Precast prestressed clinker storage silo saves time and money

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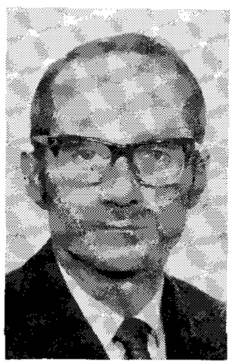
The author, who was responsible for the overall structural design of this precast prestressed, conically-shaped storage facility in St. Constant, Quebec, describes the design-construction highlights of this very functional and economically built structure.



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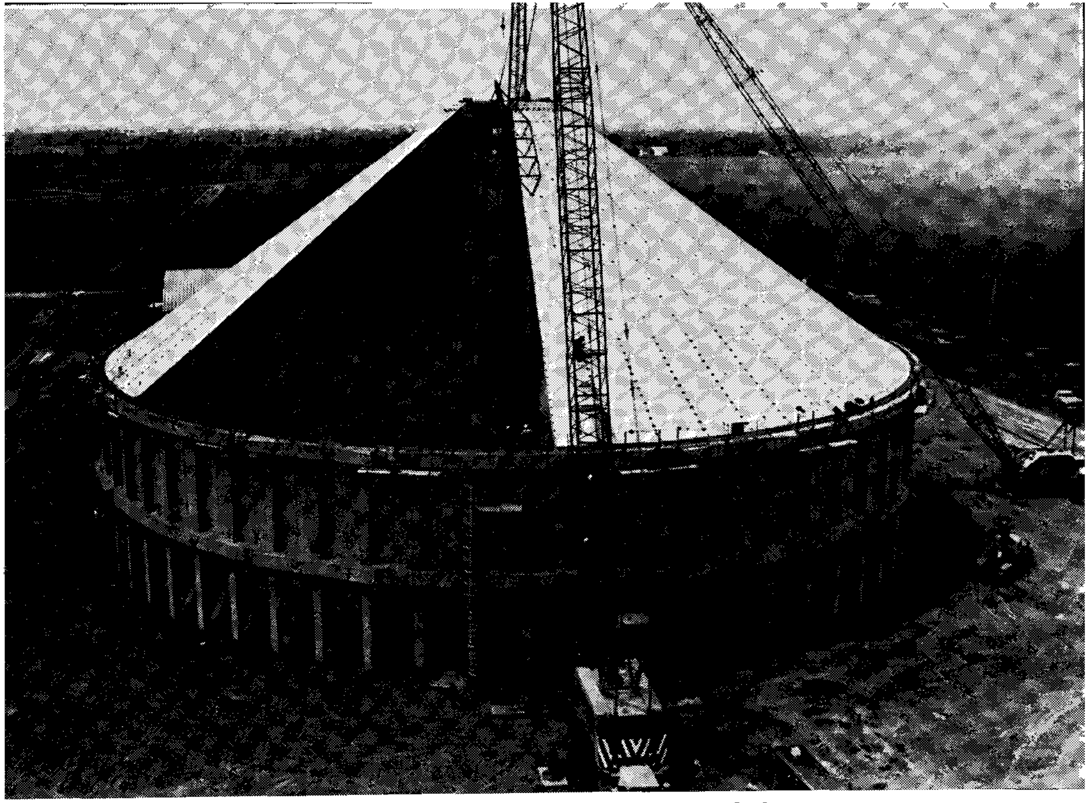


Fig. 1. Clinker storage silo nearing completion.

Precast prestressed concrete was used very effectively and economically to build a major portion of a huge cement clinker storage silo (see Fig. 1) for Canada Cement–Lafarge (Canfarge Ltd.) in St. Constant, Quebec (about 10 miles south of Montreal).

It is estimated that the precast prestressed design saved about $225,000 in construction and operating costs.

The storage silo was completed in September 1975.

This very functional structure, which will be used to store 120,000 tons of cement clinker at a temperature of 120 F, has an inside diameter of 214 ft, a height above ground of about 130 ft, and a depth below grade of 79 ft, and covers an area of 36,000 sq ft.

The structure, consists essentially of four major elements.

1. A cast-in-place foundation system made up of
   - —A ring beam supported on a concrete curtain wall. The ring beam is post-tensioned.
   - —A series of 64 pile caps interconnected by a cast-in-place ring beam. Each pile cap is supported on a group of three piles.
   - —An inverted conical substructure situated underground, and consisting of a cast-in-place reinforced concrete slab on grade.
2. An inverted conical structure starting out from Ring No. 1. (precast reinforced concrete).
3. An intermediate circular wall (precast segmental post-tensioned concrete).
4. A top conical shell roof (precast prestressed concrete).

Fig. 2 shows schematically how the four major structural elements are interconnected. Fig. 3 illustrates the statical

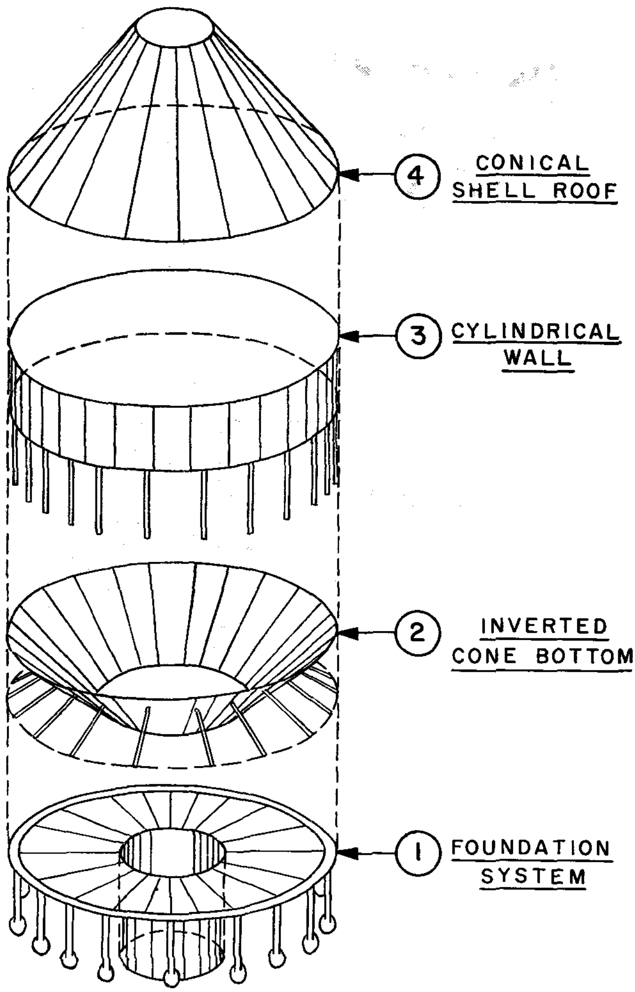


Fig. 2. Schematic diagram showing make up of four structural elements.

force interaction of the major elements of the structure.

This very heavily loaded structure makes maximum use of precast concrete combining mild steel reinforcement, prestressing, and post-tensioning techniques very advantageously. Altogether, only five basic types (see Table 1) of precast concrete components were used, each component being repeated sixty-four times.

The precast elements in the base structure include radial tie beams, slanted V-shaped columns, bottom cone tee-slabs, and wall panels. The units in the conical roof are prestressed modified single tees, 116 ft long, with flanges tapering to the top compression ring. Post-tensioning in ring beams No. 3 and 4 tie the components together.

