World's Longest Subsea Road Tunnel

STEEL FIBER REINFORCED SHOTCRETE REPLACES CAST CONCRETE LINING

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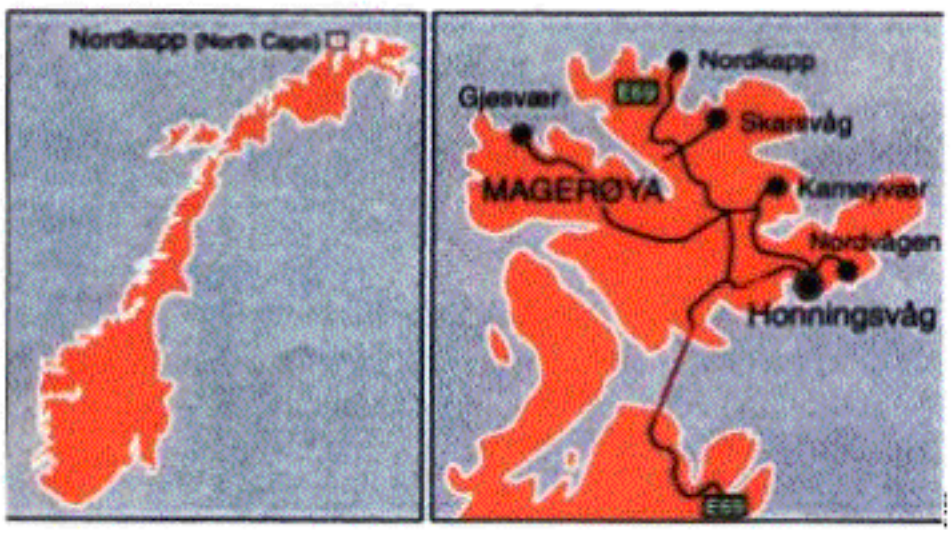
The Northcape-Tunnel in the Arctic Circle in Norway, was opened for traffic on June 15, 1999. The project is the longest subsea road-tunnel (6820 m or 22,000 ft) in the world until 1999/2000. The Northcape-Tunnel is part of the FATIMA-Project, the road connection from the mainland of Norway to the island of Magerøya and the Northcape. During the tunneling-period, many problems were surfaced, especially difficult rock conditions. This resulted in development of a new shotcrete method to replace full cast concrete linings which substancially reduced the total costs of the tunnel.

Within the last 2–3 years, there has been enormous development in shotcrete materials technology, which has made this new wet-mix shotcrete technology possible. There has been considerable improvement in the gain in high early strength and spraying thickness, by the development of a new generation of liquid alkali-free accelerators, superplastizicers, stabilizers and internal curing agents, together with higher fineness cements.



North Cape is located on the island of Magerøya, Norway, in the Artic Circle.

Figure 1.The North Cape Tunnel has 2 driving lanes with the lowest point being 212 m (695 ft) below sea level.

THE PROJECT AND GEOLOGY

The North Cape tunnel, see figure 1, has a total length of 6820 m (22,000 ft) and a cross section of 44 m^2 (474 ft^2). It has two driving lanes, with the lowest point being 212 m (695 ft) under sea level. The excavation of the tunnel started in May 1995 and was carried out from both sides, Vesterpollen (the mainland side) and Veidnes (the island side), see figure 2.

Severe rock conditions at the island side, (a sedimentary rock, consisting of shale, siltstone and sandstone) made it necessary to use a cast concrete lining from the very beginning. Because of this, progress was much slower than originally planned by using rock support with rock anchors and shotcrete. The traditional Norwegian wet-mix shotcrete method with steel fiber reinforcement and sodium silicate (waterglass) accelerator is well suited for normally good rock conditions, but with these bad rock conditions, we were neither able to spray thick enough layers to compare with cast concrete linings, nor reach sufficiently high early strength to provide acceptable rock support at the tunnel front.

At the mainland side the good rock condition (mica-schist and meta-sandstone) were as expected with only modest needs for rock support, by using rock anchors and conventional shotcrete, and the tunnelling work developed as scheduled. Because of these good rock conditions at the mainland side, it was expected that the rock condition at the island side should improve, but when the tunnel front at the mainland side reached the lowest point in late autumn 1996, sedimentary rock with more or less similar properties to the rock at the island side was encountered. Fully cast concrete linings then had to be used at both advancing tunnel fronts. The project faced a considerable delay in progress.

