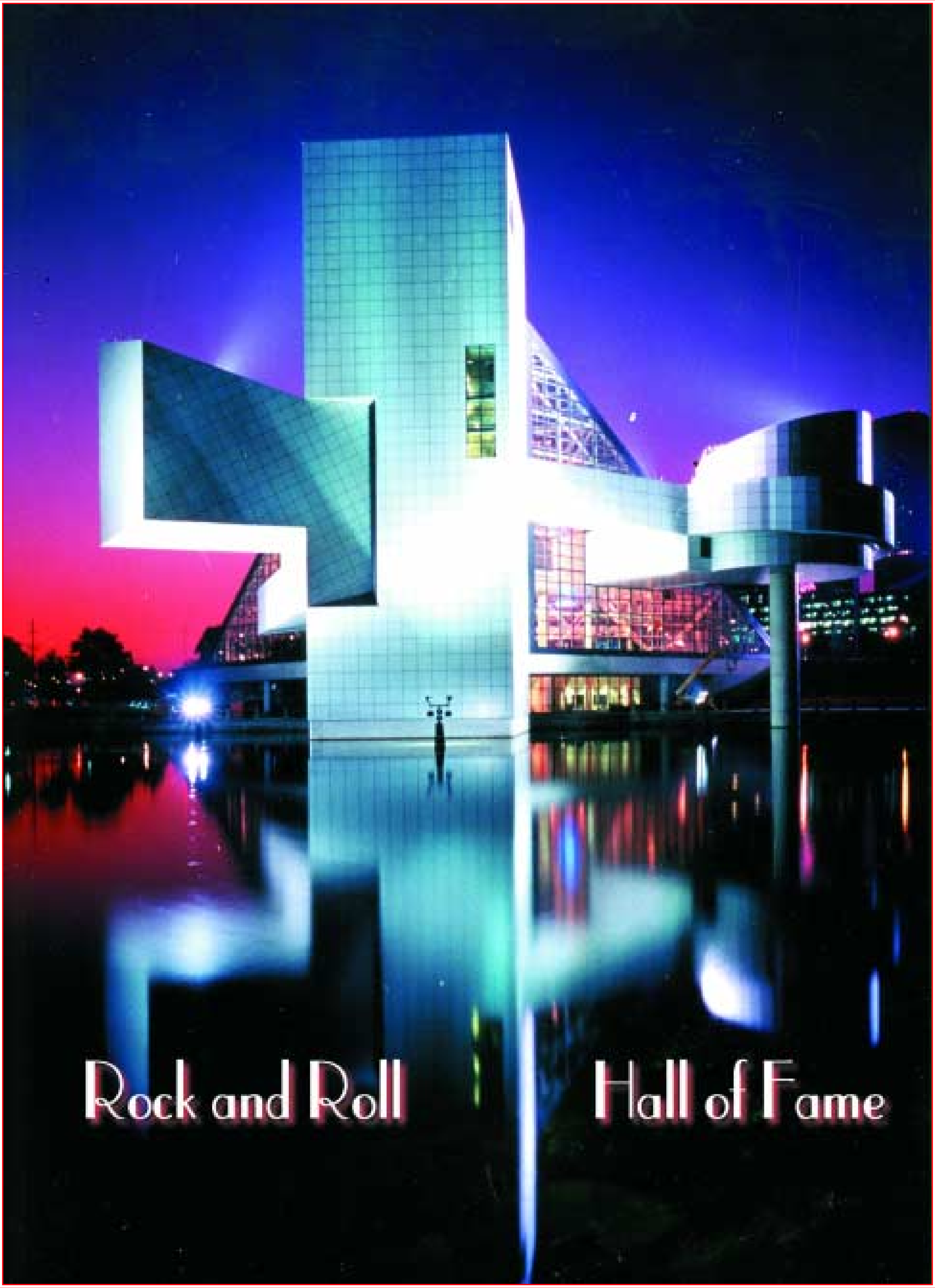
