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A Mechanized Construction Technique for Producing Lower Cost Structures

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A MECHANIZED CONSTRUCTION TECHNIQUE FOR PRODUCING LOWER COST STRUCTURES

by

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Shell structures have gained more and more importance in the last few decades. They offer an ideal solution for many engineering problems. They use space more efficiently and can also be built with less material than other types of structures which would cover the same space. Even as early as the sixteenth century some applications of shell structures can be found, e.g., the dome on St. Peter's Church in Rome. Wide utilization of shell structures did not start, however, until after 1930-1935, when the development of the shell theory gave engineers a more elaborate analysis tool. The preference for shell structures by engineers and architects is mainly because of two considerations:

a. The loads are carried mainly by membrane forces, and
b. Shell structures offer better aesthetic possibilities.

Figure 1 shows a typical thin shell with double curvature.

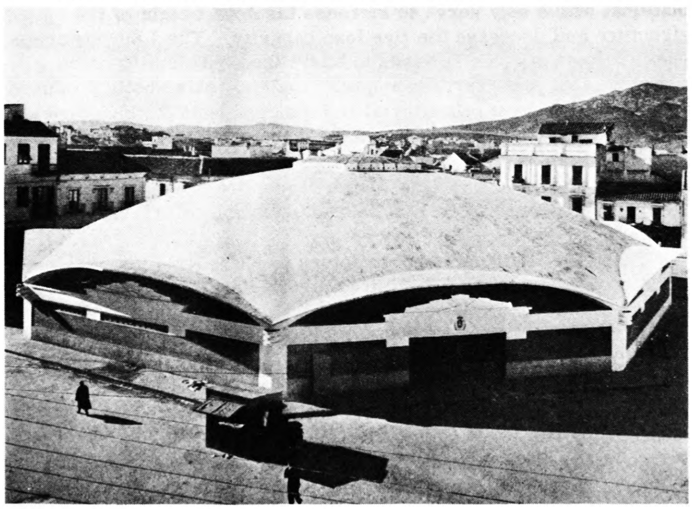

Fig. 1. A Typical Shell Of Double Curvature

A properly designed shell carries the load mainly by normal forces in the cross section. Moments occur only in certain limited regions, such as the edge areas of spherical domes. For this reason, it is possible to support large loads with small cross sections. Shell structures offer the architect a powerful structural tool because of the possible geometrical variations which help to overcome structural monotony and make a more aesthetic design. Certain types of shells of revolution are preferred mainly because of their functional advantages, e.g., cooling towers, large containers, etc.

Even with the above mentioned advantages and with the available mathematical techniques of analysis, shell structures are not widely used because of the cost and time involved in building the formwork. A recently developed construction method which does not require this sort of conventional forming opens up new possibilities of shell application.

This new process is a semi-automatic technique known as Spiral Generation. It is the on-site shaping and assembly of mass produced materials by a pivotal boom device to form shell structures suitable as a form. The process continuously heat welds planks of extruded polystyrene plastic foam together to form a monolithic structure. Generally this foam structure serves as a formwork for a true thin shell concrete structure. Sometimes, on very small shells, the plastic shell is simply painted or coated with a mastic. Figures 2A & 2B show a 100 ft. diameter spherical foam dome being constructed. Note the operator inserting the foam plank into the self-propelled heat welding apparatus. Spherical dome shells of up to 200 ft. in plan diameter ($\alpha = 50°$; R=130.5') have been constructed already. Also, arbitrary shapes of shells of revolution such as ellipsoids or hyperboloids can easily be constructed by this technique.

