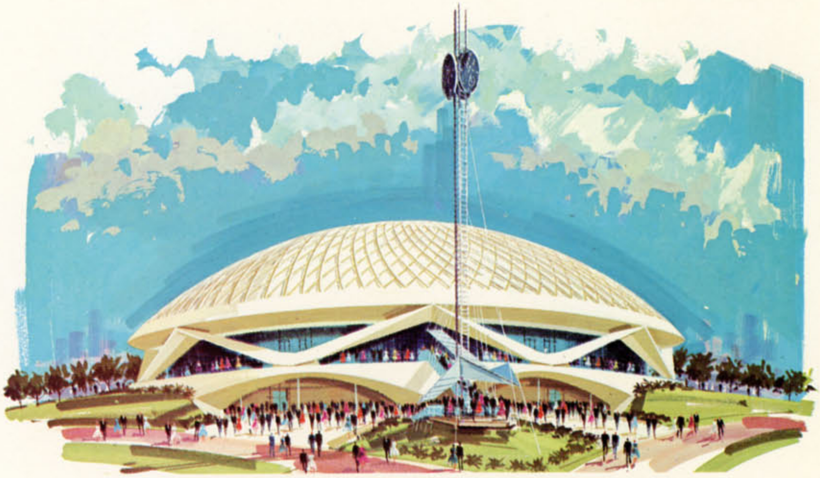
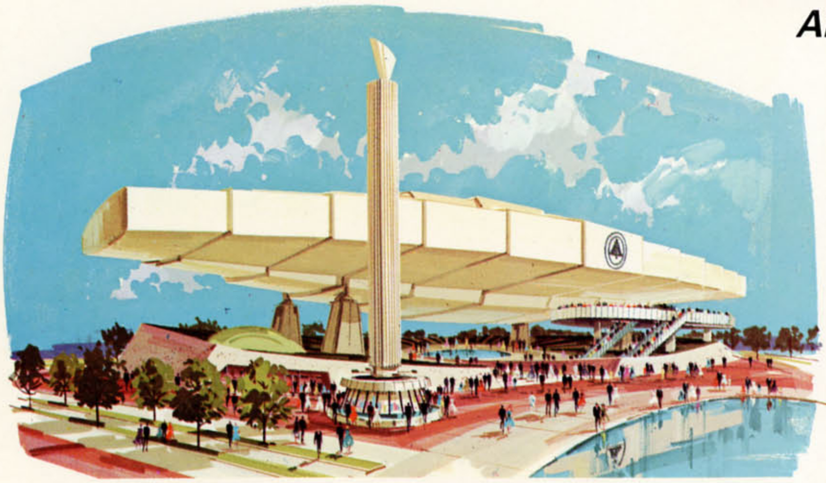


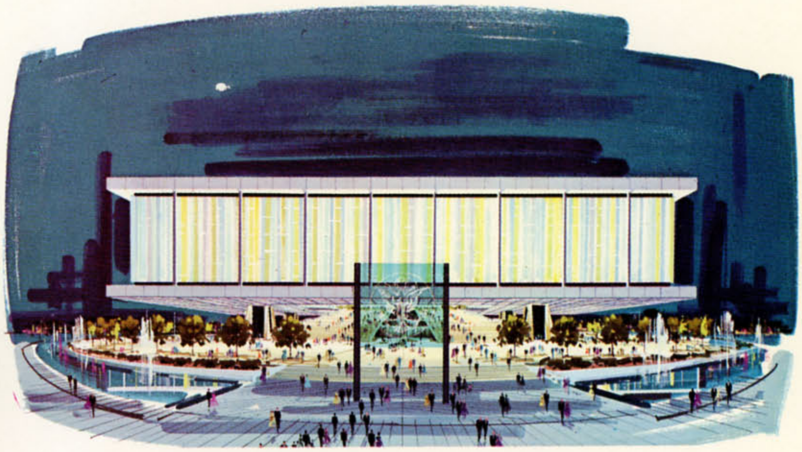
An Elegantly Domed Carousel...



A Colossal "Floating Wing"...

# World's Fair Preview

OCTOBER, 1963



A "Hovering" Hollow Square...

A New Concept in Space Structures...

...all described on the following pages

BETHLEHEM STEEL

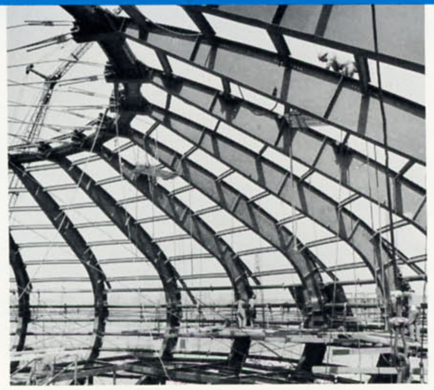
BETHLEHEM STEEL



A lamella steel pipe dome crowns the General Electric Company Pavilion

Steel U-frames connected to curving trusses frame the ride for the Bell System Exhibit

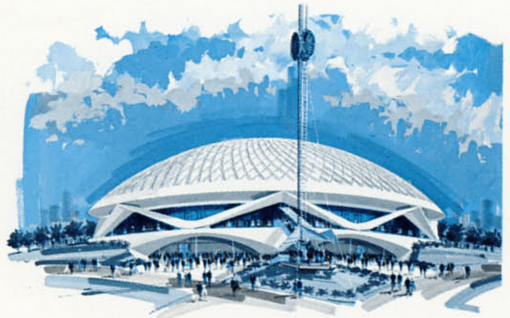
Lofty steel towers support eight giant trusses for the United States Pavilion



All-welded steel ribs, unique space structure, highlight The Travelers Insurance Pavilion

*Four remarkable structures . . . all framed with steel . . .*

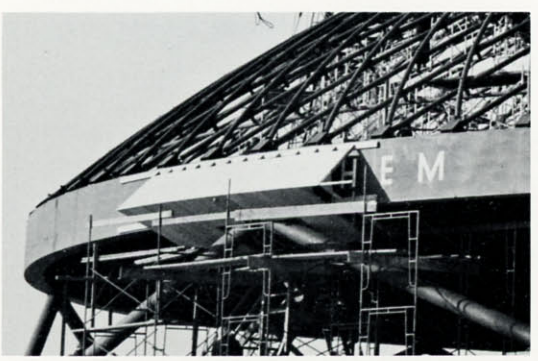
*fabricated and erected by* **BETHLEHEM STEEL**



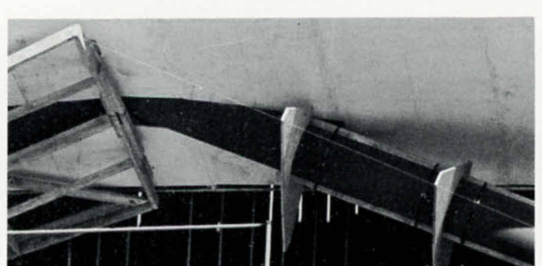
## THE GENERAL ELECTRIC COMPANY PAVILION

# *An Elegantly Domed Carousel*

Meridians of steel tubing spring from the ring girder (bottom), and support a lower course of horizontal hoops. Formed steel decking attached to the hoops was later covered with insulation, then plywood, then a continuous silicone rubber membrane.



