Retractable roof to ride on concrete

A massive, curved concrete track-beam system, poured in place 150 feet above grade, is being built to support a unique retractable roof for Milwaukee's new Miller Park

By Dan Simonides

All photos courtesy of Symons Corp.

The curved concrete beam is being cast in forms supported by trusses 150 feet above grade. The yellow tower-crane sections at midspan are topped by 200-ton jacks that allow beam elevation adjustments as the concrete is placed.

When Milwaukee Brewers' fans flock to the new 43,500-seat Miller Park next April to hear the first crack of the bat, they won't have to worry about dressing for inclement weather. Truss-framed roof sections that ride on a unique 1,050-foot-long concrete track-beam system will be able to shelter the stadium in minutes.

Like the petals of a fan, the five roof sections will unfold on tracks set atop the beam system, which arcs around the stadium behind the outfield stands (Fig. 1). In poor weather, the movable roof sections—each approximately 600 feet in radius and more than 150 feet across at the outfield end—will fan out from an attachment point on a tower located behind the stands at home plate. In nice weather, they will retract and settle above two fixed roof sections covering the left- and right-field sideline stands. Three of the movable sections will sit above the left field's fixed section, and the other two, above the right field's section. Motor-powered bogies will extend or retract all five sections in just 12 minutes.

HCH Joint Venture, the general contractor for Miller Park, broke ground in October 1996 and is scheduled to complete the stadium in April 2000, just in time for the baseball season. Project engineers chose cast-in-place concrete rather than steel for the curved beams for reasons of economy, simplicity, and aesthetics (see sidebar on page **16**).

Extremely rigid in design

The concrete track-beam system is supported 150 feet above grade by eight steel towers at 150-foot centers, and the beams will span these towers without intermediate support. The bogies mounted at each end of the roof sections will deliver concentrated live loads to the

beam system as they move the roof sections into position. Instantaneous live-load deflection of the beams at midspan must be no greater than L/1000 (about 1.8 inches) to ensure that the tracks stay level.

To achieve such great rigidity, the track-beam system's individual curved girders are 16 feet deep and 30 to 36 inches wide. Each moving roof section rides on its own girder. The girders are all at the same elevation but are not parallel (concentric) because the pivot points for the retractable roof sections are not coaxial.

The curving girders are intersected every 12 to 16 feet by 18-inch-thick, 16-foot-deep connector beams. Therefore, in plan view (Fig. 2), the track-beam system appears as a grid of rectangular beams. This structural grid helps spread the load on any one girder across all girders and counters the curved beam system's tipping force. The 16-foot girder depth and the interlocking grid also minimize deflection under the weight of the bogies.

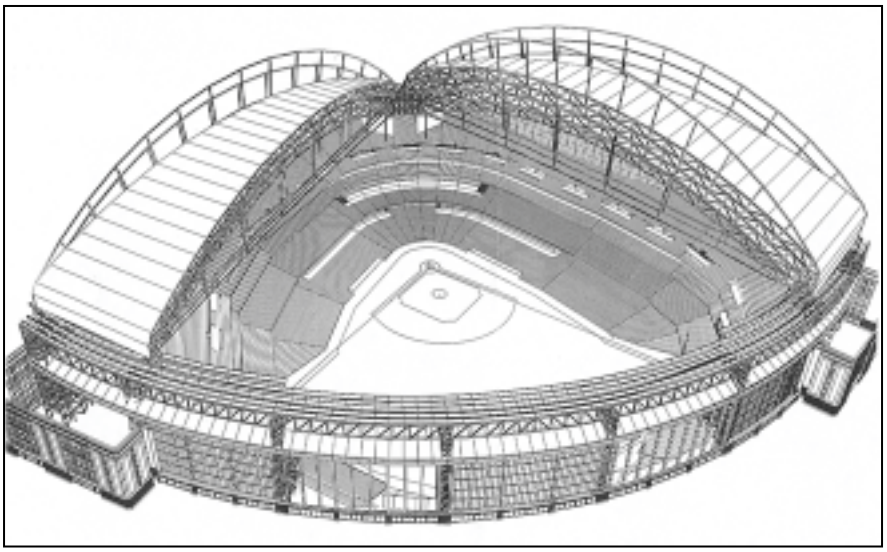


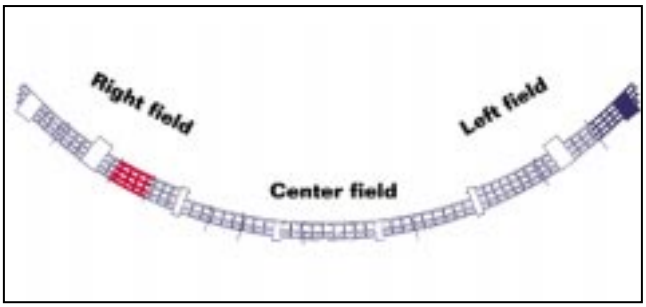
Figure 1. This sketch of Miller Park shows the roof sections (retracted) and the concrete track-beam system, which arcs around the stadium behind the outfield stands.

