Structural Repairs Stabilize a Modernist Church

By John F. Vincent, P.E.

Constructed in 1963, the Catholic Church of St. Joseph in Menomonie, WI, has as it's most daring and expressive architectural feature a saddle-type, hyperbolic paraboloid concrete shell roof (*Figure 1*). It is believed to be one of only two churches in the U.S. with this type of roof. At the southeast corner of the structure, the roof shell projects outward beyond the main exterior building walls to form a canopy over the main entrance. This canopy is structurally cantilevered from the roof shell and also is supported by two brick masonry fin walls. These fin walls rise about 50 feet from grade to the curved canopy soffit. Between and beside the fin walls, modernist stained glass windows fill the area below the canopy.

At the time the structure was designed, closed form methods (equations) were the only practical means of analyzing a hyperbolic paraboloid shell. Restrictions were placed on the shell geometry and other details so that applied loads were carried predominantly by membrane action of the shell, as assumed by the analysis methods. One particular restriction was that the shell had to be bounded on all sides by continuous edge beams. Edge beams act as collectors to carry shell membrane stresses to the buttresses.

The original designers of St. Joseph Church provided edge beams, but then projected the roof shell beyond the edge beams to form the canopy. The design thus took some liberties with the accepted methods of the time. Therefore, in order to accommodate the unknown response of the structure to the canopy overhang, the original designers introduced two fin walls and significantly thickened the shell concrete beyond the edge beams. The fin walls were constructed of unreinforced brick masonry, laid up to the canopy soffit without mechanical attachment. In other words, shear forces between the tops of fin walls and the curved soffit were transferred only by friction.

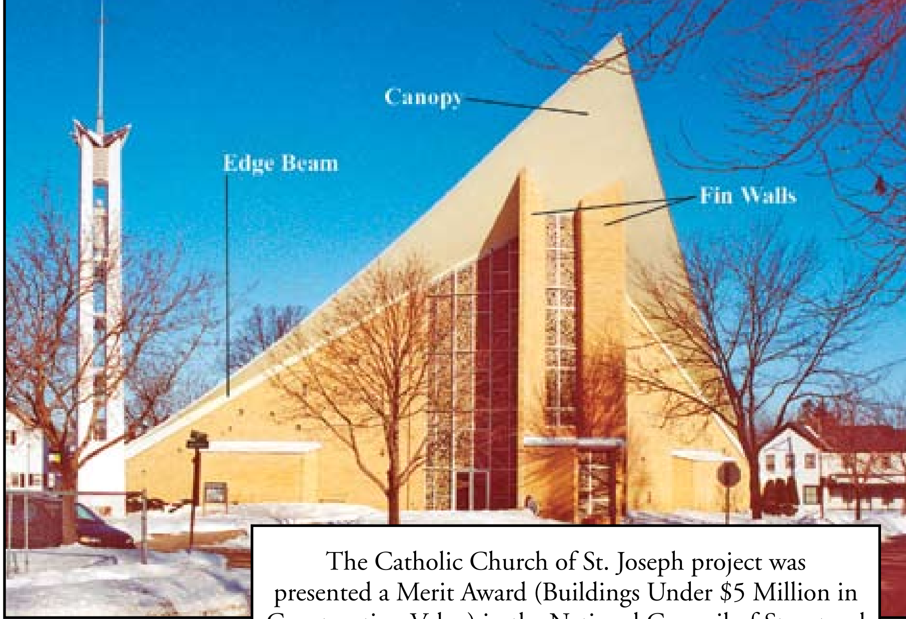

Figure 1: The Catholic Church of St. Joseph prior to repairs.

The Catholic Church of St. Joseph project was presented a Merit Award (Buildings Under $5 Million in Construction Value) in the National Council of Structural Engineering Associations (NCSEA) 2003 Excellence in Structural Engineering Awards program.