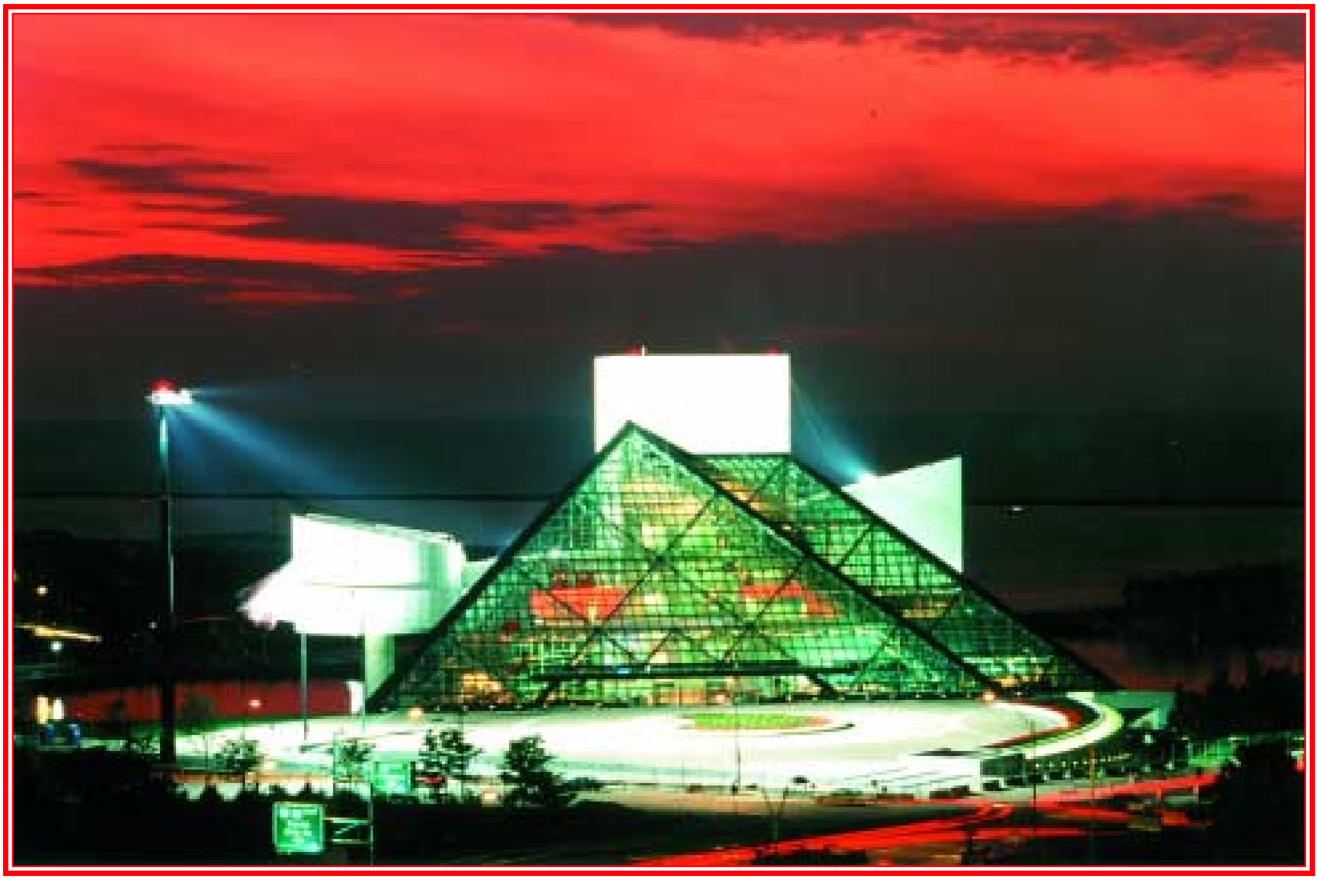