Here a decorative soffit is being applied to the all-welded ring girder, which is supported at eight points by sixteen sloping steel pipe columns, 18 in. in diameter, with 1-in. walls.



Photographs above and at right show how the pipe columns were encased in plywood forms to achieve the desired architectural effect.

This is basically a round structure with an open circular center well, topped with a unique lamella pipe dome springing from a compression ring girder at the third level. The most unusual functional feature is a circular, rotating section, mounted on the steelwork at the second level, permitting the six theaters to rotate to each of six fixed stages. The exterior wall of the theaters is exposed to view under the deep overhang of the dome roof. The over-all effect is that of a sparkling carousel, its motion simulated by the spiraling pipe members of the dome.

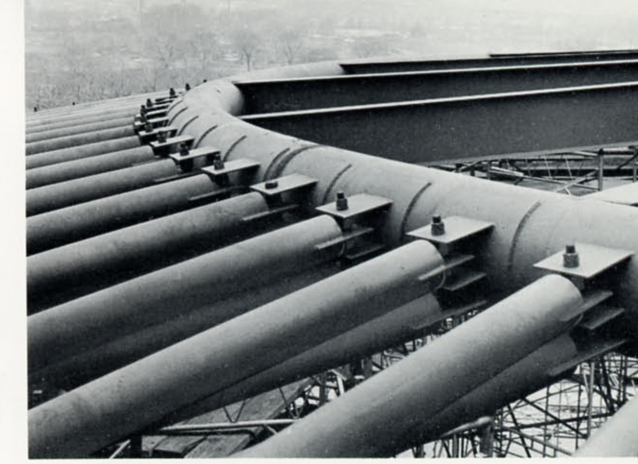
### THE DOME

This "crowning glory" of the General Electric Pavilion can be described succinctly as a 194-ft-diameter (to outside of ring girder) lamella pipe dome with a rise of 40 ft. It has two courses of steel pipe from which are suspended pipe hoops which carry the roofing material. The lantern (compression) ring at the apex is 43 ft in diameter.

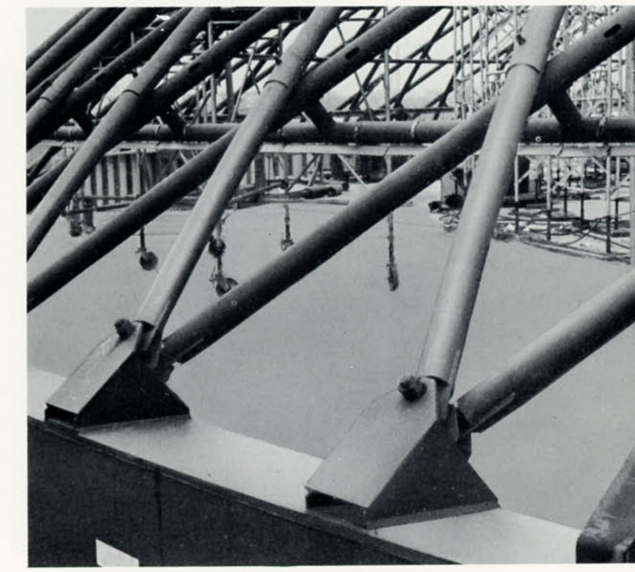
This framing system is extremely efficient. Weight of the lamella pipe and lantern ring is only 5.7 psf of roof area; 13.8 psf when the weight of the ring girder is added; and 16 psf if the hoops are included.

Of the structural steel in the building (about 750 tons), 120 tons are steel tubing. The 192 meridians required 16,000 lineal ft of 5-in. seamless tubing; the twelve concentrical hoops required another 6,000 ft of four-in. seamless tubing.

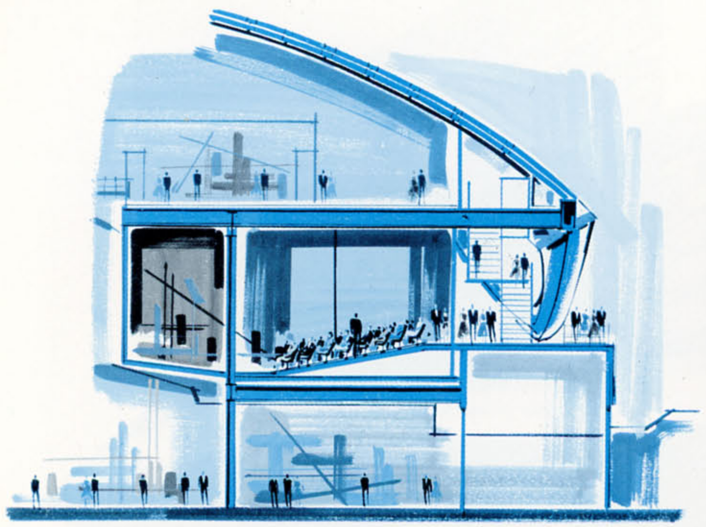
The pipe members of the lamella dome create an interesting visual effect. Each of the meridians follows a constant curve in a single plane.



In two levels, the meridians are pinned to the lantern ring (above) and to the ring girder (below), which take the thrust of the tubing.



Interior steelwork, including the ring girder, was erected before the dome. The lower level of steelwork at left supports the moving theaters; the sloping beams at center support the stages; the upper level of steelwork comprises a large exhibit area.



Cutaway sketch shows one of the six theaters. The carousel rotates slowly, stopping in front of the six stages, each of which presents a different act. At the upper level, visitors view a show including films projected on the under surface of the dome (sprayed with asbestos for smoothness).

## INTERIOR FRAMING

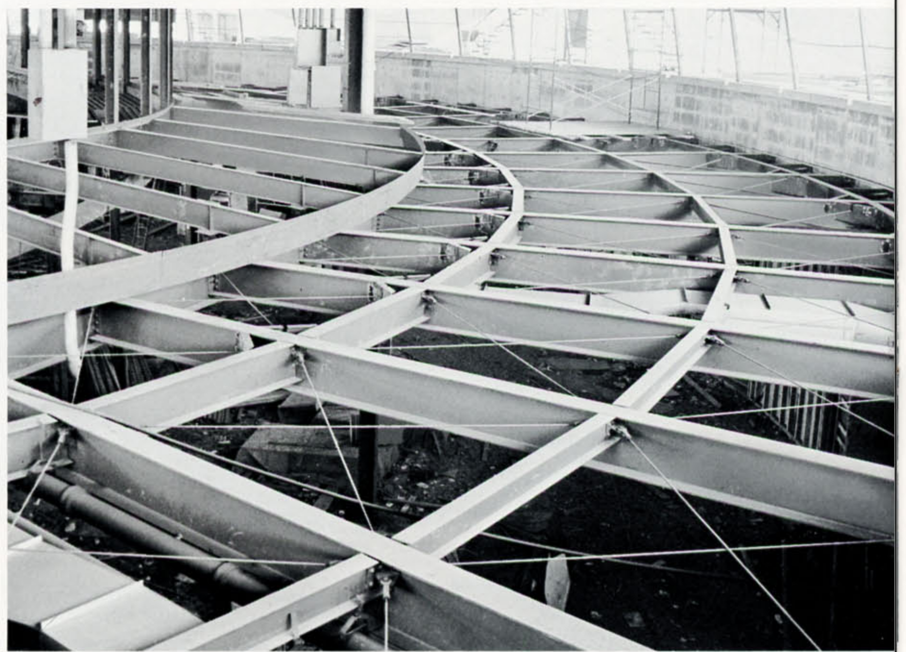
The first floor is enclosed in a 21-ft-high concrete foundation wall, much of which was later concealed from view by backfilling and landscaping. The wall is pierced by gracefully contoured entrance arches.

