Precast Vierendeel Trusses
Provide Unique Structural Façade for Parking Structure

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A major feature of an all-precast parking structure for the city of Rock Island, Illinois, is the use of precast prestressed concrete Vierendeel trusses. This article describes the planning and design considerations in the prefabrication and prestressing of the trusses and briefly discusses some special structural considerations that are important in the design of parking structures.

One major challenge encountered in the design of a parking structure is achieving an architectural character through treatment of its facade.

Unlike other commercial buildings, use of ornamental skin, to cover the major structural elements, makes the design of a parking structure heavy, expensive and unjustifiable. Therefore, in most parking garages, it is usually a necessity that
the “structure become architecture.”

To meet this requirement, large precast prestressed concrete Vierendeel trusses were used effectively in the design of a parking structure for the city of Rock Island, Illinois. Trusses held together with other precast components created a unique structural facade which unified esthetic expression, function and economy (see Figs. 1 and 2).

The parking deck is a three-level structure with overall plan dimensions of 236 x 290 ft. Four bays of 59-ft clear spans provide column-free space for parking and easy maneuvering of vehicles. The perimeter of the structure is kept level, while the central two bays slope in the same direction—permitting one-way traffic with angle parking.

Precast prestressed concrete double tees, 8 ft wide x 24 in. deep, span 59 ft to form the parking floors. In the interior bays, the tees are supported on 6-ft high single ledge precast beams at sloping floors and 2 ft 3 in. deep precast inverted tee beams at cross-overs. These beams span between the columns spaced at 32 ft.

On the exterior, 16 in. wide x 11 ft 10 in. high precast prestressed Vierendeel trusses span 32 ft between the columns. Bottom and top chords, 16
in. wide × 22 in. deep, of the trusses support the double tees at the second level and roof, respectively.

Precast spandrels, 4 ft 4 in. high, around the perimeter of the structure act as guardrails. Fig. 3 shows the typical floor framing plan identifying the different structural precast members. Fig. 4 shows the typical cross sections through the exterior and interior of the structure.

This article discusses the effective use of precast prestressed Vierendeel trusses, reasons for their use, consid-

Fig. 3. Typical structural floor framing plan showing various structural components.
Fig. 4. Cross section through exterior (left) and interior (right) of structure.

operations in determining the physical dimensions and structural design, how they are prefabricated and what role they play in an all-precast system used in the design of a modern parking facility. However, before proceeding with this discussion, it is appropriate to understand the background and the reasoning that went into selecting the design criteria.

Background

Rock Island, Illinois, is a typical middle sized midwestern city which is going through an organized program of new developments as well as revitalization within the city's central business district.

An earlier comprehensive plan study had recommended construction of "certain larger scale, visually prominent and functionally important structures" in the downtown area. This included a 550-car capacity parking structure, to be built within a one-block area bounded by 3rd Avenue (N), 4th Avenue (S), 16th Street (W) and 17th Street (E)—across from the city hall.

After the decision was made to go ahead with the parking structure, the design criteria were laid out by the...
city officials. The structure was not going to be just another anonymous service building, but, it had to be designed to play an important role within the city’s revitalization program. Besides being functional and economical, it had to be contemporary to attract visual interest. In short, the challenge was to produce a unique structure at low cost.

Selection of Structural System

From the functional parking layout, it was clear that a structural system with long span capabilities would be most economical and desirable. Prestressed concrete was the obvious choice.

A comparison made between the two systems using cast-in-place post-tensioned concrete and precast prestressed concrete proved to be almost even. However, to achieve an esthetic expression, the facade had to be developed and treated. To make the facade economically feasible, the use of nonfunctional ornamental elements was ruled out.

After a careful consideration of all the factors involved, it was concluded that if the structural components were expressed properly, the desired architectural effects could be achieved. The interplay between the structural components could then be enhanced by judicious use of color and texture of exposed concrete surfaces.

The above requirements of interesting structural forms, better quality control and uniform finish coupled with the speed of erection and economy dictated the use of a precast concrete system.

Why Vierendeel Trusses?

Two principal reasons for using the Vierendeel trusses were as follows:

Expression of the total structural system to achieve character: Large openings formed between the vertical members and top and bottom chords of the trusses allowed full expression of the double-tee floor system. The interesting arrangement of the basic four structural components (double tees, spandrels, trusses and columns), made possible only by Vierendeel trusses, created an attractive facade satisfying one of the critical design requirements.

Structural efficiency: Because of its floor-to-floor structural depth, one Vierendeel truss carried two floors, thus reducing the number of perimeter beams (that would be otherwise required) in half. Also, supporting the double tees on top and bottom chords without any eccentricity (which would be the case in a conventional single-ledge beam) resulted in elimination of extra reinforcement and special connections to resist torsion.

Thus, overall economy, not only in materials but also in transportation and field erection, was achieved by using Vierendeel trusses.

