Partial Tube Concept for Mid-Rise Structures

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THE TRADITIONAL structural systems for mid-rise structures (20 to 40 stories) generally consist of either a "frame" system or a frame combined with interior vertical trusses in the core of the building. Both approaches usually involve extensive field welding of beam-to-column connections to develop frame action. The advantages of tubular behavior over frame behavior are well known. The use of complete tubular systems has been confined to extremely tall structures such as the Sears Tower, World Trade Center, and the John Hancock Building in Chicago. The "partial tube" concept takes advantage of tubular behavior by developing the entire wind resisting system on the exterior face of the building. For a mid-rise structure, all the exterior columns are not required to develop the resistance to wind forces. Consequently, a logical structural system is a partial tube system which engages only the required number of exterior columns to develop wind resistance.

The writer has developed the partial tube concept on two major structures. Figure 1 shows the 35-story 101 Marietta Building in Atlanta. The building is trapezoidal in floor plan. Figure 2 shows the 32-story Town Center Tower in Southfield, Michigan. This tower is rectangular in floor plan. The structural concepts are similar for the two towers; the Town Center Tower will be described, as it has a simpler geometrical shape.

The office tower measures 180 x 90 ft in floor plan and is 32-stories tall. The total height of the tower is 400 ft. The partial tube is developed by the provision of diagonals extending across the entire 90-ft width of the building and diagonals in a 45-ft bay on each side of the length of the building. The diagram of the partial tube structural system is shown in Fig. 3. It can be seen that the diagonals are so arranged that they intersect the floor at the beam-column node, resulting in perfect triangulation. Lateral wind loads are primarily resisted by axial forces in the diagonal, column and beam trusswork with only secondary bending moments. The consequence of this desired behavior is a highly efficient structural system which minimizes the amount of steel used and eliminates moment connections.

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A typical floor framing plan is shown in Fig. 4. The exterior columns are spaced at 45 ft on center. The span between the interior and exterior columns is 36 ft. The structural framing of the floor consists of a special type of girder called the "stub-girder", that spans directly from the exterior to the interior columns. The girder consists of a standard 14-in. wide-flange steel section made of high-strength steel (A572) having a yield strength of 50 ksi. Stub pieces, 18 in. deep and approximately 4 ft-0 in. long, are welded onto the top flange of the girder at 9 ft-0 in. spacing, as shown in Fig. 5. This girder is then erected and attached to the exterior and interior

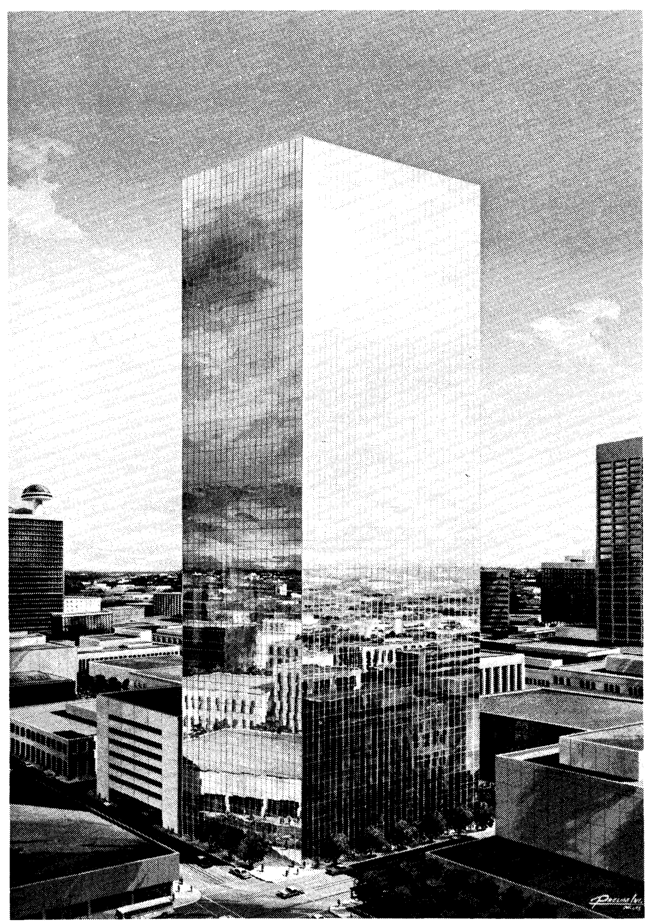


Fig. 1. 101 Marietta Building, Atlanta, Ga.

