Shotcrete Domes: A Model of Sustainability

By Chris Zweifel

Shotcrete domes are one of the most economical and sustainable building types known. Using a minimal amount of building materials, their shape provides the largest floor area and volume for the materials while also providing tremendous strength. The insulation and thermal mass provide significantly reduced energy usage. The ready availability of concrete and reinforcing steel reduces cost and construction time. The combination of all of these factors enables shotcrete domes to be recognized as "green," or environmentally friendly, structures.

Fig. 1: Construction of a typical dome foundation

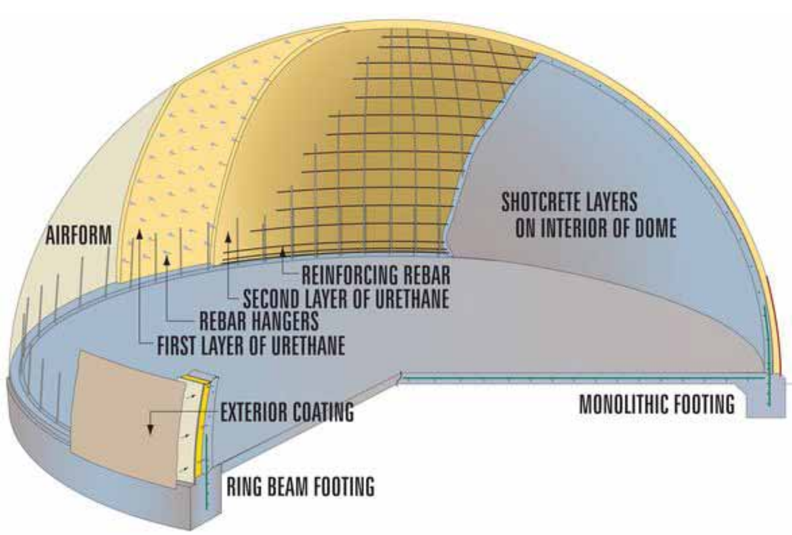

Fig. 2: Typical dome construction

Most domes begin with a simple spread footing or "ring" foundation (Fig. 1). The dome may start at the foundation, or a vertical stemwall might be included to give the dome added height or architectural appeal, or both. A prefabricated fabric form is then attached to either the top of the wall or the foundation, depending on which type of shape is required. The fabric form becomes the roof membrane for the completed structure. Large blowers inflate the fabric membrane that then serves as the formwork for the structure. Once the form is inflated, polyurethane foam is applied on the interior side of the form to the desired thickness. The initial reinforcement is attached with special fasteners embedded in the foam. The shotcrete is applied in gradually thicker layers until reinforcement is encapsulated and the concrete has reached the specified thickness (Fig. 2 and 3). Generally, the entire building enclosure is provided by a single contractor, which translates into significant time savings in the construction schedule. Another schedule saver is realized because the insulation, reinforcing steel, and shotcrete are all applied on the inside of the airform so that the construction can continue though virtually any weather.

The shape of the shell minimizes the wall surface area and maximizes the floor area. A look at two similar buildings will illustrate this advantage. Both projects are concrete warehouse structures. The first is a concrete tilt-up building