This paper will describe the functional requirements of the storage facility and then will discuss the structural design and erection aspects of the project.

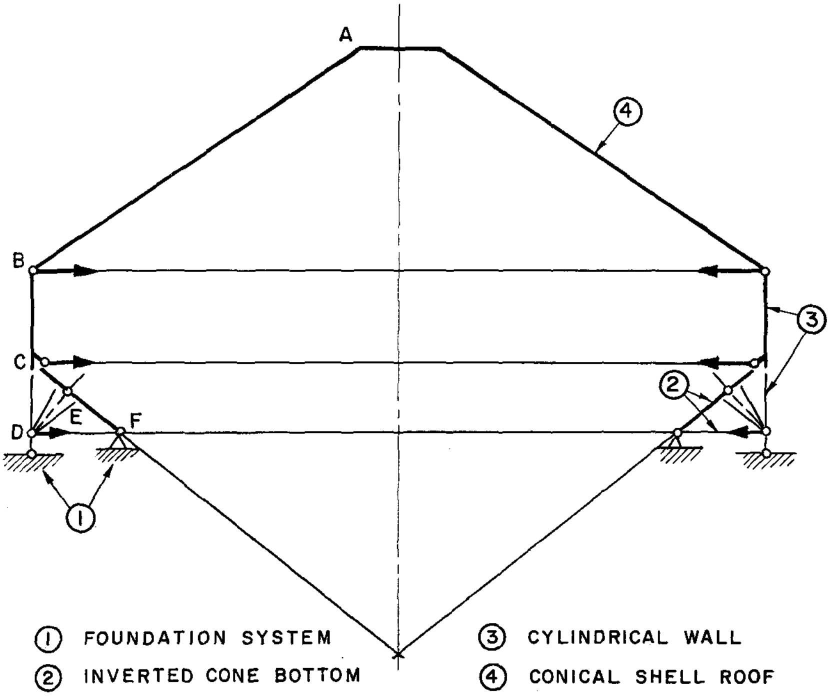


Fig. 3. Statical force system of major interacting structural elemer s.

Functional Requirements

The structure is designed to store 120,000 tons of cement clinker during those months of the year when production is in excess of sales.

Several other building systems were investigated (including structural steel) for storing the clinker. The final decision to use an essentially precast prestressed system was based on economic, functional, and structural considerations.

The filling up of the storage facility with cement clinker will be done with a belt conveyor coming through a conveyor gallery at the tip of the upper cone.

The clinker will be dropped into the silo. When the lower cone and the cylindrical portion of the facility is filled, the clinker will freely form the top cone by depositing according to its angle f repose.

Properties of clinker

Volume weight: 85 to 96 lbs per cu ft
Temperature at arrival: 120 F
Angle of repose: 31-33 deg.

The cement clinker will be reclaime at the bottom of the cone where th clinker will enter the reclaiming chamber through four large openings via gravity. The material will then be fed by feeders onto a belt conveyor situated in the reclaiming tunnel.

The advantage of the above system lies in the very simple and low maintenance mechanical installations and the economical way of moving the clinker.

We believe that this method of storage, also known and applied in the mining industry, has not yet been applied for clinker storage in North America.

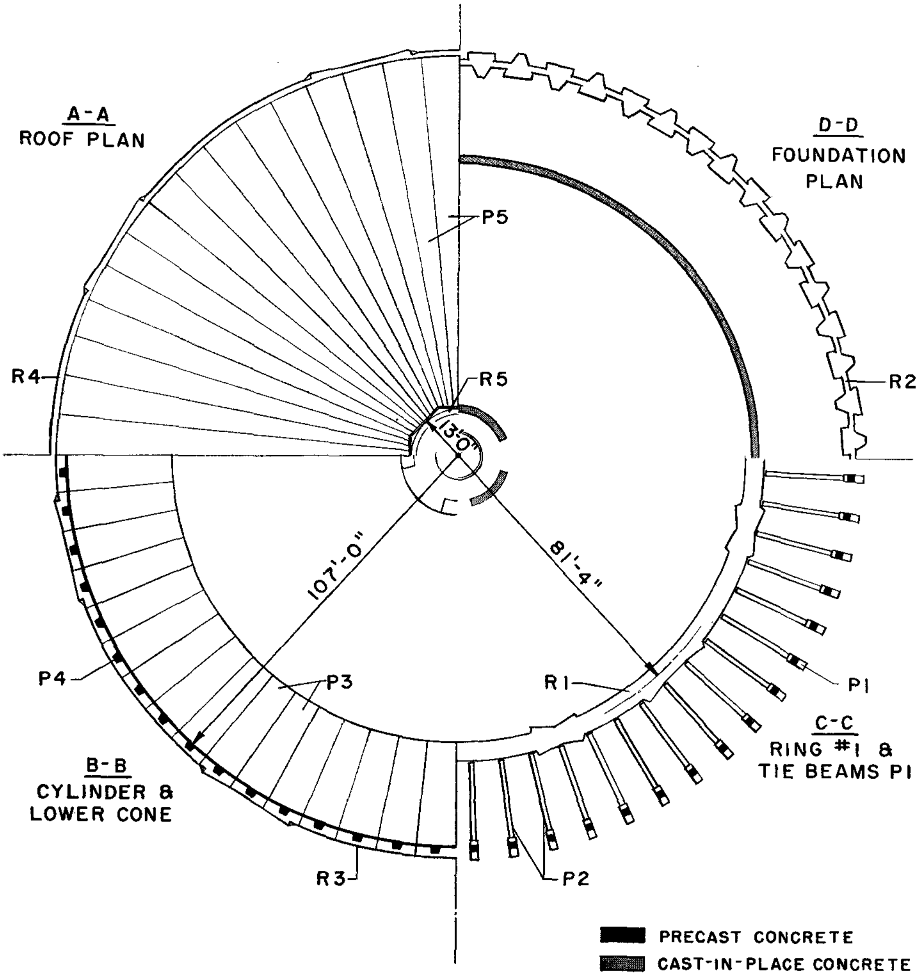


Fig. 4. Plan of structure showing main precast concrete components.

Structural Design

The shape of the structure is composed of two cones with a short cylindrical segment between them.

The lower cone is partly underground, whereas the remaining part of this cone, the cylinder and the top cone are above grade.

