

RAISING THE ROOF — A PICTURE STORY OF THE FABRICATION AND ERECTION OF THE HARTFORD CIVIC CENTER COLISEUM SPACE FRAME ROOF STRUCTURE*

By Roy H. Kinsell, *Sales Engineer*
Bethlehem Steel Corporation, New Haven

A new Civic Center in downtown Hartford, Connecticut, represents a \$75-million development to revitalize the city's central business district. The venture is being carried out through a unique partnership between the City of Hartford and Aetna Life & Casualty, an association representing the only public-private project of its kind in the nation.

Focal point in the \$30.5-million Hartford Civic Center is a 12,000-seat Coliseum. The most dramatic feature of the Coliseum's design is its steel space frame roof structure — a 1,400-ton framework that "floats" on four concrete pylons. (Plate #1)

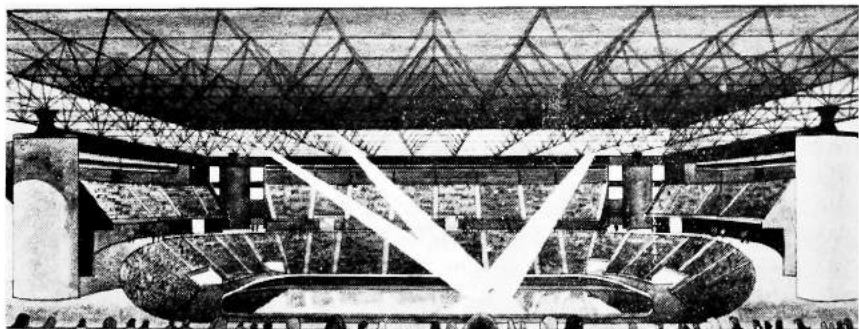


Plate #1

The space frame is one of the largest single roof structures ever to be lifted into position in this country. It measures 360 by 300 ft. (about the size of two football fields) and is 22-ft. deep. The roof structure, fabricated and erected by Bethlehem Steel at a cost of \$1.4 million, is comprised of 4,455 light steel members. Its design will give Coliseum spectators an unobstructed view from every angle because the space frame roof eliminates the need for interior columns.

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The desire of the architects to create the impression of a huge "floating" lid resulted in the selection of the steel space frame to span the Coliseum portion of the Civic Center. The roof system appears to "hover" delicately over the spatial envelope surrounding the spectators and the events taking place within. As in all contemporary coliseum structures, supporting elements which obstruct the spectator's view were unacceptable. Heavy peripheral columns would have defeated the architectural concept and lengthened spans excessively.

This immense space frame is supported by four pylons located at each corner of the seating area. This placement resulted in a rectangular roof with the pylon supports placed 45 ft. inward from each side. The spans, measured center-to-center of pylons, are 270 by 210 ft. in the rectangular directions, and 340 ft. measured diagonally. The frame overhangs 45 ft. in all four directions.

STEEL FRAMING ONLY PRACTICAL SOLUTION

Once the basic parameters of design were established, a steel space frame presented the ideal choice of framing system. No other method of framing appeared practical within the architects' intent that the thickness of roof structure not overwhelm the design elements below it. Using the steel space frame principle, it was possible to restrict the construction depth to about 22 ft. The steel framework provided greater tensile strength — size for size — than alternate systems.

The structural engineer standardized as many assemblies as possible and eliminated field welding entirely. Except for four large bearing shoe assemblies, the only other welded assemblies were the standard built-up multiplanar gusset plate units designed to receive eight steel web and chord members. These gusset units were shop-fabricated and had the advantage of being relatively small in size. Except for the web-plated W16 peripheral bottom chord members, the main chord and web framing members consisted generally of four angles arranged in a cruciform pattern, high-strength bolted together with fill plates in the shop. Bottom chord members are designed to resist wind load bending, in addition to direct stress.

The sections used for the main members ranged from 8 x 8 x $\frac{7}{8}$ -in. angles down to $3\frac{1}{2}$ x $3\frac{1}{2}$ x $\frac{5}{16}$ -in. angles. The angle assemblies were knifed onto the gusset plate assemblies in the field and connected with high-strength bolts. (Plate #?) Two grades of Bethlehem high-strength bolts, 1-in. ASTM A490 and $\frac{3}{4}$ -in. ASTM A325, were used.