Fig. 3: Shotcrete is applied in layers

Fig. 4: Dome shop with metal building in the background

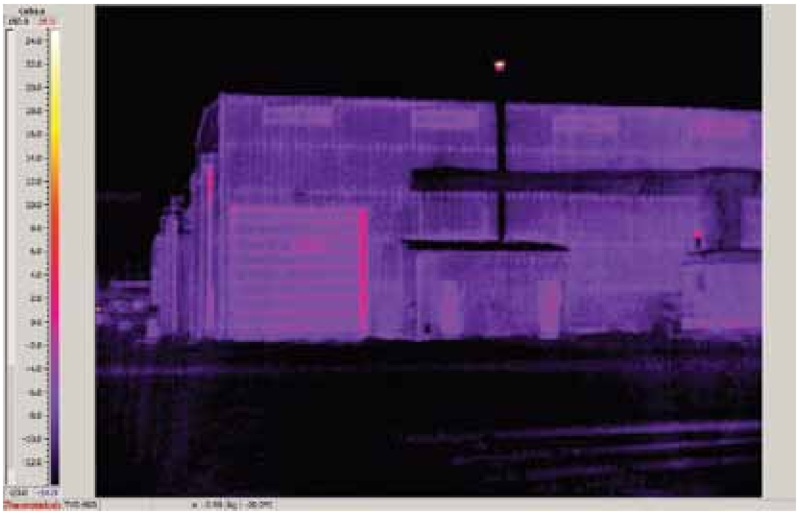

Fig. 5: Thermographic photo of steel building showing significant heat loss

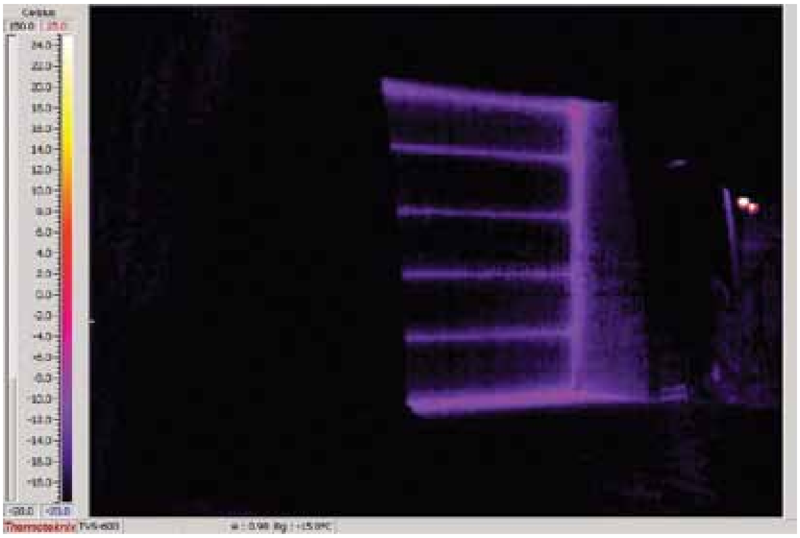

Fig. 6: Thermographic photo of dome. The only heat loss is through the door

that is 142 ft (43.3 m) square. The roof is a steel deck over steel joists. The second project is a shotcrete dome that is 161 ft (49 m) in diameter by 60 ft (18.3 m) tall. For both buildings, the floor area is about 20,000 ft^2 (1858 m^2). The outside surface area of the tilt-up building is 57,650 ft^2 (5356 m^2) and the enclosed volume is 524,200 ft^3 (14,844 m^3). In contrast, the dome has a surface area of only 31,670 ft^2 (2942 m^2) and an internal volume of 723,800 ft^3 (20,495 m^3). Even with a concrete roof, the dome option only uses about 20% more concrete, but uses approximately 40% less steel. The dome does not require any interior columns, which makes it very adaptable for various occupancy modifications over the life of the structure.

Due to their shape and construction materials, domes are inherently very strong. Much of the strength of the domes is because there are no mechanical connectors between the wall and roof. The wall and roof are the same member. Domes are so strong that the difference between a conventionally designed dome and one designed to be a storm shelter is almost negligible. To meet the strict requirement of the Federal Emergency Management Agency (FEMA) Document 361, "Design and Construction Guidance for Community Safe Rooms," the typical dome needs only 5 to 10% more reinforcing steel and no additional shotcrete. Most of this added reinforcement is not due to the increased stresses, but because of prescriptive requirements to provide protection from flying debris. In contrast, many conventional building types are never able to meet the strict requirements of a storm shelter. The ones that can, such as those constructed with reinforced concrete and masonry, often require 100 to 200% more reinforcement.

