2007 Outstanding Infrastructure Project

Whistler Sliding Centre

ConCreate USL Ltd. of Bolton, ON, Canada, in consortium with Emil Anderson Construction of Hope, BC, Canada, was selected to construct the Whistler Sliding Centre. This facility is located at the foot of Blackcomb Mountain in the resort municipality of Whistler, BC, Canada, and is the site of the bobsleigh, luge, and skeleton events for the 2010 Winter Olympics.

With the completion of this facility, the city of Whistler joins Torino, Italy; Salt Lake City, UT; Lake Placid, NY; Lillehammer, Norway; Nagano, Japan; and Calgary, AB, Canada, as members of the elite club of bobsleigh/luge track owners.

Track Geometrics

Some quick statistics of the track:

- 1860 yd (1700 m) long reinforced concrete track;
- 69,965 ft^2 (6500 m^2) iced surface;
- 62.5 miles (100 km) of cooling pipe;
- 2616 yd^3 (2000 m^3) of shotcrete;
- 16 curves;
- Design speed of 88 mph (140 km/h); and
- Expected g-force exerted on a four-man bobsleigh: 5g's.

Fig. 1: Bobsleigh taking first run on completed track

The 1860 yd (1700 m) of track are broken down into 23 sections having an average length of 82 yd (75 m). These 23 sections range in vertical height from 26 in. (650 mm) to over 11.5 ft (3500 mm) and have a grade of 25% at its steepest.

Shotcrete Material

Designing a functional shotcrete mixture for a project as complex as a bobsleigh track was a Herculean task in and of itself. The design had to fulfill the engineer's strict specifications yet had to also balance the needs of the contractor who was to place it.

ConCreate USL's experience with high-performance concrete (HPC) led us to try using a mixture with silica fume for our first full-scale mock up. Preliminary testing data indicated to us that the mixture would yield very high strength, significantly higher than the 5075 psi (35 MPa) at 28 days specified by the design consultants. In conjunction with the extremely favorable strengths that this mixture would provide, the silica fume would further add to the durability and absorption characteristics of the shotcrete.

Favorable as these characteristics are, however, the most desirable characteristic of HPC is its cohesiveness or, rather, its ability to stick and yet

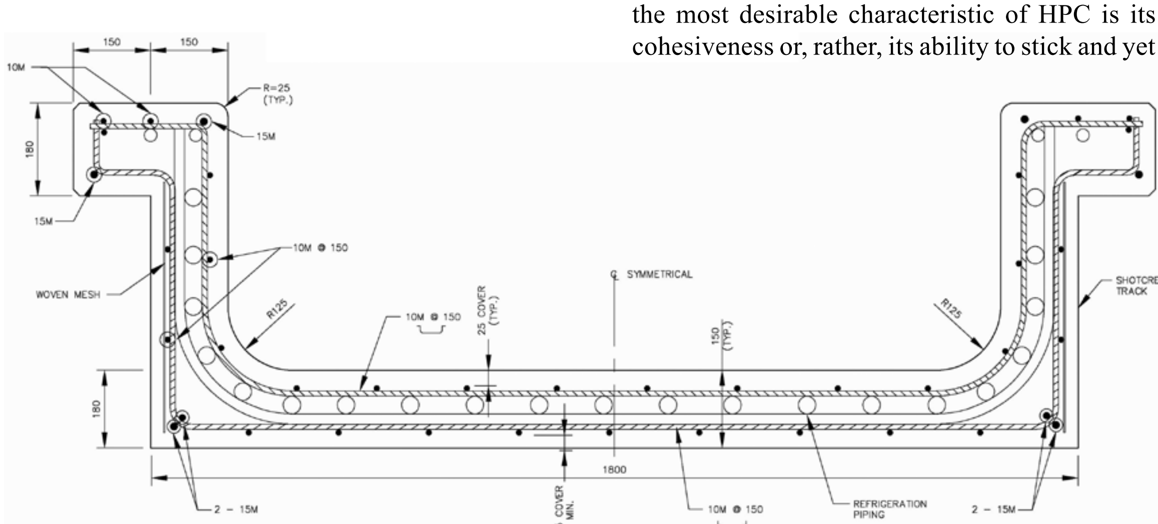


Fig. 2a: Typical track reinforcing at straight section (not to scale)

still be able to flow around and encapsulate reinforcing bar and refrigeration pipes. ConCreate's major concern was the placement of shotcrete in cross sections densely occupied by reinforcing bar and cooling pipes—this was not your average shotcrete job.

