2016 Honorable Mention

2018 PyeongChang Winter Olympics Sliding Track

By Kyong-Ku Yun, Yong-Gon Kim, and Kyu-Woon Lee

The 2018 PyeongChang Winter Olympic sliding center is a structure built in PyeongChang-gun, Gangwon Province, to host bobsleigh, luge, and skeleton events. It is currently hosting test events. This sliding center was constructed from January 2014 to October 2016, occupying an area of about 37 acres (150,000 m^2). Shotcrete construction on the main track was completed in a short period of time—from July 2015 to January 2016. Figure 1 shows a bird's-eye view of the sliding center.

The track production sequence included:

- Placing the formwork;
- Installing the curve retention screed pipe;
- Floor shotcrete placement;
- Removal of rebound material from the space between the floor and the wall;
- Wall shotcrete placement;
- Surface finish with a temporary screed pipe;
- Surface finish after the removal of temporary screed pipe;
- Surface treatment; and
- Wet curing.

TRACK MOCKUP TEST

For the mockup test, a full-sized mockup with a reduced 16 ft (5 m) length was constructed by simulating the transition curve section of the bobsleigh track. Two initial mockup tests were conducted at Kangwon National University, and the final mockup was built at the PyeongChang Alpensia site with inspection by FIBT and FIL. The main mockup test was conducted from May 22 to June 6, 2014.

On June 4, 2014, the main mockup was built by Daesang E&C Co. LTD, constructors of the track, with the help of Dr. Kyong-Ku Yun, Professor of civil engineering at Kangwon National University, Chuncheon, Korea, and with additional consulting by Dr. D. R. Morgan, P.Eng., FACI (Fig. 2).

SHOTCRETE MATERIALS

The main purpose was to develop a structural shotcrete with high strength and high durability by incorporating admixtures. Air content and slump test were measured to assess the basic properties of the concrete. Strength characteristics of the material were evaluated by compressive

Fig. 1: Overview of the sliding track

Fig. 2: Members of the mockup test

Fig. 3: Shotcrete pump with a mobile volumetric mixer

and flexural strength testing. For durability assessment, we used rapid chloride ion permeability, freezing and thawing, and surface-scaling resistance tests. Table 1 shows the targeted shotcrete's basic properties and durability characteristics, including the evaluation methods.

The pumpability was improved by incorporating 10 to 15% more air content before shooting. The air content was measured to be 3 to 6% after shooting, thus providing the desired in-place strength and durability. The durability properties were improved by substituting silica fume for 8.7% by weight of the cementitious content. The mixture design also helped to suppress early-age shrinkage cracks by substituting 7% of an expansive admixture by weight of the cementitious content. The concrete mixture was economical because the fine aggregate was set at 75% of the total aggregate weight to reduce the amount of rebound. The mixture proportions are shown in Table 2.

SHOTCRETE EQUIPMENT

Shotcrete Machine

In this project, a Putzmeister TK20 shotcrete pump was used. This delivers the concrete using two hydraulic pistons and it can produce up to 17 yd^3/h (13 m^3/h) with a maximum concrete pressure of 2000 psi (138 bars). In addition, a Putzmeister TK10 was used at the initial mockup test at Kangwon National University, where a 10 ft^3 (280 L) mixer was used. This small mixer is ideal for small-scale projects such as this. Figure 3 shows the shotcrete equipment and mobile volumetric mixer used at the track construction site.

Air Compressor

An air compressor with a maximum capacity of 390 ft^3/min (11 m^3/min) was used to provide air pressure at the nozzle.

CONSTRUCTION PROCEDURE

Bobsleigh Track Support Frame Work

First, the support frame, where the bobsleigh track will be installed, had to be placed. The support frame secures the space where the left and right walls of the bobsleigh track are attached and defines the working environment. The support frame was manufactured using steel H-beams and was designed and produced to carry the load applied to the back of the wall.