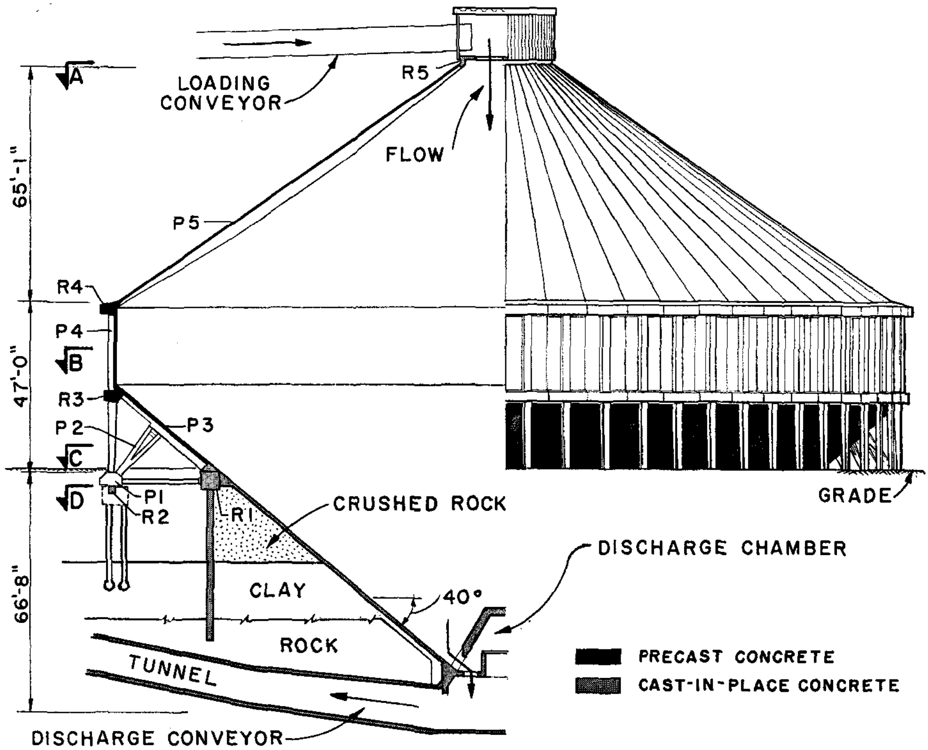
The main dimensions of the structure are:

Inside diameter: 214 ft.
Height above ground: 129 ft 6 in.
Depth below grade: 79 ft.

Figs. 4 and 5 show a plan and elevation of the structure and also indicate the major component parts. Dimensional details and weights of the five basic types of precast components are shown in Table 1 and Fig. 6.

Design requirements

The structure had to satisfy the following basic design requirements:



LEGEND

P 1 - RADIAL TIE BEAM AND ANCHORAGE BLOCK
P 2 - SLANTED V-COLUMN
P 3 - LOWER CONE ELEMENT
P 4 - WALL PANEL
P 5 - CONICAL ROOF ELEMENT

R 1 - RING BEAM NO. 1
R 2 - RING BEAM NO. 2
R 3 - RING BEAM NO. 3
R 4 - RING BEAM NO. 4
R 5 - RING BEAM NO. 5

Fig. 5. Cross section of structure showing location of main precast concrete components.

1. Be competitive with other alternative systems, including the much used method of storing clinker in a long stock pile covered with a steel-framed envelope.

2. Follow the shape of the stored clinker as closely as possible.

3. Have a roof span of 216 ft with a concentrated equipment load at the center.

4. Carry economically the very high vertical and horizontal loads of the stored material.

5. Have minimum maintenance costs while simultaneously providing a weatherproof enclosure and preventing escape of dust from the inside.

6. Use, preferably, concrete as the building material produced by the owners of the plant.

After investigating several alternatives, an essentially precast prestressed structure was found to fulfill best the above requirements.

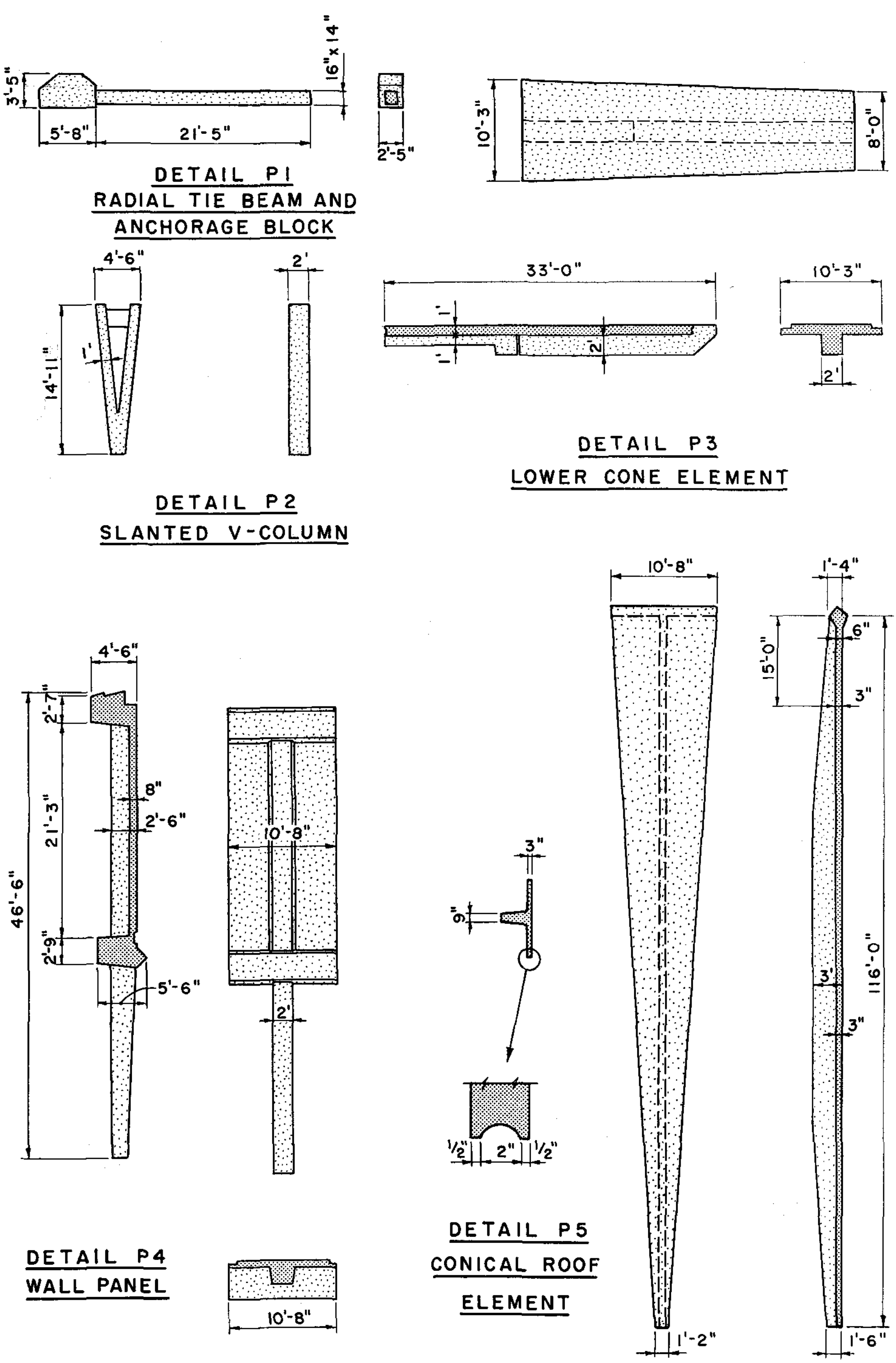


Fig. 6. Dimensional details of major precast concrete components.

Table 1. Summary of dimensions and weights of precast components

The structure is composed of five basic types of precast concrete components. Each component is repeated sixty-four times.

P1: Radial tie beams (post-tensioned to Ring 1)

Length: 27 ft 2 in. Section: 14 x 16 in.

Anchorage block: 2 ft 5 in. x 3 ft 5 in. x 5 ft 8 in.

Weight: 11.1 kips

P2: Slanted V columns (reinforced)

Length: 14 ft 11 in.

Width at top: 4 ft 6 in.

