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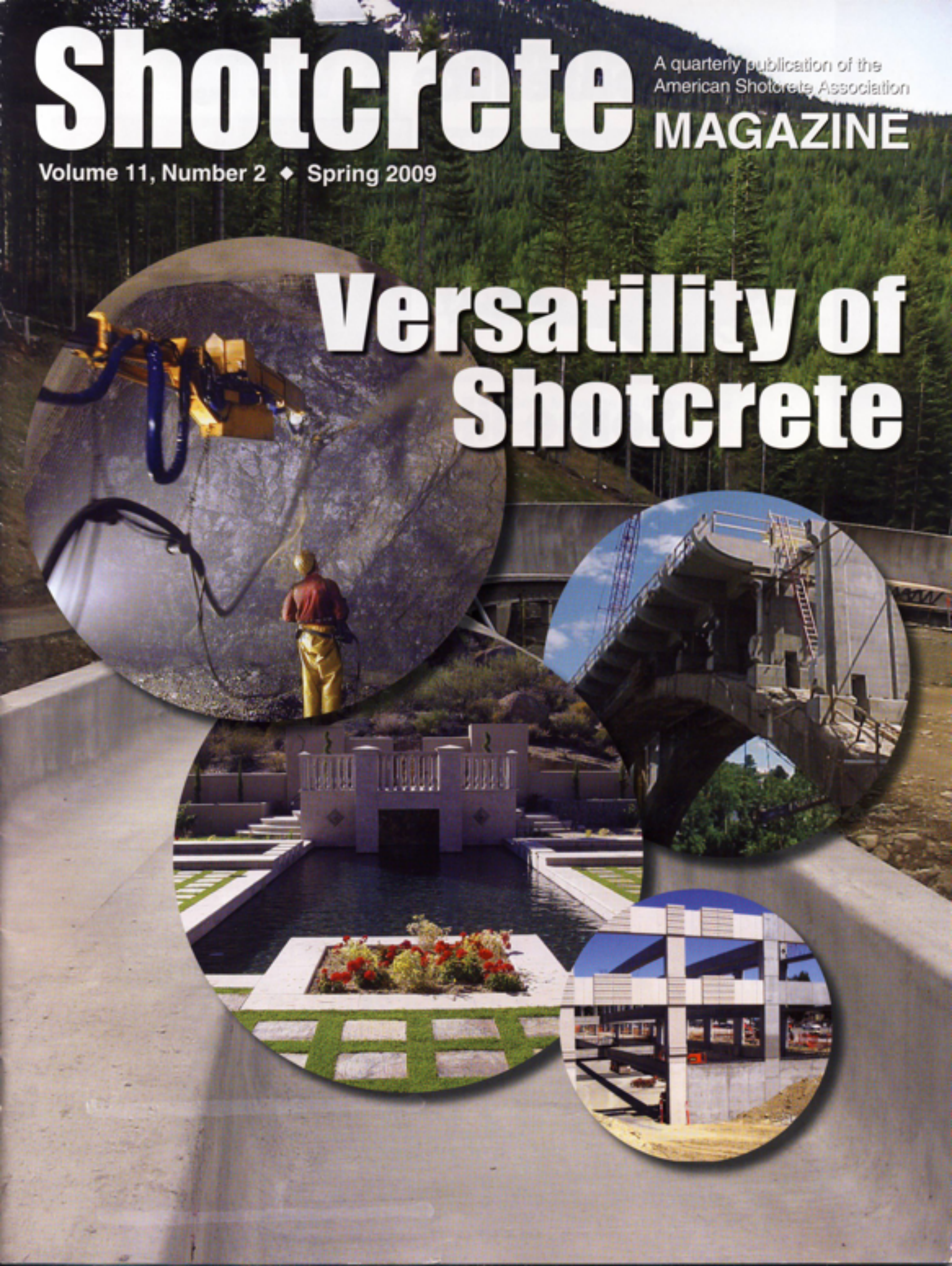
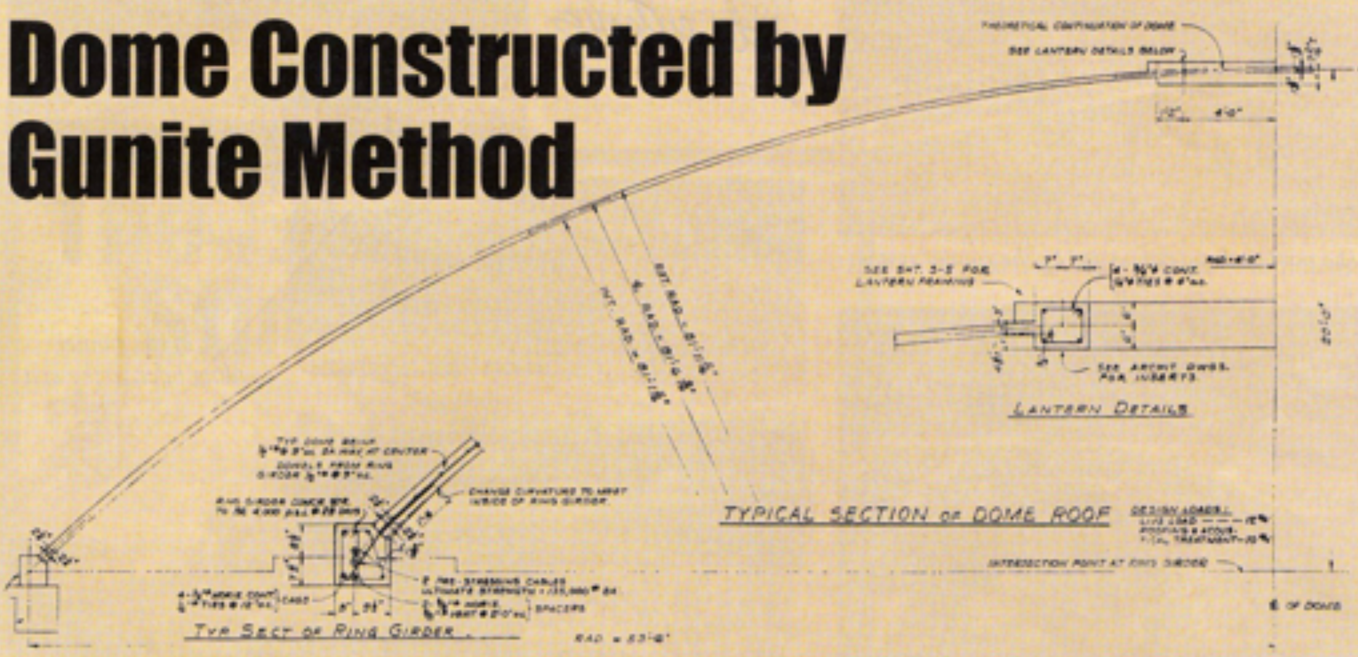
Versatility of Shotcrete



