Precast Superstructure Gives Princeton University Stadium Distinctive Flair

Rafael Viñoly, AIA
Principal
Rafael Viñoly Architects, P.C.
New York City, New York

Aine Brazil, P.E.
Principal
Thornton-Tomasetti Engineers
New York City, New York

Helmuth Wilden, P.E.
President
H. Wilden & Associates Inc.
Allentown, Pennsylvania

Harry Gleich, P.E.
Vice President—Engineering
Metromont Prestress Co.
Greenville, South Carolina

Princeton University's new multi-million dollar stadium, seating about 28,000 spectators, replaces the original structure built in 1914. Designers faced a series of challenges, including a desire to create a distinctive look and a facility to be used year-round. The stadium was conceived as a design based on performance specifications on a fast-track schedule. The structure consists of a horseshoe-shaped building surrounding lower bowl-style seating and three upper trapezoidal-shaped sections. The upper seating consists of precast concrete triple risers with built-in slots that allow daylight through to brighten the concourse underneath. Precast concrete is also used for columns, floors, stairs, shear walls, and other parts of the stadium. This article presents the conceptual design and design features of the structure, and shows how precast concrete provided the aesthetics, structural support, and facilitated erection of the stadium.

Princeton University's old Palmer Stadium, built in 1914, was outmoded, in disrepair and badly needed to be replaced in order to satisfy the university's growing athletic program and maintain its long-renowned image.

The goal set by Princeton University administrators for their new stadium was simple: build the most distinguished and intimate collegiate stadium in the United States. With help from precast concrete, the new multi-million dollar stadium, which officially opened in August 1998 before the opening of the fall football season, met that goal.

Fig. 1. Princeton University Stadium features several unique aspects including 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.

The challenges of this project, beyond raising the standards of aesthetic and logistical design, included: (1) determining how best to meet the differing needs of the football, track, soccer and lacrosse teams; (2) designing a structure that acknowledges the aesthetics of the nearby gymnasium and other campus structures; and (3) meeting the tight deadline required to complete the facility in 18 months from conceptual design to completion, allowing the 1998 football season to begin on schedule.

Precast concrete components played a key role in hurdling each of these obstacles in constructing the 28,000 seat facility. Although most stadium facilities today use precast concrete risers, the design team extended the use of precast concrete into other areas of the design. This resulted from a combination of factors, including construction costs and the short time frame, but also from the distinctive design of the façade and the seating configuration.

Fig. 2. 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.