Rock and Roll
Hall of Fame



Engineering Awards of Excellence

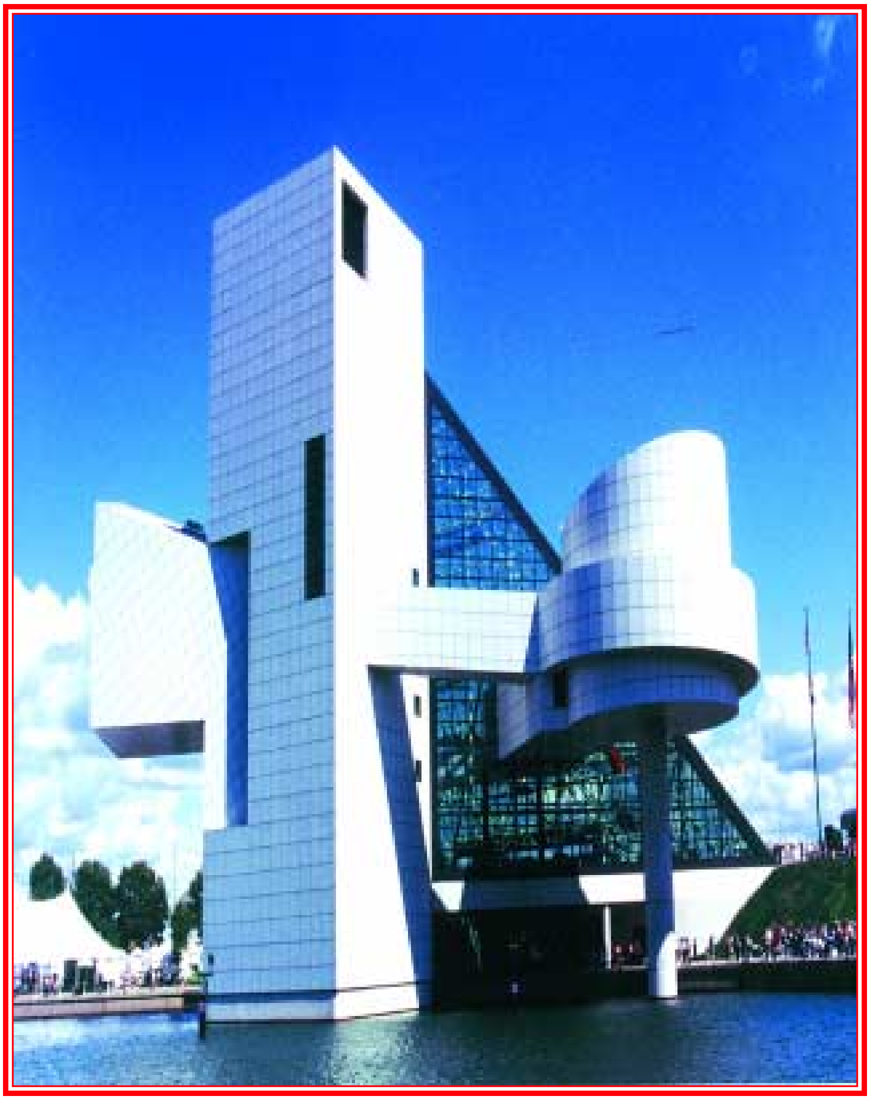
National Winner

Rising boldly from the shores of Lake Erie—with part of the building actually extending out above the water—the new Rock and Roll Hall of Fame is a vital part of the new cultural and recreational area being developed along the Cleveland waterfront. In addition to the Hall of Fame, the 150,000-sq.-ft. project houses 50,000 sq. ft. of exhibition space for rock and roll memorabilia, a grand public atrium, theater, radio broadcasting studio and other support facilities.