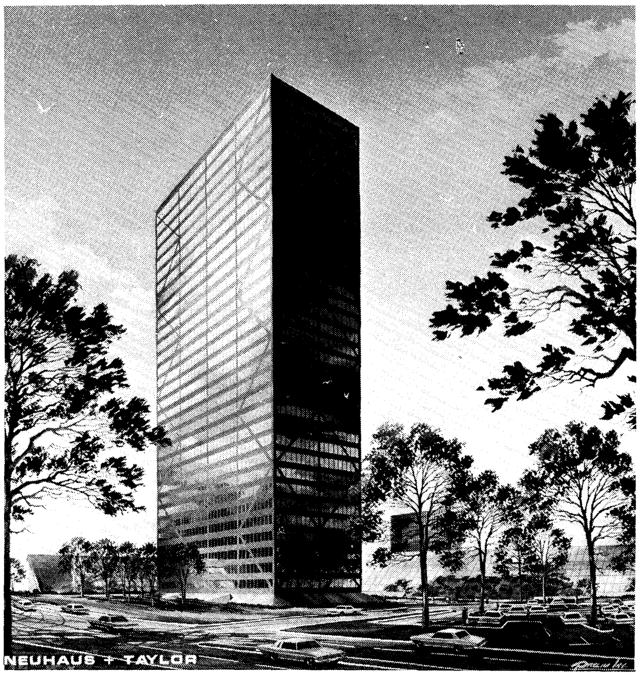


Fig. 2. Town Center Tower, Southfield, Mich.

column. Standard 18-in. deep wide-flange beams are placed transversely on the top flange of the 14-in. girders and double cantilevered to the points of contraflexure. A drop-in beam connects the ends of adjacent cantilever beams. Corrugated metal deck, 2 in. deep, spans between the 18-in. deep transverse beams. Shear studs are attached to the top flanges of all beams and stub pieces for composite action. The system is completed by the placement of 3¼ in. of lightweight concrete on top of the metal deck. The concrete has a strength of 4000 psi.

The structural behavior of the "stub-girder" is somewhat similar to that of a Vierendeel girder. The top chord is the concrete slab and the bottom chord is the high strength 14-in. wide-flange girder. The stub pieces are the vertical web members. Extensive finite element analyses and three full-size load tests have been conducted on the system. The increased depth of the girder and the double cantilevered floor beams result in a saving of approximately 2.5 lbs of steel per sq ft of floor. Moreover, the natural openings between the ends of the stub pieces and the transverse beams are designed for the passage of air-conditioning ducts. The result is that the distance between the top of the slab and the ceiling below can be reduced approximately 6 in. per floor over a conventional system where the ducts are below the girder. This reduces floor-to-floor height (for a given floor-to-ceiling height) and, consequently, reduces the cost of the exterior cladding of the building and all vertical risers.

COMPUTER ANALYSIS

The wind bracing system was computer analyzed using STRUDL (Structural Design Language). Since the project does not lie in a seismic zone, only the effects of gravity forces and wind forces were considered in the analysis.

A typical floor load consisted of dead load of 55 psf, live load of 50 psf, partition load of 20 psf, and other loads of 15 psf. Lateral wind loads varied from 20 psf for the first 100 ft of height to 35 psf at the top of the structure.

In the analysis of the wind frame, all the joints were unrestrained to eliminate moment connections. To reduce the unsupported length of the diagonals, they were braced by the horizontal beam members. It was for this reason that the system was analyzed as a three-dimensional space frame, rather than as a space truss.