Design Considerations of Vierendeel Trusses

Physical dimensions: The governing factors in determining the physical dimensions of the trusses were transportation, and repeated use of the same forms for varying truss spans. Structurally, it was advantageous to use the maximum height possible. However, precast manufacturers from three states, namely, Illinois, Iowa and Wisconsin were interested in bidding on the job. Clearance under the bridges on-route from all three precasting plants to the job-site dictated that the maximum height of trusses be about 12 ft.

Another significant factor that would affect the transportation cost substantially was the weight limita-
tion of 44 kips without a special permit. Keeping these considerations in mind, 16 x 22-in. cross-sectional dimensions for top chord, bottom chord and verticals with an overall truss height of 11 ft 10 in. were found to be optimum. This arrangement also worked very well for a floor-to-floor height of 10 ft for parking. The next step was to check the system’s structural adequacy.

Structural requirements: The structural analysis of the Vierendeel truss with optimum cross-sectional dimensions showed a definite need for prestressing in the top and bottom chords as well as the verticals. This requirement of two-way prestressing created a problem as far as pretensioning of the truss in the precasting bed was concerned.

Earlier talks with the precast manufacturers had indicated that some would prefer conventional pretensioning methods while others would prefer post-tensioning the trusses out of the precasting beds. Therefore, to accommodate all the structural requirements and to facilitate production for all the three precasters, the trusses were designed with a combination of mild steel plus prestressed reinforcement.

The choice in prestressing methods was also given—whereby trusses could be pretensioned either conventionally by use of strands, or after they were cast by use of post-tensioning tendons. In the case of pretensioning, in order to develop the full force in the strands at the ends of the members where it was structurally required, hydraulically seated strand anchors were specified. In the case of post-tensioning the tendons, grouting was found necessary and prescribed.

Structural Design

The structural design of the Vierendeel trusses was based on the same criteria as those used for the rest of the structure. For reasons discussed later in this article, a crack control approach was employed for the structural design.

The tensile stresses were kept below $6\sqrt{f_c}$ under realistic working load conditions. The ultimate capacity was obtained by supplementing the prestressing steel with mild steel reinforcement. While the analysis of the Vierendeel truss was carried out using center line dimensions, their design was based on forces at the faces of the members.

The following is a summary of the final design adopted:

A prestressing force of 300 kips was provided in the top and bottom chords. Twelve ½-in. diameter 270-ksi strands or four 1-in. diameter 150-ksi threaded bars in each chord were specified at the time of design. In the final fabrication, threaded bars were used.

In the first interior vertical member of the truss, a prestressing force of 228 kips was provided by two 1¼-in. diameter 150-ksi threaded bars. A concrete strength of 6000 psi at 28 days and 3500 psi at the time of pretensioning was specified.

Fig. 5 shows the elevation of a typical 32-ft long Vierendeel truss with dimensions. Cross sections through the top and bottom chord and the vertical show the reinforcing steel details.

Prefabrication of Vierendeel Trusses

The precasting of all the structural components was done in the plant of Blakeslee-Midwest Co., Rochelle, Illinois, located approximately 100 miles from Rock Island.

The prefabrication of Vierendeel trusses was done in the following stages:

The complete formwork for the
Fig. 5. Elevation of Vierendeel truss with sections and details showing dimensions, prestressing tendons and mild steel reinforcement.
longest truss was set up using steel forms. Fig. 6 shows the formwork for a 37-ft span set up on a "tilt" table. Two such forms were used to cast all 38 trusses varying in spans from 9 to 37 ft.

Fig. 7 shows the prefabricated cage of mild steel reinforcement set up on another table. Fig. 8 depicts the cage being lowered in position into the formwork, and Fig. 9 shows the reinforcing cage being tied in the final position.

Next, the post-tensioning tendons with ducts were carefully placed and aligned making sure that the anchors at the ends were in proper location.

Concrete having a specified design strength of 6000 psi at 28 days was cast. The fresh concrete was vibrated by externally attached form vibrators.

Fig. 10 shows the truss being tilted
in position for form removal and Fig. 11 shows the truss being carried out where it was set up for the prestressing operations.

The trusses were then prestressed and grouted in the precaster's yard. Now, they were ready to receive the architectural finish.

Fig. 12 shows the truss being sandblasted and Fig. 13 shows the finished trusses being stored.

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**Design of Connections**

The trusses were designed as simple spans, so no fixity was required at the top and bottom connections. The bottom connection was made by welding a "pin" (3/4 x 1 1/2-in. bar) to the bearing plate already cast in the truss.

The top connection between the truss and the column was provided for lateral stability only. A bolted connec-

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**Fig. 8.** Mild steel reinforcing cage being lowered in position into formwork for truss.

**Fig. 9.** Reinforcing cage being tied in its final position in the formwork.
tion with a slotted hole was furnished to permit the movement of the truss due to live load, creep, shrinkage and temperature changes.

Fig. 14 shows the typical exterior column (lying horizontally in the picture) with a notch to receive the truss.

Fig. 15 depicts the top and bottom connections between the truss and the column.

Fig. 16 shows a typical exterior column with two trusses bearing on it.

The connections between the beams and columns in the interior bays were made by using embedded structural shapes. Stability connections were made by using high strength bolts. All field connections were designed as bolted connections to reduce erection time and the cost of the structure.