Section: 1 ft x 2 ft

Weight: 9.5 kips

P3: Lower cone element (reinforced)

Length: 33 ft

Width:

High end: 10 ft 3 in. Low end: 8 ft

Slab thickness: 1 ft

Rib dimensions (below slab):

Depth: 1 ft and 2 ft. Width: 2 ft

Weight: 53.8 kips

P4: Wall panel (reinforced and segmental post-tensioned)

Height: 46 ft 6 in. Width: 10 ft 8 in.

Wall thickness: 8 in.

Column dimensions:

Width: 2 ft

Depth: variable to 2 ft 6 in.

Horizontal ribs: About 4 ft 6 in. x 3 ft

Weight: 81.0 kips

P5: Conical roof element (prestressed)

Length: 116 ft

Flange width:

Bottom: 10 ft 8 in. Top: 1 ft 2 in.

Flange thickness:

Generally: 3 in. Bottom: 3 to 6 in.

Web dimensions:

Width: 9 in. up

Depth: variable from 1 ft 4 in. to 3 ft

Weight: 68.0 kips

Site and soil conditions

The site, which is located within the cement plant, was basically level and had good access from all sides.

The profile of the subsoil is as follows:

Grade to −2.0 ft natural overburden
−2.0 to −22.0 ft gray soft clay
−22.0 to −42.0 ft dense till
−42.0 ft on bedrock

Structural components

The structure consists of the following main components:

Conical roof structure (above grade) —The components of the roof comprise 64 identical precast prestressed pie-shaped units (P5), the compression ring No. 5, and the circular penthouse slab resting on the compression ring.

The precast prestressed elements were produced in a regular single tee bed with suitable modifications to accommodate the variable dimensions of the unit.

The unusual shape of the elements combined with the prestressing presented a formidable design problem which was solved with the aid of a computer.

The stresses in the roof elements were investigated for the following load conditions:

1. Stripping, storage, and transportation, with the precast unit in a horizontal position (span = 115 ft).

2. Erection and temporary condition before completion of roof, with the precast unit in an inclined position (span = 94 ft), subject to wind loads.

3. Final position, with the roof acting as a conical shell, subject to snow, wind, and temperature effects.

A computer program was developed to check the stresses occurring in the roof units at the above stages of construction.

This program computed the variable

section properties along the entire length of the unit at 1-ft intervals, found moments and shear forces for all loading cases and calculated the stresses due to prestressing.

Computer output was received for 115 sections along the length of the unit, with all relevant information printed. Table 2 shows a sample of the output for one of the sections.

The precast roof units are connected to each other through the radial joints by welded connections and grouting of the joints.

At the top end, the cast-in-place ring No. 5 joins the members. At the lower end, the units rest on the wall panel and a cast-in-place monolithic connection between ring No. 4 and the units restores continuity.

Table 2. Sample computer output showing summary of stresses of Section 54 of roof slab.

LOADING STAGE	VARIABLE PRESTRESS	STRESSES, KSI	
		TOP	BOTTOM
STRIPPG	0.95	-0.824	-1.313
	1.00	-0.770	-1.577
	1.05	-0.716	-1.840
STORAGE	0.95	-0.792	-1.377
	1.00	-0.738	-1.641
	1.05	-0.684	-1.905
TRANSP.	0.95	-1.273	-0.177
	1.00	-1.223	-0.420
	1.05	-1.174	-0.663
ERECTN.	0.95	-0.571	-1.586
	1.00	-0.521	-1.829
	1.05	-0.472	-2.071
ERECTN. + WIND	0.95	-0.818	-1.090
	1.00	-0.768	-1.333
	1.05	-0.719	-1.576
ERECTN. - WIND	0.95	-0.324	-2.081
	1.00	-0.274	-2.324
	1.05	-0.225	-2.567
FINAL	0.95	-0.705	-0.927
	1.00	-0.662	-1.135
	1.05	-0.620	-1.344
FINAL1 +MB	0.95	-1.432	-0.260
	1.00	-1.390	-0.052
	1.05	-1.347	-0.157
FINAL2 -MB	0.95	-0.542	-1.583
	1.00	-0.499	-1.791
	1.05	-0.457	-1.999

NOTE

A=581.89 D=36.000 YT=11.973
I=72499.6 W=0.606 PR=604.20
PE=556.37 PF=476.96 EXC=21.152

Weatherproofing was achieved by applying one coat of epoxy paint on the surface of the precast units in the plant before shipping the units to the job site. After erection, the joints between the units were caulked.

Cylindrical wall and columns—The cylindrical wall is composed of 64 basically identical precast reinforced concrete elements.

The top part of the units, forming the vertical cylindrical wall of the silo, has a tee-shaped cross section.

The rib serves as a column and a moment-resisting member and the 8-in. thick flanges form the cylinder.

Below the departure of the lower cone, only the column portion is carried down to sit on the tie beams and support the wall and roof.

At the intersection of the cones and cylinder, two horizontal ribs are formed which, when joined, compose the tension rings (Rings 3 and 4).

On-site post-tensioning was used to tension the ring beams of this structure.

Connecting Rings 3 and 1—The cone-shaped bottom is composed of 64 identical precast reinforced concrete elements.

These tee-shaped members have a 12-in. thick flange forming the cone and 24-in. wide ribs with a 24 and 36-in. depth.

The precast units are supported at their ends on the rings and in between by the V-shaped precast concrete columns. The columns in turn rest on the slanted face of the tie beams.

Radial tie beam system—To carry the horizontal thrust of the tilted V-columns, there are 64 precast post-tensioned tie beams radiating outward from Ring 1.

The tie beams are supported at their outer end by the pile caps situated in Ring 2. Between the tie beam and the pile caps, there is a low-friction bearing device to allow unrestrained radial movements for the structure.

Pile caps and cast-in-place foundation below grade—Each of the 64 tie beams is supported on pile caps resting on three 20-in. diameter Franki piles. The piles are built into the very dense glacial till and their onion-shaped foot is only a few feet above the rock level.

Pile caps are connected with the cast-in-place tie ring No. 2 (108 ft radius) which also carries the small horizontal forces due to friction of the bearing pads.

Bentonite wall and tension ring (Ring 1)—A 24-in. thick concrete curtain wall, with an 81 ft 3 in. radius, was built using the bentonite slurry method.

The purpose of the wall is to:

1. Support Ring 1 and its vertical reaction.
2. Provide the cofferdam for the excavation.
3. Serve as a cut-off wall to stop inflow of ground water.

The bentonite wall is anchored 5 ft into the bedrock. On the top of the wall there is a 5 ft x 5 ft 2 in. cast-in-place post-tensioned ring beam (Ring 1).

This ring beam receives the lateral force of the tie beams and converts the load into a large ring tension force of 7500 kips.

Lower cone on ground—An approximate 20-ft thick layer of soft and weak clay was removed and replaced by compacted granular backfill.

Between the rock and/or till and the cast-in-place 1-ft thick concrete apron, a 2 to 3-ft layer of compacted crushed stone was placed.

This aggregate is used as a base for the slab and for draining any ground water inside the bentonite wall.

The concrete slab on ground is reinforced with mild steel and subdivided with control joints.

Reclaiming chamber and tunnel—These substructures were built using cast-in-place reinforced concrete. Two points are worth mentioning:

1. The top cone of the 32-ft diameter reclaiming structure supports the weight of the clinker pile, totaling 13,500 kips.
2. The tunnel was built using open excavation at the higher end, steel sheet piling and cofferdam protection at the midsection, and rock tunnelling combined with shotcrete solidification of the rock faces at the lower end.