Table 1: Shotcrete Material Properties Targeted

Test item	Targeted	Note	Test method
Slump test, mm	70 to 130	Fresh	KS F 2402
Air content, %	10 to 15	Before shooting	KS F 2421
	3 to 6	After shooting	
Compressive strength test, MPa	40 or more	Age 7, 28 days	KS F 2405
Flexure strength test, MPa	5.0 or more	Age 28 days	KS F 2408
Rapid chloride ion permeability test, Coulombs	>1000	Age 28 days	KS F 2711
Surface delamination resistance, rating	1 to 2	Age 28 days	ASTM C 672
Freezing-and-thawing test, %	80 or more	Age 28 days	KS F 2456

Table 2: Mixture Proportion of Shotcrete for the Sliding Track

Gmax, mm	Slump, mm	Air, %	*w/b*, %	*S/a*, %	Unit weight, kg/m^3				AEA, %	SP, %
					W	B	S	G		
10	70 to 130	10 to 15	40	75	184	460	1322	436	0.03	0.3

Jig Support Frame Installation and Cooling Pipe and Reinforcement Placing

The jig support frame is an essential support where all the reinforcement, cooling pipes, and stay-form are installed. Hence, the jig support frame installation is critical and required setting to a tolerance of 0.2 in. (±5 mm).

The jig support frame was produced by laser cutting 1 in. (25 mm) thick metal plate. Cooling pipes were installed in the jig support frame with a 3.5 in. (90 mm) spacing, then No. 3 (10 mm) reinforcing bars on 4 in. (100 mm) spacing in the front and rear surfaces in an orthogonal layout. The reinforcing bars behind the longitudinal reinforcing bars were placed after the lateral reinforcing bars to facilitate the stay-form installation.

Formwork and Stay-Form Installation

The floor and head portions were mounted with a wooden form. A stay-form was used in the curved portion because removable wooden formwork could not be used here. The stay-form reduced the rebound during shotcrete placement and it also served to densely fill the interior.

Temporary Screed Pipe Installation

Temporary screed pipes were used as guides to place the shotcrete with a uniform thickness. The temporary screed pipes were mounted by taping a 1.1 in. (28 mm) plastic tube in place to get a 1.2 in. (30 mm) thickness. The screed pipes alternated in the upper and lower part of the track to allow easier shotcrete placement., The pipes were installed perpendicular to the axis of the track with 3.3 to 4.9 ft (1 to 1.5 m) spacing as shown in Fig. 4.

Reinforcement Layout and Spacing Inspection

Prior to shotcreting, the invited experts from both Korea and abroad inspected the reinforcement layout and spacing of the bobsleigh track after the foundation and placing of reinforcement was completed. The 6.3 in. (160 mm) thick supports satisfactorily accommodated the cooling pipe and stay-form with the 4 in. (100 mm) spacing of the reinforcement both in the front gradient and the back right-angled portion of the track.

Shotcrete Placement

The full-size bobsleigh track was built without forming construction joints. Shotcrete placement provided monolithic sections throughout the final cross section of the track. When shooting the floor, 50% of the arranged reinforcement was still visible after placing the first layer. During shooting,

Fig. 4: Track section ready for shotcreting

Fig. 5: Shotcreting the sliding track wall

rebound had to be constantly removed using an air lance (blow pipe). The upper and lower head parts were shot with lower air pressure, and then the in-place concrete was compacted with a vibrator. The shotcrete process was completed with placement to just above the temporary screed pipes on the primary layer. Figure 5 shows the shotcreting of the inner wall surface.

Fabricating Test Specimen

For compressive strength and durability test, a 20 x 20 in. (500 x 500 mm) panel was shot and cores from the panel were tested for compressive strength. Flexural strength and a freezing-and-thawing test were performed with samples from 18 x 18 in. (460 x 460 mm) panels.

