Shotcrete Lions for Calgary's Centre Street Bridge

by Jadwiga Kroman, Dudley R. Morgan, and Lorne Simpson

The Centre Street Bridge in Calgary, Alberta, Canada, was originally built in 1916 and has ever since remained a striking landmark in the city's downtown. A pair of kiosks with observation balconies and magnificent lion figures atop each entrance of the bridge complement the historic appearance of the bridge. The lions were patterned after the bronze figures at the base of the Nelson column in Trafalgar Square, London.[1] The 3.6 m (12 ft) long, 1.5 m (5 ft) wide, and 2.4 m (8 ft) high lions were originally cast in several concrete segments and are hollow inside. Over the years, the condition of the lions deteriorated due to severe weather exposure conditions, spray containing deicing salts, bridge vibration, and carbonation. Figure 1 shows the deteriorated condition of one of the original lions. Several attempts to repair the deteriorating concrete lions produced only temporary success. In 1992, the Centre Street Bridge was designated a Municipal Historic Resource.

In 1999, the bridge structure was scheduled for major structural overhaul. At the same time, investigation into the condition of the lions revealed a critical level of deterioration. Numerous cracks, spalls, delaminations, and local loss of concrete integrity due to corrosion activity; loss of detail and form due to weathering; and numerous attempts to remedy deterioration brought about a decision to protect the original lions by placing them in a sheltered location and replacing them with new replicas.

Figure 1: Deteriorated condition of one of the original lions.

Design and Construction of Lions

The construction of the new concrete lions and the rehabilitation of other artistic features of the bridge provided an opportunity to reinstate the original appearance of this historic bridge. All four lions were removed from the bridge prior to the demolition and reconstruction of the bridge structure. One of the existing lions was used as a model for making a mold for the construction of four new lions. The restoration of this existing lion to its original degree of detail included an elaborate process of removing layers of previously applied paints and sealing compounds using several mechanical and microblasting methods. Once the effects of the many previous repairs had been corrected, the damaged sections were rebuilt and missing details reconstructed. Illyas Pagonis was the sculptor in charge of this activity. A rubber latex demolding compound was then sprayed on the reconstructed model lion, followed by sprayed-on glass fiber reinforced resin to create a mold. Once cured, the molds were stripped from the model lion. Figure 2 shows the stripped mold, which produced a faithful negative image of the model lion.

The reconstructed lions had to meet or exceed the extended life span of the bridge structure, which was estimated at 35 to 40 years. Several design and construction criteria were established for reconstruction. These were:

- Accuracy of form: the degree of detail in the final product to match the original lion;
- An aesthetically pleasing product, free from cracking, associated discoloration and staining;
- Durability of the final product: material resistance to deterioration from chloride penetration, deicing salt scaling, carbonation, and frequent freezing-and-thawing cycles in this highly aggressive environment;
- Structural strength and detailing to resist the effects of bridge structure vibrations;
- A hollow cross section of the lions was preferred over a solid one due to the undesirability of heavy weight during handling, placement, and any future maintenance operations; and

- Concrete (either cast or sprayed) was the only acceptable material for true replication of the original lions.

The final design of the lions assumed a one-piece structure for each lion, as opposed to the original segmental construction, its main advantage being the absence of cold joints. The rubber latex and glass fiber-reinforced resin mold was assembled on a precast concrete pedestal that incorporated access openings to allow the figure to be sprayed in place from inside the cavity. The hollow sculptures were constructed using a high-performance dry-bagged shotcrete mix supplied by Target Products Ltd.

The mixture was applied in a series of layers. The first layer, approximately 12 mm (½ in.) thick, was applied, followed by 6 hours of curing. A second layer of 20 mm (3/4 in.) thickness was applied and, while still wet, stainless steel tie wires were inserted to secure the reinforcing bars and mesh. Stainless steel bars 6 mm (1/4 in.) in diameter and stainless steel 1½ x 1½ x 16-in. gage welded wire mesh were used throughout the cross section of the lion structures. A final layer of shotcrete with a minimum 50 mm (2 in.) thickness was applied over the reinforcing. The surface was built up around the stainless steel bars to create an internal cross rib pattern. The shotcrete mix was applied to the inner surface of the mold using a wet-mix shotcrete technique. The shotcrete was applied with a double diaphragm pump to control the amount of shotcrete delivered to the nozzle and thus provide optimum control for the nozzleman. The steel orifice was replaced with a rubber orifice for safety in case the hose plugged.