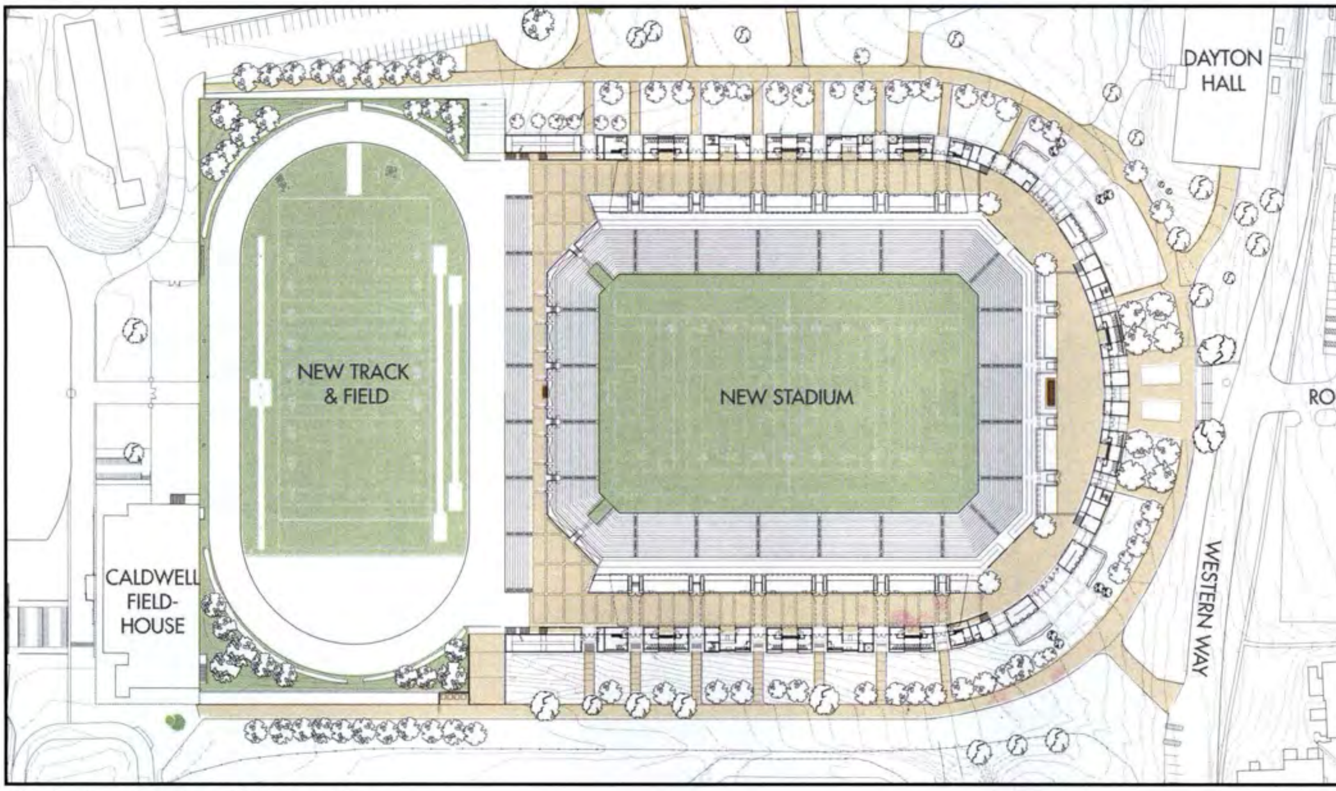

Fig. 3. Site plan of stadium complex.

Another important ingredient in this stadium job was the fact that the project design was performace based on a fast-track schedule. The close teamwork among the various team members participating in the design and construction of the stadium, which began during the early stages of design, did much to ensure the success of this project.

This article presents the conceptual design considerations and the role that precast concrete played in constructing this unique stadium.

CONCEPTUAL DESIGN

Princeton's new stadium (see Figs. 1 and 2), completed in the summer of 1998, replaces the existing stadium in the same location on the university campus. The facility consists of a

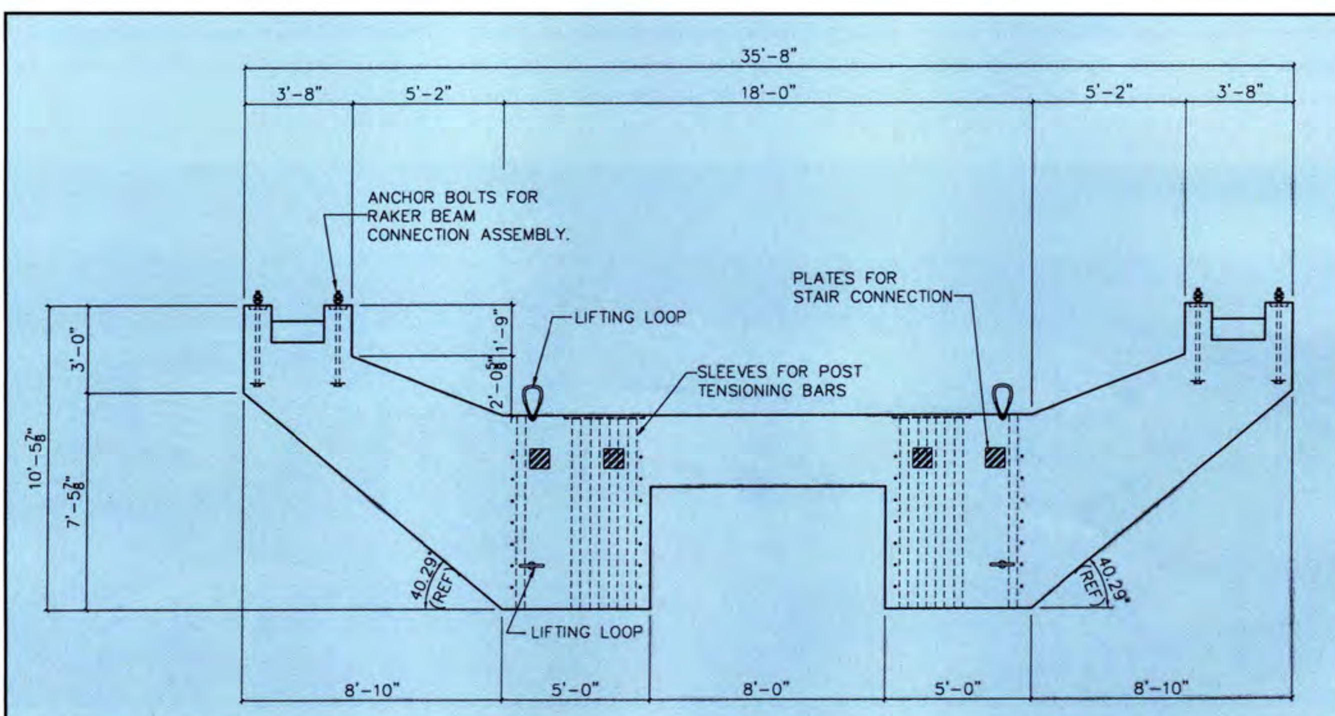

Fig. 4. Raker support beam.