Pre-Stressed, Post-Tensioned Ring Girder Resists Horizontal Component at Base of

Thin-Shell Concrete Dome Constructed by Gunite Method



REQUIREMENTS OF the owner for an auditorium-type church, economically built, determined the design of the edifice under construction at Brooklyn Ave. and Bailey St. in Los Angeles for White Memorial Seventh-Day Adventist Church. The church will seat 2000 people, one-third of them in a balcony; an adjoining chapel will seat 250. The two buildings will be connected by a classroom wing.

Cost of the buildings will approximate $600,000; the floor areas will total 49,000 sq. ft. The church, which is a Type 1 structure, will have an area of 35,000 sq. ft.; the classrooms 10,000 sq. ft., and the chapel 4000 sq. ft.

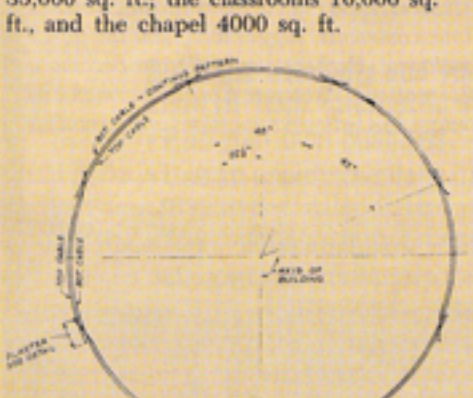
The architects are Heitschmidt & Thompson and the structural engineer is Robert M. Wilder. Hilburg, Hengstler & Turpin are the mechanical engineers, Chauncy Mauk is the electrical engineer, and Donald R. Loye the acoustical consultant. Havstad & Jensen are the general contractors; J. C. Nicholson their superintendent on the job. The gunite work on the dome was performed by the F. W. Case Corp.