Connections

Three main types of connections were used in the structure:

1. Welded connections between precast elements to secure erection stability and transfer of forces acting at this loading stage.
2. Cast-in-place concrete connections with overlapping reinforcing steel dowels to insure continuity and monolithic behavior.
3. Post-tensioning to join the segments of Rings 3 and 4.

Design Schedule and Construction Sequence

Preliminary design alternatives and estimating were conducted from January to March 1973. Final design was accomplished between August 1973 and February 1974.

The foundations and underground work were done from October 1973 through May 1974. The precast elements were fabricated between November 1973 and June 1974. Erection of the precast elements started in May 1974 and concluded in September 1974.

Due to construction strikes, the job site was shut down during August-September, 1974, and erection of the roof had to be postponed until June, 1975.

Erection sequence

Figs. 7 through 20 show in pictorial form the various construction stages of

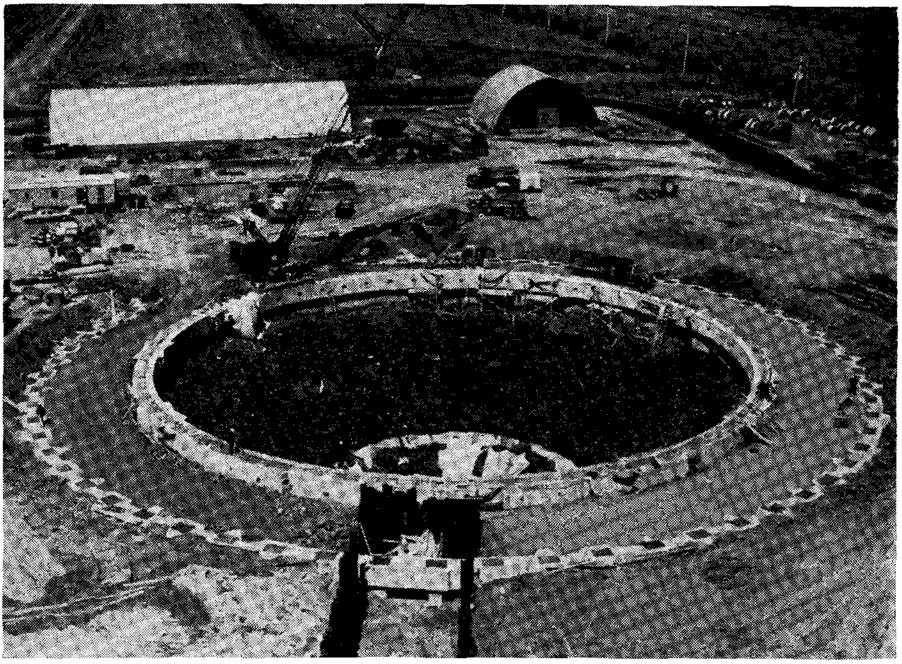


Fig. 7. Completed foundation showing pile caps and inner ring beam.

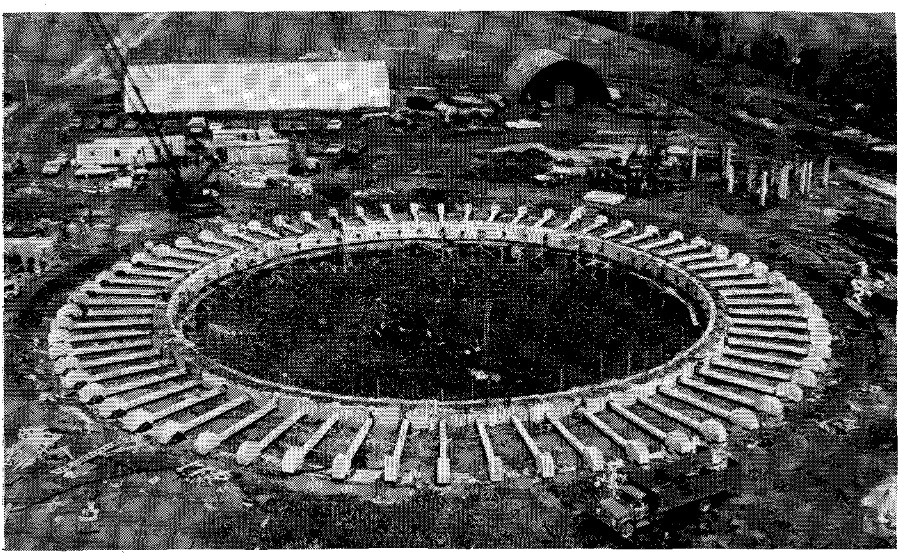


Fig. 8. Precast post-tensioned tie beams connected to anchorage blocks and inner ring beam.

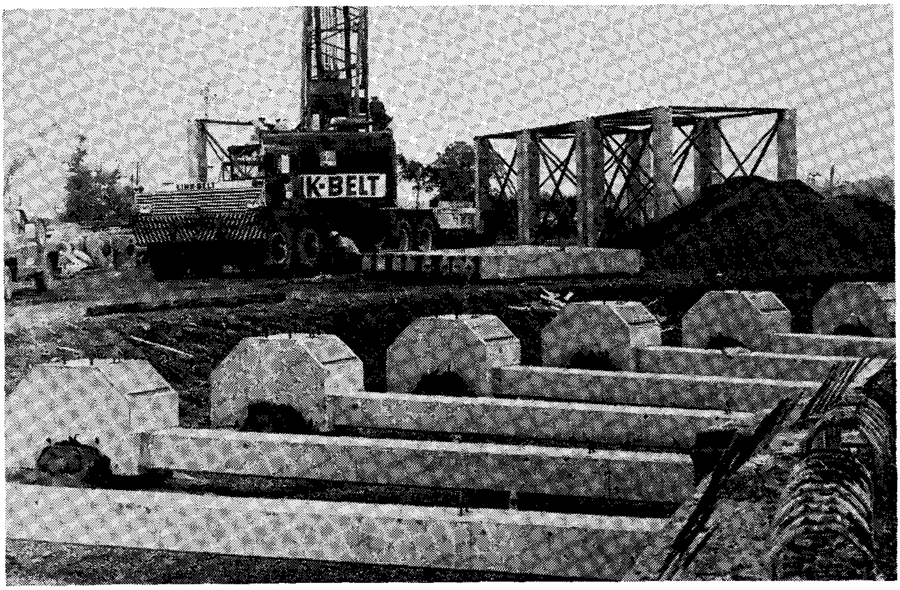


Fig. 9. Close-up of precast tie beams and anchorage blocks.