Application of this mixture to the first full-scale mock-up yielded some unexpected results. Whereas the physical properties of the mixture behaved as designed, the finishability of the mixture was found to be lacking. Inspection of the finished surface revealed inconsistencies in the surface, both aesthetically and physically.

The high heat of hydration of this mixture resulted in color differences in the finished surface that were aesthetically displeasing. Of more concern, however, was the speed at which this particular mixture began to set up. The shotcrete process for this track required time between layers, both for the material and for the work crew to be able to place and finish the material to an exacting tolerance of 1/8 in. (3 mm) under a 10 ft (3 m) straightedge. The HPC mixture was ultimately rejected for these reasons—the high heat of hydration and the excessively rapid speed at which hydration and setting occurred.

In place of the HPC mixture, ConCreate USL opted for the use of a new mixture, designed by Roland Heere of Metro Testing, Burnaby, BC, Canada. This mixture contained 708 lb/yd^3 (420 kg/m^3) of cement, 110 lb/yd^3 (65 kg/m^3) of fly ash, 708 lb/yd^3 (420 kg/m^3) of coarse aggregate, and 2022 lb/yd^3 (1200 kg/m^3) of fine aggregate. This mixture contained Polyheed, a water-reducing agent; Microair, an air-entraining agent; and Delvo hydration control admixture.

This second mixture performed much more favorably. Testing consistently recorded compressive strengths of 7250 to 8700 psi (50 to 60 MPa), plastic air content well within specification, and boiled absorption values to ASTM C642 averaging 6.5%. In addition to the favorable physical characteristics of this mixture, the finishability was much more desirable. The mixture was well balanced between the cohesiveness required to stick to vertical surfaces and cling to the reinforcing bar and Stay-form, yet it had sufficient plasticity to enable finishing to the high tolerances required. The development of an appropriate mixture design was a major factor in the success of this project.

Spending the extra time and effort to have a shotcrete mixture that we were comfortable placing was well worth the effort. This is a great example of the success that can be achieved when engineers and contractors work together in the quest of a common goal.

