CASE STUDY

Princeton Gets High Marks For Precast Stadium Design

Unique horseshoe-shaped precast concrete building and precast trapezoidal risers create a year-round facility that offers distinctive look and challenging design

When Princeton University administrators decided to replace the existing Palmer Stadium, they had one overriding goal: Make it the most distinguished and intimate collegiate stadium in the United States. Achieving that goal involved a number of design challenges that took advantage of the unique capabilities inherent in precast concrete seating units and in load- and nonload-bearing precast concrete architectural panels.

"One major objective in designing this stadium was to make it a year-round facility," explains Chan-li Lin, project architect for Rafael Vinoly Architects P.C. "All too many stadiums are closed for access on non-game days, and there usually are only six football games per year at Princeton. That meant the original stadium, surrounded by a chain-link fence, sat empty most of the time." The new design allows the perimeter building to be used for other university functions throughout the year, keeping both it and the concourse area accessible for community events, without making the field accessible, too.

Another key element in the design came in adding daylight to the typically dark space behind the seating, Lin says. "The underside of stadium seating is often a dark and unattractive area, cluttered with various stadium service elements. In the new stadium, the space between the perimeter 'wall building' and the gates for the spectator seating area is designed so that it would become an attractive place for the university community throughout the year. By moving the service function into the 'wall building,' introducing natural light and bringing extensive planting in this space, we tried to achieve a new kind of covered public space, which can be enjoyed independent of sporting events."

The stadium consists of a horseshoe-shaped structure built of precast concrete load-bearing architectural panels that houses all of the services needed for football games, including ticket offices, restrooms and concession stands. Inside this shape is the stadium, containing seating for 27,800 spectators, arranged on two tiers. The lower bowl consists of a combination of cast-in-place seating on three sides and precast concrete risers at the open end. Above this, appearing to "float" over each of the three enclosed sides, is a trapezoidal seating area composed of precast concrete triple risers. These risers feature open slots in their backs that allow light to penetrate to the concourse behind the risers, producing an airy, high colonnade that remains open throughout the year, with only the seating and field itself closed to access.

> ***'This stadium is a significant architectural wonder.'***

"The project definitely provided a distinct application for precast concrete that met this particular set of goals," says Helmuth Wilden, president of H. Wilden & Associates Inc., Macungie, Pa., consulting specialty engineer on the project. "This stadium is a significant architectural wonder with unique elements. The goal was to be unique, and it achieved that—but it also included some design ideas that other stadium designers may be able to incorporate, too."

Fast-Track Schedule Needed

Accomplishing the full range of goals, especially on the tight, 18-month time frame required, proved challenging in many ways. It required close cooperation among all construction team members, says Wilden. "During the design and shop-drawing phase of the project, we met with the architect and structural engineer every two weeks for more than three months to discuss the most efficient way to design components and go over the nitty-gritty details of how to make things work. We had great cooperation from everyone, which helped overcome some of the frustrations that a job of this complexity usually has."

Turner Construction Co. in Philadelphia served as construction manager, with Thornton Tomasetti Engineers in New York serving as structural engineer.

Planning the project took considerable time, as every aspect of the design was examined for optimum impact.

The finished stadium wall features large cutouts for entry points, as well as window bands through the top level. This upper space, now mostly empty except for the press box, will offer additional facilities for university functions throughout the year.
Photo: Chuck Choi, ESTO

Some 81 different plan options, and 27 stadium typologies in three site configurations, were considered and discussed in detail with faculty, students and administrators. In part, this helped determine the best design to accommodate not only football games, but also soccer, lacrosse and track events. After considering all options, the design team narrowed the field to two options, and finally eliminated one in which retractable seating would have been used to provide maximum seating requirements for each sports activity.

Instead, a separate track field was created directly adjacent to the stadium at the open end of the horseshoe. That shift allowed designers to create a stadium field measuring 395 by 245 feet, one of the tightest fields that would accommodate football, soccer and lacrosse. This maximized the sense of intimacy. "The general trend with stadiums today is to design them for one sport only so they are more responsive to those needs," explains Lin. "Designing to accommodate more major sports creates a design in which none of the sports really has a design that works for it."

Separating the track field took more space, but it made more sense for the activities required and provided visual continuity from the new stadium to the 1960s gymnasium nearby, he notes. "Everyone was happy with this decision, especially the track team. They knew that if they had to fight with the football team for practice time on one field, they would lose!"