Eighteen-in. WF 45 radial girders are the main members supporting the theaters on the second floor. They are tied laterally with 8 WF beams, and are braced for additional rigidity with diagonal tie rods. At their "inside" ends, they tie into 24 WF 84 girders which form a twelve-sided polygon, supported on columns at each point, on an approximate radius of 54 ft from the vertical axis of the building. At their "outside" ends they are connected to the concrete floor system at the second floor level.

In plan, the lines of the radial girders are continued with 12 B 16.5 beams (typically) and extend inward with a slight upward slope. They support the floor of the exhibit area viewed from the theaters. Wide-flange hangers extending down from the third-level framing pick up the inner ends of these beams, and help support a steel-framed ramp which spirals down through the center well and is additionally supported by steel columns.

Also, an 11-ft-wide moving ramp, carried on steel beams, extends from a point on the second level some 80 ft across the diameter of the center well to an opposite point at the third level. It carries visitors leaving the theaters to additional exhibits above, after which they descend the spiral ramp.

At the third level, radial 27 WF 94 girders connect to the circumferential box girder and extend inward to support the top exhibit area. Inboard, these girders tie into a hexagon of 36 WF 300 girders, supported by six main columns. The radial lines are continued with 18 WF beams, from each of which are hung the 6 WF 15.5 hangers that extend to the second-level framing.



Note the braced supporting members for the carousel. Stage areas, at left, are elevated above this level and slope up toward the center well.

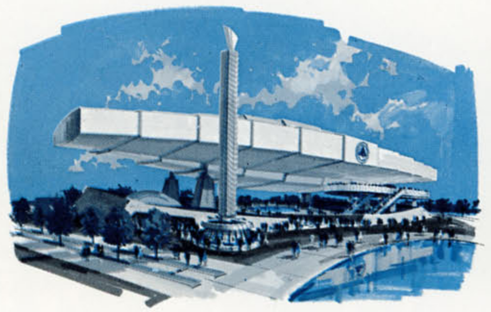


View from the second level. Steel decking for one of the stages is in the foreground. Framing for the circular ramp is cantilevered from vertical hangers. The ramp will bring visitors down to ground floor exhibits from which they proceed to the exits.

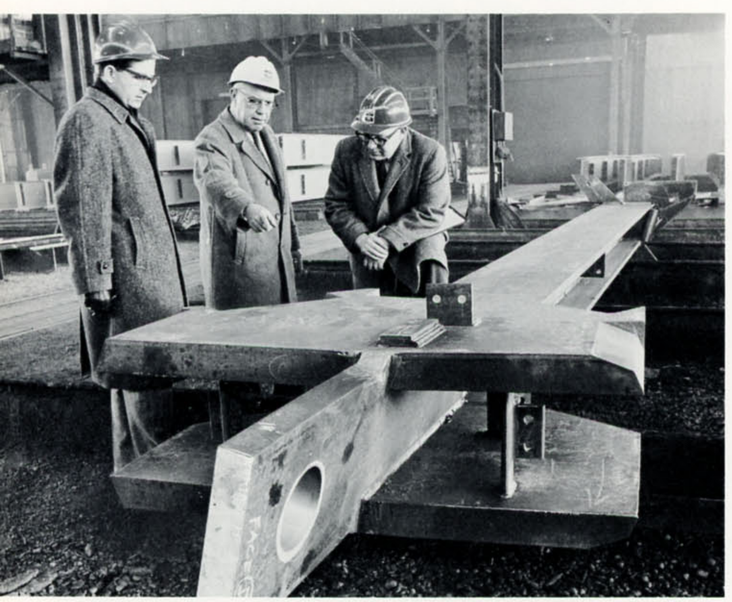
While it is true that all of the steelwork in the General Electric Pavilion can readily be disassembled at the Fair's end, and will have very substantial salvage value (the same, of course, is true of all structures described in these pages), the inherently specialized nature of the framing for exhibit areas makes it unlikely that the entire building would be re-erected elsewhere. However, the GE *dome* obviously could be re-used in any number of ways. Other than the welded box girder, all connections are pinned or bolted which, combined with the lightness of individual members, means that the dome can be taken down and re-erected at moderate cost.

*Architect:* Welton Becket and Associates; *Exhibit Design:* WED Enterprises, Inc.; *Structural Engineer:* Richard Bradshaw; *Mechanical and Electrical Engineer:* Syska & Hennessy, Inc.; *General Contractor:* Turner Construction Co.; *Steelwork:* Bethlehem Steel Company


Massive steel bents, all-welded except for the field-bolted knee braces, frame the entrance-exit arches.

## THE BELL TELEPHONE SYSTEM EXHIBIT BUILDING



A typical truss vertical shown at Bethlehem's Pottstown Fabricating Works illustrates some of the complexities of the structure. All of the verticals were built up of steel plate, with precisely skewed web plates. Note the extreme thickness of these plates.

This structure would be notable if it were just a fraction of its actual size; in fact, it is 400 ft long, and 200 ft wide at its longitudinal midpoint, where it is about 60 ft deep. It spans 180 ft between supports, and cantilevers 108 ft beyond them. Also, along the entire 400-ft length of the structure, it cantilevers from the trusses as much as 66 ft toward the front, and 38 ft to the rear.

This vast volume is supported on just four steel piers, two of which are designed for a load of 4,200 kips each, and the other two for a load of 2,500 kips each!

These steel supports, each 35 ft high from bottom of base plate at grade to center of bearings, rise through a base structure which occupies virtually the full 105,000-sq-ft site. This structure, which contains exhibits, offices, VIP reception rooms, etc., is not described here. We shall confine our description to the "wing", which houses a chair ride which transports visitors through a series of theaters.



# *A Colossal "Floating Wing"*

### THE "WING" FRAMING

Basically, the wing's framing relies on a dual backbone of two trusses which extend the entire length, supported by the four pylons, and forming a pointed ellipse. The trusses vary in depth from 15 ft 7 in. at each end to 42 ft at the midpoint. Members were fabricated by shop welding, erected piece-by-piece, and field-welded. Although the trusses curve in plan, each of the eleven 36-ft panels is straight; all curvature is provided by skewing the flanges and connection plates of the verticals.