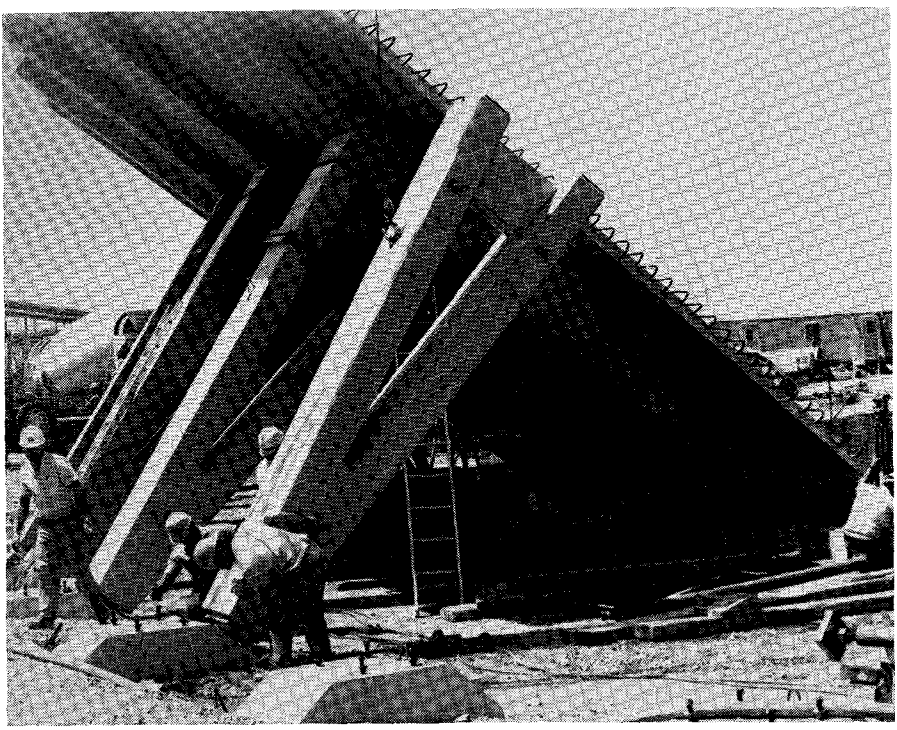


Fig. 10. Slanted precast V-columns being connected to anchorage block.

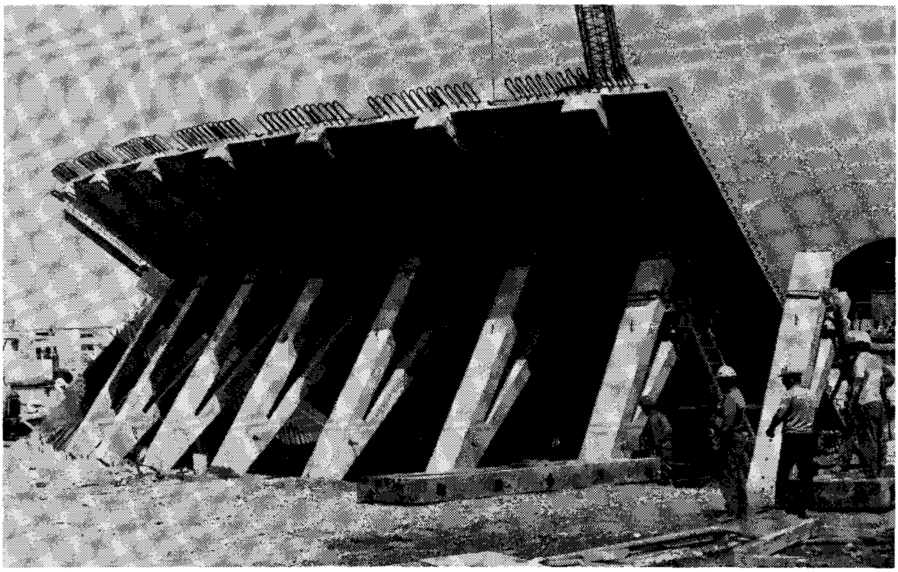


Fig. 11. Lower cone elements showing slanted precast V-columns and precast tee slabs.

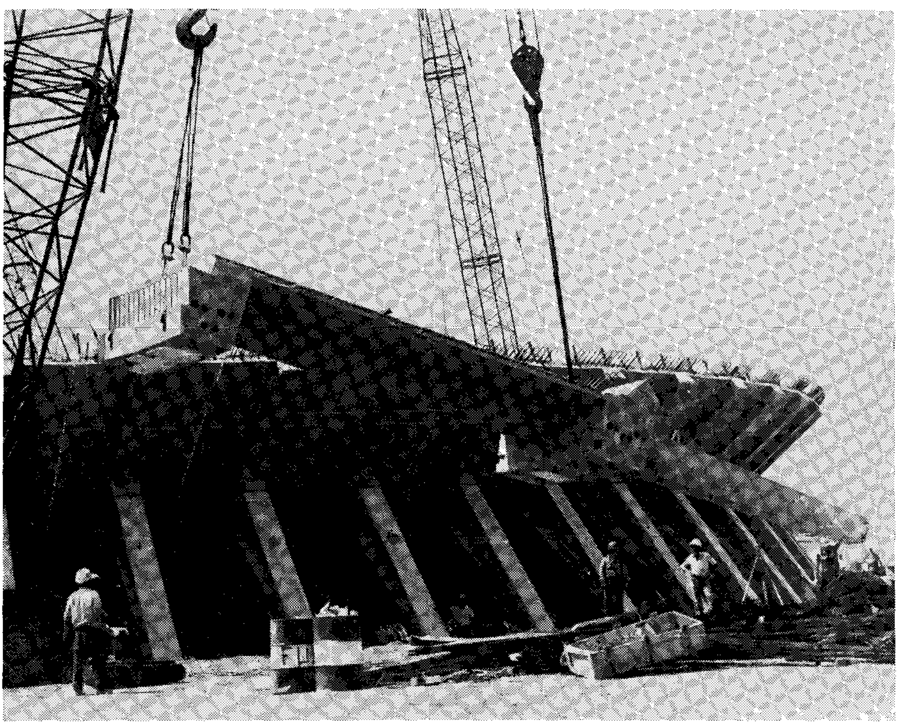


Fig. 12. Precast wall panel erection.

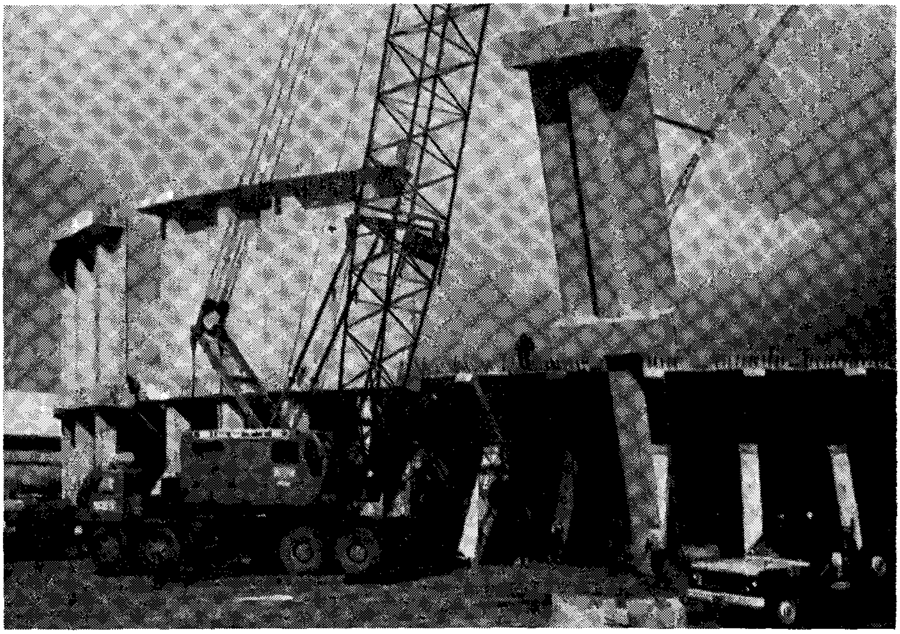


Fig. 13. Lifting of precast wall panel.