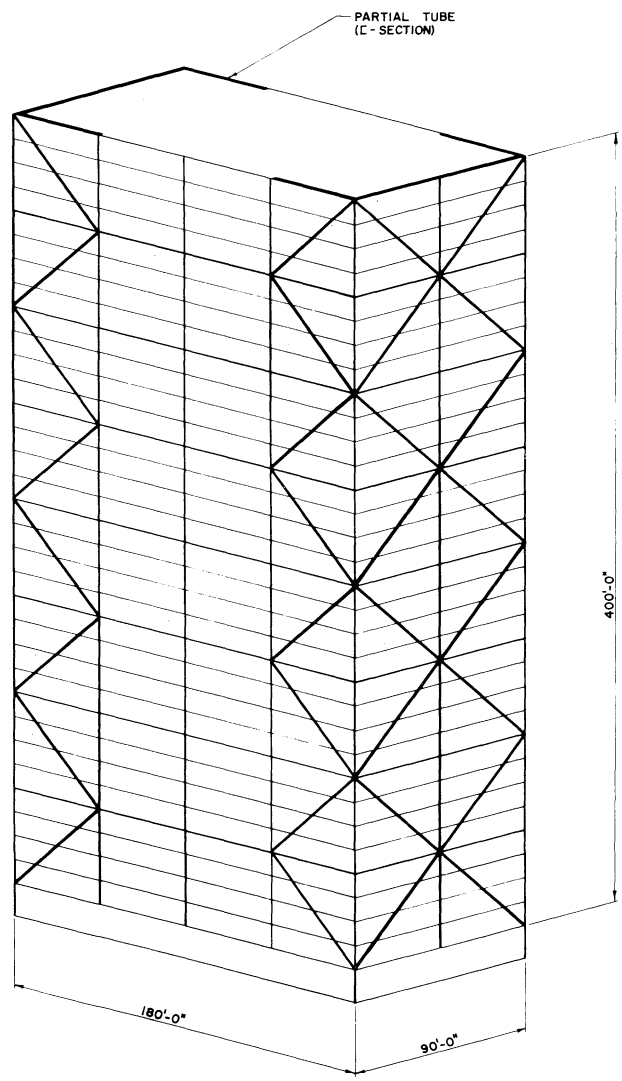


Figure 3

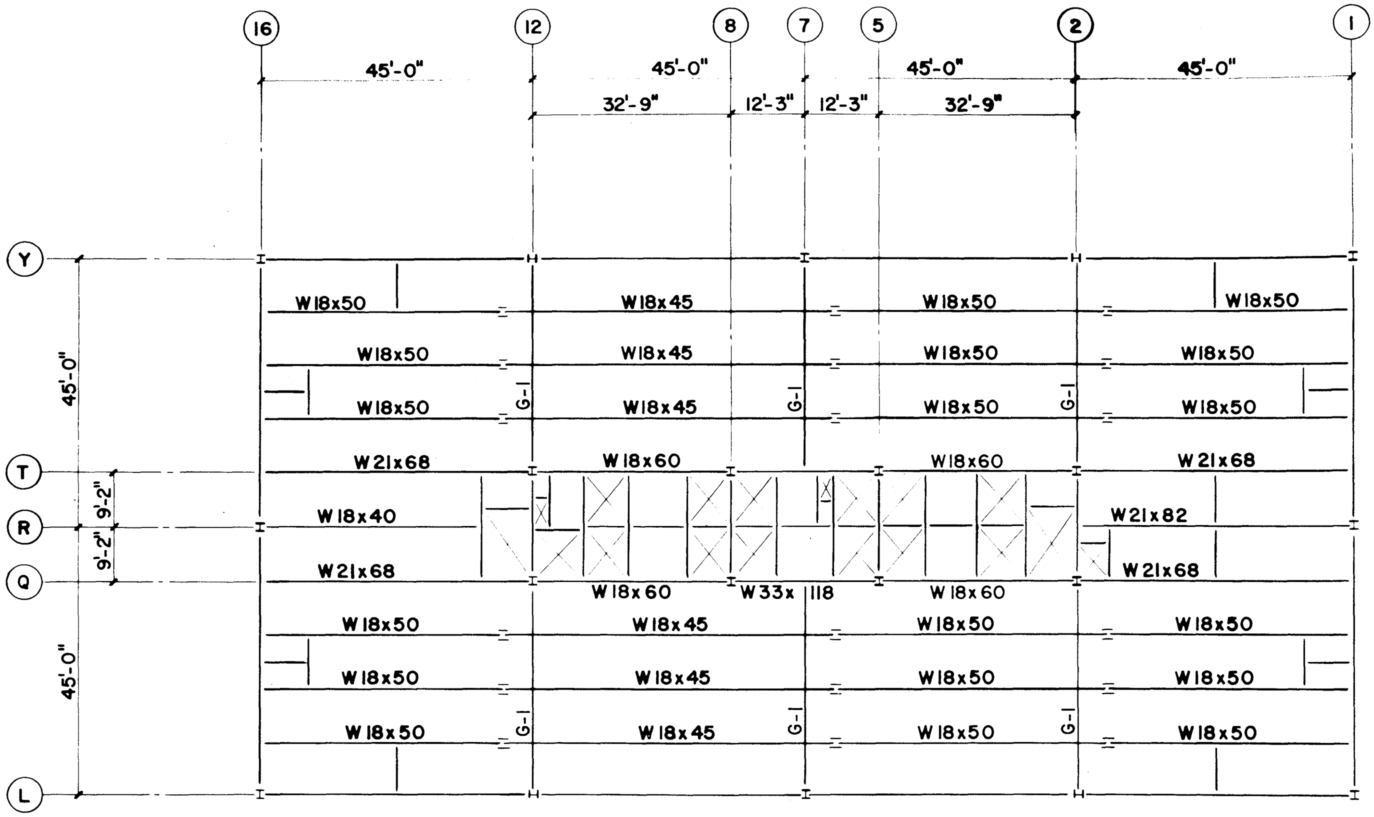


Fig. 4. Typical floor framing plan

This computer model consisted of 261 joints and 512 members. In order to simulate the floor diaphragms, equivalent finite elements capable of transmitting the loads in a horizontal plane without any significant