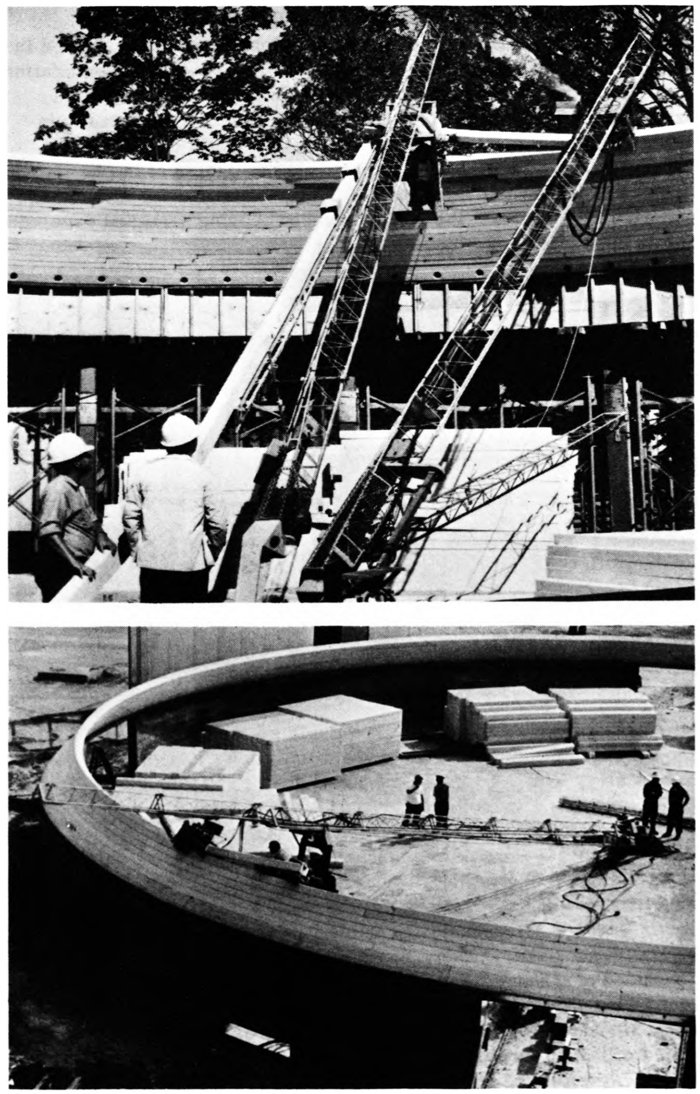

Fig. 2A & 2B. The Spiral Generation Process

The function of the foam shell is mainly to serve as a form liner for the placement of a latex modified portland cement (LMC) mortar, concrete material. After placement of the LMC mix, the foam shell remains and serves as an excellent insulation material. Structural design of these shells assumes that the structural function is provided solely by the LMC concrete shell. The validity of this assumption has been established through full scale testing on a series of 30 ft. diameter, 50° spherical domes at the structural testing laboratories of The Dow Chemical Company, Midland, Michigan. The domes were constructed as described above, "spinning" the foam dome first and then applying the LMC struc-

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tural shell. After a 28 day cure at 50% RH and 70° F the foam domes were stripped from inside the LMC shells. A simulated uniform loading was applied through a network of barrels suspended from the shells as illustrated in Figure 3. Water was carefully metered into the barrels so that a simulated uniform load was obtained. In all cases, failure was by buckling.

The shells behaved according to the classical equation for buckling of spherical shells:

$$P = \frac{K\,2E}{\sqrt{3(1-V^2)}} \quad \frac{T^2}{R^2}$$

Where P = Critical buckling load, psf
K = Test to theory correlation
E = Modulus of elasticity of the shell wall, psi
T = Thickness of shell wall, in.
R = Radius of curvature of shell, ft.
V = Poisson's ratio

The latex modified cement (LMC) concretes render this new technique possible. These concretes have superior physical and mechanical properties and develop excellent bonds when applied in layers. Also the materials resistance to freeze-thaw deterioration, to chemical attack and rain penetration make true thin shells a practical reality. The latex modification generally doubles compressive strengths and increases tensile strength by 200 to 300 percent. The 200 ft. domes (200 ft. plan diameter at the 50° spring line) had a total shell thickness of 2 inches, which was a thickness increase slightly near the edge to handle bending stresses developed due to edge effects.