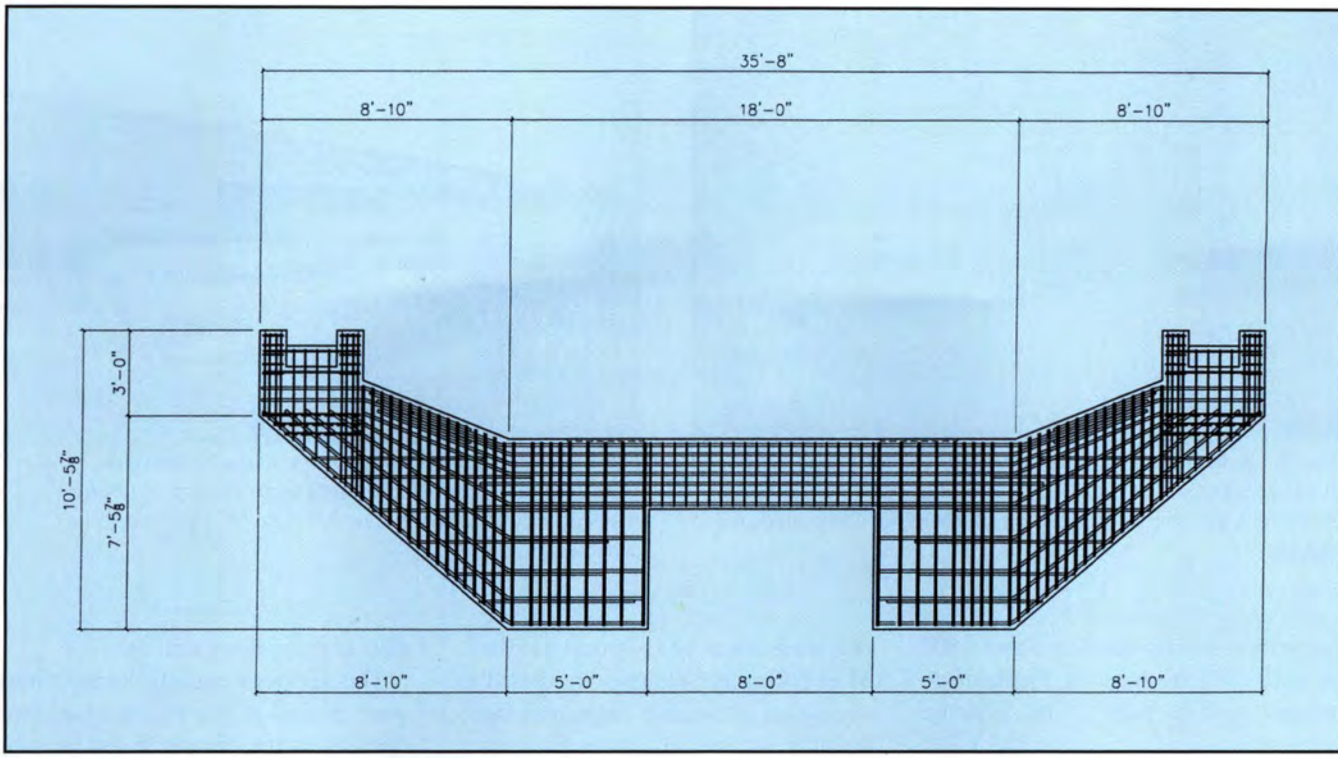

Fig. 5. Reinforcement for raker support beam.

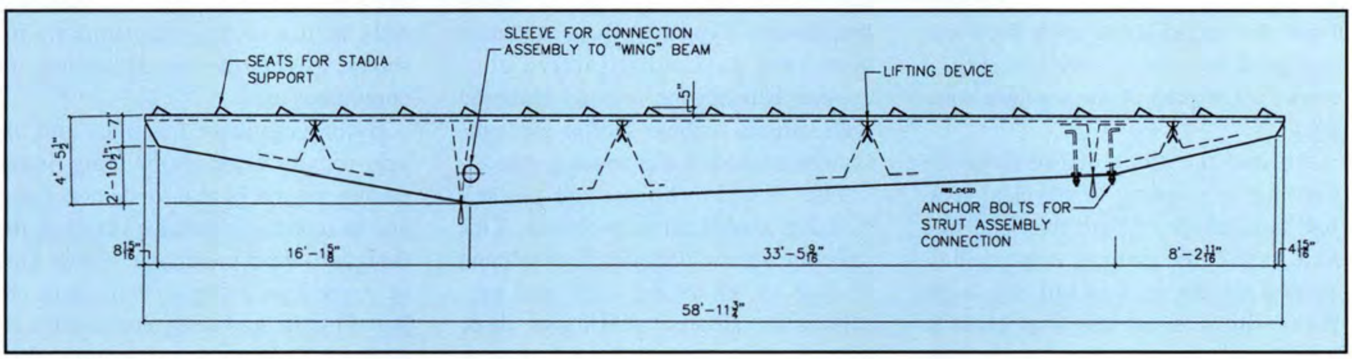

Fig. 6. Side view of raker beam.

