Shotcrete Domes: A Versatile Bulk Materials Storage and Architectural Structure Solution

by Laurel Briggs and Ryan Poole

In the business of industrial bulk storage for large quantities of materials such as cement, fly ash, clinker, and fertilizer, maintaining product integrity is a primary consideration (Fig. 1).

Open stockpiles leave materials subject to degradation during storage. In addition, there are environmental concerns with controlling dust and runoff from these piles. Domes provide capacity to store large quantities of material on a relatively small footprint while maintaining product integrity and controlling environmental impacts. Concrete domes contain and protect their products more efficiently than any other type of structure. Domes keep stored products dry and maintain a more constant temperature. The dome shape allows a large quantity of product to be piled high against the walls and encloses the most volume. Domes also provide the greatest floor area yet cover the least surface area, perimeter, and footprint (Fig. 2).

Fig. 1: Ashgrove Cement Facility, Foreman, AR

As concerns regarding the environmental impact of open stockpiles and maintaining product integrity increase, there is becoming a greater demand for covered storage. Domes have continued to gain popularity as an innovative and economical choice for superior storage solutions with multiple benefits. These include:

- Simple foundation requirements;
- Rapid construction regardless of weather;
- Condensation is virtually eliminated; and
- Better environmental and fugitive dust control.

Dust control is a constant challenge. Methods of management can be as simple as limiting the drop heights of materials to more complex solutions such as dampening the stored material or installation of expensive dust collection equipment. Keeping stored material from polluting the air, soil, and water can become a more simple process by using better storage methods.

For most domes, the construction process begins with a simple spread footing. The footing also acts

Fig. 2: Ashgrove Cement Facility, Chanute, KS

Fig. 3: Construction of ringbeam footing

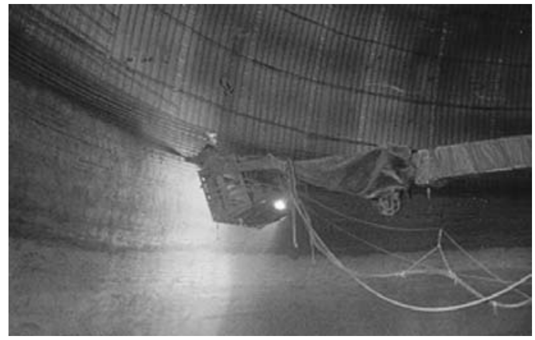

Fig. 4: Shotcrete application

Fig. 5: Bishop Nevins Academy, main entrance

as a tension ring to support the dome (Fig. 3). A prefabricated fabric form is then attached to the footing. This fabric form becomes the roof membrane for the completed structure. Once the form is inflated, polyurethane foam is applied to a 2 to 4 in. (50 to 100 mm) thickness, depending on the use of the structure. The initial reinforcement is then attached with special fasteners that are imbedded in the polyurethane foam. The first layers of shotcrete are applied. The purpose of the initial shotcrete layer is to increase the stability of the airform in the early stages of construction and provide enough strength for the installation of additional reinforcement and shotcrete (Fig. 4).

The initial shotcrete is sprayed in thin layers. As the thickness of the shotcrete increases and as the shotcrete hardens, the amount of shotcrete applied in each layer may be increased. Layers should be 1/4 in. (6 mm) up to the first inch (25 mm) of thickness and then 1/2 in. (12 mm) thereafter. All shotcrete applied in concrete domes should be done by experienced, qualified shotcrete nozzlemen with specific experience in spraying overhead and spraying on flexible air-supported forms. It is very important that the nozzlemen know how thick the layer of shotcrete being applied is. This may require shutting the pump down from time to time to measure the depth of the shotcrete layer. As the shotcrete is being sprayed, the weight of each layer must be supported by the previous layers and the air pressure within the form. Shotcrete hardening must be monitored to ensure that it has gained sufficient strength before applying succeeding layers. To achieve sufficient strength in order to continue shotcreting, temporary heat may be needed or the construction schedule may have to be revised to allow more cure time between layers. When spraying the first shotcrete on a vertical or near vertical section at the base of the dome, shotcrete is sloped to 45 degrees to cover the footing. After the first shotcrete layer is complete, the placement of depth gauges is checked, and hanger wires and bars are installed. Structural steel is then installed according to the structural drawings. Meanwhile, nozzlemen continue to spray shotcrete to properly encapsulate the reinforcing bar and achieve the designed concrete thickness.

