World's Largest Dome for Cement Storage (Silica Fume Shotcrete)

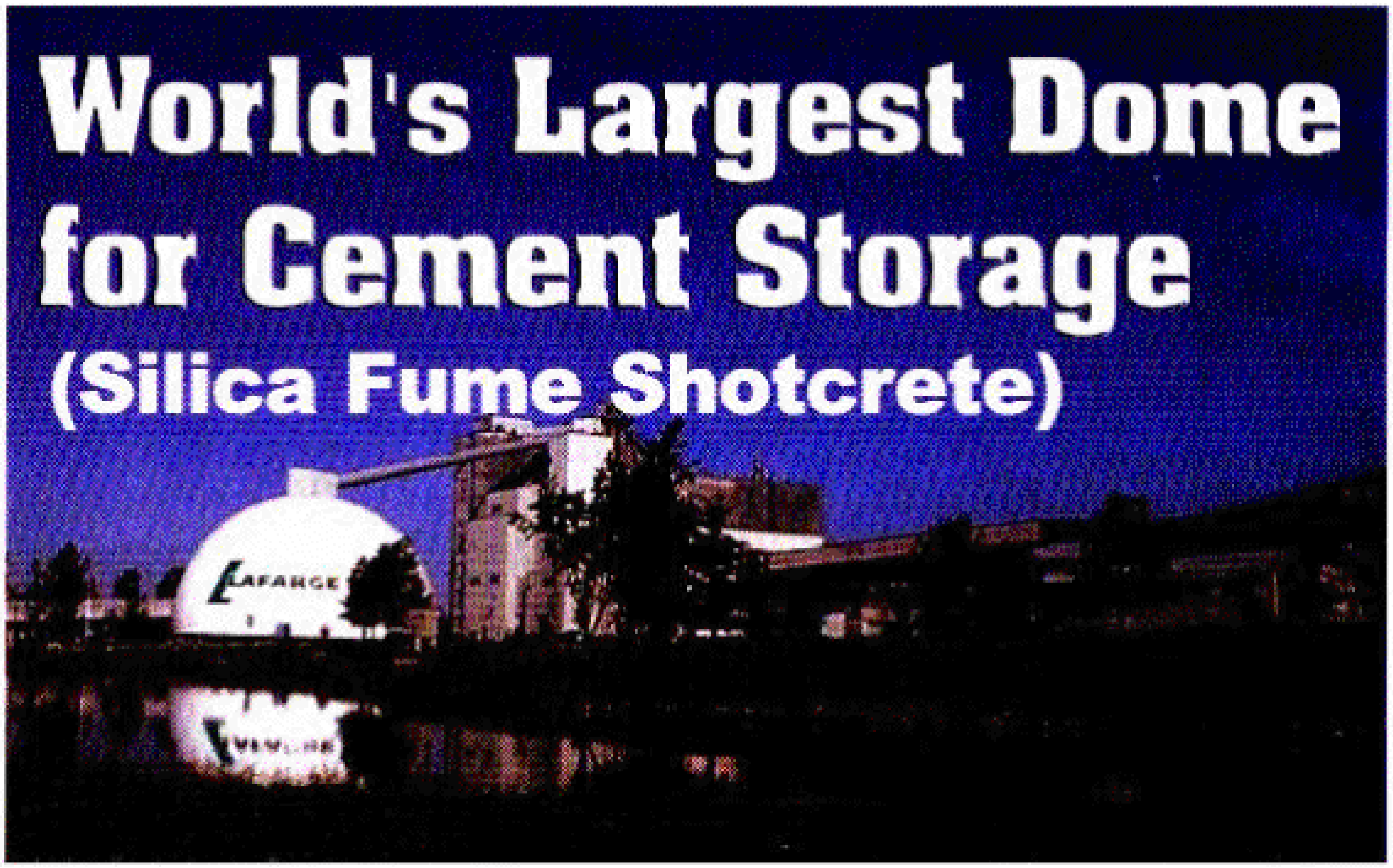

Figure 1: Concrete dome at Lafarge's Bath cement plant on Lake Ontario.

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This paper describes the construction of a concrete dome facility for cement storage at Lafarge's Bath cement plant in eastern Ontario. The dome has the capacity to store 68,000 metric tons (75,000 tons) of portland cement. The dome was constructed using an inflatable stay-in-place fabric form to the inside of which shotcrete is applied. The shotcrete was produced using a blended silica fume cement (Type 10SF) to increase strength, reduce permeability, and reduce rebound. The whole project was completed in less than 10 months at a cost of approximately $6 million. The finished project is the world's largest cement storage dome, and its completion allows the plant to produce at full capacity through the winter season, when the demand for cement is low.