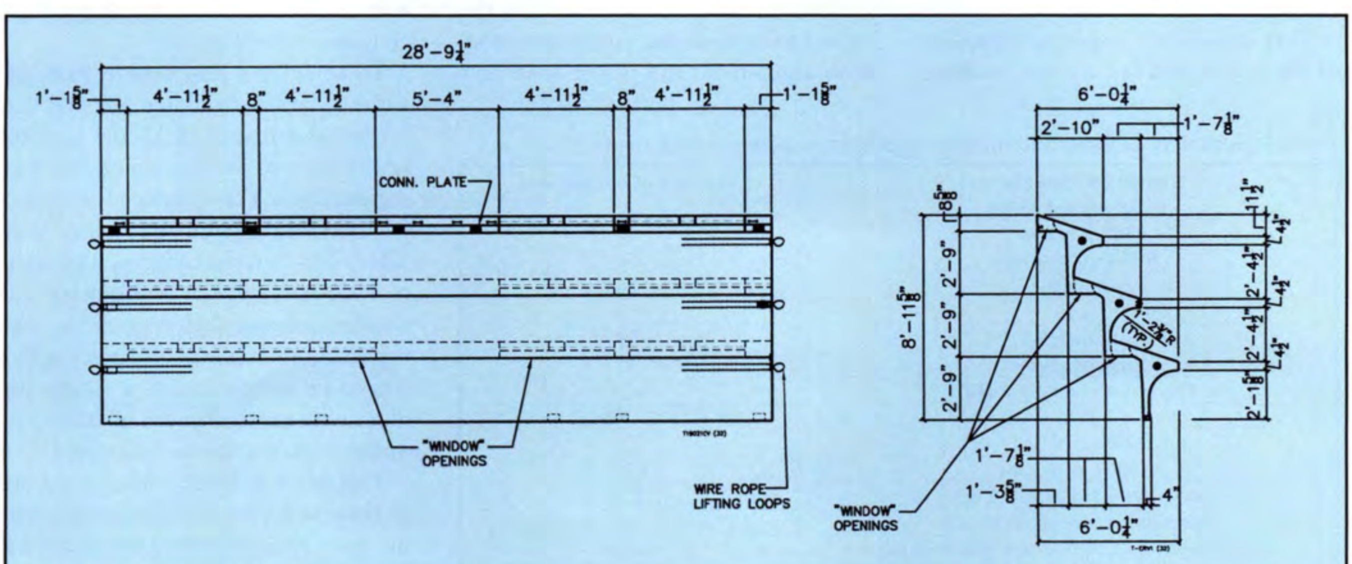

Fig. 7. Casting view of triple risers (Viñoly stadia).

Fig. 8. Underside of triple riser (Viñoly stadia) shows steel braces that were added through center of opening to provide stiffness. Openings provided extra lighting for the concourse below.

Fig. 9. Because of the uniqueness of the triple risers (Viñoly stadia) special load tests were carried out before mass production was initiated. These tests proved to be satisfactory.

horseshoe-shaped building about 1600 ft (488 m) long built of loadbearing precast concrete panels. This structure surrounds a field measuring 395 x 245 ft (120 x 74.7 m), one of the smallest possible shapes that would accommodate football, soccer and lacrosse. Note that an adjacent track field was designed for those activities. Fig. 3 shows a site plan of the stadium complex.

Around the sides of the field are cast-in-place seating in a typical football-bowl shape. Above this, one to a side, are three unique trapezoidal-shaped seating sections utilizing triple risers with slots cut into their backs to allow a visual connection between the inside and outside of the stadium seating and to provide daylight to spaces beneath the seating sections.

This design accomplished another of the key objectives, namely, making the stadium a year-round facility. Most collegiate stadiums are closed to access on non-game days, and there are only six football games per year at Princeton University. As a result, the original stadium had sat empty 359 days of the year, closed off by chain-link fences. Typically, these stadiums also have dark, unattractive concourses beneath the seating, cluttered with various stadium service elements such as restrooms and vending stands.