Precast Saves Costs

Precast concrete components were specified for the wall building and upper seating sections for a number of reasons, Lin notes. "Risers in stadiums today tend to be precast concrete, because they make such a cost-efficient choice. We also could achieve the very customized design we desired for these units in precast. We specified load-bearing precast concrete panels for the wall building due to the cost savings possible. We had a lot of area to cover and we thought we could use an approach more often incorporated into warehouse construction. That allowed us to skip the steel framing altogether in the wall building and maintain our tight schedule."

Specifying precast concrete panels for the perimeter building also gave the designers a way to acknowledge the original stadium, which was torn down to make room for the new one. Originally, they hoped to save at least a portion of the façade to reflect the stadium's heritage, but this proved infeasible. "The original stadium had been built in 1914, when reinforced-concrete technology was very primitive," Lin explains. "There were no expansion joints and not enough reinforcement in the concrete, so it kept cracking and was in a perpetual state of decline. We decided to pick up on the horseshoe configuration of the original stadium, which worked well for the site, while executing that design with modern architectural and structural techniques."

This overview shows how the horseshoe-shaped stadium connects visually to the track stadium at its open end and further along to the 1960s gymnasium at the far right.
Photo: Paul Warhcol Photography Inc.

Princeton University's new stadium features several unique aspects. These include the trapezoidal upper seating on three sides, made of precast concrete triple risers, and a perimeter building housing all services that remains open year-round, as does the colonnade behind the seating sections. *Photo: Chuck Choi, ESTO*

Curved Panels Avoided

The building consists of a series of parallel load-bearing panels spaced 16 feet apart supporting hollow-core planks, supplemented by nonload-bearing panels. The nonload-bearing panels were insulated to reduce their weight and make them easier to erect, explains Harry Gleich, vice president of engineering at Metromont Prestress Co. in Greenville, S.C. Creating the two curves of the horseshoe pattern proved challenging, because none of the panels actually curve, he adds. Each panel in the curve, which encompasses eight panels in all, has a faceted face to allow it to connect on a slight angle. This produced the feeling that the pieces were curving while allowing them to be

This layout shows the relationship among the various structures, including the perimeter horseshoe-shaped building, the seating sections on three sides above the field-level bowl seating, the track stadium (center) and the gymnasium (left).

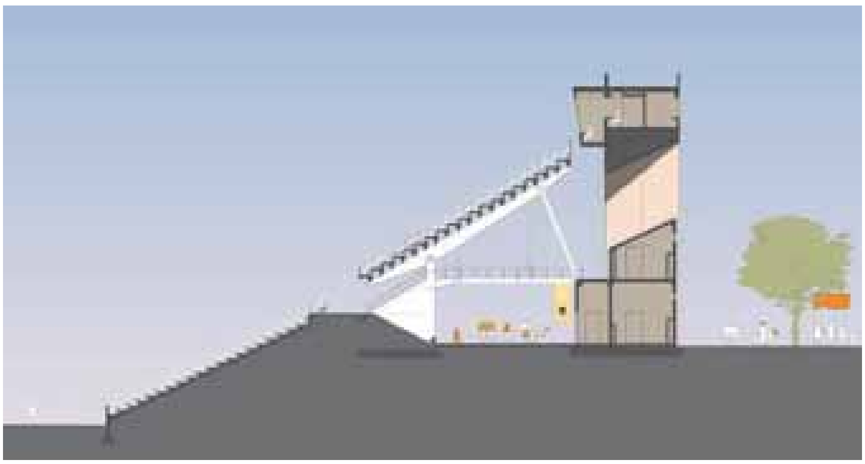
cast as a series of flat facets in a single panel.

The building, which runs 1,600 feet long, basically consists of boxes that were fit together, explains Gleich. Upper floors feature a band of windows, while other areas include angled cutouts at stair towers and tall entry spaces to the stadium. "These were basic components and were pretty typical for this construction, but there was a lot of it, which made it more challenging," he says. In addition, parts of this building had to be in place before the upper grandstands could be erected, as the building's load-bearing panels served as supports for part of the risers.

The panels feature a sandblasted, exposed-aggregate finish that was selected to produce a color in keeping with the surrounding campus buildings, Lin explains. The architect made several trips to the precaster's plant in Charlotte, N.C., to discuss prototype panels and ensure the proper color match.