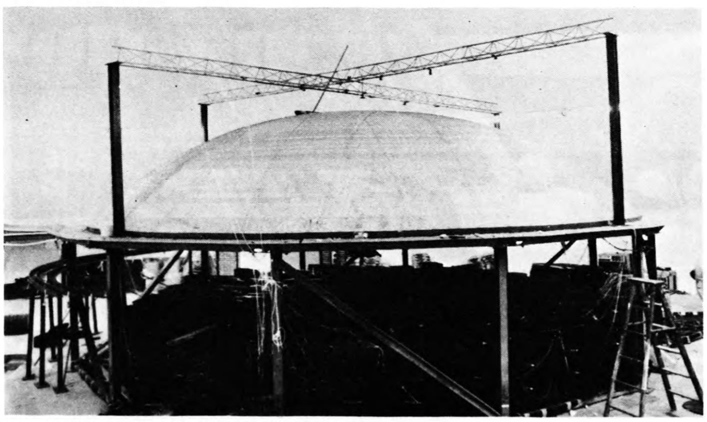

Fig. 3. Uniform Loading For Testing Apparatus

Figure 4 shows a 135 ft. foam dome being lifted onto a foundation. This dome was used to cover a trickling filter at the Chemung County, New York, Sewage Treatment Plant. "Spinning" of the foam dome was accomplished at a site to the side of the foundation. The foam form was then lifted onto the trickling filter wall. A distinct advantage was obtained from this type of construction since the trickling filter was kept in operation throughout the entire construction period. It is usually too expensive to lift foam domes larger than 135 ft. in diameter unless unique circumstances justify the additional cost.

Speed of construction is often of prime importance. Spiral Generation offers unmatched speed and simplicity for constructing forms for arbitrary shells of revolution. For instance, a time period of two to three weeks is realistic for construction of a basic dome over a 200 ft. trickling filter. It must be noted that this does not include any mechanical or electrical work. It includes the foam form, two openings, and a finished shell which requires no painting or waterproofing membrane. Conventional methods of constructing shells require weeks and even months for installing only the formwork. The shell must then be poured and the formwork removed.

Another advantage to the Spiral Generation process is the reduced number of trades which need to be coordinated and accommodated on the job site. The spinning process involves one union and the LMC placement involves another union; a total of two trades for the major part of the job. Painters are required for application of coatings to the steel edge ring and often architectural steel work such as door frames, walk ways, etc.

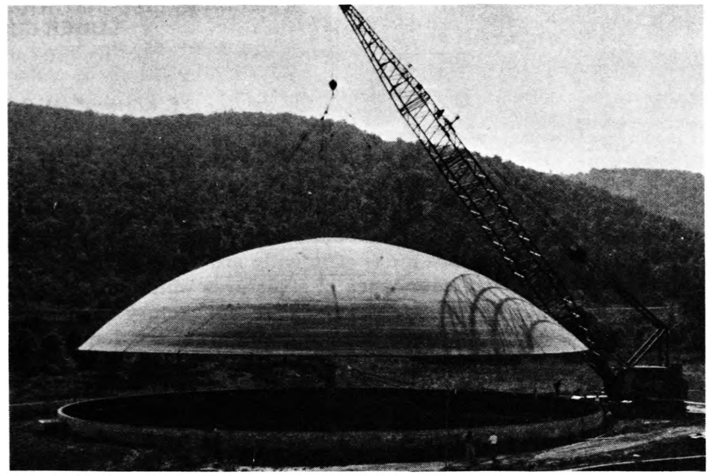

Fig. 4. 135' Plan Diameter Dome Being Hoisted Onto Foundation

A true thin shell does not require inordinate amounts of material which only serve to increase the dead weight of the structure and decrease the live load capacity. The LMC concrete shells allow very thin sections to be utilized. This difference will be noted later in a design example. The truly thin shells produced by this method save on material and the dead weight which provides the required structural performance through geometry; not through massive sections. The improved application procedures and statistically reproduceable strength properties when combined with the Spirally Generated form have made possible efficient structures promised by the thin shell concept.