Even before its opening, the building received national attention for its unusual architecture and exposed structural system, a design which, in the words of architect I.M. Pei, "echo(s) the energy of rock and roll." The design's energetic expression is readily apparent, with an unusual geometric configuration and portions of the building seemingly exploding outward from a central tower core. Needless to say, the complex geometry presented numerous structural challenges.

The desire for a signature structure resulted in a design that can be divided into five distinct parts: a sloping glass tent; central tower; cantilever theater wing; circular exhibit wing; and underground exhibit areas.

The glass-enclosed public space of the tent provides a dramatic entrance to the Hall of Fame from the plaza. The sloped surface of the tent literally leans against the tower beyond, with two vertical glass walls complet-



ing the enclosure. Structural steel pipes and tubes provided the architecturally expressed supporting structure, while the sloped surfaces are supported by an elegant system of gently tapering bowstring trusses. The interior of the tent is filled with light: balconies, stairs, bridges and escalators crisscross the space, bringing color and animation to the public spaces.

The sloped surface of the tent rises at a 45 degree angle to a height of 135' above the promenade level and is divided into two parts. The larger, triangular portion is in front of and 13.5' above the smaller parallelogram-shaped portion. Together, the sloped surfaces cover an area more than 270' wide. At the intersection of the two sloped surfaces, the tent is supported by a sloping pipe truss spanning 200' from one of the four corners of the tower down to the plaza. The top chord of this ridge truss is at the level of the triangular section of the tent; the bottom chord is at the level of the parallelogram.

The sloped glass surface is supported by a space frame grid of 16 bowstring pipe trusses varying in depth from close to zero at their ends up to a maximum of 6.5' at midspan. The bowstring trusses are oriented perpendicular to the sloped surface where they can most efficiently resist wind loads. The top chords form a planar surface, while the curve of the bottom chords was chosen by considering the deflected profile under a uniform load of a membrane having the shape of the sloped surface. The shape of the bowstring trusses produces an inherently efficient design because the greatest structural depth is provided where the most strength and stiffness are needed.

Judges Comments

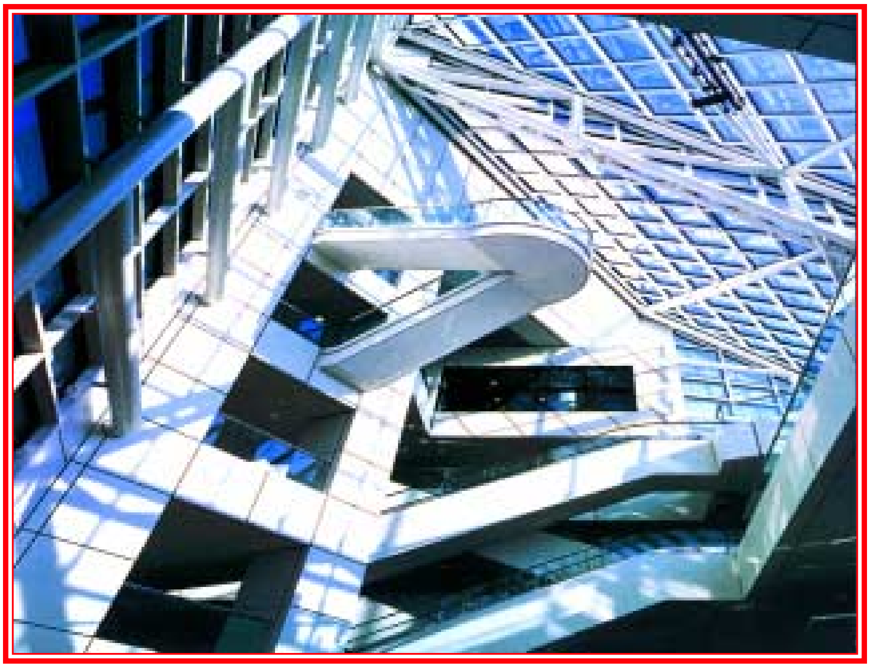
The complex geometry and variety of the architectural requirements provided the engineers with a unique opportunity to show the versatility of steel.