The church is poured concrete on conventional spread foundations, with walls of varying thickness. A system of heavy concrete girders was used to carry the balcony, which cantilevers 25′ over the main floor area. The exterior facing will be architectural concrete and brick; the interior wall treatment will be one-half board-type acoustical material and the other half exposed concrete.

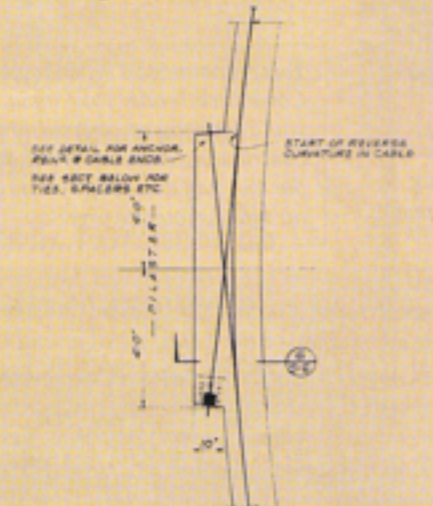
The octagonal shape of the auditorium determined the use of a dome roof, which is the principal structural feature of the building. Steel trusses and other methods of spanning the auditorium were considered; thin-shell concrete was chosen because it offered the most economical solution.

The dome

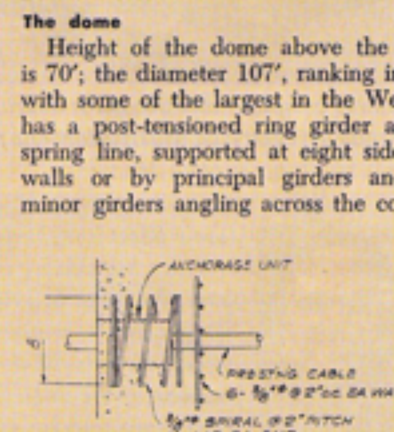
Height of the dome above the floor is 70′; the diameter 107′, ranking in size with some of the largest in the West. It has a post-tensioned ring girder at the spring line, supported at eight sides by walls or by principal girders and by minor girders angling across the corners



SCHEMATIC PLAN LAYOUT OF PRESTRESSING CABLES FOR RING GIRDER



PLAN OF RING GIRDER AT PILASTER FOR CABLE ANCHORAGE



DETAIL OF REINFORCING AT CABLE ANCHORAGE

Shotcrete Classics

From the library of Chris Zynda

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HEITSCHMIDT & THOMPSON, A.I.A.
Architects

ROBERT M. WILDER
Structural Engineer

HAVSTAD & JENSEN
General Contractors

F. W. CASE CORPORATION
Gunite Construction

of the octagon as shown in the half plan. The elimination of connections between ring and balance of structure, at the time of stressing, gave the dome a "free floating" characteristic, permitting horizontal expansion and contraction without affecting the rest of the building. After stressing, parapets and fill were poured, preventing subsequent displacement. A mineral-surfaced cap sheet goes on top of the dome; the under side will have a sprayed on acoustical material.

The following paragraphs describing the dome, including the pre-stressing elements, tensioning procedure, ring girder concrete and concrete for the shell, were taken from office record data prepared by Mr. Wilder.

The dome shell is 107′ 0″ in diameter at the spring line, with a height of 20′ 0″. The thickness varies from 4½″ at the base to 3″ at the edge of the lantern ring. It is supported directly by the walls for part of the circumference and by an appropriate system of girders for the balance, as illustrated.