Eight 168 ft. plan diameter domes (α=50° ; R=110') were constructed over trickling filters at Cedar Rapids, Iowa waste water treatment plant. A total of 27 domes were constructed at this one site. These domes are shown in Figure 5. The eight large domes are in the two rows of four domes each to the right side of the photograph.

For an economic comparison, let us examine the materials required for the 168 ft. dome mentioned above (α=50° ; R=110'). Design of the shell according to the ACI recommendations using ordinary reinforced portland cement concrete requires 393 cubic yards of concrete and 13.2 tons of reinforcing steel. A Spiral Generation dome requires 162 cubic yards of LMC concrete and 3.2 tons of hexagonal wire mesh reinforcement. The semi-automatic machine controlled procedure and the superior LMC material allow the shell thickness to be reduced to 1 1/4 inches for this shell (α=50° ; R=110').

A materials advantage is only one consideration. A <u>maximum time</u> of 2 to 3 weeks is required for Spiral Generation; a <u>minimum time</u> of 8 to 10 weeks would be necessary for conventional construction, either cast-in-place or precast. As mentioned previously, the reduced number of trades on the job for Spiral Generation is a plus factor. A considerable first cost savings has been

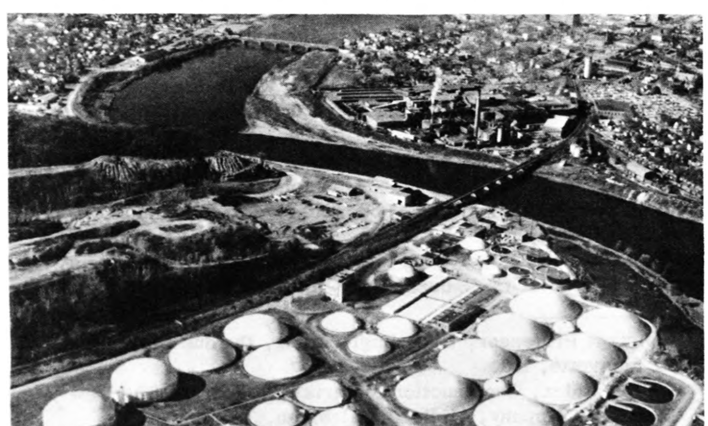

Fig. 5. 27 Spiral Generation Domes - Sewage Treatment Plant, Cedar Rapids, Iowa

indicated in recent bidding situations without factoring in the reduced construction time.

Although this construction method has been used most extensively to cover trickling filters and water reservoirs, it is applicable to any shell of revolution for most architectural applications. In fact a school, several planetariums, some museums, at least one residence, several assembly halls and a range of industrial structures have been constructed by this method. At the present time, the largest use is the fabrication of odor control domes for waste water treatment facilities. This technique could be utilized for construction of theaters, gymnasiums, community centers, shops, offices, storage, etc. Figures 6, 7, & 8 are photographs of some Spiral Generation domes in use. Figures 9A & 9B indicate one conceptual possibility as a solution to low cost housing problems.

This revolutionary new construction method will allow engineers to more fully utilize the economic character of shell structures. It offers a new future for a wide range of construction applications of arbitrary shells of revolution because of its speed, simplicity, and economic and semi-automatic character. The problem of constructing efficient and aesthetic structures at a controlled cost in an inflationary period must be solved by revolutionary new techniques and materials. Spiral Generation offers both.