The exterior horseshoe-shaped building avoids those problems. This structure stands 70 ft (21.3 m) tall and 18 ft 8 in. (5.69 m) wide and surrounds the stadium seating on three sides, leaving the south end open to the new track field. The space between this perimeter colonnade and the gates leading to the spectator seating is designed to be wide and easily traversed, with light from the upper seating's slots keeping them well lit.

The services usually located here were moved to the exterior building, opening up the concourse and creating a separate facility that can be used year-round. In this manner, gates closing off the athletic field are stationed only at the seating sections themselves, leaving the rest of the area for continuous use.

By moving these functions into the year-round colonnade building, introducing natural light into the concourse and bringing in extensive planting, the designers tried to achieve a new kind of covered public space that can be enjoyed by the university community independent of sporting events. But achieving these goals produced some challenging designs that could only be achieved cost-effectively using precast concrete technology.

To select the best choice from the various options available, the architect compiled a matrix of all the possible layout options for the tracks and seating sections. This produced a total of 81 different design options to consider, which were reduced ultimately to two, namely, the one chosen and another scheme with retractable seating sections to allow all sports activities to be conducted in a single stadium with maximum use of seating no matter what event was being held.

This second choice was rejected due to time and cost considerations, with the track field separated and located at the south (open) end of the main stadium. Although this configuration

Table 1. Summary of types and number of precast concrete components.

Component description	Number of components
Raker support beams	16
Raker beams	60
Rectangular beams	56
Columns	26
Stairs	144
Spandrels	28
Vomitory panels	12
Triple risers (Vinoly stadia)	427
Tubs	7
Solid slabs (6 in. and 8 in.)	171
Hollow-core slabs	1255
Roof and soffit panels (6 in.)	122
Inset and interior panels (6 in.)	44
Inset gray and inset architectural panels (8 in.)	1106
Solid gray panels and solid arch panels (8 in.)	137
Total number of components	3611