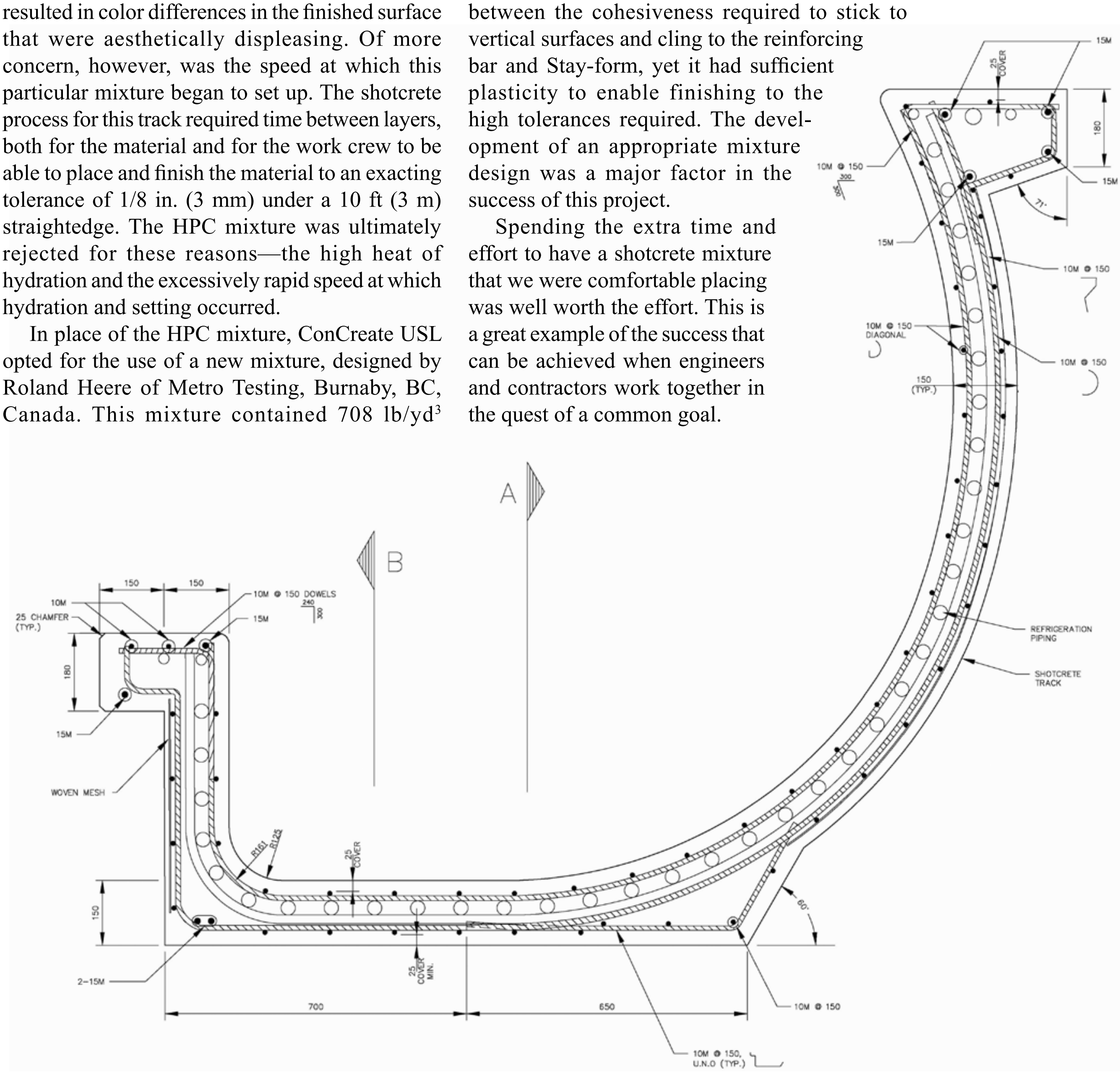


Fig. 2b: Typical track reinforcing at curved section (not to scale)

Full-Scale Mock-Ups

The use of full-scale mock-ups provided an opportunity for all parties involved to try out construction techniques and shotcrete mixtures in real-world conditions. The full-scale mock-up consisted of a 8.2 yd (7.5 m) section of track complete with metal formwork, reinforcing steel, cooling pipes, and the inserts required for the various track appurtenances that were attached to the track.

The exercise of constructing and shooting a full-scale mock-up provided both ConCreate and the design consultants with valuable information with respect to how the various appurtenances fitted together in the real world. Mistakes were identified and remedied before they were built into the finished product.

In a system as complicated as a bobsleigh track, there are so many inserts, pipes, reinforcing bar, and sensors that it is virtually impossible to ensure that there are no conflicts without a full-scale mock-up. Issues with conflicting reinforcing bar and track inserts were identified as potential problem areas.

The design team consisting of engineers from of Van Boerum & Frank Associates (VBFA), Salt Lake City; UT; Stantec, Vancouver, BC, Canada; and Ingenieuburo Gurgel (IBG), Leipzig, Germany, reviewed the issues presented during construction of the mock-ups and made corrections accordingly.