The shotcrete applied inside the mold was moist cured with humidifiers to help prevent the formation of plastic or drying shrinkage cracks. After the molds were stripped from the lions, the outside of the lions was moist cured for 7 days using mist-type lawn sprinklers. This, together with the use of a shrinkage-reducing admixture in the shotcrete, was highly effective, as the completed lions were essentially crack-free, thus satisfying one of the important design criteria. A protective silane sealer was applied to the entire exterior surface of the lions for added protection in the aggressive environmental exposure condition that prevails on the bridge. Figure 3 shows the completed lions, mounted on reinforced concrete pedestals, ready for transport to the bridge for erection.

Shotcrete Mixture Design

The shotcrete used for the project was a dry-bagged, silica fume-modified, microfiber reinforced shotcrete supplied by Target Products Ltd. of Burnaby, British Columbia, under the trade

Figure 2: Rubber latex and glass fiber-reinforced resin mold stripped from original lion.

Figure 3: Completed lions mounted on pedestals and ready for installation on bridge.

name Target SC 100D. The aggregate gradation satisfied the ACI 506R-90, Table 2.1, Gradation No. 1 requirements; that is, all of the aggregate passed the 5 mm (No. 4) sieve size. In order to further enhance the freezing-and-thawing durability and resistance to deterioration from deicing chemical spray of the installed lions, a liquid air-entraining admixture was added to the shotcrete during batching to increase the as-batched air content to approximately 10 to 13%. The air content of the plastic as-shot shotcrete was typically in the 8 to 10% range. This is an excellent range for good frost and deicing chemical resistance.

The microfibers [12-mm-long (½ in.), collated, fibrillated, polypropylene fibers] were added to help prevent plastic shrinkage cracking. In addition, 80 mL of MBT Tetraguard AS20 shrinkage-reducing admixture were added for each 25-kg bag of shotcrete to reduce the potential for restrained drying shrinkage cracking in the lions. For a description of the way in which this admixture reduces shrinkage, see Reference 2.

Performance Requirements

AMEC prepared a specification for the shotcrete mixture design and performance requirements and provided quality assurance (QA) testing for the City of Calgary for this project. The performance requirements were as follows:

- CSA A23.1-00 Class C-1 exposure, that is, structurally reinforced concreted exposed to chlorides and freezing and thawing;
- Minimum 35 MPa (5080 psi) compressive strength at 28 days;
- Plastic as-shot air content of 8 to 10%;
- ASTM C 642 Boiled Absorption maximum of 8% and Volume of Permeable Voids maximum of 17%; and
- ASTM C 457 Spacing Factor of less than 0.23 mm (0.009 in.).

These performance requirements were set so that the lions could provide long-term durable performance in the aggressive exposure environment to which they are subjected. Temperatures in Calgary can fall to as low as -30 C (-22 F) in

Table 1: Compressive Strength of Shotcrete

Panel N°.	7 days		28 days	
	MPa	psi	MPa	psi
1	38.7	5610	44.5	6450
2	40.6	5890	58.2	8440
3	33.0	4780	51.1	7410
4	39.7	5760	50.5	7320
5	35.8	5190	47.7	6920
Average	**37.6**	**5450**	**50.4**	**7310**

Table 2: Boiled Absorption and Volume of Permeable Voids According to ASTM C 642

Panel N°.	Bulk Dry Density kg/m^3	Boiled Absorption %	Volume of Permeable Voids %
1	1949	4.6	9.0
2	1977	7.8	15.5
3	2042	3.5	7.2
4	2028	1.9	3.8
5	1978	5.1	10.0
Average	**1995**	**4.6**	**9.1**

Table 3: Parameters of Air-Void System in Hardened Shotcrete According to ASTM C 457

Parameter	Value
Air Voids	10.9 %
Specific Surface	35.2 mm^2/mm^3
Spacing Factor	0.14 mm
Paste Content	59.7 %
Shotcrete Density	1996 kg/m^3

the winter and go above freezing in a matter of hours because of the Chinook Winds. There is also widespread use of deicing chemicals on roads and bridge decks, with associated airborne salt spray from traffic.