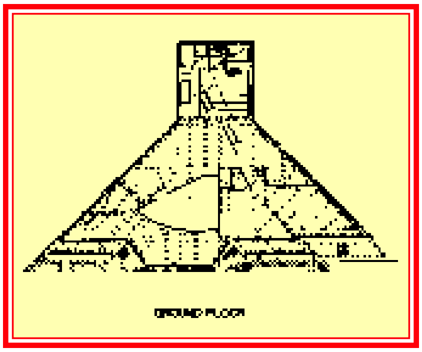
Design of the tent structure was largely governed by wind deflections. To control deflections of the ridge truss in the most efficient manner, its connections to the tower structure and to the plaza were detailed to achieve continuity. This resulted in approximately a fivefold reduction in deflections, and permitted the use of lighter steel sections that would be needed for the equivalent simply-supported truss.

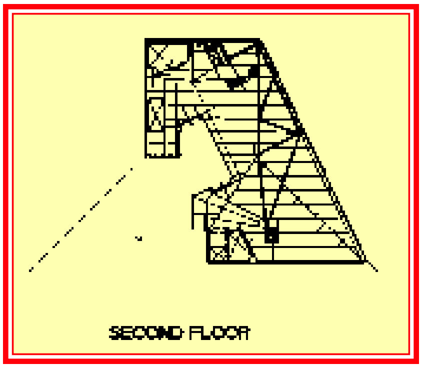
The continuous connection at the base of the truss is interesting in that it provides moment continuity between the steel and the concrete structures. Continuity is provided by creating a couple between the back leg (compression) and the leading edge (tension) of the truss. The compression force in the truss chord is delivered to the reinforced concrete construction at the plaza level through a steel casting resting on a 9”-diameter spherical bearing. The tension force is resisted by a 3.75”-diameter steel bar anchored 16’ into the wall below. These connection details are both economical and effective in providing a fixed-ended connection between a steel truss and reinforced concrete construction.

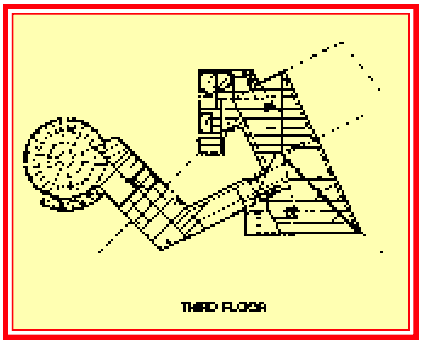
The tent structure also is unusual in that structural steel tubes were used for the mullions, rather than more conventional aluminum mullions. Tubes were used because the structural demands on the mullions are considerable: the system was designed to span across a triangular panel 38’ high and 54’ wide for 100-year wind loads. An added advantage of the steel tubing is that it gives a seamless architectural appearance to the underside of the tent structure.

With the huge expanse of sloped glazing rising from pedestrian level, even small out-of-tolerances would be clearly visible. Consequently, unusually stringent erection tolerances were specified. The curtain wall’s slope complicated matters, however, since the structure tends to deflect out of position as the