Screed and Surface Finish Using Temporary Screed Pipe

After shooting was completed, the freshly placed concrete was screeded to the 1.1 in. (28 mm) plastic tubes installed on the upper reinforcement as a temporary screed pipe. In the straight portions, it was set at a 3.3 to 4.9 ft (1 to 1.5 m) spacing to give the bobsleigh track a smooth surface and uniform thickness, necessary for the cooling pipe to efficiently create ice on the surface. The temporary screed pipes were removed after the surface was screeded and the remaining void was filled with hand-applied concrete.

Wet Curing

After the final surface finish, the concrete surface was wet-cured with a wetted woven fabric that was continuously watered. No curing membranes were applied.

CHALLENGES/CONCLUSIONS

Kangwon National University has carried out technical research on shotcrete material and construction methods for many years and is the only specialized shotcrete research institute in Korea that owns shotcrete equipment. To evaluate the best methods for use of shotcrete on this project, university staff conducted an overseas field trip, and encouraged technology and knowhow transfer by inviting foreign experts to help develop the appropriate bobsleigh track construction technology.

Fig. 6: A curved track section

The advanced research can be broadly divided as material production and construction method development. First, a concrete material appropriate for shotcrete placement with excellent strength, freezing and thawing, and surface-scaling resistance was developed and used because sleigh collisions happen frequently in bobsleigh races. Additionally, the track is continuously exposed to a very cold environment to keep ice frozen on the surface. Second, the overall frame for the bobsleigh track was constructed to place the cooling pipe and reinforcement bars by using a jig support frame with consideration of the required shotcrete placing technique to build the desired shape of bobsleigh track. Because normal formwork or lining cannot be effectively used in creating multiple-curved surface structures, the inner wall stay-form and temporary screed pipe techniques were used. Thus, with these approaches, the multi-curved concrete structure of the track creatively and efficiently used shotcrete placement as the primary construction method.

For this project, two initial mockup tests were performed at the university to confirm the materials and placement methods. The final mockup test was successfully performed at the project site in the presence of the FIBT and FIL officials and was accepted with only one trial. This is exceptional compared to other countries' experience, which

Fig. 7: Bird's-eye view of the sliding track

Fig. 8: Bobsleigh at the track on test event

required several trials to get an approval and host the Winter Olympic Games. The sliding track was constructed by Daesang E&C Co. LTD with help and consultation from Prof. Kyong-Ku Yun at Kangwon National University and Dr. D. R. Morgan from Canada, respectively. With this level of cooperation and learning from previous similar shotcrete projects, the Korean sliding track for the 2018 Winter Olympics was constructed smoothly with shotcrete placement of high-quality and durable concrete with a minimum of formwork and in a short period of time (Fig. 6-8).

HONORABLE MENTION

Project Name
2018 PyeongChang Winter Olympics Sliding Track

Project Location
PyeongChang, South Korea

Shotcrete Contractor
Daesang E&C

General Contractor
Daelim Co.

Architect/Engineer
Daesang E&C

Material Suppliers/Manufacturers
Daesang E&C | Putzmeister Shotcrete Technology*

Project Owner
Gangwon-do Province

*Corporate Member of the American Shotcrete Association

Kyong-Ku Yun *is a Professor at Kangwon National University Chuncheon-si, Gangwon-do, South Korea. He received his PhD from Michigan State University, East Lansing, MI, in 1995. His research interests include shotcrete and concrete materials. Recently, he has been heavily involved in shotcrete research and has consulted on the shotcrete material and overall procedures for this rehabilitation project.*

Yong-Gon Kim *is CEO of Daesang E&C, a leading Korean company for shotcrete research and application. He received his PhD from Kangwon National University in 2010, with an emphasis on latex-modified concrete and steel fiber-reinforced concrete. His research interests include shotcrete application.*

Kyu-Woon Lee *is a Director General of Construction at Gangwon Headquarters for the PyeongChang 2018 Winter Olympic Games. He is an inspector and is responsible for this Sliding Track project.*