Triple Risers Proved Challenging

The key challenge came in designing and erecting the triple-riser seating sections, which were produced in a configuration never before accomplished, Wilden says. They feature a teardrop shape, allowing the underside to curve, as well as slots through the back reinforced with galvanized pipe to provide additional stiffness.



The precast concrete risers making up the top portion seem to "float" over the cast-in-place bowl seating due to their support on cast-in-place piers and precast concrete wing beams on the bottom and steel posts connecting to the precast concrete building panels at the top.

Originally the risers were planned to be single-tread units. This would have allowed the slots to be cast as continuous horizontal openings between each unit, but would have been far more costly and not as stable. Instead, Metromont proposed creating triple risers and casting in discontinuous openings to create vertical struts to help support the load arrangement. This format not only cut the number of casts, but saved considerably more costs because the risers were erected on a per-piece basis. Creating triple risers essentially cut that expense by two-thirds.

The risers' cutout configuration consists of a 1-foot solid section, a 5-foot window opening, an 8-inch solid brace, a 5-foot window section, a 5'4" solid section, a 5-foot window, an 8-

The concourse under the grandstand is designed as a light-filled public galleria for everyday use by the campus community. This view shows the precast concrete triple risers forming the colonnade's "roof."

inch brace, a 5-foot window and a final 1-foot solid length. Each window opening was 8 inches tall, providing a truly unique riser design.

Casting these pieces proved not to be difficult once the design was set and the forms created, Gleich notes. However, galvanized pipe was set horizontally into the window openings to provide an additional safety measure for each section. "The architect asked that no concrete be left on the galvanized pipe, requiring extra attention to this casting," he adds. There also were tight tolerances on these pieces due to code requirements for life safety.

The architect's desire for high quality in every element of the design was particularly noted in producing these risers, Gleich notes. "The owner and architect had high expectations for the quality of the risers, and they tightened the tolerances for these pieces to the point that we were casting them on an architectural level, rather than to typical seating tolerances," he explains. "They both wanted these pieces to be very precise, and we were able to work with them to achieve this."

Load Tests Conducted

Because this type of triple riser never had been produced before, Metromont and HWA conducted load tests to ensure the risers could carry the full design load. This also was done to ensure the vertical support segments tying one seat section to the next were sized and reinforced adequately to handle the horizontal shear. The test was fully successful. "We loaded the pieces to 125 percent of their carrying capabilities, at which point they developed only a few small cracks," Gleich says. "So we added a little more reinforcing steel to boost them further and started manufacturing."

The seating sections were designed in a trapezoidal shape to add distinction and create a more-intimate feeling for the crowd. Once cast, connecting these unusually shaped risers to the lower cast-in-place bowl to provide the "floating" effect desired also proved challenging. "We wanted to design the supports to be as light as possible to enhance the feeling of the upper grandstand floating between the rear wall and the field," Lin explains.

To achieve this, the bottom end of the raker beams support the risers, which consist of a single piece of precast concrete cantilevering from the top of two cast-in-place piers. The upper ends of the raker beams are supported by inverted V-shaped steel posts, which attach to the precast concrete outer building around the perimeter. "We decided on the V-shaped steel posts at the back to visually disassociate the stands from the wall building, to make the upper grandstand look less obviously 'structured.'"

Tight Tolerances Required

Matching the connection posts to their proper positions in the wall and in the raker beam proved challenging, offering tolerances of about 1/16 inch. "This required us to focus quality-control inspections at the casting plant even tighter than usual," Gleich notes. The posts were attached to the raker beam at the point of the inverted V and hoisted into place. Once they were set, the lower ends of the posts were spread as far apart as needed to meet the connecting point on the precast concrete wall, rotating the post as needed,

The long slots between each seating row in the precast concrete triple risers allow daylight to stream into the concourse. Photos: Chuck Choi, ESTO

The adjoining track stadium features precast concrete seating covered with a fabric canopy held in place by cantilevered steel posts. The units are monolithic with precast concrete seating facing the other direction to enclose the open end of the football field's seating.
Photo: Paul Warhcol Photography Inc.

and bolted into position. C&C Erectors Inc. in Woodbury, N.J., performed the erection on all precast components while Concrete Structures Inc. in Richmond, Va., on a subcontracted basis through Metromont, produced the raker beams and wing beams.

