Composite Construction Cuts Costs

Free-spanning Vierendeels link perimeter composite supercolumns at One Detroit Center

By P.V. Banavalkar, Ph.D., P.E.

SINCE THE MID-1980S, COMPOSITE CONSTRUCTION has almost become de rigueur for the design of high-rise buildings and One Detroit Center is no exception. The 45-story office tower rises to a height of 619 ft. in downtown Detroit (plus it has two levels below grade). Neo-gothic in design, the building has approximately 1,229,000 sq. ft. of floor area with 15,000 sq. ft. of retail space. Typical floor-to-floor height is 13 ft. and the clear lease span between the core and perimeter wall is 45-ft.-6-in. In addition to a distinctive top, the buff/gray granite and glass tower has a three-story-tall entry along its east-west axis. Design architect is John Burgee & Associates and associate architect is Kendall-Heaton Associates. Developer is Hines Interests Ltd. Partnership, Houston.

In response to the architectural composition of the tower, three lateral load resisting structural systems were considered:

- All steel framed perimeter tube;
- Composite perimeter frame with concrete composite columns at 30-ft. on centers linked by steel beams;
- Perimeter Vierendeel steel frame free-spanning between eight perimeter composite supercolumns (two on each side).

In all three cases, the interior gravity floor framing consisted of composite steel beams supporting $3^1/_4$-in.-thick lightweight composite concrete slab on 3-in.-deep metal deck. The interior floor framing is supported by steel columns. Based on both architectural and cost considerations, the system with eight perimeter supercolumns was chosen. The final design utilizes 9,500 tons of structural steel, which translates to $15^1/_2$ lbs./sq. ft. of supported floor area.

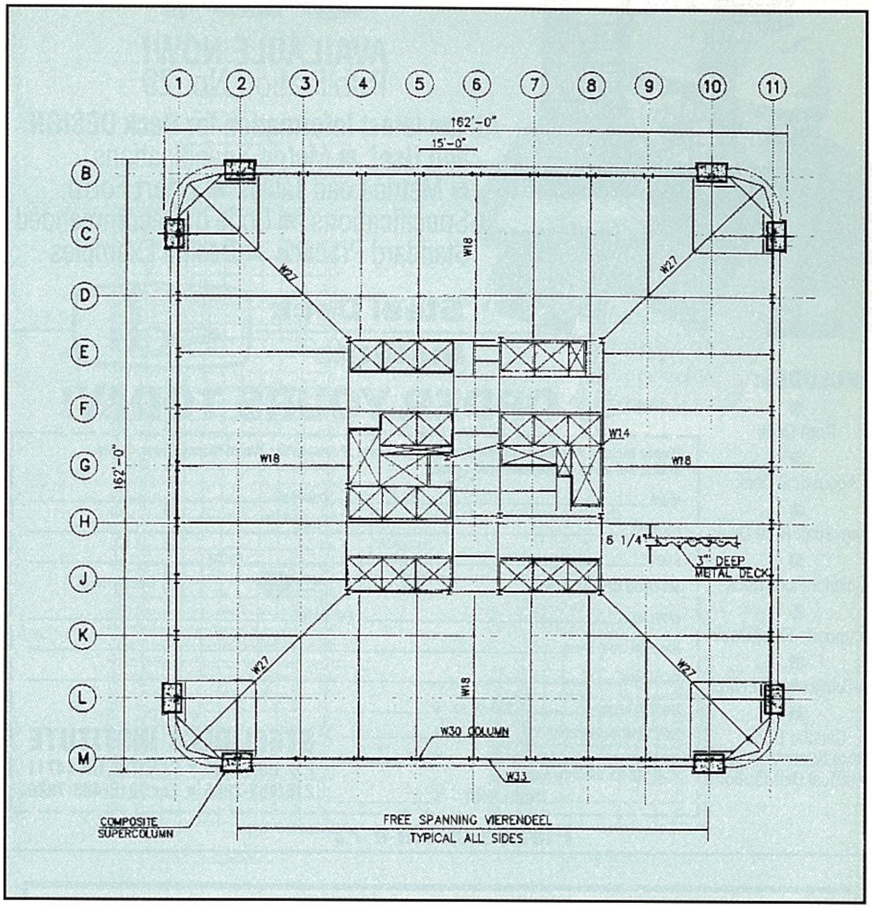
The composite concrete supercolumns have the steel erection columns encased in them and utilize 8,000 psi concrete. The maximum size of the columns is 7-ft.-6-in. x 4-ft.-9-in. at the base. To optimize the free-span of the Vierendeel, and at the same time to provide column free corner offices, the supercolumns are placed 20 ft. from the corners.