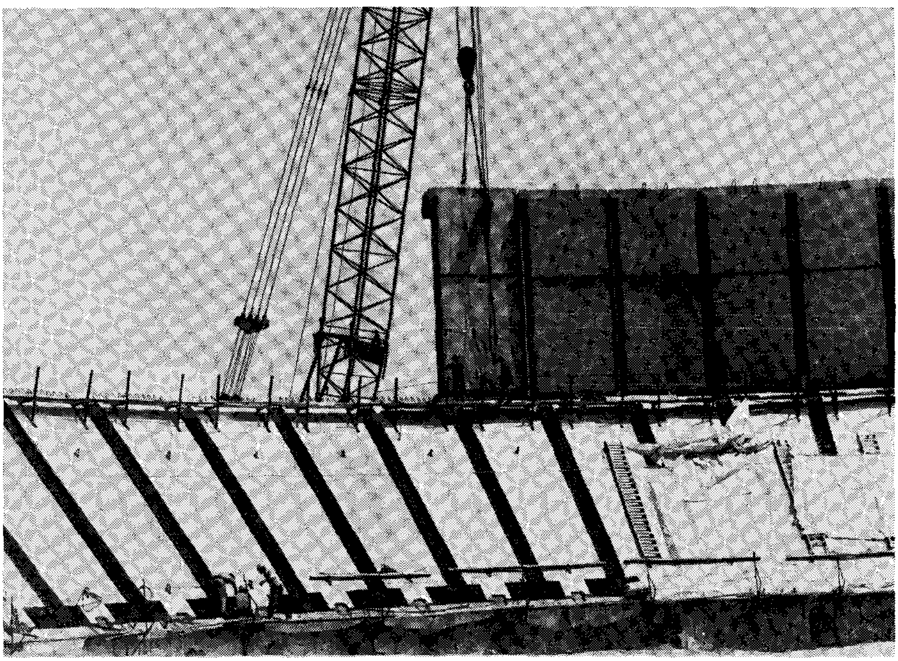


Fig. 14. Inside view of lower cone and partial wall panel erection.

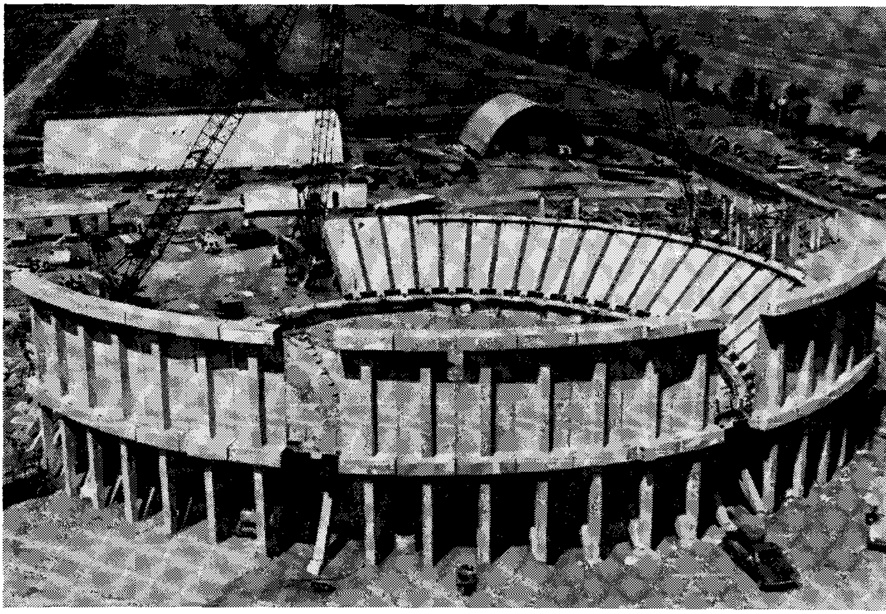


Fig. 15. Partially completed cone and wall.

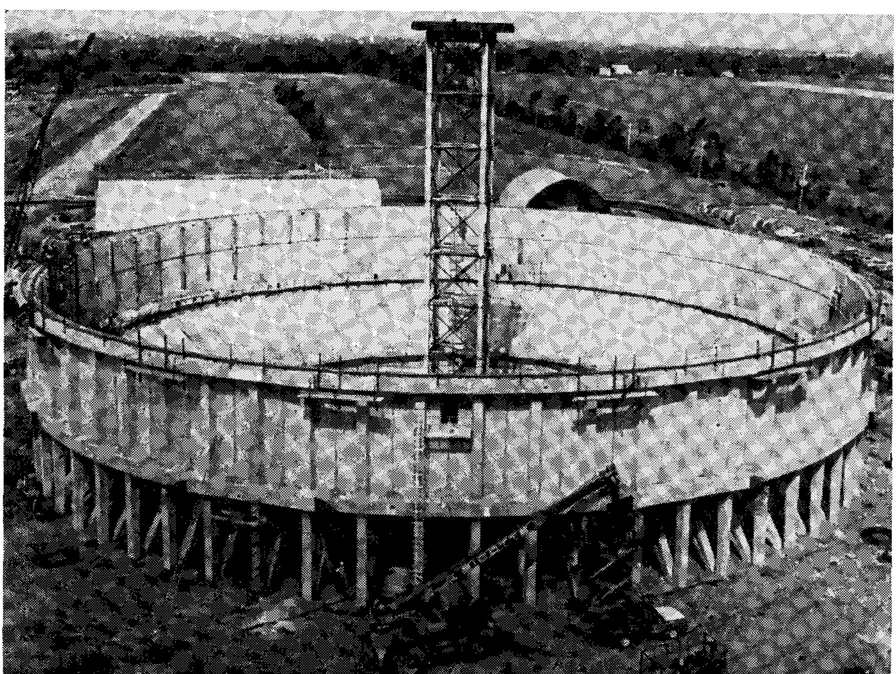


Fig. 16. Structure ready for roof erection.

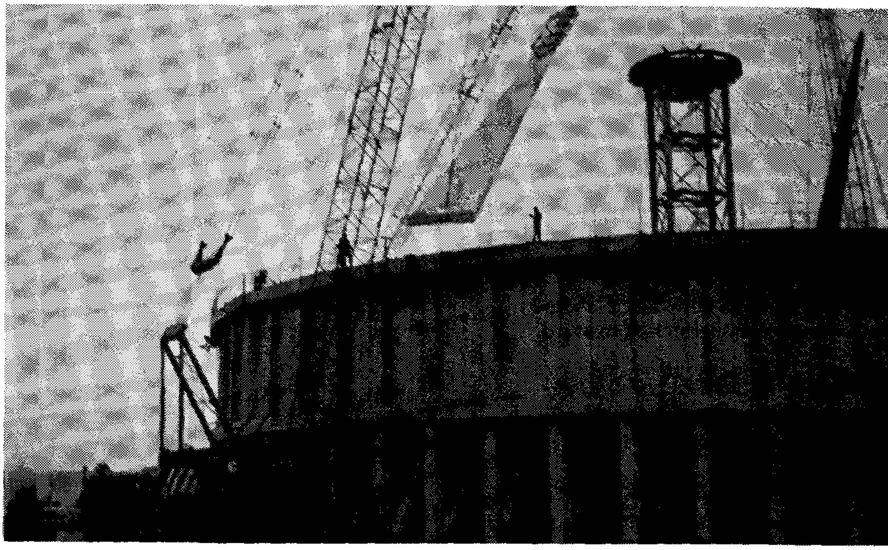


Fig. 17. First two roof units being lifted into place. Note that the segments were erected in pairs to keep the structural loads balanced.

