Shotcrete for Underground Support

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In November, 1999 I had the opportunity to attend the Third International Symposium on Sprayed Concrete: Modern Use of Wet-Mix Sprayed Concrete for Underground Support in Gol, Norway. The Symposium was co-sponsored by the Norwegian Tunneling Society, Norwegian Group for Rock Mechanics, Norwegian Society of Chartered Engineers, and Norwegian Concrete Association. This was the third symposium on this topic sponsored by this group, the previous two being held in Norway in 1993 and 1996. The symposium was well attended by some 160 delegates from around the world.

Over 50 technical papers were presented. These papers showcased the state of the art of shotcrete (sprayed concrete, as the Europeans call it) for underground support. While the majority of the papers presented Scandinavian experience in wet-mix shotcrete for underground support there were also excellent examples of the use of the technology in civil and mining application from around the world. There were many case history examples of the use of shotcrete for primary (initial) and final linings in wood, nail, and water tunnels. Particularly impressive was the Norwegian technology for replacement of cast concrete final tunnel linings with high performance steel fiber-reinforced shotcrete in undersea tunnels in difficult rock conditions.

There was an excellent slide, video, and film presentation on the use of this technology in the construction of the North Cape Tunnel in the Arctic Circle. This 6.8 km (4.25 mi.) long tunnel is the longest subsea road tunnel in the world and the final tunnel lining is shotcrete. The wet-mix shotcrete was pumped at a slump of about 200 mm (8 in.) and yet, with suitable mixture proportioning and alkali-free accelerator addition at the nozzle was able to be applied to both vertical and overhead surfaces at thicknesses of up to 500 mm (20 in.) in a single pass.

The shotcrete mixture utilized had proportions as follows:

- Aggregate 0-8 mm(0-5/8 in.) 1450 kg/m³ (2444 lb./yd.³)
- Cement, 520 kg/m³ (876 lb./yd.³)
- Silica fume 5% of cement mass, 25 kg/m³ (42 lb./yd.³)
- Alkali-free liquid accelerator, 33 kg/m³ (55 lb./yd.³)
- Plasticizer, superplasticizer, each 5 kg/m³ (8 lb./yd.³)
- Stabilizer, 2.5 /m³ (4 lb./yd.³)
- Internal curing admixture 5 kg/m³ (8 lb./yd.³)

- Steel/fibers, 40 kg/m^3 (67 lb./yd.^{3})
- Low water/cement ratio <=0.45

The silica fume enhanced adhesion and cohesion of the mix. The plasticizer (water reducer) and superplasticizer controlled the water demand of the mix and provided high workability for pumping. The stabilizer (hydration controlling admixture) provided extended working life for the long haul time needed in this tunnel and the internal curing admixture helped prevent drying shrinkage and cracking of the young shotcrete. The steel fibers were used in lieu of mesh reinforcement and provided toughness and crack control in the hardened shotcrete.

After the symposium there was a tour of Drammen in Southern Norway (near Oslo) where delegates were able to observe a shotcrete mixture, very similar to that described above, being applied in a road tunnel under construction. The shotcrete was robotically applied by a nozzleman sitting in a cab mounted on the manipulator arm. The low rebound and full-thickness application (about 150 mm [6 in.]) in a single pass were impressive.

After this, delegates visited the new E18 highway. This new highway has ten tunnels, varying in length from 100 m to 1765 m (328 ft. to 5791 ft.) and totaling some 7 km (4 mi.). All the tunnels had final steel fiber reinforced shotcrete linings. Water and ice control structures, which also utilized shotcrete were built within these tunnels. Delegates were able to observe the shotcrete linings and water and ice control structures in various stages of construction.

There is no doubt that with over 1000 km (620 mi.) of road tunnels, the Norwegians have developed the state-of-the-art tunnel lining (and water and ice control) using shotcrete, to a high degree. Owners, engineers, and contractors in other parts of the world can avoid reinventing the wheel by learning from their experience.

Copies of the conference proceedings can be obtained from:

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