With the successful completion of two mock-ups, ConCreate set about shooting the actual track. It was then noted that voiding was occurring in the shotcrete between the refrigeration pipes and the Stay-form being used. This phenomenon was not noted during the mock-up's construction and evaluation, and it presented a major concern to the designers and owners of the track, not to mention to ConCreate.

Fig. 3: Crew constructing mock-up on May 1, 2007

The voiding issue precipitated the need to construct an additional mock-up and to discover the root cause of these voids. After much debate among the various parties, ConCreate commissioned Dr. Dudley R. "Rusty" Morgan of AMEC to study and prescribe a fix for this serious issue.

Acting on the advice of Dr. Morgan, ConCreate and the design engineers made some modifications to the layout of the Stay-form and the reinforcing steel to optimize the shootability of the track. These modifications, which are discussed further in this article, were highly successful in solving the voiding issues that were being experienced.

The construction of the bobsleigh track was broken down into smaller subsets consisting of:

- Pendulum footing installation;
- Structural steel forming system installation;
- Jig installation;
- Formwork installation;
- Reinforcing bar placement;
- Refrigeration pipe installation;
- Shotcrete placement and finishing; and
- Curing and stripping.

Figures 4 through 10 give the reader an idea of the various stages of construction that were required to achieve completion of the track.

A bobsleigh track is one of the most difficult shotcrete projects to construct, at least from a technical perspective. The design of the cross sections must be carefully planned to maximize shootability of the elements. As previously mentioned, we experienced issues with voiding early on in this project directly associated with the shootability of the track.

Figures 11a and 12a illustrate two of the three methods that ConCreate tried to reduce the occurrence of voids in the finished cross section. Figure 11a shows a Stay-form mesh installed on the backface of the track with the ribs of the Stay-form orientated inwards, resting on the inner most transverse reinforcing bar of the lower mat of steel.

The configuration shown in Fig. 11a led to the creation of significant quantities of voiding. These voids had to be opened up by hand and deleterious material removed before shooting the back face of the Stay-form with shotcrete. This operation was extremely time-consuming and great care had to be taken not to damage the pipes for the refrigeration system. As with all construction projects, the old adage of "time is money" held true. Another option had to be found.

Fig. 4: Structural steel falsework system and base forms being installed

Fig. 5: Refrigeration piping being installed on jig assemblies

Fig. 6: Reinforcing bar installation

Fig. 7: Formwork and finishing screeds (plastic pipes) installed

Fig. 8: Tents, lights, and sprinkler system installed—section ready for shotcrete

Fig. 9: Shotcrete being applied under the watchful eye of David Baranowski (VBFA)

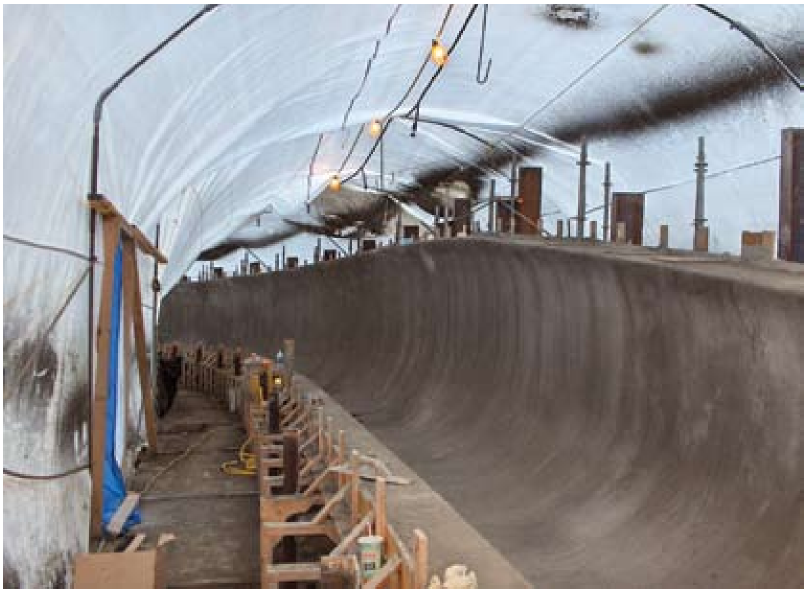
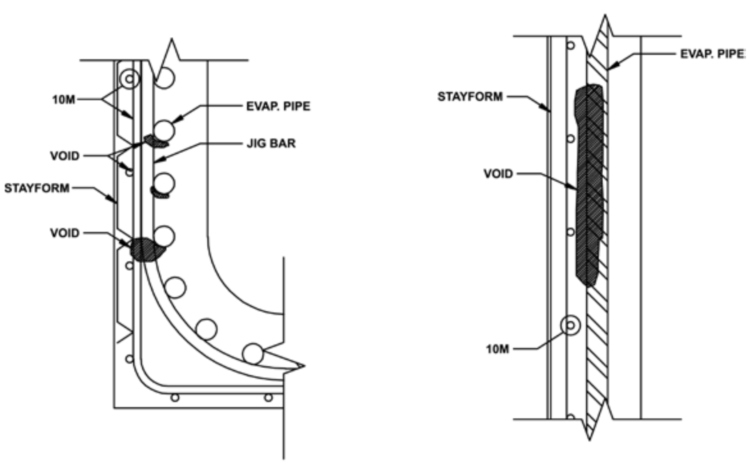