No two forms the same

Stadium architect HKS Inc., Dallas, provided a print of the track-beam system, which surveyors transferred to computer-aided-design drawings. The CAD files were then delivered to the Milwaukee office of Symons Corp., which engineered a forming system comprised of gangs assembled from Symons' Max-A-Form heavy-duty steel panels.

Each form consists of stacked gangs of two 8-foot-high panels, along with filler pieces and corners. Panel lengths vary from 1 to 8 feet. The panels for the outer faces of the girders are generally 8 feet long, supplemented by filler panel sizes down to 3 feet as necessary.

Girder cross sections are all rectangular. However, the girders are not concentric, and the voids shaped by their intersection with the transverse connector beams are different sizes. Moreover, many of the corners are not right angles. Thus, the forms must be modified for each pour with different sizes of steel fillers. Symons also supplied 60 custom, flexible stripping corners to be used where rigid corners wouldn't work because of the sharpness of the angle. Workers lower the forms to the ground



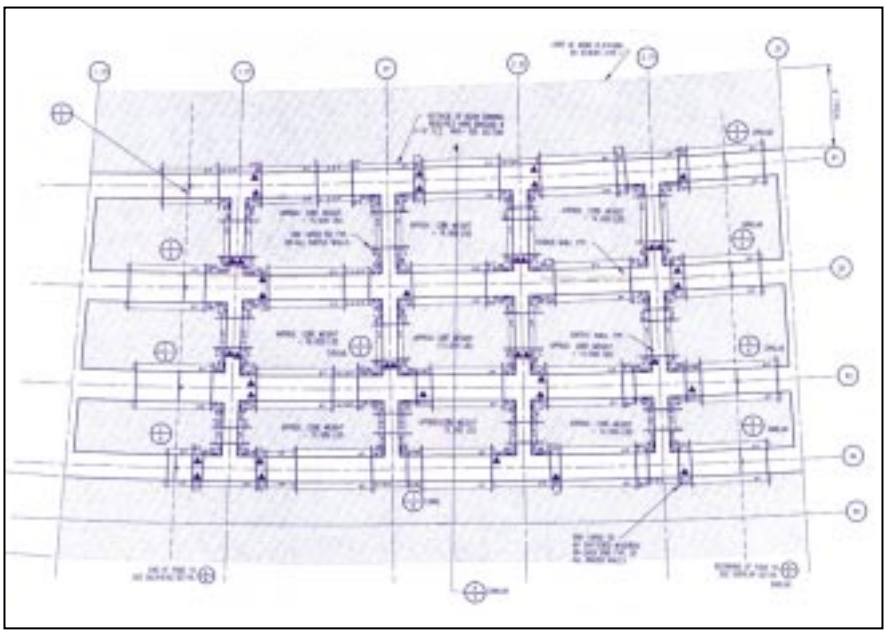
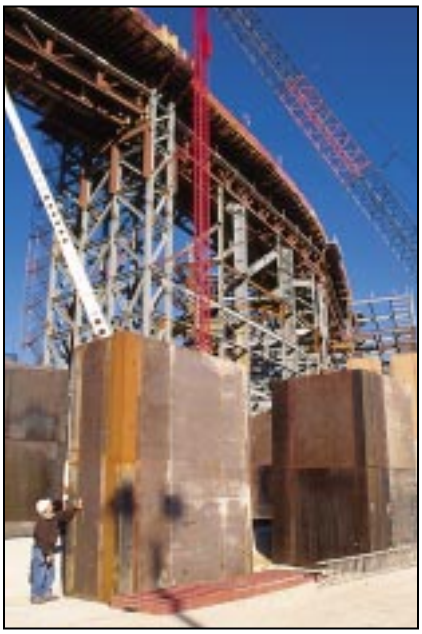


Figure 2. On the top left is a plan view of the track-beam system. Fewer track beams are required behind center field because only three of the five roof sections are designed to traverse the stadium. The track beams, which are spaced 8 to 9 feet apart, are not parallel (concentric) because the roof-section pivot points are not coaxial. The drawing on the bottom left shows the details of the forming equipment required for the right-field pour shown in red in the track-beam plan view.