Plate #2

The depth of the space frame was established in relation to the 30-ft. staggered-panel-point spacing to create equilateral triangles in all directions. This design allowed all main chord and web members throughout the entire space frame to be fabricated exactly to 28-ft. lengths. (Intermediate light single angle members, generally $5 \times 5 \times \frac{5}{16}$ -in. angles, were half as long.)

High-strength steel, ASTM A572, Grade 50, (Bethlehem V50) was selected for the 6- and 8-in. built-up angle members, as well as for all welded gusset units. For the remaining members ASTM A36 steel was used. By using high-strength steel for the highly stressed members, dead loads were reduced and the cross-shaped pattern could be maintained using standard sections. This selection contributed to the overall economy of the space frame.

“FAST TRACK” CONSTRUCTION METHOD

The plans and specifications prepared by the architects and structural engineers gave the erector the choice of selecting the method of field erection.

tion. The site had already been excavated, and, under the construction-manager "fast track" system of operation, the space frame roof had already been detailed and separately bid before much of the arena seating and other facilities within the coliseum had even been designed. (In a "fast track" concept, construction of major segments of a project may begin before other components are designed, ordered, or fabricated.)

Bethlehem Steel chose to assemble the entire space frame at ground level and raise it into its final position (85 ft. in the air — the height of a conventional 8-story building) in a single operation using 125-ft.-high, steel-framed temporary lifting towers. (Plate #3) This method could only have been accomplished under the "fast-track" system, since, in conventional construction there would have been a clutter of sloping seating framing being constructed below most of the roof area, preventing ground assembly.

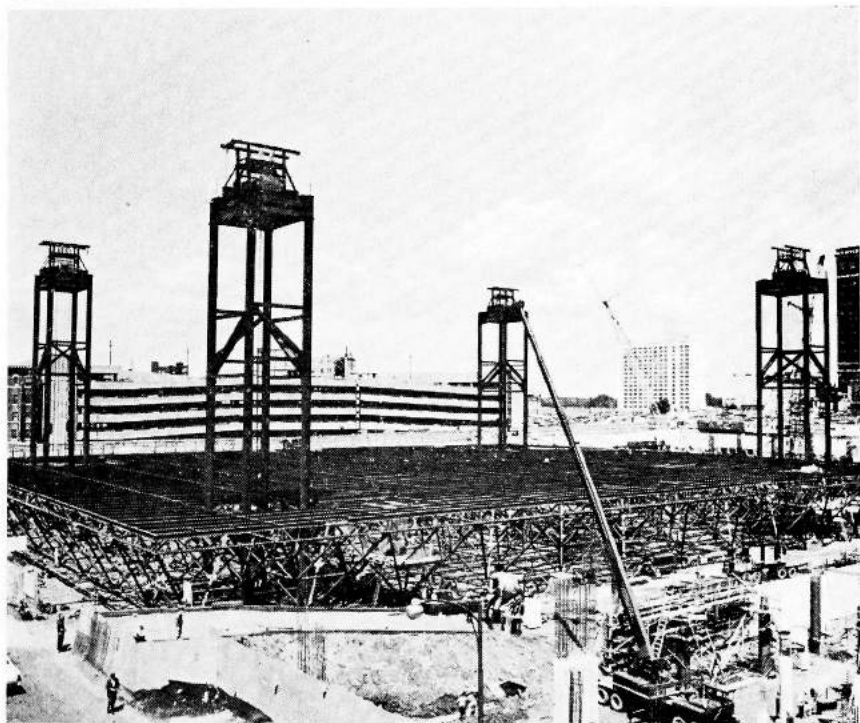


Plate #3

By anticipating the Bethlehem erection procedure, the architects and structural engineers were able to program the space frame contract at the earliest possible time, allowing seating construction within the coliseum to follow after the roof was in its final position. With the decision to assemble the space frame on the ground and lift it into position, the structural engineers designed a combined foundation for both the giant temporary lifting towers and the permanent concrete pylons.

ONE OF THE LARGEST SINGLE ROOF STRUCTURES EVER LIFTED IN THE COUNTRY

Each lifting tower consisted of four 30-in.-diameter steel pipe sections, 116 ft. long, braced by W30 sections. The pipes were located to clear space frame members and were spaced in a 17 ft., 6 in. by 25 ft. rectangular pattern. Each pipe section was shipped by truck in two pieces and field-welded in a horizontal position. Two full-length pipes were then assembled on the ground with cross-bracing and tilted into position onto pre-set anchor bolts which were lapped with rock anchors through the footing.