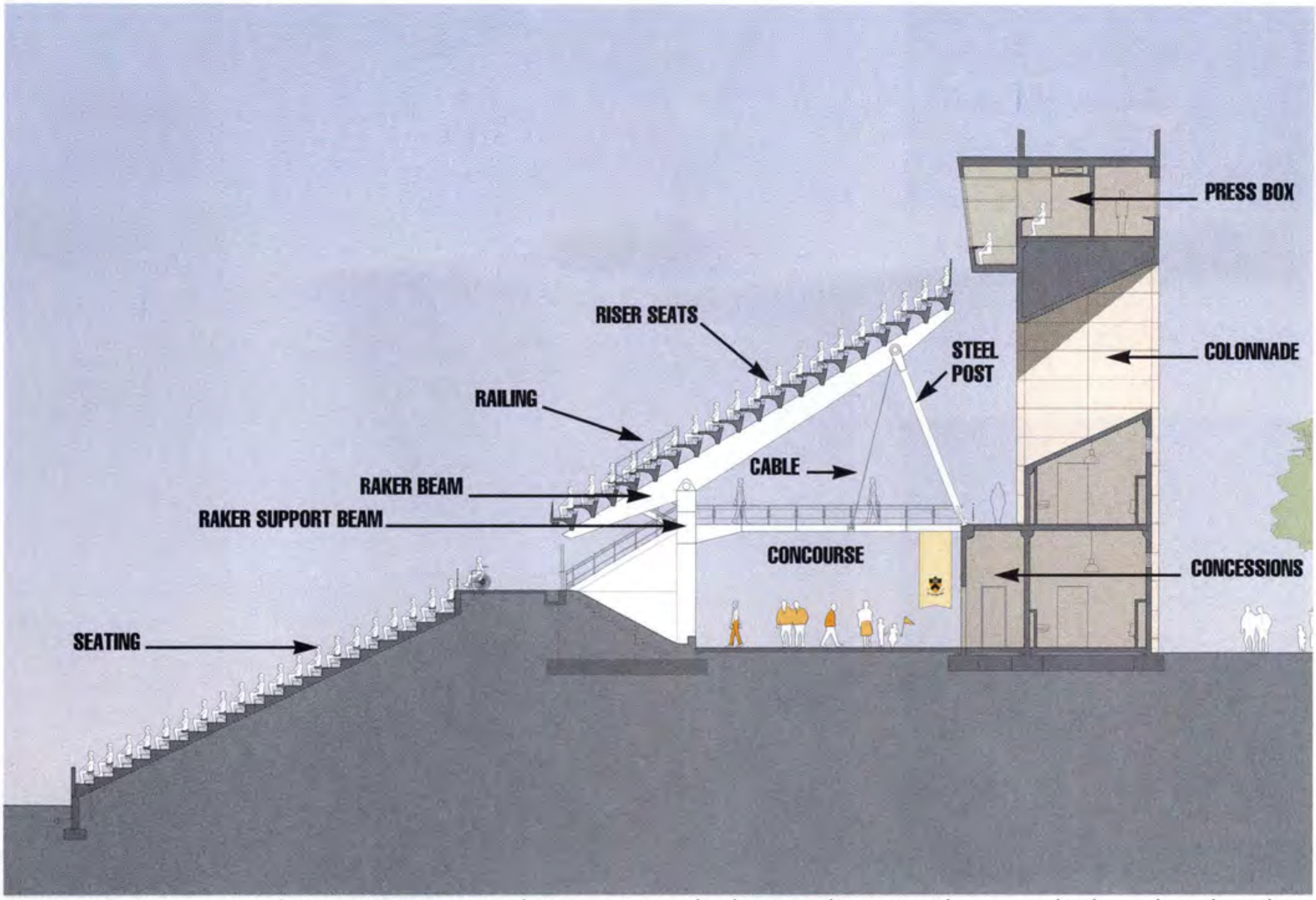

Fig. 10. Schematic section showing interconnection between risers, raker beams, raker support beams, and colonnade to the right.

meant taking up more square footage, it also provided more flexibility in accommodating both football and track.

The track team favored this alternate choice because the football team would generally be given priority if both teams required use of the facility at the same time. Separating different sports teams into their own stadiums is gaining popularity across the country for universities and professional teams in order to maximize the facility's advantages for spectators.

The horseshoe layout provides continuity among the various athletic buildings, with the track field directly south of the stadium (and in fact sharing back-to-back precast concrete seating with the new stadium) and the original 1960s era gymnasium further south in line with these structures. This design also helped formulate the approach for the upper seating, helping to cluster them together and produce a more intimate atmosphere than a fully enclosed space would provide.

To achieve the maximum advantages in designing this fast-track sys-

Fig. 11. Overview of grandstand with concourse below. The risers were designed to "float" above the bowl level and allow daylight to enter the concourse.

Fig. 12. Underside of risers showing connection detail for inverted V-shaped steel posts.

Fig. 13. Overview of concourse showing underside of risers allowing light to penetrate.

Fig. 14. Looking down into concourse. In background, risers and raker beams are visible. In foreground, base connections of steel posts to walls can be seen.

tem, a design by performance specifications format was developed in which the architect, engineer, precaster and precast consultant met regularly, usually every two weeks, for three months prior to beginning production on the job. This allowed for discussion of better ways to achieve each aspect of the project and ensure all details were covered.

GRANDSTAND DESIGN

A major feature of the stadium was the grandstand which comprised the following elements:

• Raker support beams (see Fig. 4) — The raker support beam, known by the design-build team as the "Winged Beast," supports the lower end of two raker beams. In turn, the raker support beam is supported by cast-in-place piers to which it is post-tensioned using Dywidag Thread Bars.

• Raker support beam reinforcement (see Fig. 5) — The reinforcement for the raker support beams was designed for vertical gravity dead and live loads in addition to horizontal seismic thrust forces at the raker beam support location. This resulted in significant torsional loads on the tapered section, which are resisted by an array of reinforcing steel arranged for ease of fabrication.

• Raker beams (see Fig. 6) — The raker beam that supports the triple risers is supported at the lower end (left in diagram) by the raker support beam. The upper end is supported by two 12 in. (305 mm) diameter steel pipe columns that connect through a steel plate assembly to the anchor bolts shown. These pipes splay diagonally in two directions to precast shear walls that form one side of the 70 ft (21.3 m) high colonnade.

• Triple risers (see Fig. 7) — The triple riser, also known as "Viñoly stadia" in recognition of the architect who conceived them, was developed as a triple riser with "windows" to replace single risers with a continuous slot. The windows allow light to shine on the promenade concourse below. Because this configuration had never been designed or produced before, load tests were conducted on this assembly as will be described later on.

Communication between the design/build team members was critical because of the innovative precast concrete design elements incorporated into the structure. Foremost among these were the triple risers. The risers were designed in a teardrop shape with slots piercing them to allow daylight to pass through. These were initially designed as individual, single-tread components with continuous horizontal openings through them. After seeing the design, the precaster suggested redesigning them as triple risers with isolated openings supported by vertical struts spaced through the length of each component.

Not only did this suggestion provide more stability for the risers, but it also saved considerable cost, especially in

Fig. 15. A crane was used to erect the precast panels comprising the perimeter building surrounding the seating elements. The perimeter structure consists of both loadbearing and non-loadbearing panels, and hollow-core slabs.