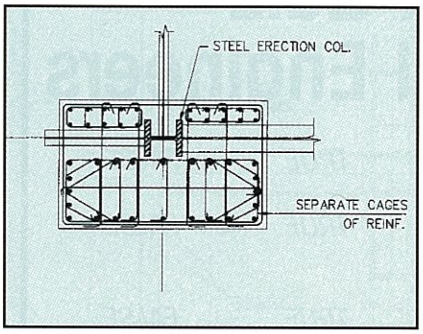
Vierendeel System

Vertically stacked four-story-high Vierendeel girders span between the composite supercolumns to provide shear resistance to lateral wind loads, while at the same time to providing column-free entrances at the base of the tower. The lateral shear resistance of the Vierendeel system can be partitioned into two parts: the shear resistance provided by the superframe without the stubs (frame action) and the shear resistance provided by the stubs and the beam assembly (Vierendeel action).

While the vertical load carrying capacity of the Vierendeel is well documented, more consideration was needed in the analysis of the horizontal beams.

The horizontal beams are typically 33-in. deep, and the 30 WF vertical stubs are spaced at 15-ft. on center. The intersection of the horizontal beam and the vertical stub is braced by floor beams spaced at 15-ft. on center. The horizontal beams and vertical stub sizes are optimized to reflect the variation in the local bending moment and the shear diagram of the Vierendeel girder itself. The vertical stubs are rigidly connected to a continuous horizontal member. Doubler and continuity plates are provided at the joints. The stubs are spliced





Shown above is a typical floor framing plan, while pictured at left is a detail of the composite super column of One Detroit Center.

at mid-floor height by using a bolted cap plate detail. The thickness of each cap plate is determined accounting for the prying action due to moment and corresponding axial forces at the connection.

Four-story high Vierendeels are interlinked in the final form by hinges that are capable of transferring only horizontal shear between two adjoining Vierendeels. The vertical freedom between adjoining Vierendeels is provided for several reasons:

- The unwarranted effect of creep and shrinkage of composite supercolumns on the design of connections and members of the Vierendeels is eliminated.
- The gravity load is transferred uniformly by four-story Vierendeels directly to the supercolumns. This transfer mechanism eliminates an unwarranted gravity load transferring arch action at the base of the tower. The arch action creates non-uniformity in sizes for both horizontal beams and vertical stubs, which then have to be designed at columns. The four-story Vierendeel achieves uniformity

in transfer of moment and shear between horizontal steel beams and composite supercolumn throughout the height of the tower.

- The structural impact of an architecturally desirable entryway with elimination of vertical stubs is contained within a localized area.
- The architectural expression of the four-story distinctive banding also is consistent with the structural concept.

Composite Column

The W14 steel column, used as an erection column to facilitate the steel erection, is eventually encased in a high-strength composite concrete supercolumn. The steel column supports gravity loads during construction of the tower and also acts as a medium in transferring moment from the horizontal steel members to the composite supercolumns.

The design of the rigid joint to the composite supercolumns was done in accordance with research conducted at the University of Texas-Austin.

Construction Sequence

The design of both the erection steel and the free-spanning Vierendeel is affected by the construction sequence.