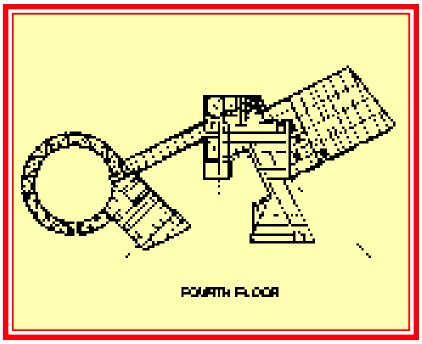


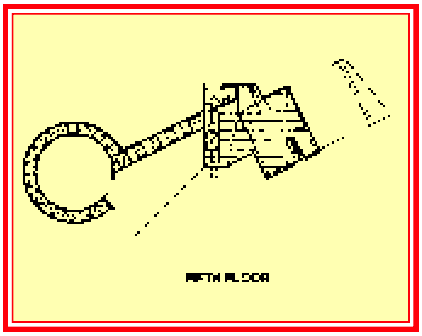


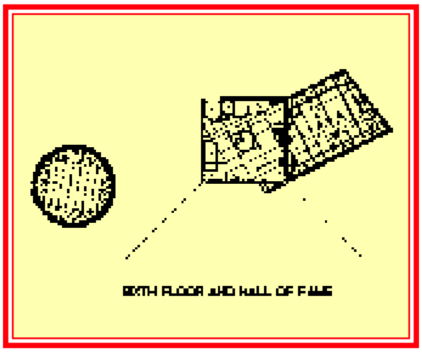


weight of the curtain wall is gradually applied. The requirement for strict tolerances led to an innovative system of cambering and pre-deflecting the trusses prior to installing the steel tube mullions and glass. The idea was to provide the curtain wall workers with a sloped surface that was essentially a true plane prior to the installation of the mullions and glass, and that would not deflect form this position as the weight of the curtain wall was gradually applied during installation.

The bowstring trusses were fabricated with upward camber to







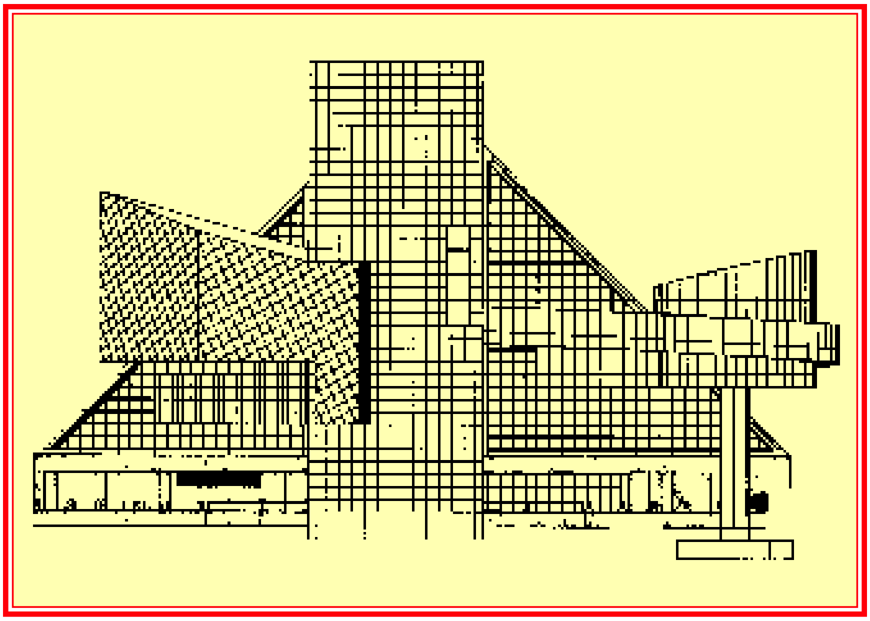
compensate for the full dead load. The trusses were erected complete and then ballast was hung from predetermined locations on the truss with the weight of the ballast equal to the weight of the future mullions and glazing. The ballast was suspended slightly above the ground and the space between ground and ballast was shimmed just enough to close the gap without transferring any of the ballast weight to the ground. With the total load on the trusses equal to the full dead load, the cambered trusses deflected such that the top chords formed a nearly planar surface.

As the weight of the mullions and glass was added, the weight of the ballast gradually and automatically shifted from the trusses to the ground, without further deflection of the structure.

Another structural challenge was the 162'-tall, six-story central tower, which rises dramatically from the waters of Lake Erie. In addition to housing the HVAC and other operational systems, the steel-framed tower provides ground exhibit space, a radio broadcast studio and the museum's café on floors that extend out from the tower proper into the atrium. The actual Hall of Fame is housed in a cubic room near the top of the tower. From the east side of the tower, the 175-seat theater wing cantilevers 80' out over the water. The tower is founded on steel piles that extend 100' below to a single concrete pile cap.