Fig. 16. Side of perimeter building with steel posts supporting the upper precast concrete risers already connected.

erection. This design reduced the number of picks, and the erection cost for each component, by about two-thirds.

The precaster also helped determine the final riser shape. Initially, a sloped brace was designed but this proved impossible to cast as there was no way to strip it from the forms. The designer and precaster met with Hamilton Form Company, the form manufacturer, to find the most advantageous design that combined aesthetics and castability.

The addition of the slots to the back of the triple risers was also designed in a joint effort with the precaster, designer and precast consultant. Dimensions and other details of the triple risers (Viñoly stadia) can be seen in Fig. 7. Also shown are the window openings which formed an integral part of the riser design.

Casting these components proved to be relatively easy once the design was set and the forms were fabricated. However, galvanized pipe was set into the window openings to provide a safety net for each section. The architect specified that no concrete was to be left on the galvanized pipe, requiring extra attention to carry out this casting. There were also tight tolerances on these components due to code specifications regarding the size of the bracing (see Fig. 8).

The high quality of fabrication expected by the architect came through in casting the risers. The allowable tolerances were tightened to the point that the precast components were cast on an architectural level rather than according to the tolerances typically provided in most stadium seating. This was in-keeping with the overall aesthetic design the architect wanted to achieve, and the precaster and designer worked closely to ensure that these tolerances were met in a cost-effective and timely manner.

Because such triple risers had not been fabricated before, Metromont and its consultant, H. Wilden & Associates Inc., carried out load tests to ensure the risers could carry the full load required. This also was done to ensure that the vertical support segments (struts or braces) tying one seat section to the next were sized and reinforced adequately to handle the horizontal shear.

The load tests were fully successful as the risers easily supported three times the design load. At 125 percent of full load, a few cracks developed in some of the struts. Therefore, as a precaution, the precaster added some supplemental reinforcing steel in the struts to ensure that the component capacity exceeded the designated load (see Fig. 9).

The project required about 1500 individual details and 241 erection drawings, along with 200 different pieces of hardware for connections. In all, 3611 precast concrete components were cast. A break-down of the types and number of components is listed in Table 1.

Connecting the trapezoidal-shaped risers to the lower cast-in-place bowl also proved challenging. This unique shape helped create a more intimate comfort level for the seating, which could not follow the traditional full-wrap format that makes larger stadiums feel more "cozy." The goal here was to allow these upper seating elements to "float" above the bowl seats. This meant attaching them to the rear walls and base with a series of steel posts rather than with types of connections that are more substantial in appearance.

A schematic section showing the grandstand, concourse and colonnades is shown in Fig. 10. Various other views of the interconnections between risers, raker beams, raker support beams and steel support posts are shown in Figs. 11 through 14.

The bottom edges of the raker beams that support the risers sit on wing beams, which consist of a single precast concrete component sitting on top of two cast-in-place piers. The upper ends of the raker beams are supported by inverted V-shaped steel posts, which are attached to the precast concrete outer building around the perimeter.

Matching the connection posts to their proper positions in the wall and in the raker beam proved challenging, with tolerances of only approximately 1/16 in. (1.59 mm). Such tolerances were produced by monitoring quality control inspections at the casting plant even more closely than usual.

The steel posts were attached to the raker beam at the point of the inverted V and hoisted into place. When they were set, the posts were spread as far apart as needed to meet the connecting point on the precast concrete wall, rotating the post as needed, and bolted into position.

C&C Erectors Inc. performed the

Fig. 17. Although the corners of the horseshoe-shaped building appear to curve, the panels were in fact faceted on their face to allow them to remain flat while making the two required curves.

Fig. 18. The adjoining track stadium features precast concrete seating covered with a fabric canopy held in place by cantilevered steel posts.

erection on all precast components. Concrete Structures Inc. produced the raker beams and wing beams on a subcontracted basis through Metromont.

Also challenging to erect were the pedestrian bridges that connect the upper seating elements to a concourse level around the building over the colonnade space. These rest on two steel posts 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 bridges consist of steel channels and bracing with a metal deck finished with concrete topping.

ARCHITECTURAL PANELS

The building to which these elements are attached, which contains the concession stands, restrooms, ticket offices and press box, was a simple project in comparison to the grandstand structure. But it too was more distinctive than a typical stadium façade. Precast concrete loadbearing panels were specified for cost, time and aesthetic reasons.

The precast concrete provided continuity with the former Palmer Stadium at the site, which had been built of reinforced concrete. At one point, in fact, consideration was given to retaining part of that façade. However, the original structure did not have expansion joints or enough reinforcement, and considerable cracking had occurred. Rather than try to salvage the original building, the decision was made to reference it through textures and coloring in the new architectural precast concrete panels.