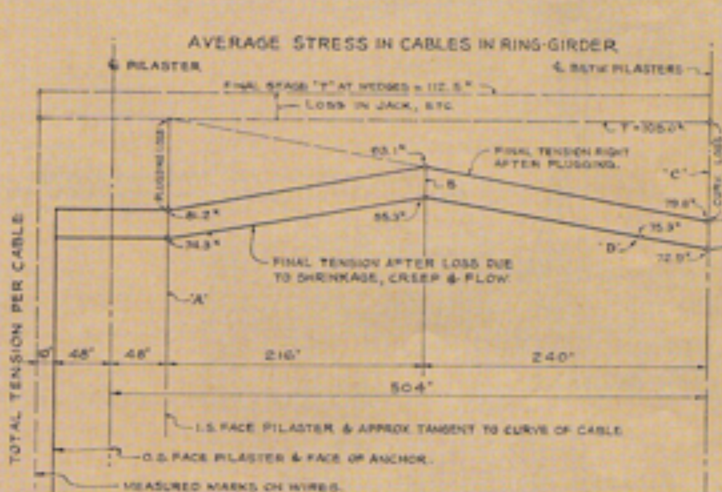
The horizontal component at the base is resisted by a ring girder of concrete containing high-tensile, pre-stressed, post-tensioned cables. By this method some of the difficulties of using the usual reinforcing bars were avoided. When conventional reinforcing is used the tensile stress must be kept quite low or the elongation under load could result in a considerable drop of the crown and distortion of the shell from its calculated position. But if low stresses are used, then a considerable number of the largest size bars would be required and the size of the ring girder is much larger. Furthermore, when conventional reinforcing is stressed, the concrete in the ring girder is necessarily in tension. Yet, the concrete in the portion of the shell immediately adjoining is calculated to be in compression. By post-tensioning, this anomaly is overcome and the other difficulties are avoided.

Pre-stressing elements

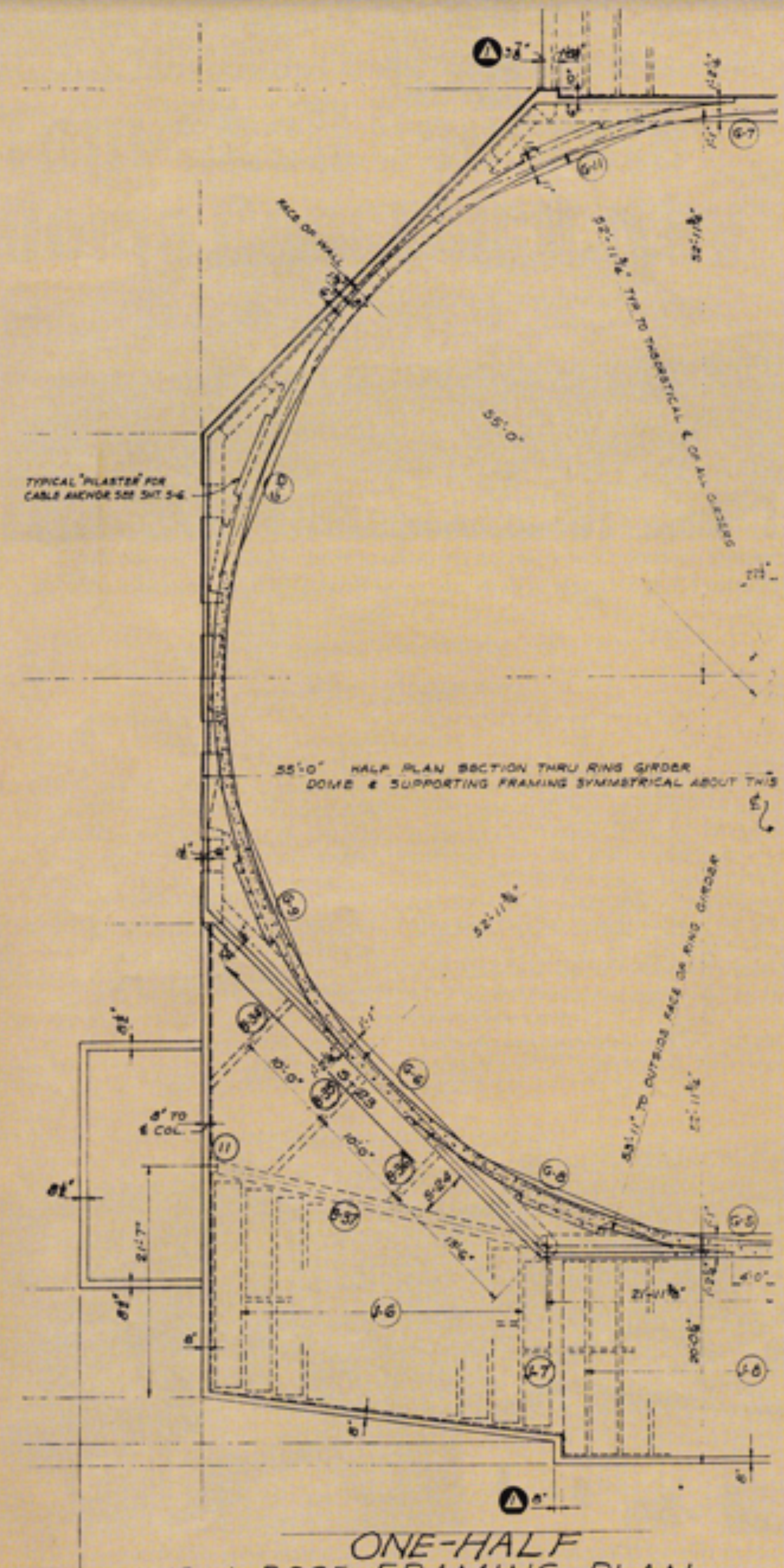
It was decided to use eight separate cables in the entire circumference, each covering an area of 90 degrees. In order to provide for anchorage and tension-