NEW METHOD FOR WET-MIX SHOTCRETE

In the winter of 1996/97 an investigation was started to find out if the fully cast concrete lining could be replaced by a less time consuming method for rock support. The new method should comply with both the structural and geometrical requirements of the

project. Shotcrete with waterglass accelerator gives a flash set, but has a slow early strength development, and seldom reaches layer thicknesses above 50 mm (2 in) in one spraying operation. We were looking for a spraying method that could give us up to 500 mm (20 in) thickness in one spraying operation and provide high early strength and a final compressive strength of at least 45 MPa (6500 psi).

New types of accelerator, liquid alkalifree accelerators for wet-mix shotcrete, were developed in 1996/97 and introduced to the Norwegian market. These accelerators increased the spraying thickness in one operation and also provided high early strength development, compared to waterglass accelerators. Similary, the development of new types of superplasticizers and finer grind cements provided further early strength gain of the shotcrete.

The contractor, VEIDEKKE ASA, closely followed this development and contacted MBT (Master Builders Technologies) to discuss the possibility of replacing the fully cast concrete lining with a rock support made of wet–mix shotcrete with alkalifree accelerator in combination with rock anchors. At first, the Public Road Authorities in northern Norway was a bit apprehensive about this new spraying method, but with reference to good results obtained both abroad and in shotcrete tests in southern Norway, arranged by the Public Road Authorities in the Stømsås tunnel in Drammen, full scale testing was started in the Northcape tunnel in the spring of 1997.

MIX DESIGN DEVELOPMENT

It was of our special interest to develop mix designs for wet-mix shotcrete (combinations of cements, accelerator and plasticizing admixtures) to obtain optimal properties as actually needed for rock stabilization such as sufficient spraying thickness, and good security, work progress and shotcrete quality.

High demands were required of the shotcrete as rock support at the tunnel front, especially in bad rock conditions, due to adherence problems. Shotcrete with an alkalifree accelerator achieved high spraying thickness of up to 500 mm (20 in) in one spraying operation. This new type of accelerator is more expensive than waterglass accelerator, but the increased material costs are negligible compared to the huge costs saving achieved by higher work progress. By using a mean accelerator dosage of about 6-8 % by mass of cement both high spraying thickness, low rebound and downfall, and good early strength and fiber orientation were obtained.

Plasticizing admixtures were also chosen to provide positive effects on both spraying thickness and early strength. But other properties are also important, such as obtaining long term stability of the fresh concrete mix, high slump stability and low rebound together with good adhesion to get good build-up and bond on the rock surface.