1.0 INTRODUCTION

The use of pneumatically applied mortar known as "gunite" dates back to the beginning of this century, and the material has since been used in a wide range of applications, particularly in the repair of concrete structures, slope stabilization, and various mining and tunneling uses. Today the gunite technique is commonly referred to as dry-mix shotcrete, and there are a variety of excellent references on the process (for example, Morgan 1994) including the "Guide to Shotcrete" produced by Committee 506 of the American Concrete Institute (ACI 506R-90, 1990).

Two major developments in shotcrete technology occurred during the 1980s: the advent of fiber-reinforced shotcrete, and the incorporation of silica fume (Morgan 1994). The use of silica fume increases the cohesiveness of shotcrete allowing the build-up of much thicker layers, reducing rebound (especially in dry-mix shotcrete) and increasing resistance to "washout" when exposed to moving water. In addition, the use of silica fume imparts significant improvements in the mechanical properties and durability of hardened shotcrete in much the same manner as it benefits conventionally placed concrete. The incorporation of between 8 to 12% silica fume has been used extensively in shotcrete for mining ground control for the last 10 years in Canada, primarily in Ontario, Quebec, and Manitoba.

A unique application for shotcrete is in the construction of concrete domes using stay-in-place inflatable forms (Hunter and Robert 1998). This paper describes the construction of the world's largest cement storage dome in Ontario, Canada, using the wet-mix shotcrete process.

2.0 CONSTRUCTION

Lafarge's Bath cement plant near Kingston, Ontario has the capacity to produce 1 million metric tons (1.1 million tons) of finished cement per year. Prior to 1998, the production capacity was not exploited, as there was insufficient storage available to accommodate the material produced during the winter months when demand for cement is low due to reduced construction activity in the region. To address this problem, a 68,000 metric ton (75,000 ton) cement storage facility was constructed from 1997 to 1998. The facility consists of a concrete dome 55 m (180 ft) in diameter and 29 m (95 ft) high (Fig. 1).

The foundation consists of a ring beam spread footing (cast in conventional concrete) to which the inflatable form is attached. This type of construction has relatively simple foundation requirements (that is, no piling required) as the load is spread over a large area. After the form (which is made of a single-ply roofing fabric) was inflated

Table 1 Results of compressive strength tests

	Concrete cylinders		Cores from shotcrete panels	
	7 days	28 days	7 days	28 days
Number of tests	89	89	12	24
Mean strength	43.1 MPa (6250 psi)	55.8 MPa (8093 psi)	32.9 MPa (5685 psi)	43.9 MPa (6367 psi)
Standard deviation	3.4 MPa (493 psi)	4.7 MPa (682 psi)	6.9 MPa (1001 psi)	5.4 MPa (783 psi)

Table 2 Results from ASTM C 1202 and C 642 tests on cores taken from shotcrete test panels

	Panel # 1	Panel # 2	Mean
ASTM C 1202 Rapid chloride permeability, coulombs	192	364	278
ASTM C 642 Boiled absorption, %	6.3	6.8	6.6
ASTM C 642 Volume of permeable voids, %	13.7	14.5	14.1

by air pressure, the interior surface was sprayed with polyurethane foam insulation. Up to four mats of 30 mm (1.2 in.) diameter reinforcing steel were then tied in position and shotcrete sprayed from the inside of the dome to achieve a wall thickness ranging from 0.51 m (20 in.) at the base to 0.15 m (6 in.) near the top of the dome. These walls were built up as a single layer. After construction, the form stays in place and serves as a permanent waterproofing membrane to the finished system. The structural requirements of the finished dome are that it be able to withstand cement piled to heights of up to 26 m (85 ft) against the dome walls.

This type of construction relies heavily on the skill and experience of the shotcrete nozzlemen as it involves spraying overhead against a flexible form and ensuring proper embedding of up to 4 layers of reinforcing bars that were spaced only 90 mm apart (3.4 in.). Special training is required to ensure a suitable level of proficiency. It was also observed that the silica fume cement mixture maintained good flow characteristics under pressure in the pump lines.

The finished cement is supplied at a rate of 250 metric tons (275 tons) per hour to the top of the dome by a 108 m (354 ft) long air slide and is allowed to freefall into the dome. A series of 18 air gravity conveyors, which are incorporated into the sloped floor of the dome, are able to reclaim more than 90% of the dome's capacity to feed the plant's existing belt conveyor via a belt bucket elevator and conventional airslide. This system discharges cement at a rate of 1200 metric tons (1325 tons) per hour. Only about 5000 m³ (6540 yd³) of the dome's storage cannot be withdrawn by the automated reclamation facility, and it is intended that the dome be completely emptied using front-end loaders once a year.

Construction commenced in June 1997, and the dome was ready for filling in April 1998, some nine-and-a-half months later.