Another element that proved to be an erection challenge was the pedestrian bridges that connect the upper seating elements to a concourse level around the building over the colonnade space. These consist of a steel deck covered with concrete sitting on two steel posts that are braced against the upper end of the raker beams and the building wall, with a cable extending down from the top of the raker to the middle of the bridge for additional support.

The seating section in the south, open end of the stadium was designed with seats facing both sides, creating a monolithic element that combines seating for both the football and track stadiums. These were produced as solid risers, as there is no concourse area connected with them. The track seats also feature a fabric canopy overhead, supported by cantilevered steel struts attached to the upper end of the precast raker beams.

Although the corners of the horseshoe-shaped building seem to curve, the panels were in fact faceted on their faces to allow them to remain flat while making the two required curves. *Photo: Chuck Choi, ESTO*

The result of this unique blend of precast components and distinctive architecture is a stadium that serves as a multiuse facility. Throughout the year, the building is used by students, faculty and administrators for a variety of events, keeping the space alive even when no activities are planned for the field. And all involved see additional inspirations that this project can provide.

"This was one of the largest precast concrete projects we've been involved in," says Lin. "It was unusual for us in that, in other building types, we often use precast concrete only as an economical cladding material. In a stadium, where much of its architecture tends to be about its structure, the use of precast concrete allows the structural elements to be designed and built with architectural care in an economical manner. This project gave us an opportunity to achieve this rare and satisfying combination where architecture and structure became one. It's a good way to design a stadium project."

Wilden agrees. "The seating design may be more expensive than most stadium developers would want to use in order to provide brighter spaces beneath the seats," he says. "But the horseshoe building concept offers some substantial ideas for other designers. It's a unique element and may have more uses that would help other stadiums, especially in a college-type atmosphere where seating remains in the 30,000-seat range. It's very enjoyable to go by the campus and see the complex open all the time and being used by the university for many functions." ■

— Craig A. Shutt

Component List

Princeton University's new stadium was a challenging precast concrete job requiring close contact between all members of the design-build team. The project required 1,499 piece details and 241 erection drawings, along with 198 different pieces of hardware for connections. Some 3,611 concrete components in all were cast. These broke down as:

Raker support wings	16
Raker beams	60
Rectangular beams	56
Columns	26
Stairs	144
Spandrels	28
Vomitory panels	12
Stadia	427
Tubs	7
Solid slabs (6" & 8")	171
Hollow-core	1,255
Roof and soffit panels (5")	122
Inset and interior panels (6")	44
Inset gray and inset architectural panels (8")	1,106
Solid gray panels and solid arch panels (8")	137
Total pieces	**3,611**

Additional details and diagrams on this project are available in the May/June 1999 issue of the PCI JOURNAL. To purchase a copy, contact PCI, 175 W. Jackson Blvd., #1859, Chicago IL 60604; 312/786-0300; fax: 312/786-0353. Or visit PCI's website at www.pci.org, where the complete article will be uploaded.

Precast Stadium Construction

Across the country, designers are using more and more precast concrete components to create stadiums and indoor arenas of all shapes and sizes. Riser sections, especially economical triple risers, comprise a key ingredient, becoming the seating format of choice for many designers. It offers cost savings and design advantages that are hard to beat. But other precast components also are gaining more adherents. Designers also are using other structural components and architectural precast concrete panels for cladding in stadiums.

Here is a cross-section of recent stadium and arena projects completed around the country by PCI members. The list indicates how extensively precast concrete components are being used as the solution of choice for these projects.

EAST

Name	Location	Precaster
Altoona Ballpark	Altoona, Pa.	New Enterprise Stone & Lime Co., Inc.
The Apollo of Temple Univ.	Philadelphia	New Enterprise Stone & Lime Co., Inc.
Baltimore Ravens Stadium	Baltimore	The Shockey Precast Group & High Concrete Structures, Inc.
Byrd Stadium	College Park, Md.	The Shockey Precast Group
Civic Arena Renovation	Pittsburgh	Sidley Precast, Inc.
Corestates Center	Philadelphia	The Shockey Precast Group
Erie Stadium	Erie, Pa.	Sidley Precast, Inc.
Marine Midland Arena	Buffalo, N.Y.	Sidley Precast, Inc.
Marshall Univ.'s Henderson Center Renovation	Huntington, W.Va.	Marietta Structures Corp.
MCI Center	Washington, D.C.	The Shockey Precast Group
North Eastern Civic Arena	Wilkes-Barre, Pa.	High Concrete Structures, Inc.
Orioles Park at Camden Yards	Baltimore	The Shockey Precast Group
Princeton Univ. Stadium	Princeton, N.J.	Metromont Prestress Co.
Penn State Convocation & Events Center	University Park, Pa.	New Enterprise Stone & Lime Co., Inc.
PSINet Stadium	Baltimore	The Shockey Precast Group
Redskins Stadium	Washington, D.C.	Metromont Prestress Co.
RFK Stadium	Washington, D.C.	The Shockey Precast Group
The Sandcastle	Atlantic City, N.J.	Universal Concrete Products Corp.
Three Rivers Stadium Addition	Pittsburgh	Sidley Precast, Inc.
Univ. of Va. Scott Stadium Addition	Charlottesville, Va.	The Shockey Precast Group

