Construction of Concrete Shells Using Inflated Forms

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Chair

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This report provides information on the construction of structural concrete shells using an inflated form. Major facets of the construction process are covered, including foundations, inflation, monitoring, and backup systems. Other aspects, such as the geometric variations of inflated forms, thickness of polyurethane foam, and mixture proportions for shotcrete, are also considered.

Keywords: dome; fabric; inflation; polyurethane foam; reinforcement; shotcrete; thin shell.

CONTENTS

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CHAPTER 1—GENERAL

1.1—Introduction (Fig. 1.1)

For centuries, arched and dome-shaped structures have efficiently enclosed large clear-span volumes. The strength of compound-curved surfaces allowed early builders to construct self-supporting thin-shell buildings from a variety of materials. Due to the tremendous amount of time and effort needed to create the desired shapes, construction of these thin-shelled structures sometimes spanned several decades.

Knowledge of the design and construction of thin-shell concrete structures has greatly increased over the past 100 years, both from research and practical experience. In the past 40 to 50 years, the use of inflated forms has allowed shells to be constructed more economically (South 1990). This new type of construction process presents new challenges and concerns. Safety measures and construction tolerances are addressed in this report for many types of systems using inflatable forms.

1.2—Scope (Fig. 1.2)

This report contains the lessons learned in the construction of thin-shell concrete dome structures using inflated forms. As this method of construction continues to gain popularity, additional research is needed to increase understanding of the behavior of this type of shell so that inflated-form structures continue to meet adequate levels of safety and serviceability. Included are construction procedures, tolerances, and design checks to ensure that the finished structure meets adequate safety and serviceability levels. This document focuses primarily on inflated form thin shells using polyurethane foam as part of the construction process. Many structures are built using fabric forms where the concrete is applied directly to the form either from the outside or the inside. These general guidelines apply to all methods.

1.3—History (Fig. 1.3)

Since the early 1940s, several methods of construction using inflatable forms have been used. These methods include

Fig. 1.1—Faith Chapel Christian Center, Birmingham, Ala.: 280 ft (85.35 m) diameter and 72 ft (22 m) tall that includes a 3200-seat sanctuary, classrooms, and an administration building.

Fig. 1.2—Price City Works Complex, Price, Utah. Four domes: 130 x 43 ft (40 x 13.1 m) fire station; 130 x 43 ft (40 x 13.1 m) storage facility; 130 x 43 ft (40 x 13.1 m) maintenance shop; and 90 x 40 ft (27 x 12.2 m) office and administration building.

Fig. 1.3—U.S. Borax and Chemical Co., Boron, Calif.: two 20,000 ton (18,000 tonne) borax storage domes, 150 x 79 ft (45.7 x 24.1 m).

shotcrete applied to the form exterior, and foam and shotcrete applied to the form interior.

In 1942, Wallace Neff received a patent on a system where the form was inflated to the shape of the structure, and then the reinforcing bar and shotcrete were placed on the exterior of the form (Neff 1942). Dante Bini later developed and received a patent on a system where the reinforcement and concrete were placed on the exterior of the form before it was inflated. It was then raised by air pressure to form the dome (Fig. 1.4) (Bini 1986).

In 1972, Lloyd Turner received a patent on a process in which the inflated form was sprayed with foam on the inside to a desired thickness creating a self-supporting foam dome

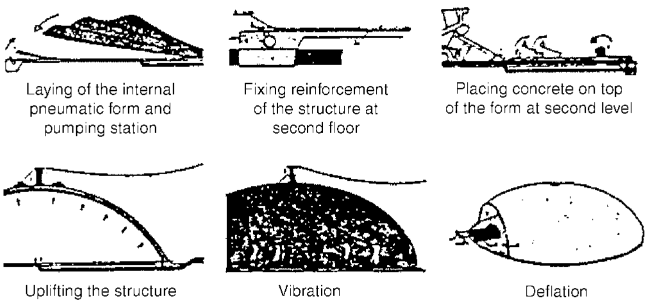

Fig. 1.4—Construction of Bini shell.