Plate #4

The parallel pipes were similarly tilted. Bracing was added to tie the two pairs together into a stable cluster of four. The entire design of the towers and lifting equipment was Bethlehem Steel's responsibility. Bethlehem supplied the structural engineers with data on the temporary loadings anticipated on the foundations during erection and afterwards, until the permanent pylons were installed. Footings were designed measuring 22 by 30 ft., over 6-ft. deep, bearing on 15-ton rock. The footings were tied down at each corner by four rock anchors.

After the basic temporary tower framing was in position, jacking equipment was installed atop a heavy steel grillage. (Plate #4) Sixteen hydraulic jacks with a 75- or 100-ton capacity each were required — four at each tower.

During the lifting process, the four jacks at each tower exerted their force upward against lifting beams, which in turn pulled on four 1¾-in.-diameter wire rope cables. (Plate #5)

Extended from each permanent bearing shoe were wing plates to which the cables were attached, double-roped through a sheave assembly. Each

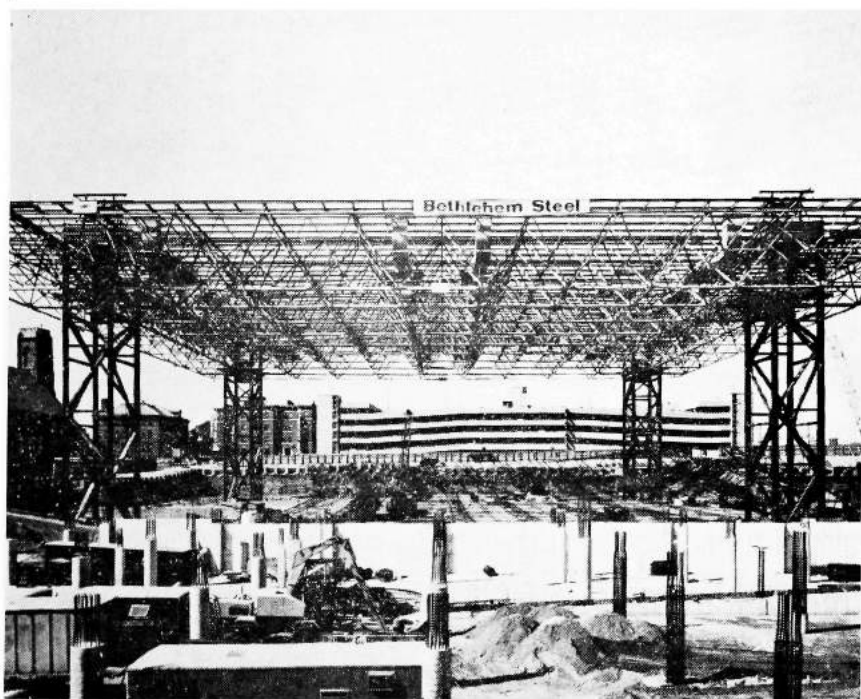


Plate #5

rope passed through a set of Lucker grips, so that the jacks could be reset after each lift of about 18 in. (Because of the double roping, each lift took the space frame up about 9 in.) During the lifting process, in order to clear space frame diagonals, the tower bracing required either installation or removal, depending on its position in the tower. (Plate #6) Alternate positions for tower bracing were provided, to insure positive stability against wind forces on the frame at any stage of erection. The overall lifting time from start to finish was less than one week.



Plate #6

Once the roof was jacked into position, it remained on the temporary towers for eight weeks while the massive concrete pylons were constructed. The weight of the roof was then shifted from the towers to the pylons, after which the towers were disassembled and removed. (Plate #5)

STEEL FRAME ASSEMBLED ON THE GROUND

Prior to lifting, the mechanical trades had taken advantage of the ground assembly of the space frame to install most of the heating and ventilating ductwork, roof drain piping, and other mechanical items. This

ground level installation and subsequent lifting of the mechanical equipment in place in the space frame saved many man-hours and scaffolding costs. Because the frame rested on wood dunnage blocking only a foot or two above leveled and compacted grade, workers of all trades were able to walk safely on most of the structure without the need for safety belts, or other safety equipment, which would have been required had the frame been in its permanent position.

In fact, in the steel erection itself, iron-workers had their feet on solid ground while installing over one-third of all the high-strength bolts. For the balance, except for the tower framing, they were within 25 feet of the ground. The procedure resulted in great erection economies.