Bowing Prompts Investigation

After 36 years of service, the upper portions of the fin walls showed visible bowing. Concerned for the safety of parishioners and the stability of the structure, the parish engaged CTLGroup to perform a structural evaluation. Investigations revealed masonry cracks (approximately ⅛ to ½ inches wide) that were associated with the wall bowing. Furthermore, the tops of the fin walls had displaced laterally about 6 inches from their original locations at the canopy soffit (*Figure 2*). The tip of the canopy is the high point of the roof. The walls were sliding "up" the soffit surface as the roof was displacing downward. Because the fin walls were displacing relative to the canopy, the structural integrity of both the walls and roof shell were in question.

A finite element model of the church structure was used to study the fin wall/canopy interaction and help determine the causes of fin wall displacement. The model was subjected to gravity loads and seasonal temperature-induced volume changes. Creep was modeled by modifying the modulus of elasticity of the elements. Analyses results indicated that frictional restraining forces between the tops of the fin walls and sloping shell soffit were insufficient to accommodate applied interfacial shear forces. Based on this finding, it appeared that some displacement of the walls relative to the shell had occurred at the time of original construction, when shoring for the shell concrete was removed. These initial wall displacements were aggravated over time by seasonal temperature changes, which displaced the walls further in small increments each year. The accumulation of wall displacements over the life of the structure led to the distress observed in the walls.

Figure 2: Top of original fin wall shows bowing of wall and displacement at canopy soffit.

Model Helps Generate Repair Design

The finite element model was used to predict the strength and ductility needed to properly design new fin walls and their connection to the canopy and edge beams. The new walls were designed as reinforced masonry elements, with matching brick from the manufacturer of the original brick. The new fin walls were tied to the roof with a new reinforced concrete diaphragm at the canopy soffit, and have sufficient ductility to move with roof volume changes without damage.

At the tops of the fin walls, the masonry terminates a few inches beneath the canopy soffit in a stair-step configuration. The new diaphragm, located at and between the fin walls, transfers shear force between the walls and the canopy soffit

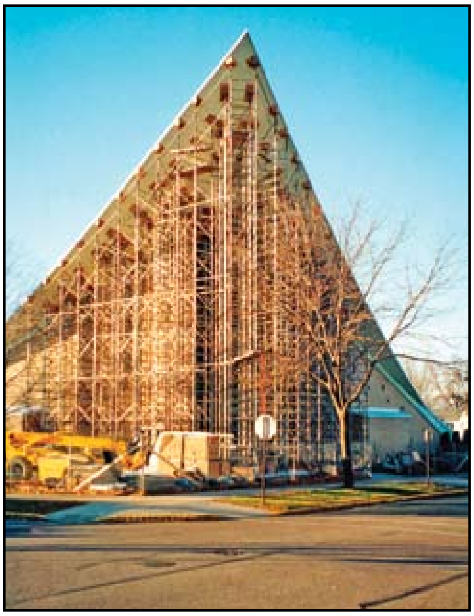

Figure 3: Shoring supporting the concrete shell roof during fin wall reconstruction.

through shear friction. With the new detail, the masonry only resists shear force through application of lateral loads or lateral displacement of the roof. This detail eliminated the shear force from gravity-load transfer that the original sloping concrete/masonry interface detail had applied to the wall.

Shoring System Maintains Roof Support

The finite element model also was used to analyze various methods of shoring the roof shell during reconstruction of the fin walls. Shoring was required to support the canopy and interior regions of the roof structure tributary to the fin walls. It was important to minimize axial strains and settlement in the shoring to avoid imposing large stresses on the canopy. Minimizing the shoring plan area to avoid encroaching on space within the church, and thus allow services to continue throughout construction, was an important criteria. Shoring design was the responsibility of the repair contractor. The shoring system that was developed to meet these requirements involved:

1. Closely spaced tower shores supported by concrete foundations (*Figure 3*);
2. Custom-fabricated oak blocks (cut from 12- x 12-inch timbers) set atop the shore posts to accommodate the compound and variable slope of the roof soffit (*Figure 4*); and
3. Regular monitoring of shore footing elevations to ensure that footings were not settling. An emergency plan was prepared that would have been implemented had foundation settlement been discovered.

Figure 4: Custom-cut oak block fits canopy profile at top of shoring post.