distortion of the diaphragm were used. Eleven different loading combinations of dead load, live load, and wind load were considered, in order to determine the most critical forces in the individual members. The efficiency of the partial tube system is evident from a study of the column stresses in Fig. 6a. Under gravity loads, the diagonals distribute the load so that the stresses in the columns forming the partial tube are almost equal. Under wind loads, a tubular behavior pattern is discernible, as in Fig. 6b. There is, however, some shear

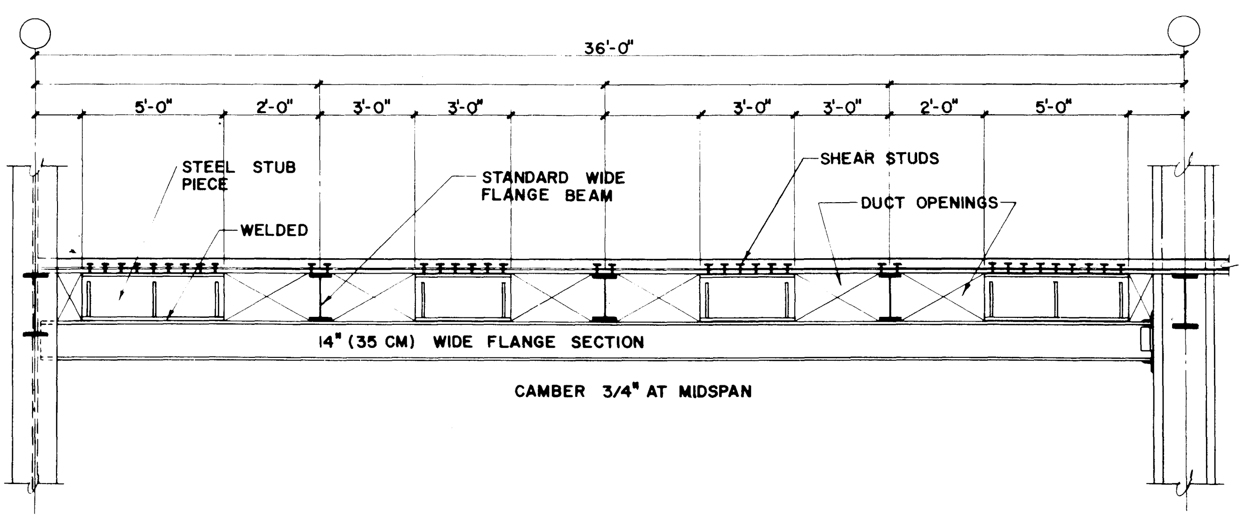
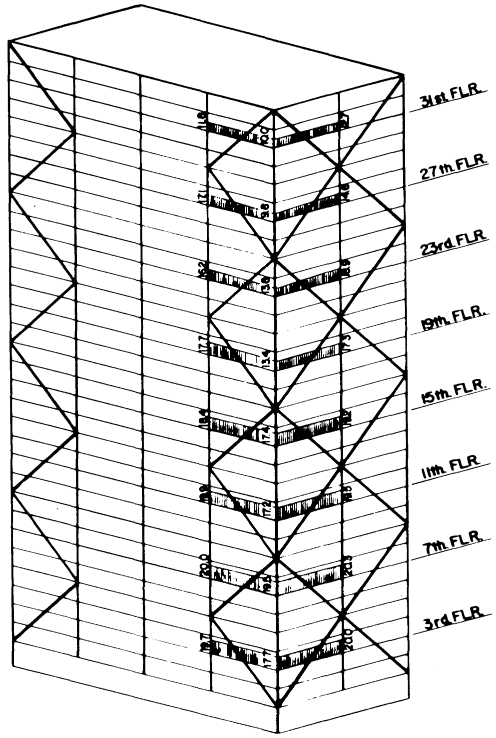
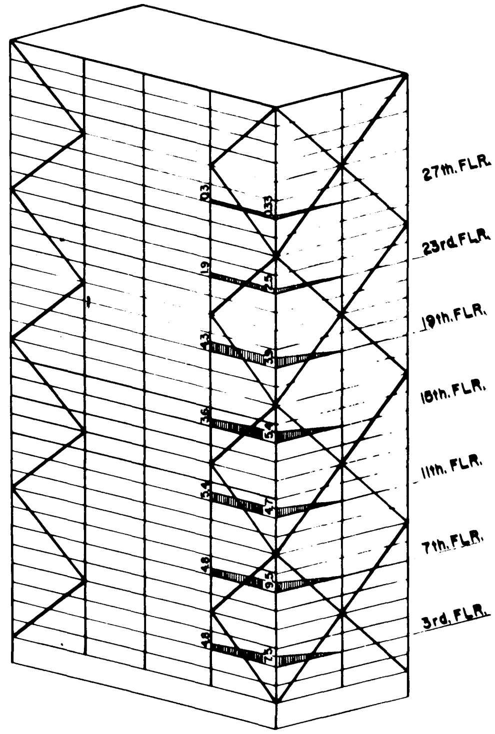