This form, photographed from the top of the track beam, is ready to be stripped. The form created two 16-foot-deep track girders (topped with two rows of stud inserts for affixing the bogie track) and two cross members.



Upright on the ground are two 16-foot-tall core-form gangs ready for lifting into place.

Beam curvature calls for concrete

Until the Miller Park project, all retractable stadium roofs in the United States have been designed to move linearly, their bogies traveling along straight track-beam systems fabricated from steel. Building a straight track-beam system of steel is not particularly complex, but building one in an arc, as required by Miller Park, would call for the use of costly curved steel beams with sufficient strength and rigidity to counter an inward tipping force. This tendency to tip results because the center of gravity of a horizontal ring-shaped beam covering a partial circle is not in the beam itself but at a point along the beam's radius.

Added to this tipping force at Miller Park will be the live loads of the roof sections riding on the beams. Not only will a major portion of the weight of each roof section fall on the track-beam system, but so will snow and wind loads.

With a curved steel-beam system, the inward tipping force would be counteracted by extensive bracing, the cost of which is relatively high. Miller Park's architect also found such bracing to be undesirable for aesthetic reasons, since it would interfere with the lines of the stadium's external facade of glass curtain walls and precast-concrete panels decorated with inlaid brick.

A curved cast-in-place concrete beam system, on the other hand, is less expensive to build along an arc than a steel one, and it can be braced by internal connector beams. A cast-in-place concrete system can be smooth-curved or slightly chorded. Chorded beams are being used for Miller Park because they can be produced using rigid steel wall forms, which are more economical than wood or flexible steel radius forms. Over the 600-foot radius of curvature, the 8-foot-long chords are never more than an inch from the true circumference and will not affect beam strength or track placement.

after each pour to modify them and then lift them back up to their new locations.

The interior form corners are cut at 45-degree angles to permit the side panels to be individually stripped into the voids. Only two corners have to be disassembled and one side pulled back to strip all four sides, which speeds the work of stripping, disassembling, and flying individual panels to the ground.

The entire 1,050-foot project will require 13 pours, some including a tower cap plus girder lengths on either side of the cap. Because of their thicknesses, the tower caps are tied with she-bolts and lag studs. The caps range in size from 12 to 26 feet wide by 45 feet long.

To keep the project moving efficiently, Symons supplied three sets of forming components. While one crew is assembling a set of forms, other crews are casting and curing concrete in the second set and stripping forms from concrete previously cast in the third set. Each pour requires 250 to 1,200 cubic yards of 5000-psi concrete, delivered via a truck-mounted 52-meter boom pump and a conveyor system.

Ironworkers install rebar between the core forms. This pour of the curved track-beam system will be four girders wide. The bases of the girders contain as many as nine layers of #11 rebar.

Trusses provide support between towers

Supporting the forming system and the weight of the concrete from tower to tower are 150-foot-long steel trusses custom designed and built for the project by structural engineer Fink, Roberts, and Petrie Inc., Indianapolis. Three or four trusses are being used per span. On top of the trusses is a deck system designed by Aluma Systems USA Inc. consisting of 18-inch I-beams, aluminum joists, and two layers of plywood. Serving as the deck over the tower caps is a permanent 3-inch slab poured over metal decking.

As alternatives to the trusses, HCH evaluated both 20- and 100-kip shoring towers but found those options inadequate for the loads or too labor intensive. However, a single temporary midspan shore—consisting of tower-crane sections topped by 200-ton hydraulic jacks—is being used to adjust the beam level as the concrete is placed. This midspan shore also facilitates stripping of the deck.

The track-beam system is heavily reinforced, and no rebar lap splices are allowed—only mechanical splices using couplers or bar locks. The bases of the girders contain as many as nine layers of #11 rebar, with as little as 1 inch clear spacing between bars. Because of this density, the contractor specified a pea-gravel mix with superplasticizer for the bottom 2 feet or so of each girder, topped by a conventional mix with ¾-inch aggregate.

Credits

Owners: Southeast Wisconsin Professional Baseball District and the Milwaukee Brewers

Architects: HKS Inc., Dallas; NBBJ, Los Angeles; and Eppstein Uhen Architects, Milwaukee

General contractor: Joint venture of Huber, Hunt & Nichols Inc., Indianapolis; Clark Construction, Chicago; and Hunzinger Construction Co., Brookfield, Wis.

Roof contractor: Mitsubishi Heavy Industries of America, Chicago

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Publication #C99I014