Regionally Symbolic Tunnel Portals at Expressway

By Kyong-Ku Yun, Yong-Gon Kim, and Sung-Yong Choi

Since the construction of the first expressway in the 1970s, the total length of expressways in Korea has increased to 2757 miles (4437 km), of which 542 miles (872 km) include 1055 tunnels. These tunnels are characterized by their portals. Currently, the local inhabitants demand a much higher standard of living. When considering improvement of transportation quality, environmental protection and ecological conservation aesthetics of the tunnel portal must also be provided.

The tunnel portals were constructed using shotcrete technology with carving for texturing and acid staining for coloring, creating an artificial rock (Fig. 1). These tunnel portals were designed with input of the local inhabitants, who wanted the portals to represent their regional characteristics. The inhabitants were very satisfied with the final work, as they appreciated each portal was a beautiful and symbolic representation of their community. All the various portal designs were made possible with shotcrete's inherent ability to adapt to curved and irregular surfaces, allow for different surface finishes, provide excellent physical properties, and as a fast and economical process.

Fig. 1: Overview of symbolic tunnel portal

Fig. 2: Concept of cellular sprayed concrete

CELLULAR SPRAYED CONCRETE

A new adaptation of the shotcrete process "cellular sprayed concrete" was developed for the project. Cellular sprayed concrete is produced by introducing cellular and mineral admixtures while remixing and dispersing the mineral admixture in ordinary ready mixed concrete at a jobsite. Higher strength and durability are produced by the addition of the mineral admixtures. Production cost and construction time can be reduced because the high-performance cellular sprayed shotcrete is produced by adding silica fume in the ready mixed concrete on the jobsite without the need for production, transportation, and storage, which are required when special blended cement is used.

The processes of cellular sprayed concrete are as follows:

1. Bring an ordinary ready mixed concrete having a low slump in a truck to a jobsite;
2. Add a preformed cellular material with 20 to 30% by volume into a truck, then the stiff concrete would become more fluid with a very high slump;
3. Add silica fume, and remix to disperse it. The silica fume could be easily dispersed in the high-slump concrete; however, the concrete contains lots of air inside so it requires more mixing; and
4. Supply the cellular concrete to a mobile concrete pump with a boom that has the nozzle at the end and spray the cellular concrete with a high air flow. The high-velocity impact disperses much of the air in the concrete, thus producing a low-slump, high-performance concrete in place. Figure 2 illustrates the concept of cellular sprayed concrete.

SHOTCRETE MATERIALS

The cellular sprayed concrete was developed to be cost-effective. Table 1 shows an ordinary and high-performance concrete mixtures. The slumps were measured to be 3 in. (80 mm) in the ordinary ready mixed concrete, 7.5 in. (190 mm) after adding the cellular material and silica fume,

Table 1: Concrete Mixture Designs

Type	W/B	S/a (%)	Unit content (kg/m³)						
			Water	Cement	S.F.	Sand	Gravel	AE	Cellular
OPC	0.42	65	164	390	—	1146	619	3.9	—
HPC	0.43	65	164	390	30	1146	619	3.9	220

and then 0.4 in. (10 mm) after spraying. The final targeted total air content was between 3 to 6% after spraying.

CONSTRUCTION METHOD

Cellular sprayed concrete reduced construction time because a very high volume of concrete could be placed using standard ready mixed concrete and a concrete pump with a remotely manipulated boom for the nozzle. The additional equipment required is a foam generator and an air compressor. It is a very efficient production system for high-performance concrete because not too much specialized equipment is required. This method enables top-down or bottom-up concrete construction of the tunnel portal without formwork, as shown in Fig. 3.

Spraying (Fig. 4), carving (Fig. 5), and coloring natural rock patterns is an eco-friendly technology that harmonizes with the surrounding landscape. This method was adopted to the tunnel portals. It was designed to meet the demands of the local community, and represent their regional symbolic characteristics in the final concrete surfaces. The towns were very happy with the beautiful and symbolic appearance of their own tunnel portals.

Fig. 3: Construction of tunnel portal using cellular sprayed concrete

Fig. 4: Spraying at tunnel portal

Fig. 5: Carving regional symbol at tunnel portal

TEST RESULTS

The high-performance shotcrete required strength and durability because it is exposed to weather on the face of the tunnel portals. Three specimens of the shotcrete were prepared on site for strength and durability tests. The test results are as follows:

The slump and air content test performed on the fresh concrete gave a result that satisfied the targeted values. The targeted slump before shooting was between 2.8 to 5 in. (70 to 130 mm), and it was measured to be 4.3 in. (110 mm). The targeted air content after shooting was between 3 and 6%, and it was measured to be 4.6%. Thus, both slump and air content were satisfied.

Compressive strength and flexural strength were measured only at 28 days. The compressive strength was 6570 psi (45.3 MPa), which is higher than the targeted 5000 psi (35 MPa); flexural strength was also higher than the targeted 720 psi (5 MPa), measured as 770 psi (5.3 MPa).

Durability was evaluated through three kinds of tests: rapid chloride permeability test, freezing-and-thawing resistance test, and surface scaling test. Rapid chloride permeability test was performed at 28 days on a core specimen. The result was 876 coulombs. Any value below 1000 coulombs is considered to have very low permeability. The freezing-and-thawing resistance test was conducted by "Type A," which is a method of freezing and thawing in water, and then the relative dynamic modulus is measured every 30 cycles up to a total of 300 cycles. The relative dynamic modulus after 300 cycles of freezing and thawing was 87%, which is higher than the criteria of high durability performance, 80%. The surface scaling resistance test was performed by repeating freezing and thawing for 50 days with the concrete surface saturated with 4% calcium chloride solution; the amount of peeling and the state of aggregate exposure on the surface was measured and observed. As a result, the surface scaling resistance was excellent and ranked as Grade 1 in the ASTM C672 standard and measured below 0.1 kg/m^2 in the SS 13 72 44 standard.

Conclusions

The steel reinforcement was placed and tied according to the shop drawings for the tunnel portals, and then high-performance concrete was placed by shotcreting using a modified concrete pump and boom and cellular sprayed concrete. Cellular sprayed concrete is a very simple and economic method to produce a high-performance shotcrete by adding cellular material and silica fume into an ordinary low-slump ready mixed concrete.

High volume placement of high-performance cellular sprayed concrete was possible in shooting the bulk of the thickness. After shooting, the final layer was carved and colored to create the natural rock patterns. This technique is an eco-friendly technology that harmonizes with the surrounding landscape by creating natural rock shapes and coloring the placed high-performance shotcrete before it hardens. The carving and coloring after shooting met the requirements of the local community to represent their region. Figures 6 and 7 show some of the beautiful regionally symbolic tunnel portals constructed in Korea by the Korea Expressway Corporation.

Fig. 6: Regionally symbolic tunnel portals at Pohang

Fig. 7: Regionally symbolic tunnel portals at Sangju

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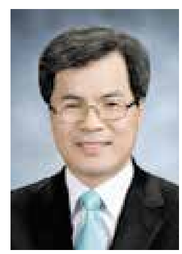

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2017 Outstanding International Project

Project Name
The Regionally Symbolic Tunnel Portals at Expressway

Project Location
Gangwon-do, South Korea

Shotcrete Contractor
Daesang E&C

General Contractor
Doosan E&C

Engineer
Daesang Engineering Co.

Material Supplier
Daesang E&C

Project Owner
Korea Expressway Company, Korea