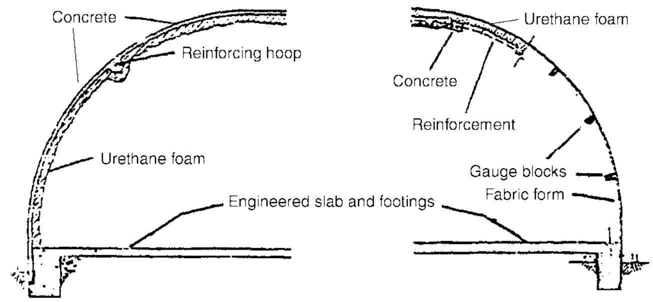

Fig. 1.5—Construction of Turner shell.

(Turner 1972). The patent was later reissued with concrete applied to the interior of the foam (Fig. 1.5).

In 1979, David and Barry South were issued patents on a method similar to that of Turner's (South 1979). Their method differed in that the structure was self supporting only after the shotcrete was in place (Fig. 1.6) (South 1986).

All patents for the use of inflated forms in construction of thin shells are now in the public domain with one exception: the Crenosphere™, the technique patented by David South for the construction of thin shell domes of diameters larger than 300 ft (91 m) using a cable net restraint system and ribs.

When the concrete is placed on the outside of the form, the cables will be buried in the concrete and function as reinforcement. When the concrete is placed on the inside of the form, the cables are removed once the structure is solid.

Bridges and arch buildings have been built using inflated forms where inflation forces are restrained by steel hoops placed on the exterior of the inflated form. Some very large dome-type structures have used steel tie-down systems to allow higher inflation pressures.

1.4—Methods (Fig. 1.7)

Inflated-form, thin-wall shotcrete construction has become one of the most common and widely used methods in the construction of domes. The Monolithic Dome Institute estimates over 2000 thin shells have been built over the last 30 years using the fabric form method, whereas those built with conventional forming methods are few in number.

Until recently, only a few contractors have possessed the skills and the equipment necessary to undertake this type of construction. As architects and engineers are becoming aware of the advantages of this inflated form method and its use increases, industry design and construction standards are needed.

Shotcrete can be placed on the inflated form from either the outside or inside. Some systems use higher air pressure and the inflated fabric form to support all the loads, whereas others support some construction loads with a reinforcement layer and initial layers of shotcrete.

Although each method has unique construction challenges, they all have many similar characteristics. This report does not distinguish between the different methods or make judgments as to the validity of each. It discusses the construction factors that are common to all of the inflated form methods:

- *Inflated form manufacturing*—shape, size, fabric, and fabrication;

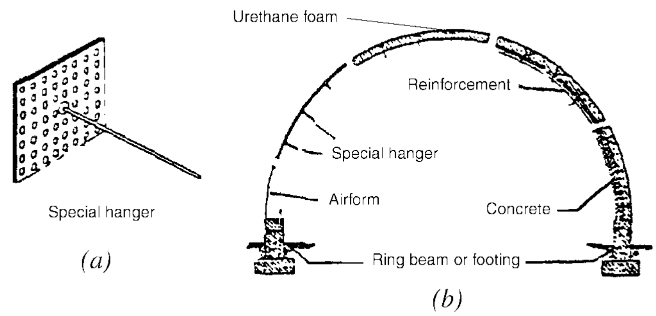

Fig. 1.6—Construction of South shell.

Fig. 1.7—"Eye of the Storm," Sullivan's Island, S.C.: prolate ellipse residence—80 ft (24.4 m) long, 57 ft (17.4 m) wide, and 34 ft (10.4 m) tall.

- *Foundation details*—anchor system, uplift prevention, layout, and form tension;
- *Air pressure*—backup system, monitoring, and collapse prevention; and
- *Applied loads*—live loads and dead loads.

1.5—Definitions

basket—the personnel aerial lift platform that raises workers to work on the dome.

dead loads—the fixed weight of a structure plus any fixed loads such as attached equipment, bridges, supports, head houses, platforms, catwalks, ceilings, and conveyors resting or hanging from the structures.

embeds—anchor bolts, inserts, pipe sleeves, pipes, conduits, reinforcement, wiring, flashing, instruments, and other devices encased in the concrete.