All of the steel members which make up the space frame will be visible from within the finished coliseum, and were painted a light tan to show off the myriad arrangement of steel shapes. (Plate #7)

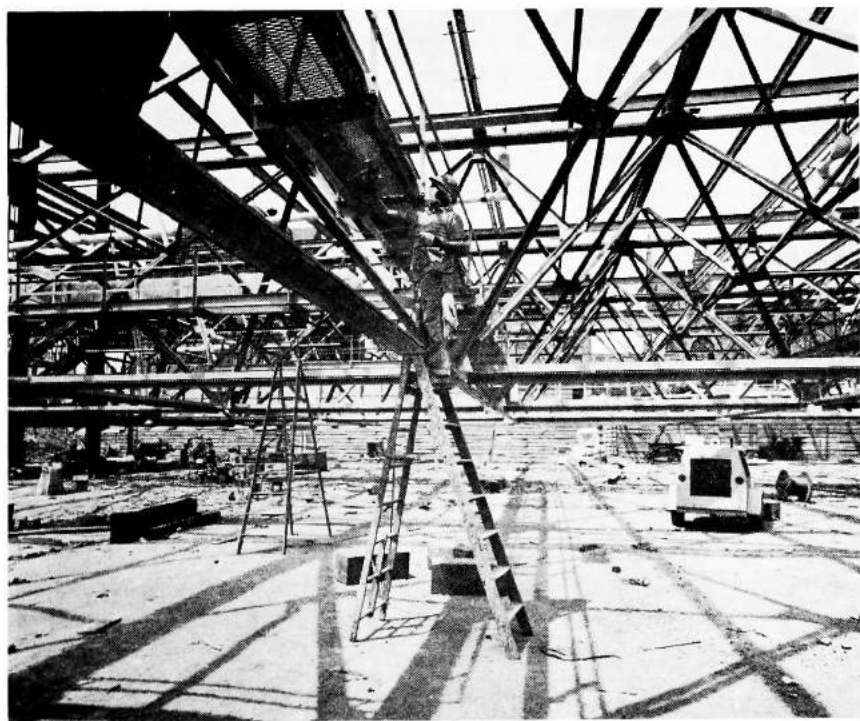


Plate #7

The roof deck system, consisting of cementitious fiber planks on steel bulb-tees, is supported on a rectangular system of light W14 purlins and

girders. These, in turn, bear on short W6 steel stub columns welded to the upper gusset plate assemblies. The stub columns vary in height, creating positive drainage of the large area. It was necessary to provide a sloping surface for this drainage; but because of the geometric, as well as stress, problems which would result if it were built into the top chords themselves, the purlin system was made completely independent of the space frame top chord system. The purlins were therefore designed only for bending caused by the dead load and 30 psf live load. The top chord members were sized only for direct stresses due to the frame action. Conventional built-up roofing over insulation provided the waterproofing of the entire roof.

An attractive metal paneling along the perimeter, following the sloped back line of the edge of roof, followed installation of sloping girts. A large multi-sided scoreboard will be suspended from the center of the roof, along with lighting and public address speaker clusters.

Catwalks with wire mesh floors are located throughout the 22 ft. height within the space frame. These will be used to service electrical motors, arrange connections for rigging, and provide access wherever necessary. They were all installed as part of the assembly at ground level.

PROVISION MADE FOR FRAME EXPANSION AND CONTRACTION

Since the space frame will be exposed to extreme heat and cold for some time before the entire building is enclosed, provision was made for expansion and contraction. One column is considered "fixed" against movement, while the diagonally opposite column allows free movement of up to 3 in. in all directions. The remaining two pylons are partially fixed and free.

This expansion capability was accomplished by a set of sliding plates in the large shoe at each lifting point. Also in each expansion assembly is a ball and socket joint, allowing for rotation in any direction. This joint and the expansion devices prevent the buildup of stresses that might be detrimental to the structure as a whole. (During the lifting process, these shoe assemblies were temporarily locked together to provide stability.)

The Coliseum is just one part of the City's portion of the \$75-million development. There will be adjacent parking for 3,000 automobiles, a 70,000 sq. ft. exhibition hall, and a 17,000 sq. ft. assembly hall. The balance of the Civic Center — Aetna's portion — will be comprised of a three-level commercial and retail complex including 140,000 sq. ft. of rental office space, 280,000 sq. ft. of retail space, an enclosed pedestrian mall, and an Aetna-ITT-Sheraton 21-story hotel.

When completed late next year, the Hartford Civic Center will be the largest convention and entertainment complex in New England.