Repairs Preserve and Strengthen Original Design

The design preserved the building's architectural character, and allowed the church to remain in use through the entire course of the repairs. Matching brick from the original supplier were used to construct new reinforced masonry fin walls. Original stained-glass windows were carefully removed, stored, and reinstalled in the strengthened structure. A view of the repaired structure is shown in *Figure 5*. The investigation and repairs saved this landmark church, and will extend its useful life for many years to come.▪

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Project Credits

Owner
Catholic Church of St. Joseph, Menomonie, WI

Structural Engineer
CTLGroup, Skokie, IL

Repair Contractor
Oscar J. Boldt Construction

For readers interested in more technical information about this project, refer to the paper entitled, "Evaluation of Distress in Hyperbolic Paraboloid Shell," in *Journal of Performance of Constructed Facilities*, Volume 20, Number 1, February 2006 published by the American Society of Civil Engineers.

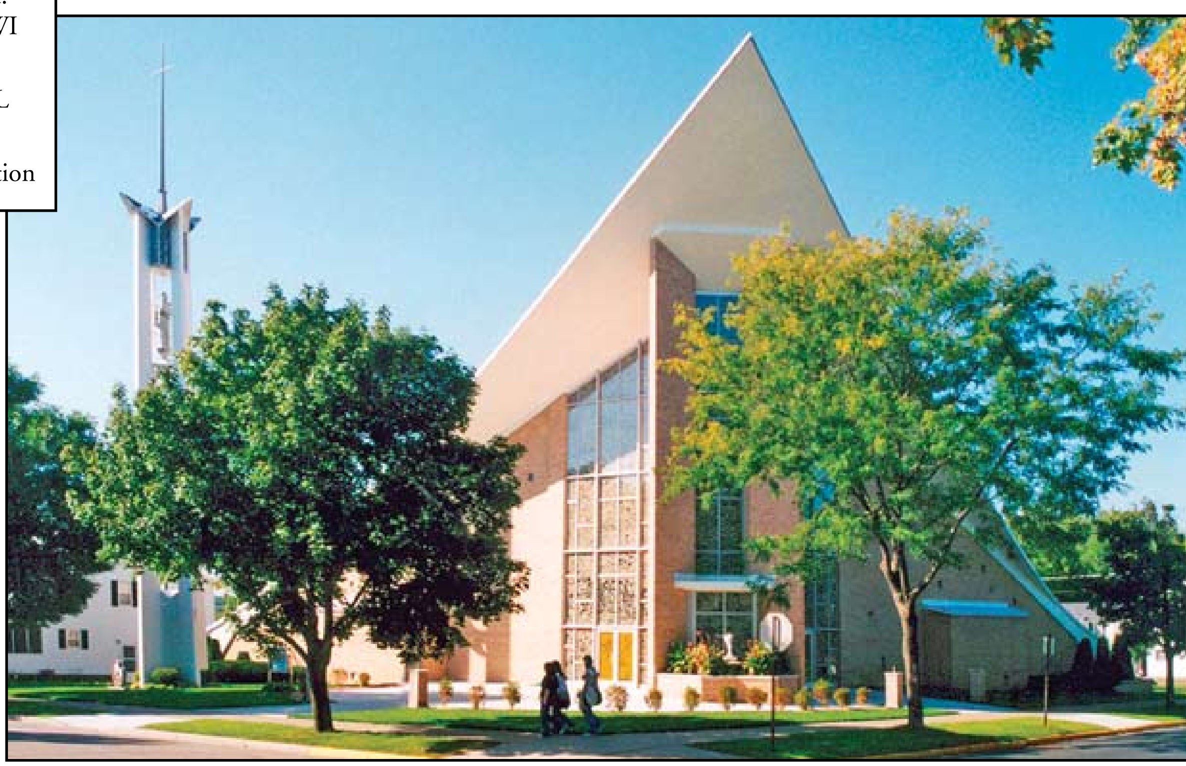

Figure 5: The Catholic Church of St. Joseph after completion of repairs.