Photographs by Gunite Contractors Association

Guniting operation under way on the dome of White Memorial Seventh-Day Adventist Church. Height of dome above the floor is 70 ft; the diameter is 107 ft



Overall view of White Memorial church and classroom wing which connects it to chapel (not in picture). Dome ranks in size with some of the largest in the West



ing, eight pilasters at 45 degree intervals were detailed as a part of the ring girder. One cable from each side could thus terminate at the opposite face of the pilaster and one cable pass by, thus providing a minimum of two cables at all points. The "Schematic Plan Layout" illustrated will clarify this arrangement. Each cable consisted of a flexible galvanized metal sheath containing 18 ungalvanized wires 0.196" in diameter. The total area of the wires in each cable is 0.543 sq. in.

The specifications required the wire to have a minimum ultimate strength of 250,000 psi. with a minimum elongation in 10" of 2%. The wire was furnished by the American Wire Rope Co. and manufacturers tests showed a strength of from 250,000 to 255,000 psi. with an elongation of about 5%. Confirming tests made by Smith-Emery Co. of samples of the wire furnished showed an average strength of 268,670 psi. and elongation from 4% to 6%. A certificate was furnished by the Blue Diamond Co. that material furnished to the jobs was the same as that sampled and tested by Smith-Emery.

The cables were installed and stressed by the Blue Diamond Co. The cables were laid to a uniform curvature in a cage of conventional reinforcing and attached to anchorage assemblies by the Freyssinet method. Care was taken that the form at the anchorage face of the pedestal was a plane at right angles to the cable at that point. As the sheath was rather flexible and the wires contained inside tended to regain the original curvature of the coil in which they were shipped, there was some difficulty in maintaining the cable at a uniform curve until the ring girder was cast, and considerable additional ties had to be secured to the cable for this reason

Tensioning procedure

As soon as the type of anchorages and other elements had been selected by the contractor and approved, a detailed procedure was prepared covering each step to be followed, giving the required jack pressures and expected elongations at each stage. A chart was also prepared for recording all observations.

The actual tensioning was carried out in two stages; the first when the ring girder concrete had sufficient strength and before casting the dome shell; the second and final stage when the shell itself had acquired sufficient strength. This procedure had two advantages. The first stage could be used as a test run to uncover any "bugs." Since the stress at this stage was only about ⅜ of the final, any such "bugs" could not be serious and time would be available to program changes in the procedure before starting the final stage. Also, initial adjustments due to early shrinkage and other adjustments could take place before final stressing and recording of elongations.

After attaching the hydraulic jacks to the wires in the first stage, they were first pumped up to a piston pressure of 500 psi. This initial tension took up the slack in the wires, so that elongation measurements were meaningless. Consequently this part of the elongation was calculated and added to subsequent observed elongations to arrive at a figure for the total elongation. Three wires at each end were then marked with scotch tape at a constant distance from the anchorage to the near edge of the scotch tape and subsequent measurements could be made at any stage to determine actual elongations at different increments of stress. A much smaller elongation than anticipated might indicate that the stressing was not effective over the entire length, and these observations were desirable for that and other reasons. A further precaution that might be desirable would be to mark all wires, even though only three would be measured. This would make possible visual observation if any single wire should slip or otherwise not move in unison with the others.