The erection of the bare steel structure is allowed to proceed 12 floors (six floors with concreted metal deck and six floors of metal decked floor only) above the completed concrete supercolumn. In addition to these floors, there are usually two floors of erected bare steel. The erection steel column not only has to support the dead weight of the structure along with the construction live load, but also acts as a frame member to provide lateral stability to the erected frame during construction. The horizontal beams of Vierendeel frames are moment connected to the erection column. Typically, a W14x257 column section is used as the erection column.

The erection of the free-spanning Vierendeels have two important issues to be addressed: Launching of the Vierendeel at the base and stacking of the four-story Vierendeel frames above.

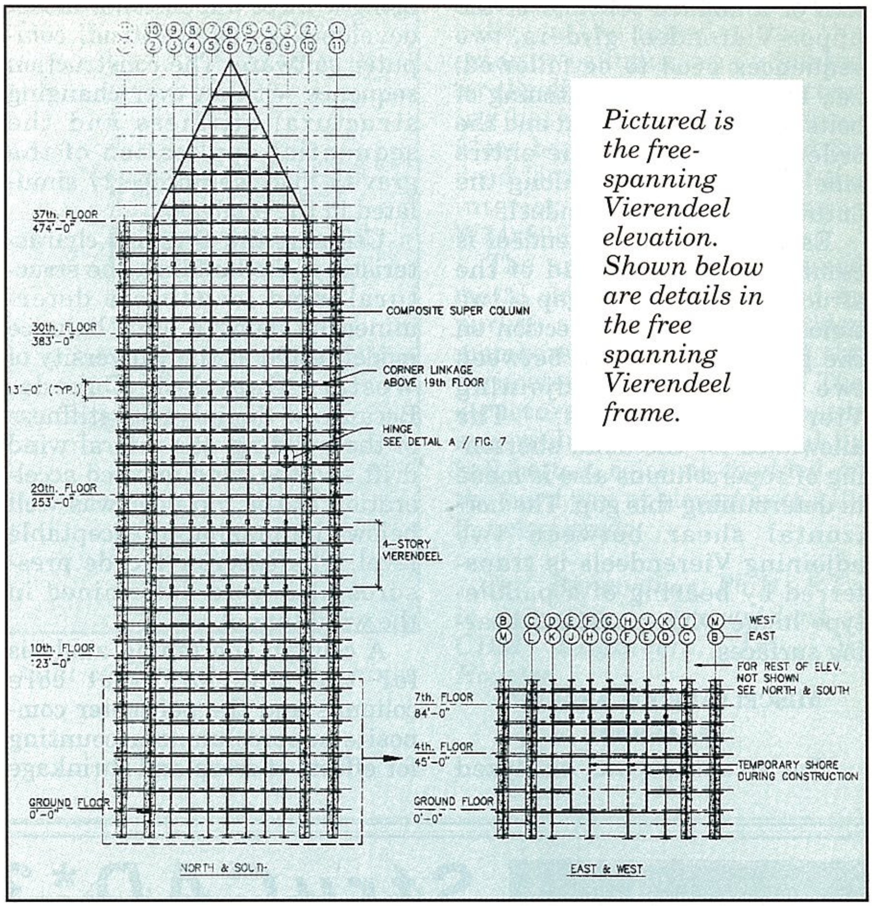
To achieve efficiency in the underground parking, the columns below the ground level have to be spaced wider than the 15-ft. spacing of the vertical stubs at upper levels. Secondly, the opening in the Vierendeel for the entry to the tower requires reconfiguration of the lower Vierendeel. To address both these issues, temporary shoring is required to launch the Vierendeel frame at the base. At times, temporary vertical bracing also is required to stabilize and control the deflection of the lower portion of the structure. Steel fabricator on the project was AISC-member Southern Ohio Fabricators, Inc., and erector was Steelcon. Contractor was Walbridge-Aldinger.