Transverse rigid bents connect the two trusses, spanning 38 ft c-c of truss verticals near the ends of the wing, up to 94½ ft at the longitudinal midpoint. The three end bents are of welded-plate design; the rest are trussed.

An early stage of steel erection. Virtually all field connections were welded and radiographed.


The transverse frames at the extreme ends were erected after all U-frames were in place. The completed structure gives no outward hint of the pointed effect so evident in this picture.

The heavy diagonal members shown here help transmit the "kick" from the long U-frames.

To achieve the cantilevers along the front and rear of the wing, U-frames are connected to the truss verticals at each panel point. These frames are shop-welded, using reinforced 36-in. wide-flange shapes. All but those at the ends (and the bottom members at the pylons) are pin-connected to the truss verticals.

Tension ties extending from the "front" truss U-frame connection points diagonally downward to the lower members of the transverse bents, help take the "kick" from the U-frames. They are made up of two 18-in., 58-lb channels, back-to-back, with spacer plates.

**Lateral Secondary Framing.** It should be noted that there are no floors, per se, in the wing. Its huge volume is occupied by the ride and its framing members, a series of theaters, a projection booth, the mechanical equipment, and necessary catwalks and platforms for access. There is, therefore, no conventional floor framing, nor the added rigidity ordinarily furnished by a floor system.

The primary lateral members between transverse frames are beams of various sizes, welded in place. Generally speaking, the exterior shape of the wing is established by L Series open-web joists, equipped with outriggers which establish the architectural overhang at each bent line.

A major problem in fabrication and erection was the requirement that all external steel members adhere to a trace line with an accuracy of $\pm\frac{1}{16}$ in., to assure absolute smoothness of the skin.

**Supporting Columns.** Although given an architectural finish that disguises their structure, the wing's supports are structural steel. The trussed pylons, used at the front of the wing, have 14 WF 228 legs. The one shown at right measures 30 ft 8½ in. from top of base plate to bottom of bearing shoe. Whereas all other bearings are fixed, this one has rollers which permit slight horizontal movement to compensate for expansion and contraction due to temperature changes. All bearing shoes are massive, measuring 7 ft 6 in. by 7 ft 2 in. in plan.

The two rear pylons are free-standing clusters of four 14 WF 184 columns, groove-welded to plates top and bottom. They are not braced, and permit slight bending.

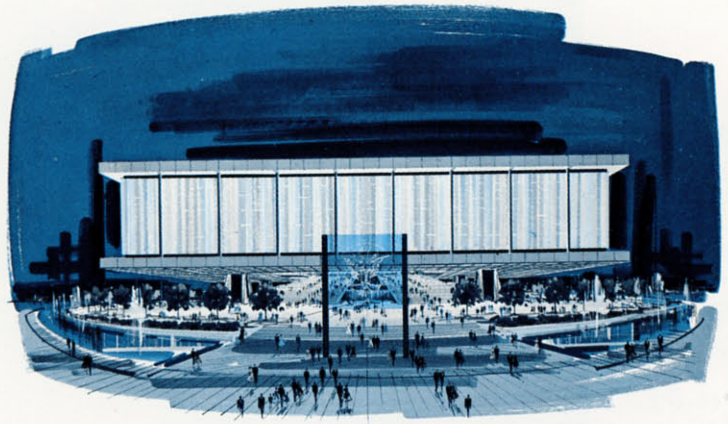
**Ride Framing.** The chair ride, which will take 4,000 visitors an hour on a 1,000-ft-long ride lasting twelve minutes, required a rather complex framing system. It not only follows an irregular path in plan, but it has two lanes, one higher than the other, as well as a number of changes of elevation.

The main carrying beams are 18 WF 96 sections, with 6 B 15.5 filler beams. Along the front of the wing, within the U-frames, the ride rests on 18 WF beams connected to the upper flanges of the lower members of the U-frames. Elsewhere, however, the entire ride is elevated on columns.

Cutaway sketch of the structure at its midpoint shows how the ride passes through the "long" U-frames; mechanical equipment is housed in the "short" U-frames.


One of the two front, trussed pylons. It is the only support equipped with rollers to permit slight movement, horizontally on the "wing's" longitudinal axis.

*Architect:* Harrison & Abramovitz; *Exhibit Design:* Harrison & Abramovitz; *Consultant:* Henry Dreyfuss; *Producer-Designer, Ride:* Jo Mielziner; *Structural Engineer:* Paul Weidlinger; *Mechanical and Electrical Engineer:* Syska & Hennessy, Inc.; *General Contractor:* George A. Fuller Company; *Steelwork:* Bethlehem Steel Company



## THE UNITED STATES PAVILION

# A "Hovering" Hollow Square

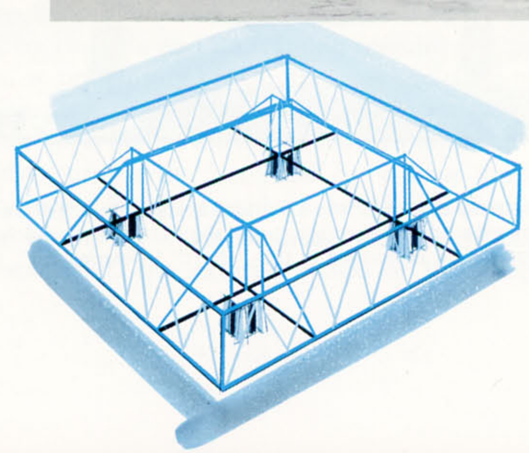
Functionally it's a building, but structurally it's a bridge. Or, more accurately, *four* bridges.

The sketch below illustrates the basic structural scheme. Essentially, it consists of four 310-ft-long inner trusses, spanning some 174 c-c of the supports, and extending out 68 ft to support the outer trusses. Both inner and outer trusses are 57 ft high, c-c of top and bottom chords.