3.0 SHOTCRETE

Wet-mix shotcrete was produced in a local ready-mix concrete plant using a blended cement that contained 8% silica fume interground with Type 10 portland cement. The mixture proportions used were as follows:

Cement, Type 10SF	480 kg/m³ (809 lb/yd³)
Coarse aggregate, (10 mm [3/8 in])	200 kg/m³ (337 lb/ yd³)
Fine aggregate	1340 kg/m³ (2259 lb/ yd³)
Water	215 kg/m³ (362 lb/ yd³)

Water-reducing, set control, and air-entraining admixtures were used to produce the desired plastic shotcrete characteristics: a slump of 100 to 125 mm (4 to 5 in.) and an air content of 5 to 8%. The amount of rebound in the shotcrete was reduced from a typical 15 to 18% down to 7 to 8%, which translates to considerable time and money savings. This is attributed to the use of silica fume and somewhat to the relatively low volume of 10 mm (3/8 in.) stone in the mix.

Concrete cylinders were cast from the concrete delivered to site (that is, prior to discharge into the shotcrete pump). Shotcrete test panels (approximately 500 x 500 x 200 mm [20 x 20 x 8 in.]) were sprayed, and cores were drilled from these panels for compressive strength testing at 7 and 28 days. Table 1 compares test data for the concrete cylinders and the cores taken from the shotcrete panels. The strength of cores taken from the test panels was considerably lower than the strength of cylinders cast from material sampled from the ready-mix truck. The strength data for the shotcrete cores also showed a higher degree of variability than the cylinder data. This is hardly surprising considering the methods of production of the two different specimen types.

Cores were also taken from the test panels at the age of 1 year for rapid chloride permeability testing using ASTM C 1202, and for determining the absorption and volume of per-

Figure 2: Preparation of ring beam.

meable voids using the procedure given in ASTM C 642. The results are given in Table 2. These test results indicate that the shotcrete is of good quality. These results are a little surprising because lower values, consistent with excellent quality, are readily achieved with silica fume shotcrete (Morgan 1994; Wolsiefer and Morgan 1993). The results from the rapid chloride permeability test are very low and are typical of very-high-quality shotcrete or high-performance concrete.

Figure 3: Placement and preparation of inflatable form.

Higher than expected values for absorption and permeable voids may be indicative of inadequately consolidated shotcrete. However, in this case it is suspected that the relatively low volume of 10 mm (3/8 in.) stone resulted in increased porosity (that is, as the volume of stone is reduced, the volume of paste and, hence, the porosity, increases). This does not necessarily result in reduced durability or increased permeability, because these factors are more strongly influenced by the water-cement ratio and the type and quantity of mineral admixtures (for example, in this case, silica fume). The very low coulomb values observed certainly indicate that the mature shotcrete (approximately 1-year-old at the time of test) has a very low permeability and can thus be expected to have a high level of durability.

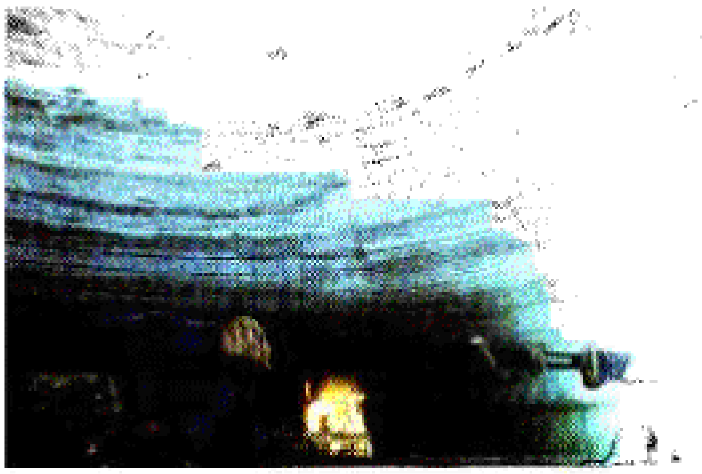

Figure 4: Inside view of the dome under construction shotcrete placement.

4.0 SUMMARY

The shotcrete dome was completed in less than 10 months at a total project cost of approximately $6 million (U.S. dollars). This type of cement storage has specific advantages over traditional types of storage (for example, silos) including:

- Lower cost;
- Efficient use of interior volume;
- Simple foundation design;
- Improved blending;
- Ability to fill large capacity vessels from a single storage facility;
- Simple withdrawal system;
- Speed of construction;
- Condensation is at a minimum and waterproofing is excellent; and
- Effective dust containment.

The only disadvantage of this type of storage facility compared with multiple silos (to give the same storage capacity) is that only one type of product can be stored at any one time. However, this dome was constructed specifically to store the plant's main Type 10 cement production.

REFERENCES

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