To the west of the central tower, a drum-shaped circular exhibit hall perches on top of a single 10'-diameter concrete column rising from the water. Access to the circular exhibit space is via bridges from the tower and tent. Like the tower, the circular exhibit wing is founded on steel piles; however, the single pile cap is hidden completely underwater.

Much of the project's engineering challenge emerged from dealing with the buildings unusual shapes, which often required special connections not often encountered in more conventional steel projects. The circular exhibit wing is a prime example



of the difficult design requirements presented by this job. In addition to having to support the 75'-diameter steel-framed exhibit hall on top of a 10'-diameter concrete column is the problem of the unbalanced loading on the exhibit hall, which resulted in an overturning moment at the top of the column.

The solution was to wrap the concrete column with a 1½"-thick steel plate anchored into the concrete with Dywidag threadbars to resist the overturning moment. Steel plate girders are welded to this ring and cantilever radially outward from it. The remainder of the steel framing is supported by plate girders.

Another challenge was the design of the cantilevered theater wing. The wing cantilevers more than

Project Team

Structural Engineer: Leslie E. Robertson Associates, New York City

Architect: Pei, Cobb, Freed & Partners, New York City

Assoc. Arch: Robert P. Madison Intnl., Inc., Cleveland

Contractor: Turner Construction Co., Cleveland, in assoc. Colejon Corp., Choice Construction Co., Inc., & Bradley Construction Co., Inc.

80' from a tower only 60' in width. In addition, the wing is skewed in plan with respect to the tower and the top and bottom of the cantilever wing do not correspond to framed levels in the tower.

The solution included the use of full-depth cantilever trusses in the walls of the theater wing. Partial support is provided at the south wall of the cantilever wing by a story-high cross truss, which spans between the northeast corner of the tower and a column in the glass wall of the tent.

The tension and compression components of the overturning moment are resisted by the diaphragms of the sixth floor and second floor, respectively. At the sixth floor, the concrete slab is cast on a steel plate diaphragm. This diaphragm is used to distribute the cantilever truss reactions to braced frames located around the perimeter of the tower since a direct connection to the braced frames would have been difficult on account of the skew between the theater wing and the tower. In addition, the substantial eccentricity between the location of the cantilever work point and the elevation of the sixth floor diaphragm had to be resolved in the same connection detail.

At the second floor, there are large architectural openings in the floor where the compression load from the cantilever truss is delivered. To work around these architectural constraints, a horizontal truss was built into the floor framing to span past the openings. Similarly, numerous architectural openings through the south wall of the tower, in the area most critical to resisting the loads from the cantilever wing, meant that braced frames were not acceptable in this area. To work around this, a substantial moment frame system was provided around the openings to provide stiffness and strength requirements.

The cantilever wing was even more of a concern from a stiffness point of view rather than strength. Even under dead load, the overturning moment from the cantilever wing tends to induce significant horizontal side sway in the tower structure. With stringent architectural tolerances for the construction of the tent's structural and glazing systems—which are supported directly by the tower—it was desirable to erect the tower with minimal built-in side sway.

In the interests of structural efficiency, the engineers took full advantage of all available sources of stiffness. The significant stiffness of the tent structure was used to limit the side sway of the tower, and even the stiffness of the circular exhibit hall, which is connected by a bridge to the tower, was taken into account. Relying on other sources of stiffness to reduce construction-phase deflections of the tower meant specifying that steel erection and concrete pours at the cantilever wing be postponed until other portions of the structure had been completed. Additionally, the tower was horizontally cambered to the west to reduce some of the side sway effects.

The careful attention to detailing and coordination with the architectural systems paid off: despite the complexity of the project, erection proceeded smoothly and quickly and the building was completed on time and on budget.