The polyurethane foam, applied inside the fabric form of the dome, creates a continuous thermal barrier from the footing to the top of the dome. It also creates an envelope that allows minimal air infiltration. This has a great effect on reducing interior air quality issues. The thermal mass of the shotcrete improves the system by storing energy in the form of heat throughout the building. This destratifies the temperature in the building, which reduces the HVAC and ductwork requirements. The electrical requirements to the mechanical system of the building are therefore reduced. This insulation, combined with the dense thermal mass of the shotcrete, translates into significant energy savings. A great visual representation of the energy efficiency of the dome can be shown with a thermographic photograph. Robert Phillips, President of Canadian Dome Industries Ltd., used a thermographic camera to create photographs that show the heat loss. He owns a metal structure next to a dome (Fig. 4) and used the thermographic camera for measurement on a day when temperatures read –13°F (–25°C). Although the metal building is well insulated, the camera picked up significant heat transfer (Fig. 5). On the dome, however, the only measurable heat loss came from the garage door panels (Fig. 6). The dome itself showed virtually no heat loss.

While the portland cement in the shotcrete used to construct the dome requires a lot of energy to produce, studies show that the most significant environmental impact from buildings comes from their long-term energy use and not the construction products used. An example of the energy savings found in heating and cooling the dome can be seen in the Beggs, OK, school district. The superintendent of the Beggs School District provided solid numbers on the energy savings. During the 2006-2007 school year, the district paid \$5500 to heat and cool a 10,000 ft^2 (929 m^2) dome classroom building as opposed to \$30,650 for a metal classroom building of the same size. For the school's 30,000 ft^2 (2787 m^2) Event Center dome (Fig. 7), the district paid \$6600 for utility costs compared to \$42,000 for a similarly sized metal building. Imagine the energy savings that could be achieved if every community had a similarly efficient school.

According to the U.S. Green Building Council (USGBC), sustainable buildings save energy, water, and materials; preserve the local surroundings; assure the health of their occupants; and require little maintenance. USGBC created the Leadership in Energy and Environmental Design (LEED) as a rating system to certify and measure green building design. Shotcrete domes meet the USGBC definition for sustainable design and can also earn significant LEED credits. Some of the ways these credits are earned include the following: using recycled aggregates; savings on formwork, steel, and concrete; transportation savings by using local supplies; reduction of waste and formwork because the airform stays in place; labor and construction speed savings; and thermal mass and operations energy savings. Also, the life cycle of the buildings can be significantly longer. Typical metal buildings have a 50-year life span, but shotcrete domes' life spans can be several times that.

Other benefits include the fact that the controlled atmosphere in the dome allows for the living/working environment to be held to the strictest standards and, because of their shape and construction, domes can be a shelter for natural disasters such as tornados, hurricanes, and earthquakes.

The economic impact is likely the best advantage. New construction is done more efficiently with thinner structural sections using fewer materials. This affects the bottom line by using less time, labor, and materials. A recently constructed charter school in Phoenix, AZ, illustrates that point. The Robert L. Duffy High School has a finished cost of \$119 per square foot. By contrast, the average cost of permanent charter school buildings in that area is \$130 to \$150 per square foot (Fig. 8).

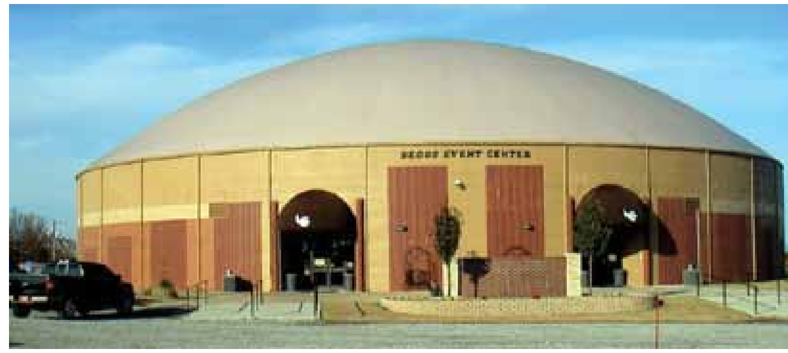

Fig. 7: Beggs Event Center (gymnasium)

Fig. 8: Architectural rendering of Robert L. Duffy High School

Shotcrete dome structures have many economical and structural advantages. Domes use building materials sparingly, produce savings in heating and cooling costs, and their shape allows for an open structure with tremendous flexibility with a variety of uses that include public events centers, schools, auditoriums, storm shelters, and residential, industrial, and storage use. All of these things combine to demonstrate that shotcrete domes make a very green and sustainable building.

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