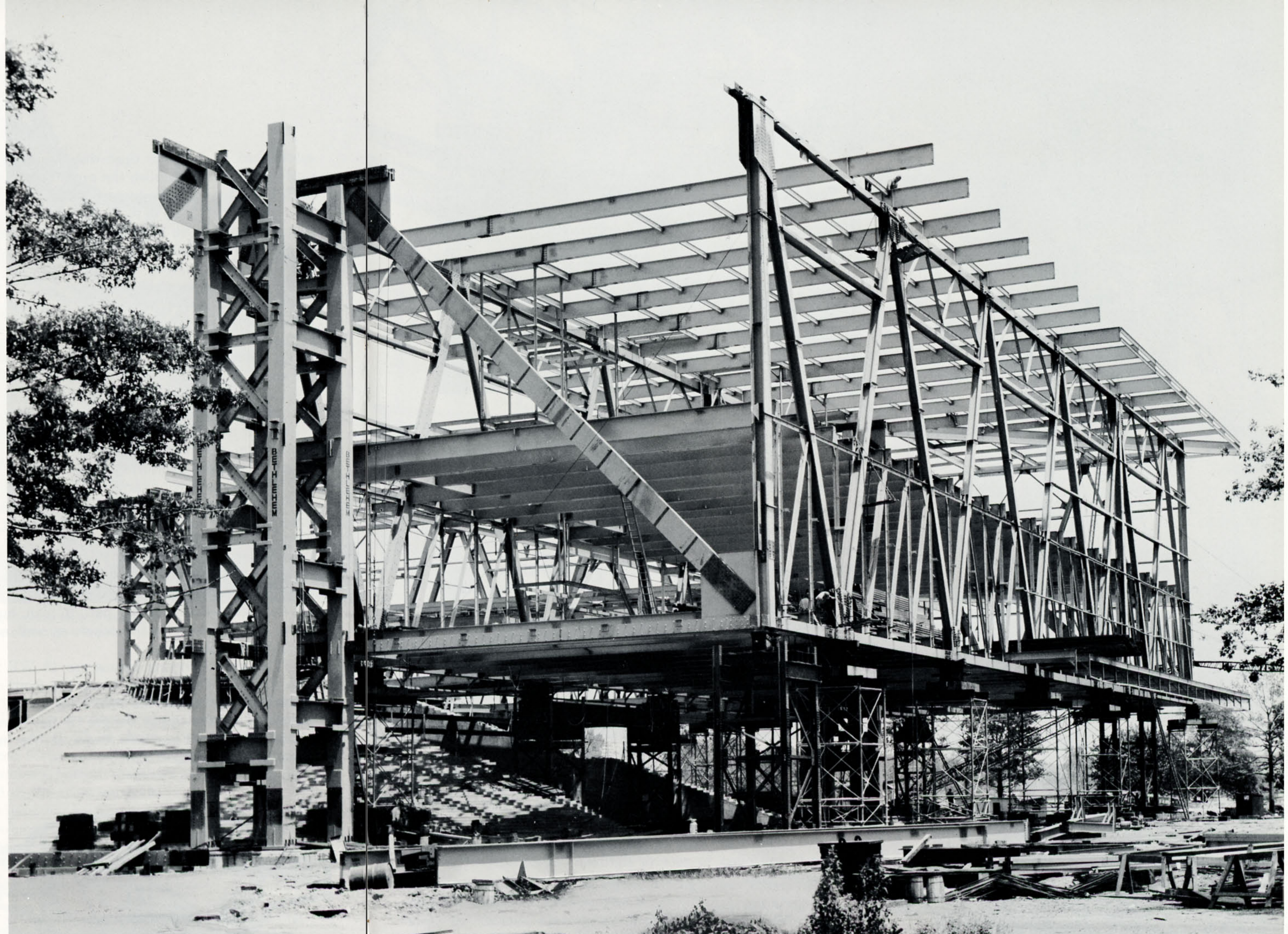
Design of the outer trusses is evident in the photograph at right. The top and bottom chords, and the major vertical and diagonal members are 14 WF sections of various weights, while secondary horizontals, verticals, and diagonals are back-to-back angles up to 8 x 4 x 5/8 in size.

The most unusual truss members are the hangers of the inner trusses (the massive diagonal shown at right), which are 81 ft long and are designed for a load of 3595 kips. They are made up of two 32-in.-wide by 2½-in.-thick plates of A441 steel, with added reinforcement at each end, tieing into massive (roughly 8-ft-sq x 2¼-in.-thick) A441 gusset plates top and bottom.

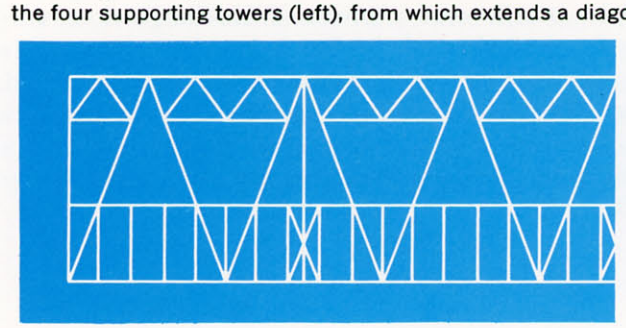
The United States Pavilion occupies a 4½-acre site. It rises above a landscaped plaza, or podium, about 6 ft above grade. Visitors proceed under the structure, and up escalators to a court atop a truncated pyramid, from which point they cross to the lower level of the building by means of 39-ft-long steel bridges. Exhibits illustrating the exhibit theme, "Challenge to Greatness," are located on the first floor, along with an auditorium, VIP reception rooms, and staff offices, all of which occupy one entire segment of the first floor. A ride transports visitors through the second floor exhibition areas.



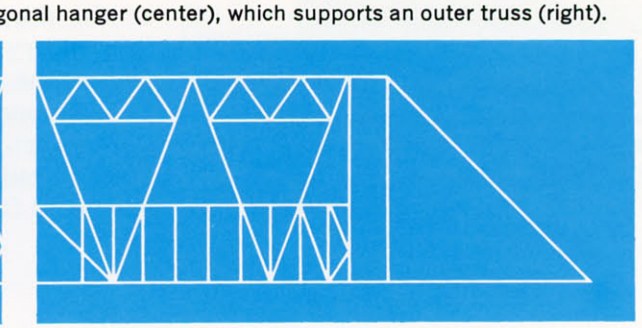
Simplified sketch of the basic structural scheme—eight giant trusses.



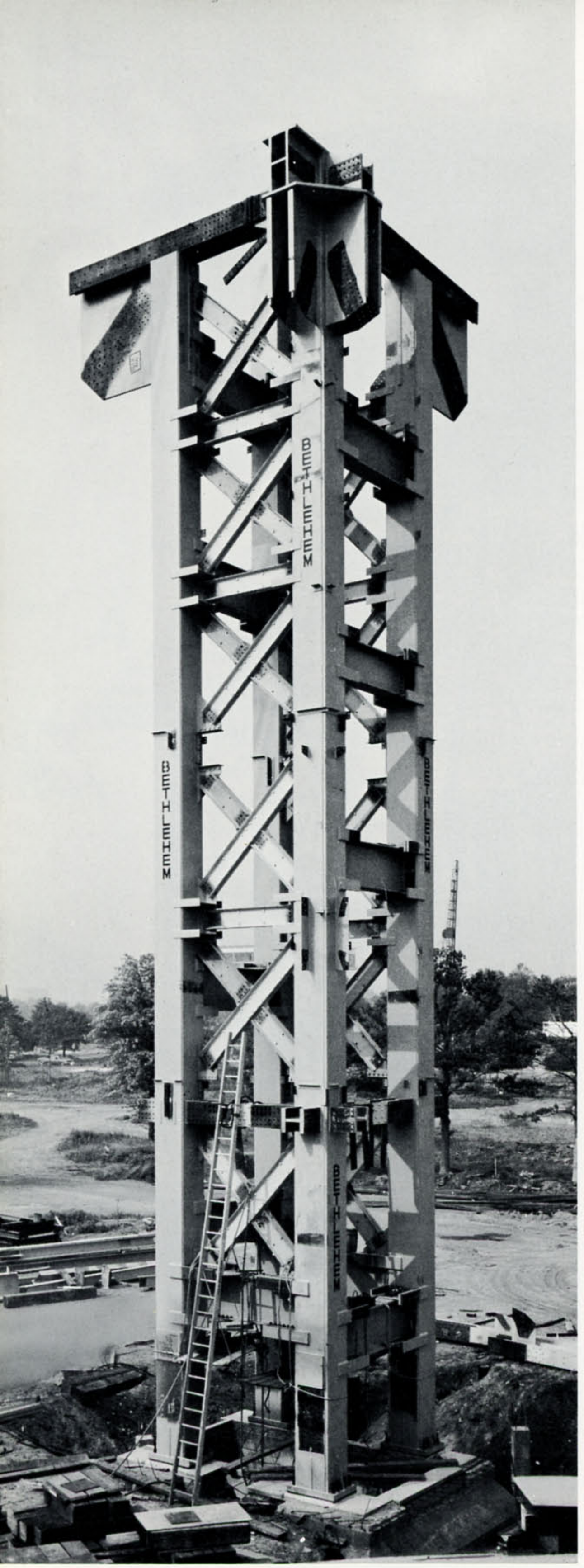
The overpowering size of the structure became evident as the steelwork took shape. Of particular interest is one of the four supporting towers (left), from which extends a diagonal hanger (center), which supports an outer truss (right).