WEST

Name	Location	Precaster
Bank One Ball Park	Phoenix	TPAC—A Division of Kiewit Western Co.
Boise State Univ. Stadium	Boise, Idaho	Eagle Precast Co.
Bruce Huast Stadium	St. George, Utah	Eagle Precast Co.
Centennial Garden Arena	Bakersfield, Calif.	PCL Construction Services
Delta Center	Salt Lake City	Eagle Precast Co.
"E" Center	West Valley City, Utah	Eagle Precast Co.
Eagle County Fairgrounds	Eagle, Colo.	Eagle Precast Co.
Frontier Days Grandstand	Cheyenne, Wyo.	Eagle Precast Co.
Garden of Champions	Indian Wells, Calif.	Clark Pacific
Golden Spike Arena	Ogden, Utah	Eagle Precast Co.
Hass Pavilion	Berkeley, Calif.	Willis Construction Co., Inc.
Mountain State Univ. Stadium	Bozeman, Mont.	Central Pre-Mix Prestress Co.
Murray Ice Center	Murray, Utah	Eagle Precast Co.
Oakland Alameda County Coliseum & Stadium	Oakland, Calif.	Willis Construction Co., Inc.
Ogden Baseball Stadium	Ogden, Utah	Eagle Precast Co.
Pacific Bell Park	San Francisco	Willis Construction Co., Inc.
Peoria Spring Training Facility	Peoria, Ariz.	TPAC—A Division of Kiewit Western Co.
Qualcomm Stadium at Jack Murphy Field Expansion	San Diego	Coreslab Structures (LA) Inc.
Spokane Arena	Spokane, Wash.	Central Pre-Mix Prestress Co.
Staples Center	Los Angeles	PCL Construction Services
Weber State Ice Rink	Ogden, Utah	Eagle Precast Co.

SOUTH

Name	Location	Precaster
Alltel Arena	Little Rock, Ark.	Metromont Prestress Co.
Ballpark at Union Station	Houston	Heldenfels Enterprises, Inc.
Ben Hill Griffin Stadium	Gainesville, Fla.	Dura-Stress, Inc.
Bilo Center	Greenville, S.C.	Metromont Prestress Co.
Broward County Civic Arena	Sunrise, Fla.	Gate Precast Co.
Bryant-Denny Stadium	Tuscaloosa, Ala.	Metromont Prestress Co.
Carolina Panthers Stadium	Charlotte, N.C.	Metromont Prestress Co.
Charlotte Coliseum	Charlotte, N.C.	The Shockey Precast Group
Charlotte Motor Speedway	Charlotte, N.C.	The Shockey Precast Group
Chattanooga Stadium	Chattanooga, Tenn.	Metromont Prestress Co.
Clemson Univ. Stadium	Clemson, S.C.	The Shockey Precast Group
Cumberland Coliseum	Fayetteville, N.C.	The Shockey Precast Group
Donald W. Reynolds Arena & Convention Center at University of Tulsa	Tulsa, Okla.	Tulsa Dynaspan, Inc.
Dowdy Ficklen Stadium	Greenville, N.C.	Metromont Prestress Co.
East Carolina University Stadium	Greenville, N.C.	The Shockey Precast Group
Entertainment & Sports Arena	Raleigh, N.C.	Metromont Prestress Co.
Ericsson Stadium	Charlotte, N.C.	The Shockey Precast Group
Gatorbowl	Jacksonville, Fla.	Metromont Prestress Co.
Hawks Arena	Atlanta	Metromont Prestress Co.
Kyle Field at Texas A&M Univ.	College Station, Texas	Heldenfels Enterprises, Inc.
Legends Field	Tampa, Fla.	Coreslab Structures (TAMPA) Inc.
Olympic Stadium	Atlanta	Metromont Prestress Co.
Olympic Tennis Stadium	Stone Mountain, Ga.	Metromont Prestress Co.
Raymond James Stadium	Tampa, Fla.	Coreslab Structures (TAMPA) Inc.
RDV Sportsplex	Orlando, Fla.	Dura-Stress, Inc.
Space Coast Stadium	Brevard County, Fla.	Dura-Stress, Inc.
Tennessee Titans Stadium	Nashville, Tenn.	Metromont Prestress Co.
The Ballpark At Arlington	Arlington, Texas	Coreslab Structures (TEXAS) Inc.
The Ice Palace	Tampa, Fla.	Coreslab Structures (TAMPA) Inc.
The Pyramid	Memphis, Tenn.	American Precast Concrete, Inc.
Turner Stadium	Atlanta	Metromont Prestress Co.
Williams Brice Stadium	Columbia, S.C.	Metromont Prestress Co.
Wofford College Stadium	Spartanburg, S.C.	Metromont Prestress Co.