Most bulk material terminals are located near water where the environment is especially harsh. Also, domes are often constructed in areas that may be subject to earthquakes, hurricanes, tornados, and other natural disasters. Shotcrete domes have proven resistant to these environments and disasters. Domes are also very efficient for use in architectural applications as well as storage facilities. Bishop Nevins Academy in Sarasota, Florida (Fig. 5), is a K-6 school made up of four shotcrete domes containing classrooms, a cafeteria, a kitchen, labs, a chapel, and administrative offices. After its first year of use, Bishop Nevins Academy was designated a community disaster shelter in the event of a hurricane emergency (Fig. 6). In the construction of the dome at the Bishop Nevins Academy, a total of approximately 1500 yd^3 (1147 m^3) of shotcrete was required for all four domes (Fig. 7).

The most widely used application for domes is for bulk storage of various commodities. Typical products stored in domes include portland cement,

Fig. 6: Interior, Bishop Nevins Academy

Fig. 7: Aerial shot of Bishop Nevins Academy

Fig. 8: Agricultural storage, Tifton, GA

fly ash, gypsum, fertilizer, coal, and assorted agricultural products. Examples of some of these type projects are:

- Two fertilizer storage domes, each 123 ft (37.5 m) in diameter by 61.5 ft (19 m) high with 12,000 tons (10,886 tonnes), built for Farmer's Cooperative in Bayard, IA. A total of 1549 yd^3 (1184 m^3) of shotcrete was applied on this project.
- In Georgia, three agricultural domes, each 170 ft (52 m) in diameter by 85 ft (26 m) high with a capacity of 10,000 tons (9718 tonnes), were built with a total of 3865 yd^3 (2955 m^3) of shotcrete applied (Fig. 8).
- A 200 ft (61 m) diameter by 104 ft (32 m) high, 100,000 ton (90,718 tonnes) capacity cement storage dome in Missouri was built with a total of 4112 yd^3 (3144 m^3) of shotcrete (Fig. 9).

On average, DOMTEC shotcrete nozzlemen will spray approximately 80 to 100 yd^3 (61 to 77 m^3) a day. Depending on the surface area of each dome, lower quantities may be sprayed in smaller domes. However, the quantity can often increase to as much as 200 yd^3 (153 m^3) a day in the larger domes.

Nearly 5 billion tons of industrial and post-consumer waste byproducts are generated annually in the U.S. that are readily recyclable. Specifically within the concrete industry, fly ash, a byproduct of burning coal for generating electricity, can be used to make a more durable and higher quality concrete.[1] High-volume fly ash (HVFA) mixtures are proving to be a promising constituent in using by-products efficiently to create structures that are more durable than those made of portland cement concrete alone. In the past, the HVFA shotcrete mixtures did not perform well with regard to durability, drying shrinkage, and strength development. This was due to the poor coal burning technologies that produced coarser, high-carbon fly ash.

Today's modern thermal power plants, however, produce fly ash with low carbon contents and high fineness, which is being used to produce high-quality, durable shotcrete.[2] An example is the Brayton Point Power Plant, owned by Dominion Power. It is the largest fossil-fuel burning (coal fired) power plant in New England. A 165 ft (50 m) diameter by 105.5 ft (32 m) high dome was built as part of a multi-million dollar fly ash recovery project at this site. The dome will store more than 40,000 tons (36,287 tonnes) of fly ash recovered from the coal burning process (Fig. 10).

Not all concrete domes are the same, though some may appear to be. The differences are often not seen from the outside. As stated previously, the majority of construction occurs inside the air-inflated form. DOMTEC International's structural engineers collectively have designed over 600 shotcrete domes. These domes are designed with the latest design tools such as finite element analysis modeling. Each dome is custom-designed for a specific application. All pertinent design criteria are taken into account to determine the appropriate dome size and shape and to perform engineering calculations. DOMTEC is dedicated to delivering the best domes by employing the world's most experienced dome design engineers and qualified shotcrete nozzlemen and by continually improving construction methods and efficiencies. Project-

Fig. 9: Holcim Cement Plant, Clarksville, MO

specific inspection plans are implemented for each project. Each inspection plan cites applicable codes and standards, and establishes inspection criteria and responsibilities (Fig. 11).

Maintaining product integrity and addressing environmental issues are vital in today's bulk material storage market, as are safety and structural integrity. Concrete domes provide an innovative and economical solution to many of the problems encountered in both material storage and architectural applications. Quality domes built by a competent contractor, using qualified, experienced nozzlemen with specific training in applying shotcrete overhead on flexible air-supported forms provide durable, low-maintenance structures with enhanced resistance to natural and man-made disasters.

References

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2. Mehta, P. K., Greening of the Concrete Industry for Sustainable Development, *Concrete International*, V. 24, No. 7, July 2002, pp. 23-28.

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Fig. 10: Dominion Power, Brayton Point Station, Somerset, MA

Fig. 11: DeBruce Fertilizer, Creston, IA