Loadbearing precast concrete panels were selected over other options as a cost-saving measure, which included hanging architectural precast panels from a steel frame. Studies conducted prior to the preliminary design indicated that the loadbearing panels offered the most cost-effective design to achieve the needed goals.

The structure essentially consists of a series of boxes, each comprising several loadbearing and non-loadbearing panels (see Figs. 15 and 16). The loadbearing panels were solid, whereas the non-loadbearing panels were insulated in order to lighten their weight.

The perimeter building consists of three floors, with each portion consisting of two facing spandrel panels and hollow-core slab flooring. The ground and second floors contain restrooms and concession stands, while the third floor, featuring a windowed gallery, currently contains mostly open space, except along the west side where the pressbox and suites are located.

Fans can watch the activities from the promenade (roof) level, which is entirely open. The building also contains four precast concrete stair towers and two ramp towers. Some panels include cut-outs and tall openings, giving the building the feeling of a stadium entry as well as that of an office facility.

A significant challenge came in making the curves at the curved end of the horseshoe shape. The spandrels were faceted in eight 8 ft (2.44 m) sections to provide the contour of the curve, but in fact each section was flat (see Figs. 17 and 18) resulting in a 64 ft (19.5 m) long spandrel beam. Connections for these panels were typical. The real challenge came in the sheer volume of material required to surround the seating elements on three sides, creating a long narrow building with two major curves.

The panels' finish featured aggregates and pigments selected to blend with the surrounding university buildings. The panels received a heavy sandblast to add texture and dimension. Several mockups were produced, and the architect visited the precaster's plant on several occasions to ensure the final textures and coloring met everyone's expectations.

The track stadium was placed at the south, open end of the horseshoe. It features precast concrete raker beams and solid triple stadia back-to-back so seating is available for both the track field and the football stadium. The track seating features a cantilevered fabric canopy on steel struts attached to the upper ends of the precast raker beams, providing shade for the small seating section. This seating offers a secure, lateral connection to the adjacent football stadium while allowing the track field to maintain its separate identity and function.

Finished views of the stadium with spectators already enjoying the facility are shown in Figs. 19 and 20.

The full project was completed in 18 months, from March 1997 to August 1998, finishing in time for the new collegiate football season.

Fig. 19. Spectators on opening day of football season enjoying new facility.

The total cost of the stadium was $38 million, with a precast concrete contract of approximately $12 million. Administrators estimate the total contract to be perhaps $10 to $15 million more than would have been necessary with a more traditional design. However, this would have sacrificed both the aesthetic and year-round functional elements that make this structure unique.

CONCLUDING REMARKS

The use of precast concrete components helped ensure that both economics and innovation could be achieved. But it was not an easy precast concrete project to design. The project required very close coordination between all members of the design-build team.

Certainly, this project offers significant design options that stadium designers can consider for future projects. The ability to create a year-round facility rather than one that is used only a handful of times each year makes the building more functional and expands the available space for university operations.

The use of precast concrete components in a variety of applications offers much potential for future designs as well. The colonnade space between the building and the seating provides a long-term attraction, especially for university organizers looking for an event-oriented atmosphere where seating is somewhat limited.

Since opening, the new stadium has received many accolades, including the Merit Award in the Cultural category in the 36th Annual New Jersey Concrete Awards program, sponsored by the New Jersey Concrete & Aggregate Association and the American Concrete Institute.

Fig. 20. Main entrance of stadium. A heavy sandblasted finish was applied to the building's panels to help tie its look to the site's original concrete stadium.

Today, visitors can walk through the stadium any day of the week, and they no doubt will run into other students, professors or staff in the vicinity. The goal of making this stadium part of the day-to-day life of the campus has been achieved, and that is an achievement that other universities can emulate. In less than a year, the new stadium has become a well-recognized landmark on campus with the precast concrete an integral part of that visibility.

CREDITS

Owner: Princeton University, Princeton, New Jersey

Architect: Rafael Viñoly Architects P.C., New York City, New York

Structural Engineer: Thornton-Tomasetti Engineers with Structural Design Group, New York City, New York

Construction Manager: Turner Construction Co., Philadelphia, Pennsylvania

Precast Prestressed Concrete Manufacturer: Metromont Prestress Co., Greenville, South Carolina

Precast Prestressed Concrete Manufacturer (raker beams): Concrete Structures Inc., Richmond, Virginia

Precast Prestressed Concrete Engineering Consultant: H. Wilden & Associates Inc., Allentown, Pennsylvania

Precast Prestressed Concrete Erector: C & C Erectors Inc., Woodbury, New Jersey

Formwork Manufacturer: Hamilton Form Company, Inc., Fort Worth, Texas