Fig. 18. Close-up of temporary erection tower.

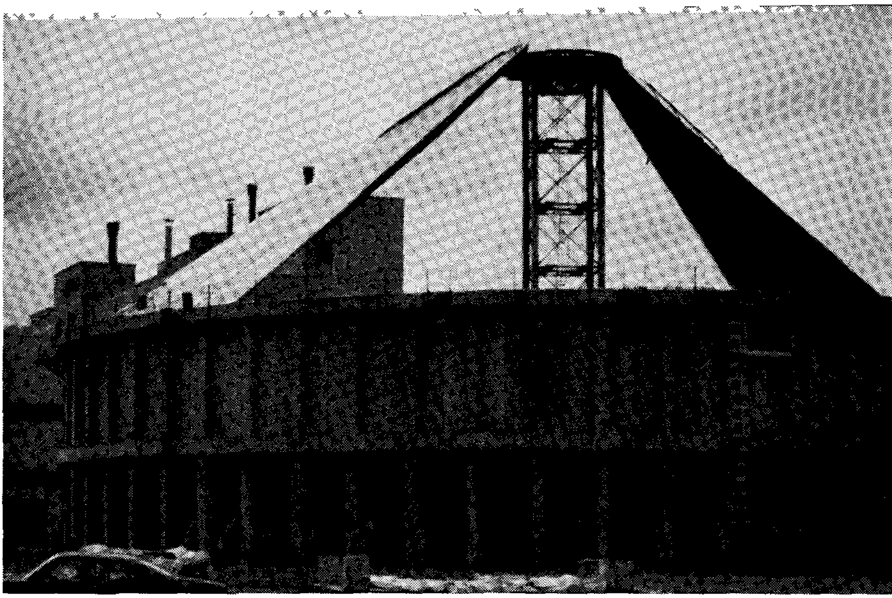


Fig. 19. Partially erected roof.

the storage silo from casting of the foundation to roof erection.

The first precast units to be erected were the radial tie beams, connecting the inner at-grade tension ring with the perimeter ring. After these were post-tensioned, erection of the V-shaped intermediate columns got underway. The erection of the above-grade sloped floor slabs followed, as soon as several of the V columns had been erected and braced.

After concreting the floor slab, exterior column/wall panels were erected, all site concrete joints were cast, and the lower tension ring was segmentally post-tensioned with tendons anchored at quarter-points around the perimeter of the silo.

Initially, the upper tension ring was only 50 percent post-tensioned, with the balance of the prestressing force to be applied after the dead load of the roof slabs had been added, and the roof had become self-supporting.

To provide temporary support for the ends of the roof slabs at the center of the silo, a 150-ft high square scaffold was erected, extending from the top of the reclaiming chamber at the base of the silo, to the peak of the roof. Built up of a series of 14 x 14 x 14-ft cubes, the scaffold rested on sand jacks, and was cable guyed at three levels with eight tendons per level, each tensioned to 10,000 lbs.

Erection of the silo superstructure, including the perimeter column/wall panels, and the center bearing scaffold tower, was finished by the end of July, 1974. However, a series of strikes, coupled with winter weather, stalled erection of the roof slabs until June 1975.

Using two 200-ton cranes, the contractor erected the 64 roof slabs in only nine working days, simultaneously erecting two slabs at a time to keep the structure balanced. The units were temporarily supported at the perimeter on the wall and at the center of the scaffold.

After the required concrete strength was attained in the concrete compression ring at the peak of the roof, the scaffold jacks were lowered, and the scaffold cubes were withdrawn by crane, through the opening in the roof.

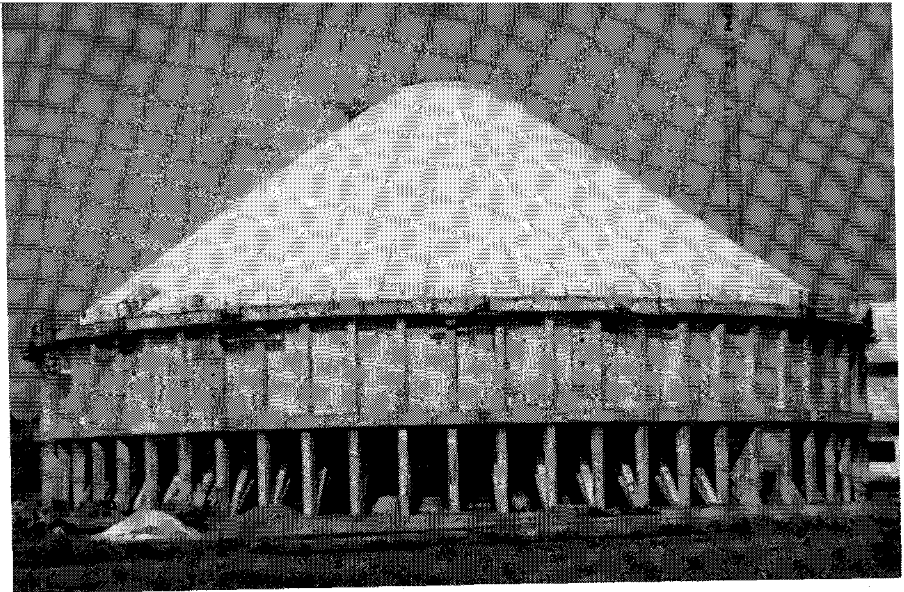


Fig. 20. Storage silo nearing completion.

The final 50 percent of the post-tensioning was applied to the upper tension ring before decentering. The precast closure slab was then placed atop the silo peak compression ring.

The structure was completed in September, 1975.

Concluding Remarks

Comparative cost figures worked out to be as follows:

Structural steel bid ....
........$33.40 per ton of clinker

Precast prestressed alternate ......
........$31.60 per ton of clinker

The precast prestressed design resulted in a total savings in construction and operating costs of $225,000.

The structure has been in operation since October, 1975. Because of the very unusual loads and temperature effects imposed on the structure, an extensive observation and surveying program extending for about 2 years was specified and is now in progress. Results of this study will be reported upon in the future.

This structure was honored in the 1975 PCI Awards Program.

In conclusion, it is felt that a very large and heavily loaded structure was designed very efficiently and economically using only five different types of precast concrete components in combination with mild steel reinforcement, prestressing, and post-tensioning techniques.

Finally, it is believed that the above design and construction method can be applied advantageously to similar silo storage structures.

Credits

Structural Engineer: William E. Pery, P. E., Kilborn Engineering, Ltd., Toronto, Ontario.

General Contractor and Supplier of Precast Prestressed Concrete: Francon, Division of Canfarge Ltd., Montreal, Quebec.

Construction Manager: Cipriano DaRe.

Post-Tensioning: Potenco, Inc., Montreal, Quebec.

Owner: Canada Cement LaFarge Ltd., Montreal, Quebec.