Stacking Frames

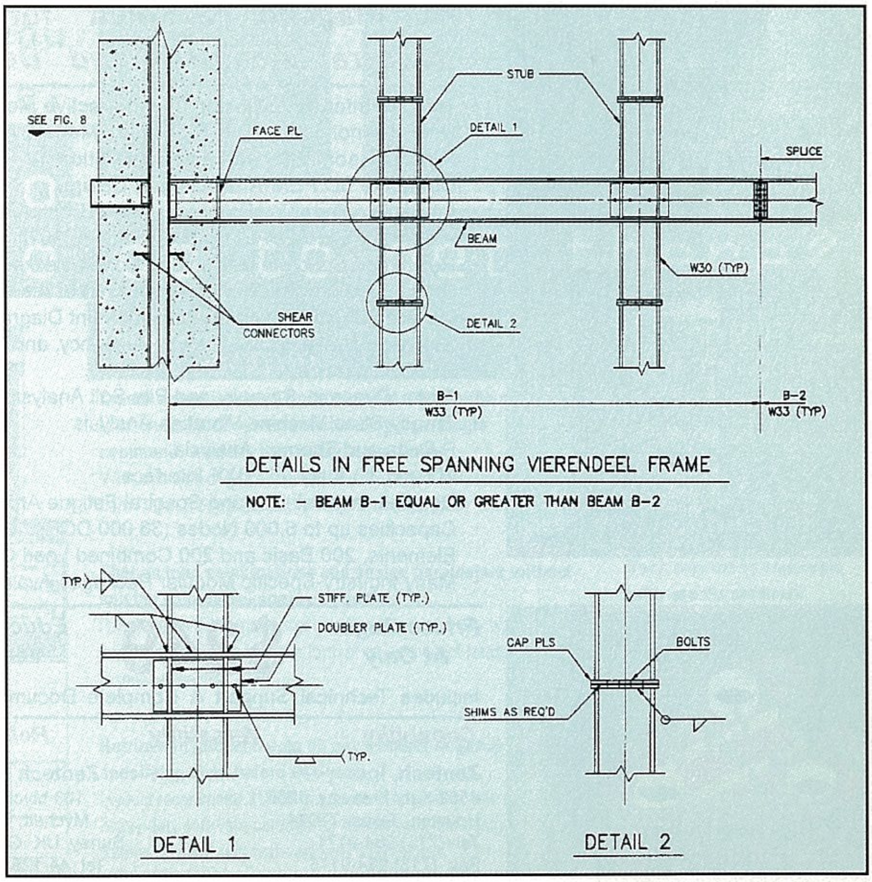
The stacking of the four-story Vierendeel frames have to consider two design aspects:

- The typical vertical stub connection with cap plate at mid-height of each floor requires shims to level the upper and lower part of the Vierendeel structure.
- The stacking of the four-story Vierendeels requires the installation of the pin and the temporary support. The temporary vertical support between upper and lower levels can be provided by shims. However, removal of the shims to eliminate vertical load transfer can be at times quite cumbersome.

As opposed to using shims between the two Vierendeels, temporary connection between vertical stubs is provided by two flange plates bolted to the flanges by six $1^{1}/_{4}$-diameter A325 slip critical type bolts with vertical long slotted holes. This connection is designed to carry 12 floors of load as described for the erection column. In order to prevent overstressing of this connec-



Pictured is the free-spanning Vierendeel elevation. Shown below are details in the free spanning Vierendeel frame.



tion or a sudden rebound of the upper Vierendeel girders, two sequences need to be followed, i.e., the order of untightening of bolts within a connection and the order of removal of the entire side plate connection along the entire span of the Vierendeel.

