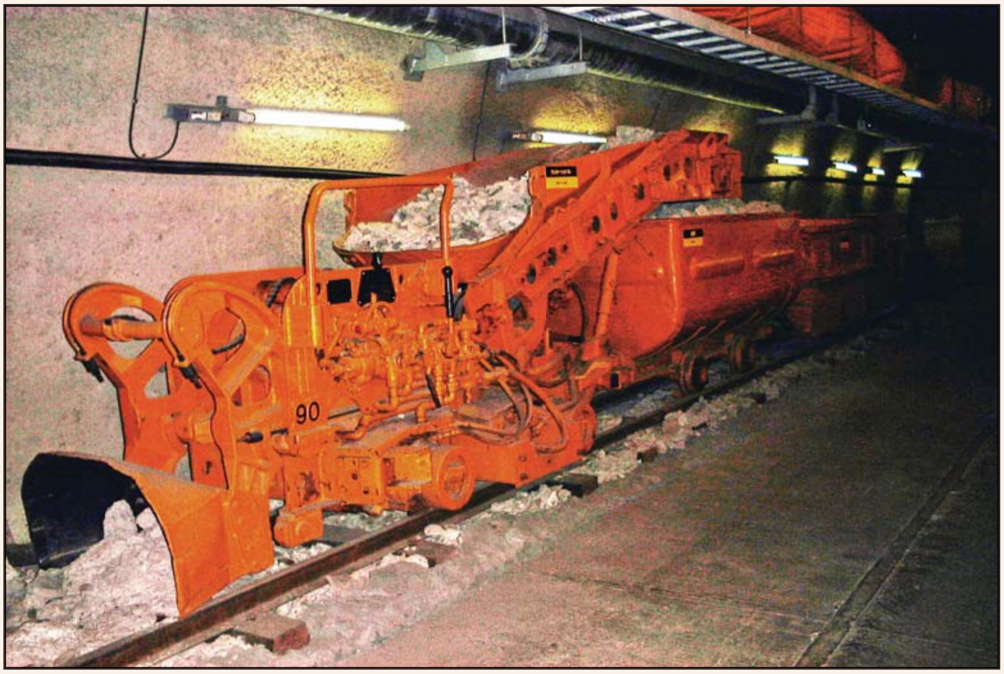

Fig. 3. A model display of mechanical excavators.

Fig. 4. A model view of shotcrete pump operator.

concrete (Figure 4).

Almost half of the 34 miles of tunnel actually lies under the sea. This segment of the tunnel length was the most challenging and costly. In an effort to reduce seepage from the sea, the tunnel was cut more than 300 feet beneath the seabed. For a day worth of drilling, it took two to three days of grout injection to strengthen the native rock. A pilot tunnel was driven ahead of the main and service tunnels to provide advance warning of difficult conditions. In spite of all these precautions, there were at least four major floods.

In the May 1976 flood, over two miles of the service tunnel and one mile of the main tunnel were totally flooded, delaying work for months. The service tunnel was detoured past the region of difficult rock, and additional mining techniques were used to get the main tunnel through the same region without further problems. With all these efforts to stabilize and strengthen the weak rock, continuous seepage requires that four independent pumping stations be operational without cessation otherwise the tunnel would fill with water in 78 hours.

Fig. 5. The inside of Seikan Tunnel.

Air is pumped into the tunnel through shafts on either side of the strait. This generates a steady breeze of about 2 miles an hour throughout the tunnel, which is enough to keep the air fresh and prevent overheating from traveling trains. The air pressure in the service tunnel is slightly higher than that in the main tunnel to ensure that air always flows from the service to the main tunnel, not the other way around. This is vital to maintain a safe place for passengers escaping to the service tunnel in case of a fire. The tunnel is also provided with elaborate heat detection systems, sprinklers, and smoke exhaust blowers. At its deepest point the tunnel reaches 787 feet below the sea (Figure 5). The total cost of the tunnel amounted to $8.3 billion versus the original estimate of $783 million.

Although the number of air travelers between Tokyo and Hokkaido increased sharply over the years, tunnel traveling has not experienced similar increase. However, those traveling by train through the tunnel marvel at this extraordinary feat of engineering. All train cars are provided with many illuminated displays that chart the progress of the trip, speed, depth, pressure, and temperature, in addition to continuous feed with entertainment. The train stops for two minutes in the middle of the tunnel to allow passengers to take a look through the windows of panels on the tunnel wall. Passengers' impression is always one of awe and amazement. After every trip, almost all passengers agree that tunnel traveling was a memorable experience that they like to repeat and enjoy again.

Acknowledgment

Credit for the photos shown in this article is due to Mr. Chris Lee.

Sincerely,
Ashraf Ghaly, Ph.D., P.E.
ghalya@union.edu

About the Author

Ashraf M. Ghaly is a Professor of Civil Engineering at Union College, Schenectady, NY. He is a registered Professional Engineer (PE) in NYS. He received his B.Sc., M.Sc., and Ph.D. degrees in Civil Engineering with concentration on Geotechnical Engineering and Construction Materials. His Postdoctoral was also in the field of Geotechnical Engineering with emphasis on shallow and deep anchor foundations. He has over 16 years of teaching experience and 23 years of industrial experience including land development. He has authored or co-authored numerous journal and conference papers, and technical reports; and has supervised over 44 research projects. Dr. Ghaly is a member of several professional societies. He is a member of the Chi-Epsilon National Civil Engineering Honor Society, and is a Fellow of the American Society of Civil Engineers (ASCE).