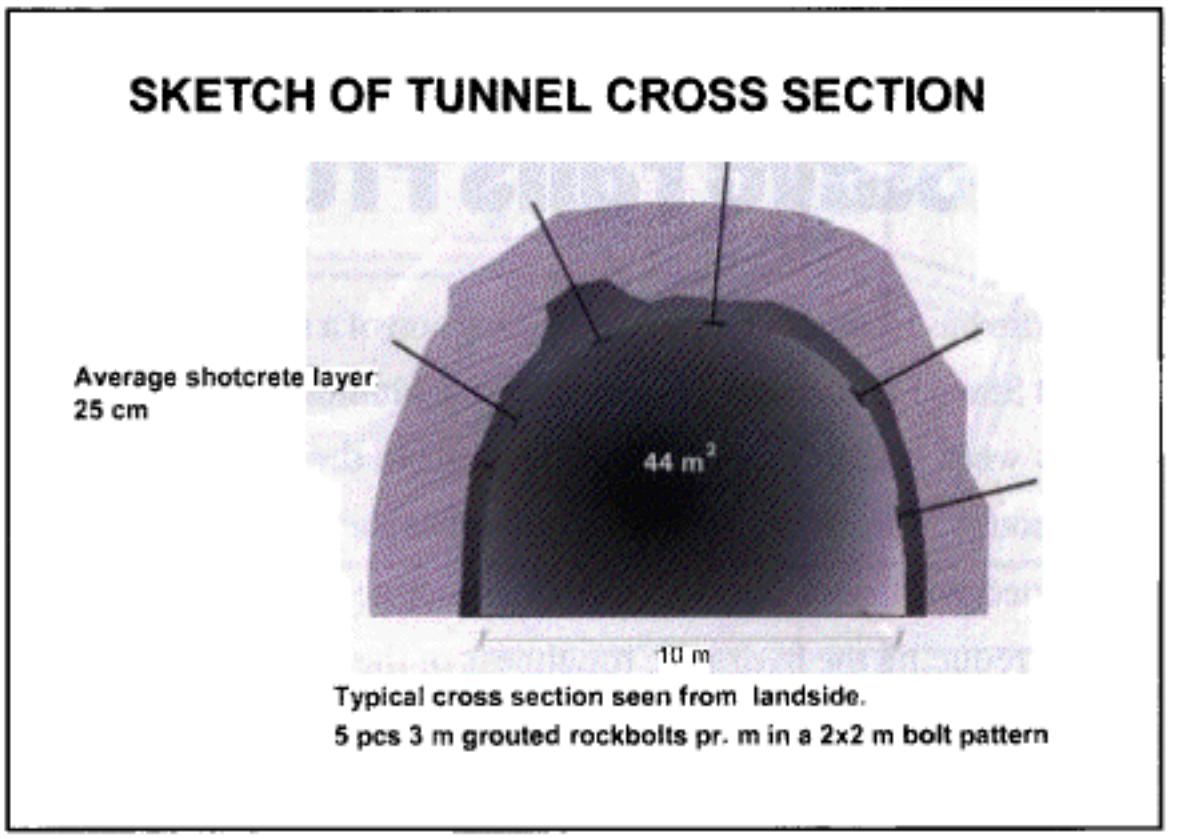


Figure 2. Excavation of the tunnel was carried out from both the mainland and island sides.

To achieve these properties, new types of admixtures called stabilizers and internal curing agents were used. A stabilizer prolongs the working time of concrete (depending on the dosage used), and delays the cement reaction until an activator, as for instance an accelerator, is added at the nozzle during spraying. A stabilizer is very useful when high fineness cements are used, or in the case of long transport/delayed spraying. So, the wet-mix shotcrete never gets too old (stiff) for spraying. Internal curing admixtures are helpful to protect the freshly applied shotcrete from excessive drying shrinkage. This admixture is added at the mixing plant, and thereby provides a better protection than membrane curing compound sprayed on the shotcrete surface, as was done in the past.

EXPERIENCE

In June 1997 a full scale test with the new shotcrete concept took place in the North Cape Tunnel. At first the traditional shotcrete used for stabilization was replaced with the new shotcrete concept before additionally casting the concrete lining. Then the 3 last rounds before the summer vacation were sprayed with the new shotcrete concept without any cast concrete lining. See figure 3 on page 39, which shows the final lining. After summer vacation the shotcrete lining was investigated for cracks and deflections and none were found. Also drilled cores for compressive strength showed compliance with the project requirements. In this special case the most important issue was that the work force accepted the method. The thick shotcrete layers provided a good arch effect and the smooth shotcrete surfaces gave a rather solid impression.

After the end of August 1997, cast concrete lining at both tunnel fronts were replaced with final

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Shotcrete Corner

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placeable shotcrete mixes can be developed with rebound that is actually lower than in shotcrete made with virgin aggregates.

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shotcrete linings. The control period was extended to October 1997. At the end of the testing period it was decided to approve this new shotcrete method for permanent support. Due to the weak rock, deflections in the support layers are possible. To be able to deal with this possibility it was decided to spray only half the thickness of shotcrete just after mucking out and spray the final shotcrete thickness after the next mucking out. The total thickness of the shotcrete layer was 250 mm (10 in) on average, which means some 7 m^3 (247 ft^3) of shotcrete per meter of tunnel. It was clearly emphasized that the best possible arch-effect should be aimed at providing the shotcrete with a layer of similar load carrying capacity to the fully cast lining. In addition a 2 by 2 m pattern (6½ by 6½ ft) of 3 m long (10 ft) grouted rock-bolts were installed, approximately 3–5 days after final spraying.

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Figure 3. The final lining

The new shotcrete method has been very successful even although there were some zones of rock of such a poor quality that a fully cast concrete lining had to be chosen. Altogether since the method started, there was an average progress of 30 m (98 ft) per front per week compared to 17.5 m (57 ft) earlier which represents a 70% increase in progress. Just taking into account the weeks when the fully cast concrete lining was not necessary, the increase in progress was more than 100%. The technical and economical advantages of this new method for wet-mix shotcrete over conventional cast concrete linings were well demonstrated on this challenging project.

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