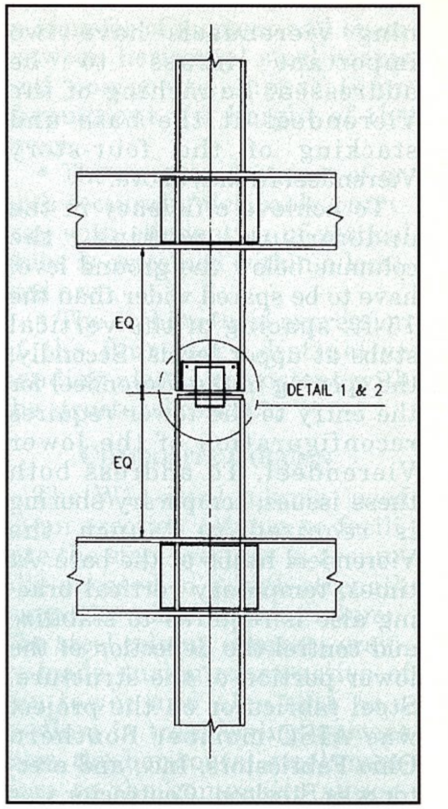
Each four-story Vierendeel is cambered for dead load of the structure. A minimum gap of two times the live load deflection on the girder is provided between two vertically adjoining Vierendeel girders. The allowance for the axial shortening of supercolumns also is made in determining this gap. The horizontal shear between two adjoining Vierendeels is transferred by bearing of a paddle-type hinge with machined bearing surfaces.

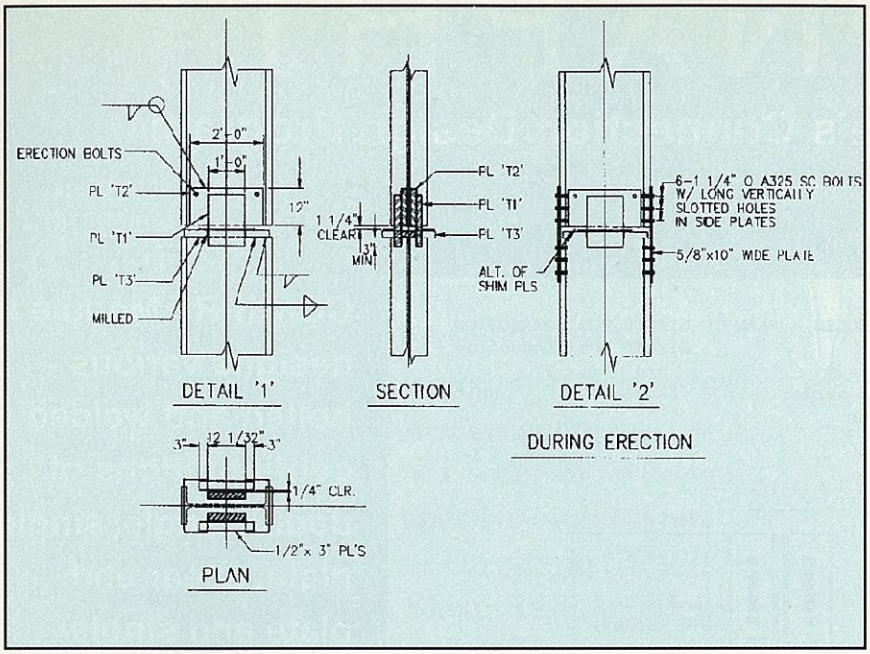
Miscellaneous Analysis & Design

The structure was analyzed using a three-dimensional model developed using GTStrudl computer software. The construction sequence with an ever changing structural stiffness and the sequential application of the gravity load was properly simulated in the analysis.

Utilizing the dynamic characteristic of the building, the structural wind loads were determined by using a force balance model tested at the University of Western Ontario in Canada. Because of the inherent stiffness of the building, the lateral wind drift and the wind induced acceleration at the top floor was well below the maximum acceptable level. The exterior facade pressures also were determined in the wind tunnel.

A column shortening analysis for the interior steel core columns and the perimeter composite supercolumns accounting for effects of creep and shrinkage





Pictured above and at left is the fnial configuration of the hinge details for One Detroit Center.

was conducted. The elevation between the interior and the exterior columns was adjusted for the differential axial shortening between these elements. Floor beams were cambered for dead load. Maximum size of the interior steel core columns is W14x808.

The upper triangular-shaped metal clad roof is supported by purlins spanning between ridge members, floor beams, and the perimeter Vierendeel frame. The structure, including perimeter supercolumns, is supported by bell bottom caissons founded on the hard pan at elevation of 110-ft. below grade.

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