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**Erection of Precast Components**

Erection of the two interior bays with conventional beam-column framing was done first. The exterior columns and the trusses were set next with the floor and roof double tees following. The precast spandrel guardrails were bolted to the perimeter trusses completing the precast erection. Figs. 17 through 20 show the erection of the structure at various stages.

In total, 733 precast pieces were used to frame an approximate area of 123,000 sq ft in the main structure,
Fig. 12. Sandblasting of Vierendeel truss.

Fig. 13. Storage of the finished trusses in the yard.

Fig. 14. Typical exterior column (shown in horizontal position) with a notch for Vierendeel truss.
four stair towers and one elevator
tower. Some 607 pieces consisting of
38 Vierendeel trusses, 75 columns, 50
single ledge beams, 35 inverted tee
beams, 135 spandrel guardrails and
274 double tees provided framing for
the main structure.

Erection time for the main structure
was 34 work days, averaging 18 pieces
per day. In all, 126 pieces consisting
of 97 stair panels, 16 stairs and 13
hollow-core slabs provided framing
for the four stair towers and one
elevator tower. Erection time for
these towers was 18 work days averag-
ing 7 pieces per day. The total job was
erected in 52 work days with an aver-
age of 14 precast pieces erected per
day.

Additional Features

- Architectural finish on precast
  components: The desired architec-
tural effects were achieved by varying
the color and texture of the finished
surfaces of the precast components.

  The Vierendeel trusses and exterior
columns were cast with warmtone
cement, limestone coarse aggregates
and a special sand. The surfaces were
lightly sandblasted. Spandrel guard-
rail surfaces were deep waterblasted
to expose hard pebble aggregates
creating an interesting contrast. The
exposed ends of the double tees were
finished smooth with grey cement.

- Stair towers: One stair tower was
  located in each corner of the structure
to highlight serviceability and user
security.

  These towers were framed with full
height precast concrete wall panels
and glass on the front side. The panels
were cast in an “L” shape or channel
shape to avoid the problem of corner
matching and to soften the visual im-
pact of the masses.

  The front face of the tower was
framed with glass to create a feeling of
“openness.” An exposed pebble
aggregate finish on the warmtone
concrete panels harmonized the tow-
ers with the rest of the structure (see
Fig. 21).

Special Considerations

Considerations that are special to
parking structure design come from
the fact that the garages are:
1. Constantly exposed to extreme

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Fig. 15. Typical connection between
Vierendeel truss and exterior column.
weather changes (as regards moisture, temperature, and wind).

2. Continually used under corrosive conditions caused by such factors as rain, ice, snow and road salts.

The preceding factors manifest themselves as volume changes in the structure and drainage and must be accounted for in the structural design.

For this project, these factors were given careful consideration. Particular attention was paid in the structural design and detailing to eliminate water retention areas and to control the cracking of concrete. Volume changes in the structure were handled by relieving the forces rather than resisting them. The following are some of the concepts and details used in the project:

- Limited moment capacity was pro-
Fig. 18. Erection of inverted tee beam at crossover.

Fig. 19. Erection of double tee on bottom chord of Vierendeel truss.
vided at the base of exterior precast columns to form a “hinge” under certain loading conditions.
- Precast columns were kept free of cast-in-place foundation walls by providing a 1-in. joint around the columns.
- Connections between precast components were designed such that they provided the necessary stability to the

Fig. 20. Progress photograph taken in September 1976.

Fig. 21. Stair and elevator towers in north-east corner.
structure without making it too rigid.

- Several expansion joints were provided in the structure. The main expansion joint ran through the middle of the building in the east-west direction dividing the structure into two parts. Stiff stair towers were also separated from the main structure.
- Control joints were provided in the topping concrete over the precast double-tee flanges where they butt. Tooled joints at every 8 ft on center created several inherently weak planes in the decks to permit movement without losing structural integrity.
- Camber of the prestressed tees at the time of erection was considered very carefully in calculating the slope of the decks for drainage. Extra topping (about 3 in. of concrete) was provided along the perimeter and along the beams on the interior to insure proper drainage.
- Most precast connections were patched with concrete to avoid moisture penetration. However, some exterior connections which could not be protected satisfactorily (such as bearing plates under the exposed tee stems around the exterior of the structure) were specified in stainless steel.

**Conclusion**

The objective of designing a modern parking structure at low cost was achieved by developing a unique structural facade.

Precast prestressed concrete Vierendeel trusses were used successfully to highlight the esthetic expression of the functional and economical structural system.

This 565-car parking facility covering a total area of 189,000 sq ft was constructed for about $10 per sq ft in less than 9 months despite difficult foundation conditions, inclement weather and labor strikes.

Since completion in November 1976, the structure (see Fig. 22) has performed quite satisfactorily.

**Credits**

General Contractor: Priester Construction Co., Davenport, Iowa.
Prestcast Manufacturer: Blakeslee-Midwest Prestressed Concrete Co., Rochelle, Illinois.
Owner: City of Rock Island, Illinois.