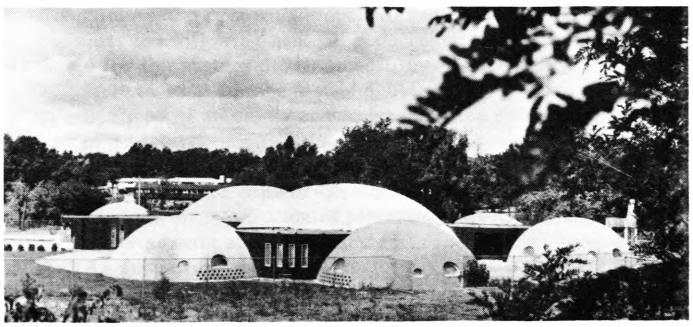

Fig. 6. A School Complex Utilizing Spiral Generation Domes

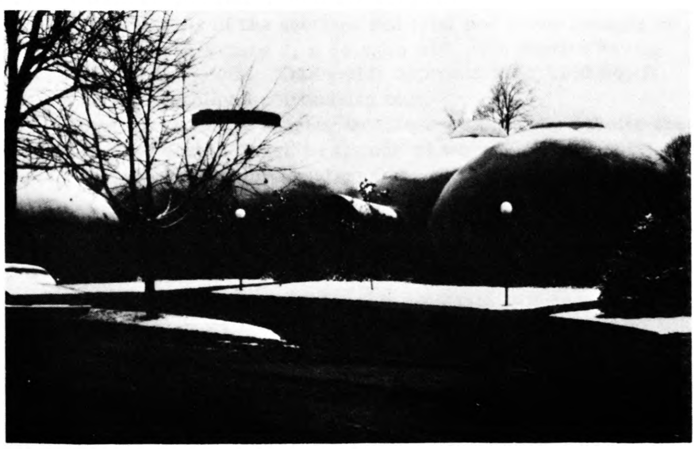

Fig. 7. An Office Complex In Lafayette, Indiana

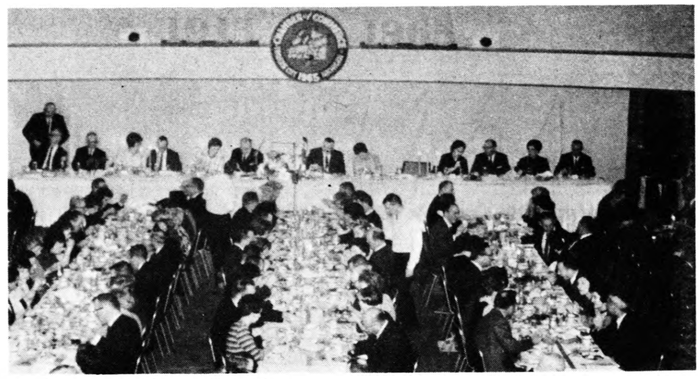

Fig. 8. Interior Of Assembly Hall

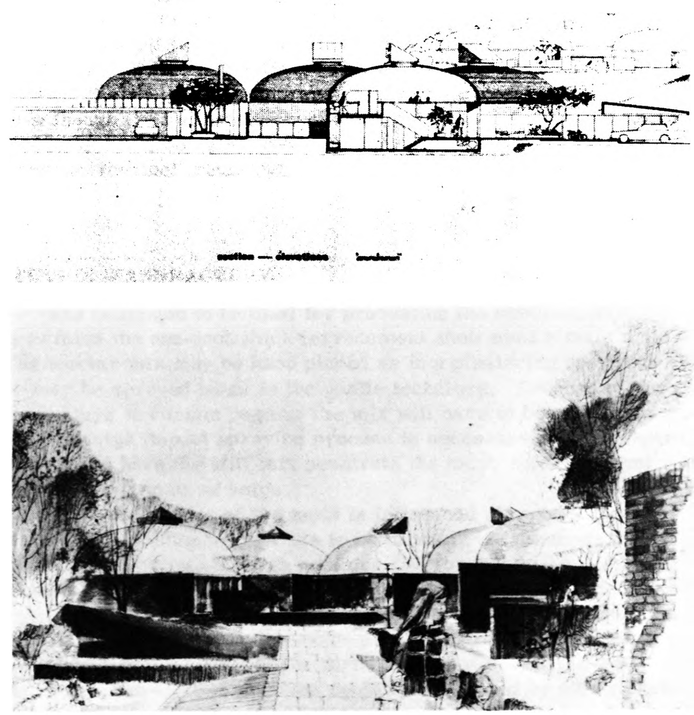

Fig. 9A & 9B. Conceptual Possibility For Spiral Generation Applied To Low Cost Housing