MIDWEST

Name	Location	Precaster
Bradley Center	Milwaukee	Spancrete Industries, Inc.
Cafaro Field	Youngstown, Ohio	Sidley Precast, Inc.
Canal View Park Stadium	Akron, Ohio	Sidley Precast, Inc.
Cleveland Browns Stadium	Cleveland	Sidley Precast, Inc.
Greenbeck Field House	Schofield, Wis.	Spancrete Industries, Inc.
Gund Arena at Gateway	Cleveland	Sidley Precast, Inc.
Indiana Fieldhouse	Indianapolis	American Precast Concrete, Inc.
Indianapolis Motor Speedway	Indianapolis	American Precast Concrete, Inc.
Jacob's Field	Cleveland	Sidley Precast, Inc.
Kohl Arena	Madison, Wis.	J.W. Peters & Sons, Inc.
Kohl Center	Madison, Wis.	Spancrete Industries, Inc.
Lambeau Field Renovation	Green Bay, Wis.	Spancrete Industries, Inc.
Louisville Slugger Field	Louisville, Ky.	American Precast Concrete, Inc.
Memorial Stadium	Ft. Wayne, Ind.	American Precast Concrete, Inc.
Miller Park	Milwaukee	Spancrete Industries, Inc.
Nationwide Arena	Columbus, Ohio	Sidley Precast, Inc.
North Central College Stadium	Naperville, Ill.	DuKane Precast, Inc.
Northwestern Univ. Nicolet Football Center	Evanston, Ill.	Spancrete Industries, Inc.
Ohio State Univ. Baseball Stadium	Columbus, Ohio	Concrete Technology, Inc.
Paul Brown Stadium	Cincinnati	Metromont Prestress Co.
Perry Stadium Renovation	Bowling Green, Ohio	Sidley Precast, Inc.
Pettit Ice Center	Milwaukee	Spancrete Industries, Inc.
Physical Education Center at the Univ. of Wisconsin-Parkside	Kenosha, Wis.	Spancrete Industries, Inc.
Rose Hulman Institute	Terre Haute, Ind.	American Precast Concrete, Inc.
Schottenstein Arena	Columbus, Ohio	Sidley Precast, Inc.
Seymour High School Training Center	Seymour, Wis.	Spancrete Industries, Inc.
Shawano Grandstand	Shawano, Wis.	Spancrete Industries, Inc.
Stambaugh Stadium Addition	Youngstown, Ohio	Sidley Precast, Inc.
Sturgeon Bay Grandstand	Sturgeon Bay, Wis.	Spancrete Industries, Inc.
Univ. of Illinois Memorial Stadium	Champaign-Urbana, Ill.	American Precast Concrete, Inc.
Univ. of Louisville Cardinal Stadium	Louisville, Ky.	American Precast Concrete, Inc.
Univ. of Nebraska-Lincoln Memorial Stadium	Lincoln, Neb.	Kroeger Precast Concrete, Inc.
University of Notre Dame Football Stadium Expansion	South Bend, Ind.	Prestress Services, Inc.
Victory Field	Indianapolis	American Precast Concrete, Inc.
Wisconsin Center at Univ. of Wisconsin-Madison	Madison, Wis.	Spancrete Industries, Inc.
Xavier Convocation Center	Cincinnati	American Precast Concrete, Inc.