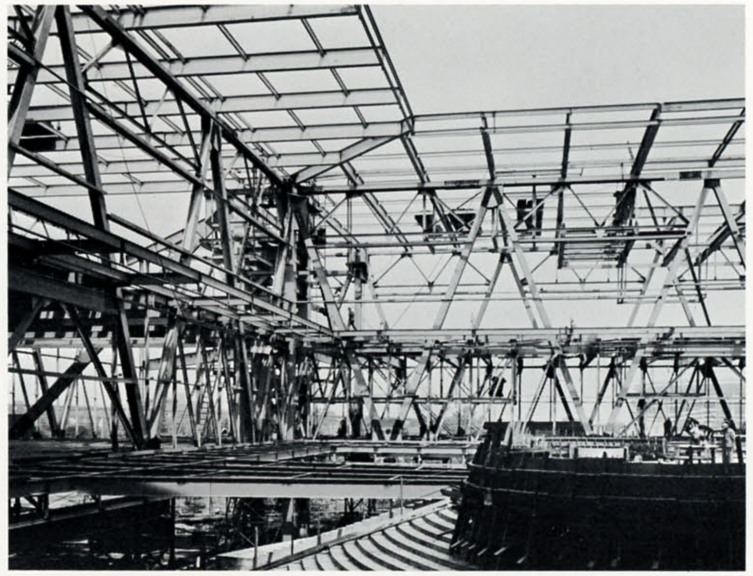
Outer truss



Inner truss




The supporting towers, 83 ft high, are made up of braced box columns, weighing as much as 55 tons. Each column was erected *in one piece!* The big splice plates at top left and right are used for connecting the massive diagonal hangers.



View from inner court during steel erection.

## THE SUPPORTING TOWERS

The structure's four supports, too, are of major interest. Each is a tower, comprising four individual box columns on 11-ft centers, tied together with heavy bracing. Three of these cores form stairwells, while the fourth contains an elevator shaft. The columns are of welded plate construction, about 26-in. square, using plates as thick as $2\frac{3}{8}$-in., and with additional reinforcing plates.

*Steel* supports saved 20 per cent of the total weight. Originally, the structural design specified that the column bearings would be located just below the first floor level, where they would stand on reinforced concrete piers some 25 ft high, and nearly 25 ft sq in plan. However, the poor substructure conditions made it necessary to lighten the total structure as much as possible. Re-examination disclosed that by simply extending the steel columns another twelve feet down, thus eliminating about one-half of the reinforced concrete, the total dead load was reduced by some 20 per cent!

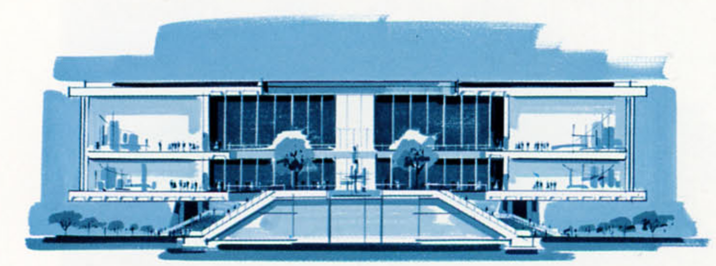
To provide for leveling the gigantic structure, each tower is equipped to receive eighteen 300-ton-capacity hydraulic jacks.

## THE FLOOR FRAMING

The framing spanning 66 ft between the inner and outer trusses is also of extremely heavy construction, especially at the deeply cantilevered corners. Wide-flange floor beams vary from 16 through 36 in., both at this level and at the second floor, while roof beams range from 14 in. through 36 in. Both floors and the roof are concrete slabs over 3-in.-deep formed galvanized steel decking. Floor-to-ceiling height of the lower level is 18 ft; second level is 23 ft.



Relationship of the Pavilion with the center court can be better comprehended from this view. Note, at extreme left, the steelwork for one of the bridges that extends from the plaza atop the pyramid to the lower level of the building.

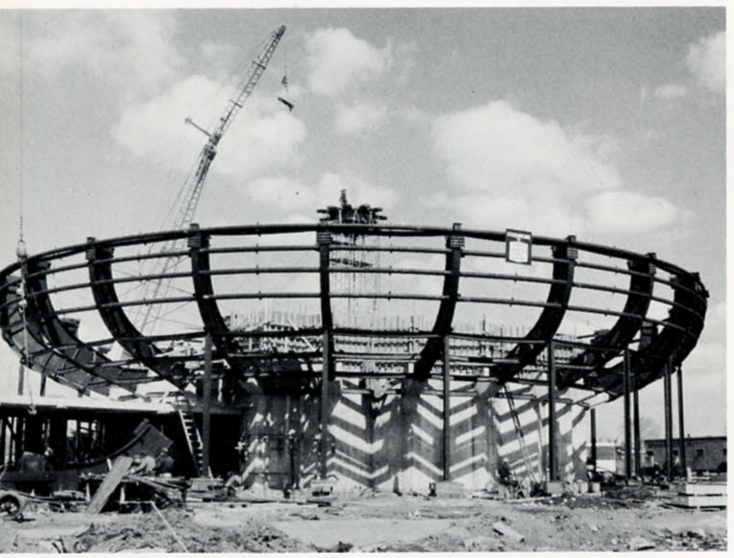


This section view, at right, through the centerline clarifies additional details. The outer balcony, not accessible to visitors, extends 12 ft from the truss centerline. It is partially supported by steel mullions on 37-ft centers, painted white for architectural effect. The interior roofline cantilevers 32 ft into the inner court, whereas the pedestrian balconies cantilever 14 ft from the centerline of the inner trusses. The exterior weatherwall is an illuminated plastic screen, while the inner court is faced with natural-finish vertical wood slats relieved by white-painted steel mullions on 9-ft-3-in. centers.