Shotcrete Test Results

A total of five 600-mm-square (4 ft^2) x 100-mm-deep (4 in.) panels were shot for QA testing during shooting of the four lions, with at least one test panel for each lion (Lion 2 had two test panels shot). Test results for compressive strength at 7 and 28 days on cores extracted from the panels are given in Table 1. Test results readily met the minimum specified value of 40 MPa (5800 psi) at 28 days, averaging 37.6 MPa (5450 psi) at 7 days and 50.4 MPa (7310 psi) at 28 days. Similarly, in the ASTM C 642 test, the boiled absorption values (average = 4.6%) and volume of permeable voids (average = 9.1%), were well below the specified allowable maximum values of 8 and 17%, respectively, for these two parameters, as shown in Table 2.

Only one core was tested according to ASTM C 457 to determine the parameters of the air void system in the hardened shotcrete. Test results are shown in Table 3. With a specific surface of 35.2 mm^2/mm^3 and spacing factor of 0.14 mm (0.0055 in.), this shotcrete can be expected to provide excellent frost and deicing chemical resistance.

Installation

Figure 4 shows a view of one of the lions mounted on a kiosk at the north end of the bridge. Flexible material bearing pads were used under the lion's base to limit the effects of bridge vibration due to traffic. A removable hold-down device, capable of facilitating any future removal of the lions, was installed. It is interesting to note that the new shotcrete lions are much lighter and stronger than the original concrete lions. They weigh only 8640 kg (19,000 lb), as compared with 12,730 kg (28,000 lb) for the original lions. With the high-performance shotcrete materials used, meticulous construction practice, and conformance to the rigorous shotcrete specifications, it is expected that the citizens of Calgary will continue to enjoy this invaluable contribution to their heritage for many decades to come.

References

1. Zwarun, S., "Rebuilding a City's Pride," *Concrete in Canada*, Spring 2001, pp. 10-11.

2. Morgan, D. R., and Chan, C., "Understanding and Controlling Shrinkage and Cracking in Shotcrete," *Shotcrete Magazine*, V. 3, No. 2, Spring 2001, pp. 26-30.

Figure 4: Lion mounted on kiosk on Centre Street Bridge in Calgary.

Figure 5: Rehabilitated bridge with lion on kiosk.

Figure 6: Completed lion.

Acknowledgments

Owner: The City of Calgary

Engineer: Jadwiga Kroman, P.Eng., Senior Structural Engineer, The City of Calgary

Materials Engineer: AMEC Earth & Environmental Limited; D. R. Morgan, Ph.D., P.Eng.

Architect: Lorne Simpson, Simpson Roberts

Contractor: Brian Hunter, Concrete Restorations Ltd.

Subcontractor: Stonecast Products Ltd.

Sculptor/Nozzleman: Illyas Pagonis

Shotcrete Supplier: Target Products Ltd.

Jadwiga Kroman, P.Eng., is a Senior Structural Engineer with the City of Calgary. She graduated from the Technical University in Gdansk, Poland, and completed a master's degree in 1976. Ms. Kroman's technical expertise includes structural engineering with respect to new structures as well as rehabilitation of existing structures, from conceptual design to construction management. Since joining the City of Calgary, she has been responsible for technical standards, design and construction management of bridge and structure rehabilitation, strengthening, as well as new bridge projects. Ms. Kroman's particular interests include advancement of methods, and materials for structure upgrading and restoration, as a vehicle for optimization of the bridge structure's life cycle.

Dudley R. (Rusty) Morgan is Chief Materials Engineer with AMEC Earth & Environmental Ltd., an international consulting engineering company with some 2200 employees in North America. He is a civil engineer with over 35 years' experience in concrete and shotcrete technology and the evaluation and rehabilitation of infrastructures. Dr. Morgan is a Fellow of the Canadian Academy of Engineering and the American Concrete Institute (ACI), and is Secretary of ACI Committee 506, Shotcrete. He is a member of several ACI, ASTM, and Canadian Standards Association (CSA) technical committees, and a founding member and Secretary of the American Shotcrete Association. Dr. Morgan has provided consulting services on concrete and shotcrete projects throughout North America and around the world.

Lorne Simpson is a Partner in Simpson Roberts Architecture Interior Design Inc. in Calgary, Alberta. He has a Bachelor of Architecture degree from the University of British Columbia and a M.A. Conservation degree from the University of York in England. He has been the project architect responsible for a variety of major projects in Alberta, including the Calgary Olympic Saddledome and several projects for the Canadian Olympic Organizing Committee. He has specialized in conservation projects and has received numerous awards for his work, including the Governor General's Medal for Architecture. Lorne was responsible for the architectural design concepts for the Centre Street Bridge lions.