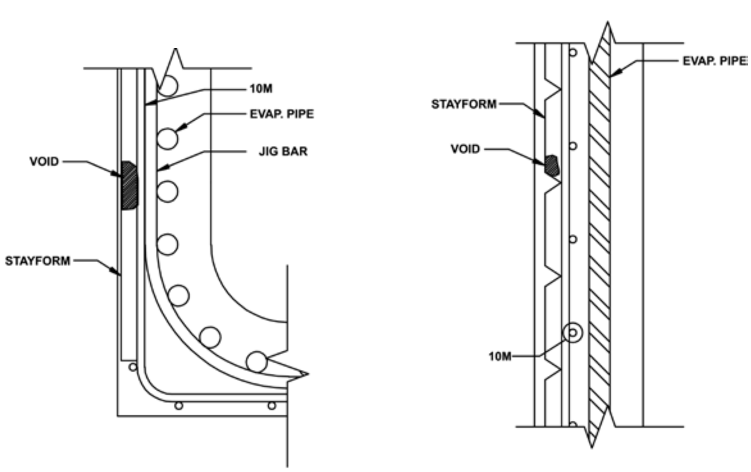
Fig. 10: Completed section of track finished to required profile and tolerance (±1/8 in. [3 mm])



a: LOW WALL DETAIL

b: PLAN—LOW WALL

Fig. 11: Stay-form ribs horizontal—inward



a: LOW WALL DETAIL

b: PLAN—LOW WALL

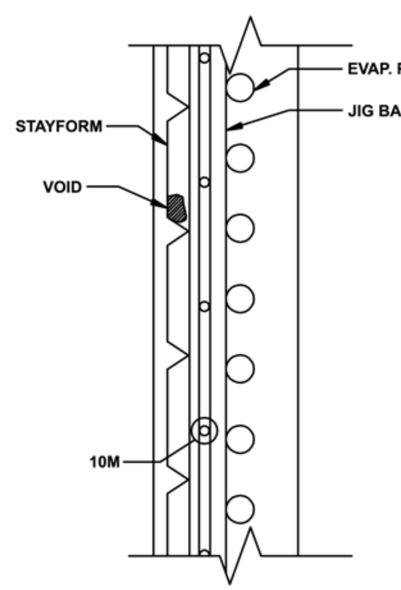
Fig. 12: Stay-form ribs vertical—inward

Our inclination at first was to blame the voiding on the ribs of the Stay-form acting as a dam to the flow of shotcrete. Building on this hunch, the Stay-form was oriented in a manor so that the rib of the Stay-form intersected the outermost reinforcing bar in a perpendicular fashion, similar to that illustrated in Fig. 12a.