*The United States Pavilion is operated by the United States Commission, Department of Commerce,* Norman K. Winston, Commissioner; *Construction Supervision:* General Services Administration; *Architect:* Charles Luckman Associates of New York and Los Angeles; *Exhibit Design:* Usher-Follis, Inc.; Cinerama Camera Corporation; *Structural Engineer:* Severud-Elstad-Krueger Associates; *Mechanical and Electrical Engineer:* Slocum & Fuller; *General Contractor:* Del E. Webb Corp.; *Steelwork:* Bethlehem Steel Company

THE TRAVELERS INSURANCE COMPANIES PAVILION

# *A New Concept in Space Structures*

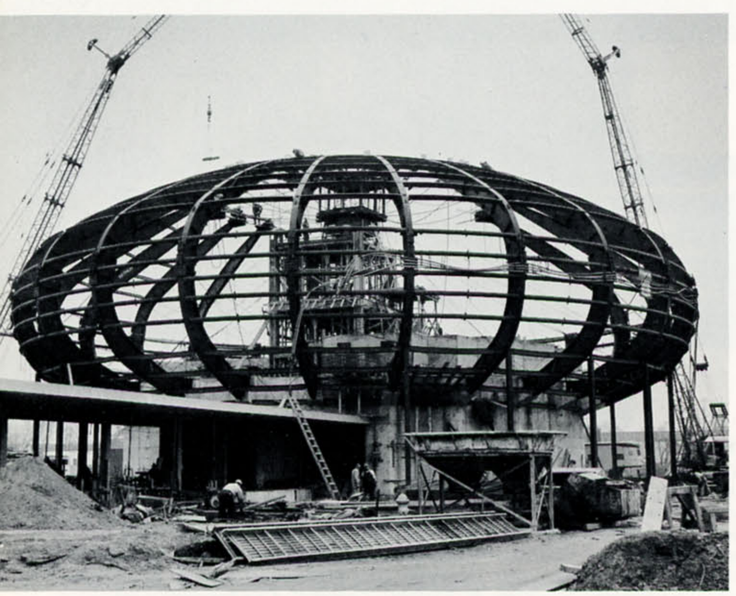


Bethlehem's crew first erected the lower halves of the ribs and the connecting purlins.

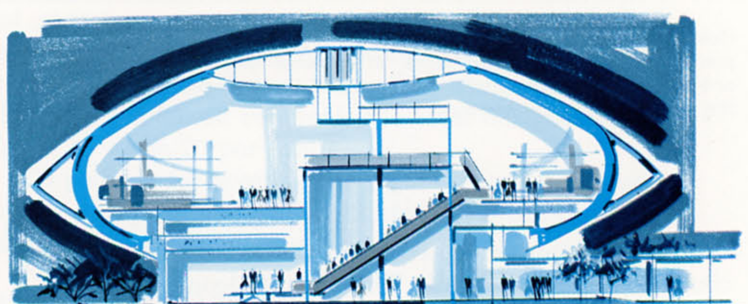
Here is a case where ingenuity in engineering design was required to produce, economically, a structure whose unusual shape was determined by promotional considerations.

The Travelers' symbol is an umbrella, so it was essential to base design of their exhibit building on this shape. The final result was an abstract adaptation of the umbrella, mirrored by a similar form below, resulting in a scalloped-edge saucer which appears to be floating above a continuous wall of water jetted up from a circumferential pool.

Actually, the main structure is an oblate spheroid in elevation, with light outriggers added to establish the umbrella "points." It springs from abutments appended to a 23-ft-high, scalloped-edge (in plan) masonry wall which encloses the ground floor of the exhibit building. Twenty-four welded-plate ribs, shaped like boomerangs, curve up and out, then inward, leaving a 66-ft-diameter opening at the apex. Diameter of the spheroid at its equator is 132 ft. Total height above grade is 63 ft.



Next step was to erect the upper halves of the ribs (welded splices), and install purlins. Meanwhile, the tension ring was positioned on falsework. When all cables were tensioned, the basic structure was complete.



This sectional view greatly simplified, gives some idea of the interior. It does not show a free-standing, steel-framed stairwell at the approximate center of the structure. Visitors enter, ascend ramps through exhibits to an escalator, rise to the next level, and walk through additional display areas spiraling around the building, then descend to the exit. Administration and VIP offices are in the main building, with mechanical equipment in a 100 ft-long one-story wing.



Note how the addition of outriggers and miscellaneous steelwork transformed the basic spheroidal shape into that of an umbrella mirrored by a similar shape below.

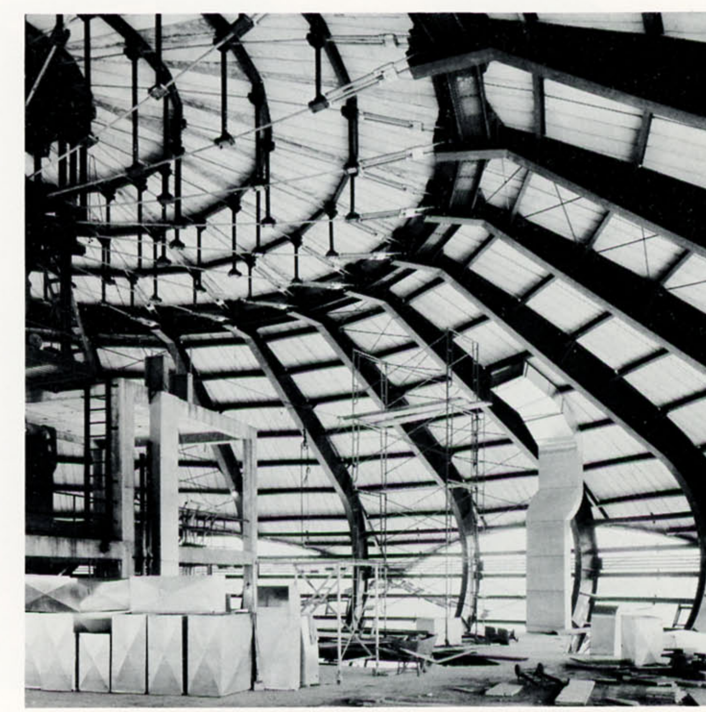
Closure at the pole is accomplished with a remarkable space structure which, essentially, is a tension "hub" of steel plates, to which the outward thrust of the ribs is transmitted by steel cables.

Finally, the ribs are girded at the equator by four post-tensioned steel cables positioned in saddles fastened to the outer flanges of the ribs.