The balance of the first stage pressure was then applied, elongation recorded, the anchorage units plugged, and elongation again recorded. In the final stage, the cables were brought up to the final desired tension and plugged, with elongations recorded as before. Grout was then injected to fill the space between the wires and the sheath. The ends of the wires were not cut off, as they would later be encased in concrete roof fill on the area adjoining the dome.

Using the average of observed actual final tensions and the average of the actual loss of elongation at plugging, the total elongation was calculated and found to agree with the average of the total observed elongation within 2%, although, as might be expected, there were deviations in the individual cables from this mean value. The diagram shows the final tension along its length of this "average" cable.

Ring girder concrete

The concrete for the ring girder was cast on a trowelled surface which had been treated with an anti-bonding material so as to permit free movement when the post-tensioning took place. A 28-day strength of 4000 psi. had been specified and a design mix was set up by Smith Emery Co. with the dry loose proportions of 1C:1.77: 2.41R(1"), 4.75 gal. of water per sack and 0.5 lb. Plastiment per sack. The yield was 7.65 sacks of cement per yard. Special qualifying cylinders showed strengths from 2760 to 2890 psi. at 7 days, and from 4665 to 4755 psi. at 28 days. Job cylinders showed an average strength of 3145 psi. at 3 days, 3785 psi. at 7 days, and 5890 psi. at 28 days. The ring girder was cast July 26. The first stage of post-tensioning was done at an age of 5 days, when it had an approximate strength of 3785 psi. The final stage of post-tensioning was done at the age of 28 days, when it had a strength of 5890 psi. Concrete was kept nearly continuously moist from the time it was cast until stressed.

Concrete for dome shell

The concrete for the dome shell was specified as only 2000 psi. at 28 days, as the actual dome stresses were quite low. Because of concern about placing

This photograph shows special staging used by the guniting contractor to enable workmen to stay off of the concrete. In shooting the job he used two units working from opposite sides of the dome

Here, workmen are shown shooting one of the four annular rings of gunite, shot on four successive days. Principal reinforcing is No. 4 bars, 9 in. o/c both ways and centered in slab

Control of curvature was provided by using pencil rods set on 6 in. spikes driven into the sheathing. As shown here, the rods were removed before screeding began difficulties at the steepest part of the dome, the contractor elected to use gunite instead, with a mix designed to reach 3000 psi. in 28 days. The guniting was done by the F. W. Case Corp. under the supervision of a registered deputy inspector. Work was started at the bottom by two crews and brought up to annular pour joints at the end of each day. In addition to the usual test cylinders, special small panels were shot for each day's pour from which cores could be taken and tested. The cylinders had an average 28-day strength of 4948 psi., while the cores had an average 28-day strength of 440 psi.

The shell was gunited from Aug. 8 to Aug 11 and was sprayed continuously during the curing period. It was approximately 16 days old at time of final stressing, with an approximate strength of over 4000 psi. Shores were lowered Aug. 29 by starting at the center and loosening uniformly all the way to the outside, after which the work of stripping forms was commenced. Any settlement at the crown was so small it was not measurable and, thus, demonstrated the value of pre-stressing the ring girder. At conclusion of guniting it was noticed that some areas showed high spots and flat spots. Small cores were drilled to make sure the thickness of shell had not been reduced at the flat spots. It was found that minimum thickness was as calculated and that thickness was exceeded at high spots.

Gunite application

Good control of curvature and proper screeding to get a uniform finish were essentials in concreting the dome shell to design requirements. At first the gunite contractor considered doing the work in vertical panels, like the segments of an orange, but decided he would have better control with horizontal joints and shot the job in a series of four annular rings on four seccessive days.

His control was provided by the use of pencil rods (removed before the screeding began) set on 6" spikes driven into the sheathing to the proper depth. The rods were placed about 4' apart, circumferentially, at the elevations required to give correct taper to the finished dome.

In shooting the job, the contractor used two units working from opposite sides of the dome. He also doubled up on the number of finishers employed, using twice as many as is customary in order to keep the slope uniform.

Particular care was taken to keep the joints clean in order to get good bond between annular sections. Reference to the accompanying photographs will show the special staging used by the contractor to enable workmen to stay off of the concrete.

Forming for the dome concrete, performed by the general contractor, was from 50' to 70' in the air. Four-by-four shoring was used, tied at frequent midpoints, and the form was composed of 1x6's, placed in an annular pattern. Shimming for final levels was done at the top of the shoring.