Fig. 5. Typical stub-girder



(*a*) *Column stresses—wind on broad face*



(*b*) *Column stresses—gravity loads*

Figure 6

lag evident, in that the corner column carries greater stress than the first column on the broad face away from the corner column.

This system of utilizing an exterior partial tube to resist wind also proves to be very effective in limiting lateral deflections. The maximum deflection for wind against the broad face is 7.2 in. (1 in 667). For perfect tube action, the computed deflection would be 5.8 in., indicating that the partial tube has 80 percent efficiency as compared to a complete tube.

STRUCTURAL DETAILS

Except for the columns and stub-girders, which are of A572 grade steel (yield strength of 50 ksi), the rest of the structure is fabricated from A36 steel, which has a yield strength of 36 ksi.

The gusset plates are shop-welded to the columns; the horizontal beams and the diagonals are then field-bolted directly to these gusset plates. Figure 7 shows a typical interior column-to-diagonal connection. Figure 8 shows the corner column-to-diagonal connection.

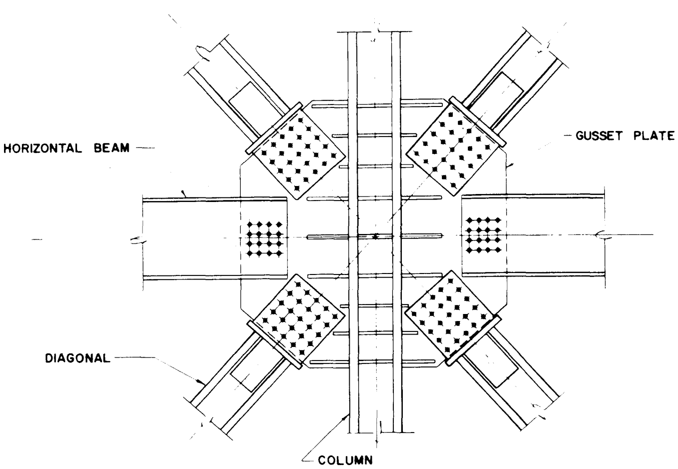


Fig. 7. Typical interior column-to-diagonal connection

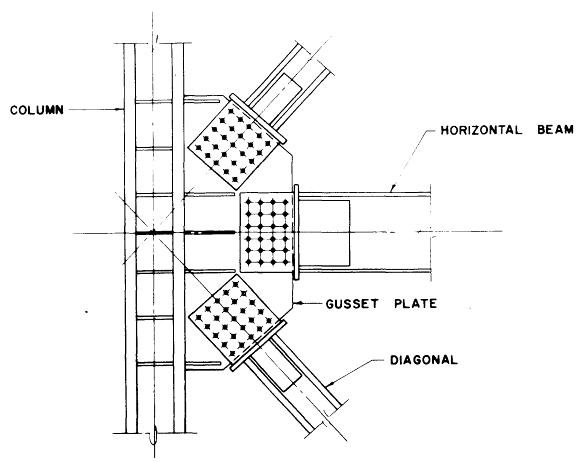


Fig. 8. Corner column-to-diagonal connection

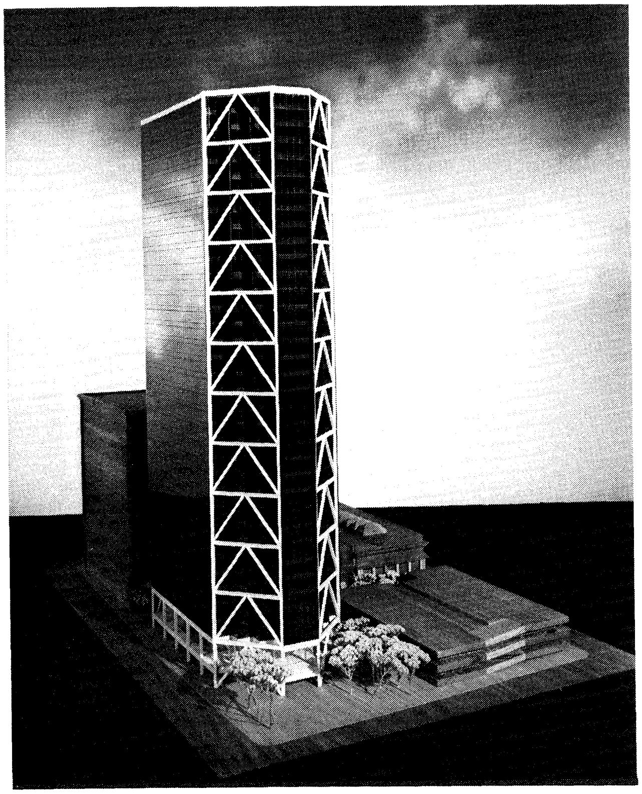


Fig. 9. Mercantile Tower, St. Louis, Mo.

The ends of the diagonals are welded to a yoke-like cap plate assembly, which slides over the gusset plate and can then be bolted with the bolts in double shear. The beam-to-gusset plate connections are similar in concept.

This straightforward rational consideration of structural details helped to eliminate almost all welding in the field, reduced time of steel erection, and was a significant factor in effecting economy.

"CHANNEL BRACING"

A variation on the partial tube concept is the "channel bracing" system developed for the Mercantile Tower in St. Louis, shown in Fig. 9. The building is 230 x 106 ft in floor plan, with the four corners cut off at 45°. These diagonal sides are sawtoothed. Across these diagonal sides, K-trusses were placed in three-story tiers. To complete the "channel", one bay on each broad face adjacent to the trusses and the one bay of the short side are welded frames.

The behavior of this system resembles partial tube behavior for wind on the narrow face of the building. However, for wind on the broad face, the behavior is analogous to that of a frame-truss interactive system.

ACKNOWLEDGMENTS

The Town Center Project in Southfield, Mich. is a development of PIC Realty Corporation, A Subsidiary of the Prudential Insurance Company of America. The architect is Neuhaus & Taylor, Houston. The General Contractor is the Henry C. Beck Co. The steel fabricator is the American Bridge Div., U. S. Steel Corporation. Mr. H. Mahendra is the project engineer.

The 101 Marietta Tower in Atlanta, Ga. is a development of Hicks-Pendley. The architect is Neuhaus & Taylor. The general contractor is Henry C. Beck Co. The steel fabricator is Bristol Steel Company. Dr. P. V. Banavalkar is the project engineer.

The Mercantile Center is a joint development of the Mercantile Bank, St. Louis, and Crow, Pope & Land Enterprises, Atlanta. The architects are Sverdrup & Parcel & Associates and Thompson, Ventulett & Stainback. The general contractor is Henry C. Beck Co. The steel is fabricated by a joint venture between Stupp Bros. Bridge & Iron Co. and Mississippi Valley Structural Steel Div. of Debron Corp. The project engineer is Dr. P. V. Banavalkar.