## TENSION RING AT APEX

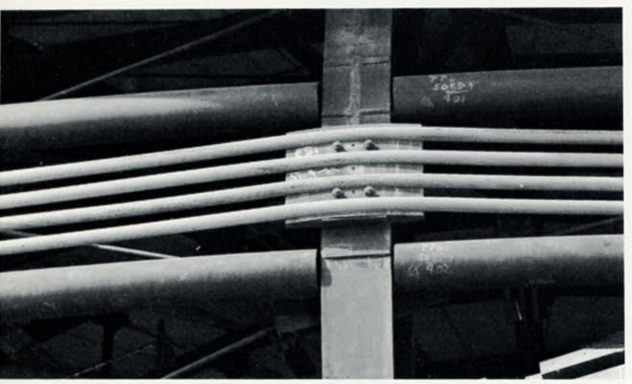
The tension plates are $\frac{3}{4}$-in. thick (upper) and 1-in. thick (lower), each equipped with twelve grooved saddles to receive the cables. The plates and saddles are held 8 ft-5 in. apart, c-c, and braced by hub framing which consists primarily of steel pipe and channels.

The cable structure uses $1\frac{1}{4}$-in. galvanized bridge strand for the top course, and $1\frac{5}{8}$-in. strand at the bottom. Each individual length of strand, top and bottom, extends from sockets on one rib, through the saddle, and back to a neighboring rib and again socketed. The cables are spaced vertically with 3-in.-diameter pipe, the upper connections of which receive wide-flange purlins which support the roofing material.



Interior view during construction gives a better idea of the large volume of space created by this ingenious design.

The ribs extend upward and inward, and tie into a compression ring. Each cable of galvanized bridge strand is socketed to the top of one rib, runs through a saddle connected to a tension plate, and returns to an adjoining rib. Purlins atop the cable structure are solely for support of roofing material.



Close-up of circumferential cables encircling the ribs.

Note the extremely light structure of the footings and lower portions of the ribs.

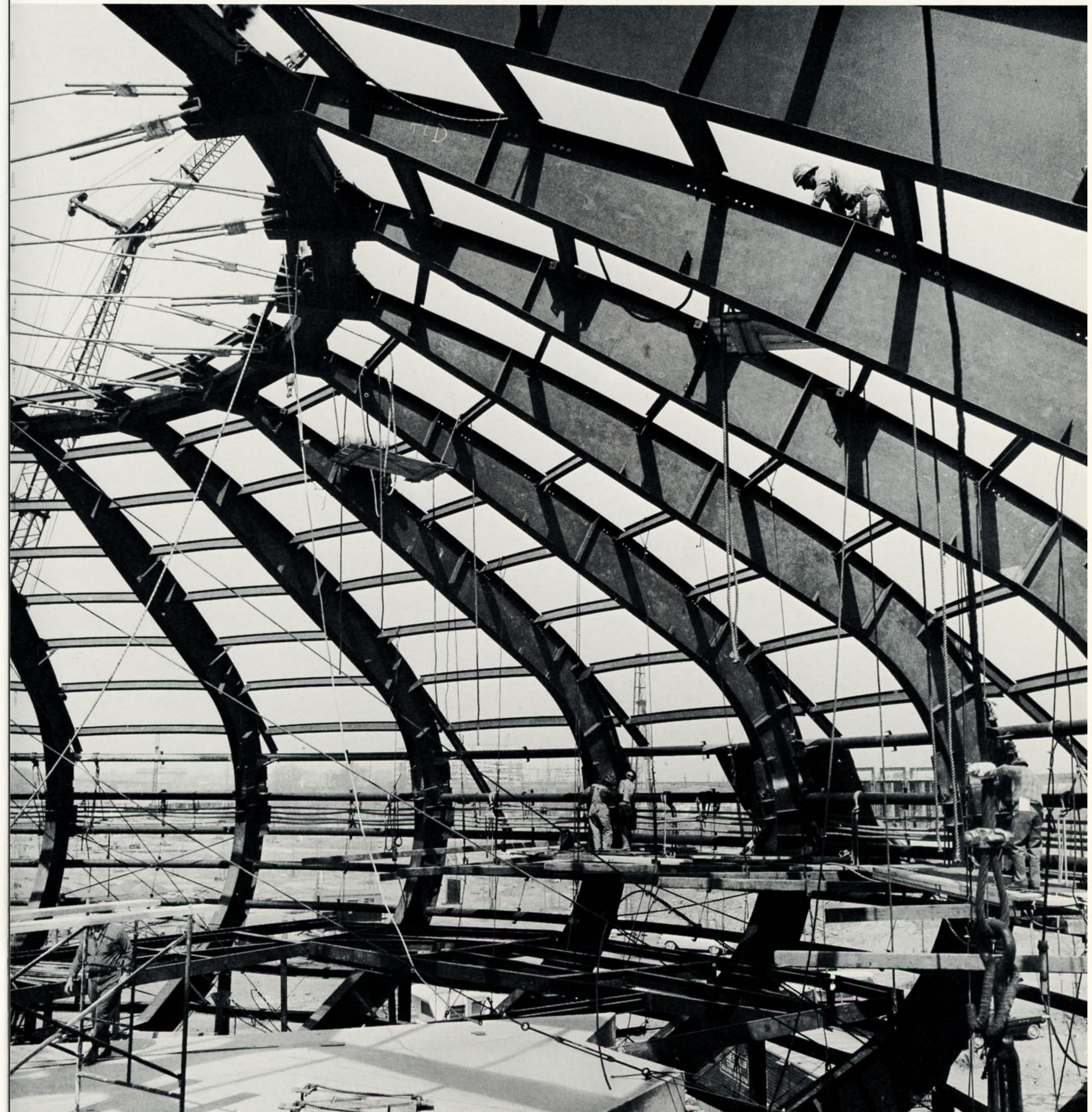
## THE RIBS AND PURLINS

The welded-plate ribs have $\frac{3}{4}$-in. webs and 12-in.-wide flanges (thickness varies) to the height of the welded field splice, at which point the web plate changes to $\frac{3}{8}$ in. It can be seen that the depth of the rib is only 36 in. at the "neck" of the base connection, increases to a maximum of 42 in., and measures only 16 in. at the top. Purlins are, typically, 10 B 19, on 6-ft centers, except for five courses of 8-in. pipe purlins at the equator, and edge purlins which form the sweeping curves for the "fringe" of the umbrella. All bays are braced with diagonal, $1\frac{1}{8}$-in.-diameter tie rods.

Each rib is equipped, at the equator, with a four-grooved saddle to receive $2\frac{1}{2}$-in.-diameter galvanized bridge strand cables. These cables were post-tensioned, and were designed for a working stress of 200 kips per cable. Result: avoidance of non-uniform distortions of the structure due to unsymmetrical loads.

The result is a structural system which utilizes three-dimensional prestressing, resulting in a stress pattern the opposite of what would be expected in a "conventional" clearspan structure. In a more prosaic solution the dome would be in compression and thick at the apex, as would be the junction of the ribs with the pedestals. In fact, in the very early stages, thought was given to achieving the double-umbrella shape by cantilevering trusses out from the supporting wall, and spanning the top with trusses; total weight of steel would have been about 40 psf, in comparison with the new system, which used only about 9 psf.

In addition to economy, this scheme resulted in a stable structure with an advantageous distribution of material throughout, and with a shallow space frame at the apex, allowing ample headroom. Also, it provides a maximum of usable interior space with eye-appeal and pleasing proportions. Obviously, such a system has considerable potential for arenas and auditoriums.



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