This new configuration, while not 100% successful, provided fewer voids than encountered using the previous configuration. Having the stiff ribs of the Stay-form parallel to the direction that the track cross section curved, however, made this application impractical for all but the low wall section. The low wall was the only portion of the track having a straight vertical wall. Thus, another solution had to be found for curved walls that had no ribs.

The solution settled upon was the use of a lathe-type mesh material that had no ribs. It was our intention that by installing this material, the rib of the Stay-form would be removed from the equation and with it the dam effect would be corrected. This solution proved to be better than that of the Stay-form. The voids, however, were still present and in sufficient quantity to still be a very real concern for the durability of the track.

It was at this time that Dr. Morgan was commissioned to study the design and placement techniques used to construct this track. He reviewed the existing mock-ups, the sections of track previously shot, and the voids present; and he



SECTION—MOCK UP #1

Fig. 13: Stay-form ribs horizontal—inward. Transverse reinforcing bar mat outermost

monitored the placement techniques being used by ConCreate.

It was determined that the voids were not being created due to placement techniques or the use of Stay-form mesh as previously thought. Rather, the voiding was caused by a lack of space between the mesh and reinforcing bar for the shotcrete to be able to flow and wrap around the reinforcing bars and pipes from behind in the track cross section. Further investigation of the two mock-ups previously constructed revealed two minor differences between them.

Mock-up No. 1 (Fig. 13) was constructed with the bottom mat of reinforcing bar reversed from that shown on the design drawings to aid in constructability. In contrast, Mock-up No. 2 had the lower mat of reinforcing bar installed as per the design. This minor variation had a significant effect on the creation of voids. Mock-up No. 1 contained almost no voids, and detailed investigation of Mock-up No. 2 showed that the voiding present in the track sections was also present in the mock-up.

As it turns out, the solution to this issue was as simple as reversing the bottom mat of the reinforcing bar. By doing so, the Stay-form was "chaired" off the back bars by the v-groove in the Stay-form and the shotcrete was given that needed extra room to allow for build-up from behind the bars inside the cross section. This minor but important detail was validated in a third mock-up and allowed the balance of the track to be completed with only minimal voiding.

Quality Control

Quality control is an area of extreme importance and is at the forefront of concerns to owners, consultants, and shotcrete contractors alike. This project, being built in Canada, was built to Canadian Standards Association (CSA) specifications augmented with reference to ACI 506R-05, "Guide to Shotcrete."

At the onset of this project, ConCreate USL retained the services of Metro Testing Laboratories Ltd. of Burnaby, BC, Canada, to be part of our quality control team. Metro was tasked with creation of a shotcrete mixture design that fulfilled the requirements of the project specifications as well as providing ease of placement. This final mixture designed by Roland Heere functioned flawlessly and achieved strengths and absorption characteristics far in excess of that required in the specifications. In addition to creating a suitable mixture design, Metro provided full-time consulting and testing services.

Conclusions

Completing a project as technical and as complicated as the Whistler Sliding Centre would not have been possible except for the cooperation of contractors and engineers working alongside each other to achieve a common goal. To this end, ConCreate USL extends thanks to all those who assisted us in the creation of this exceptional facility.

Outstanding Infrastructure Project

Project Name
Whistler Sliding Centre

Project Location
Whistler, BC, Canada

Project Owner
Vancouver Organizing Committee for the 2010 Olympic and Paralympic Winter Games

Shotcrete Contractor
ConCreate USL Ltd.*

General Contractor
Emil Anderson Construction

Architect/Engineer
Stantec Consulting Ltd.

Concrete Supplier
Cardinal Concrete Ltd.

Concrete Finishing
Cemental Concrete
Beton Projete MAH

Material Testing and Engineering
Metro Testing Laboratories Ltd.*
AMEC Americas Ltd.

Refrigeration System
Ideal Welders Ltd.

*Member of the American Shotcrete Association