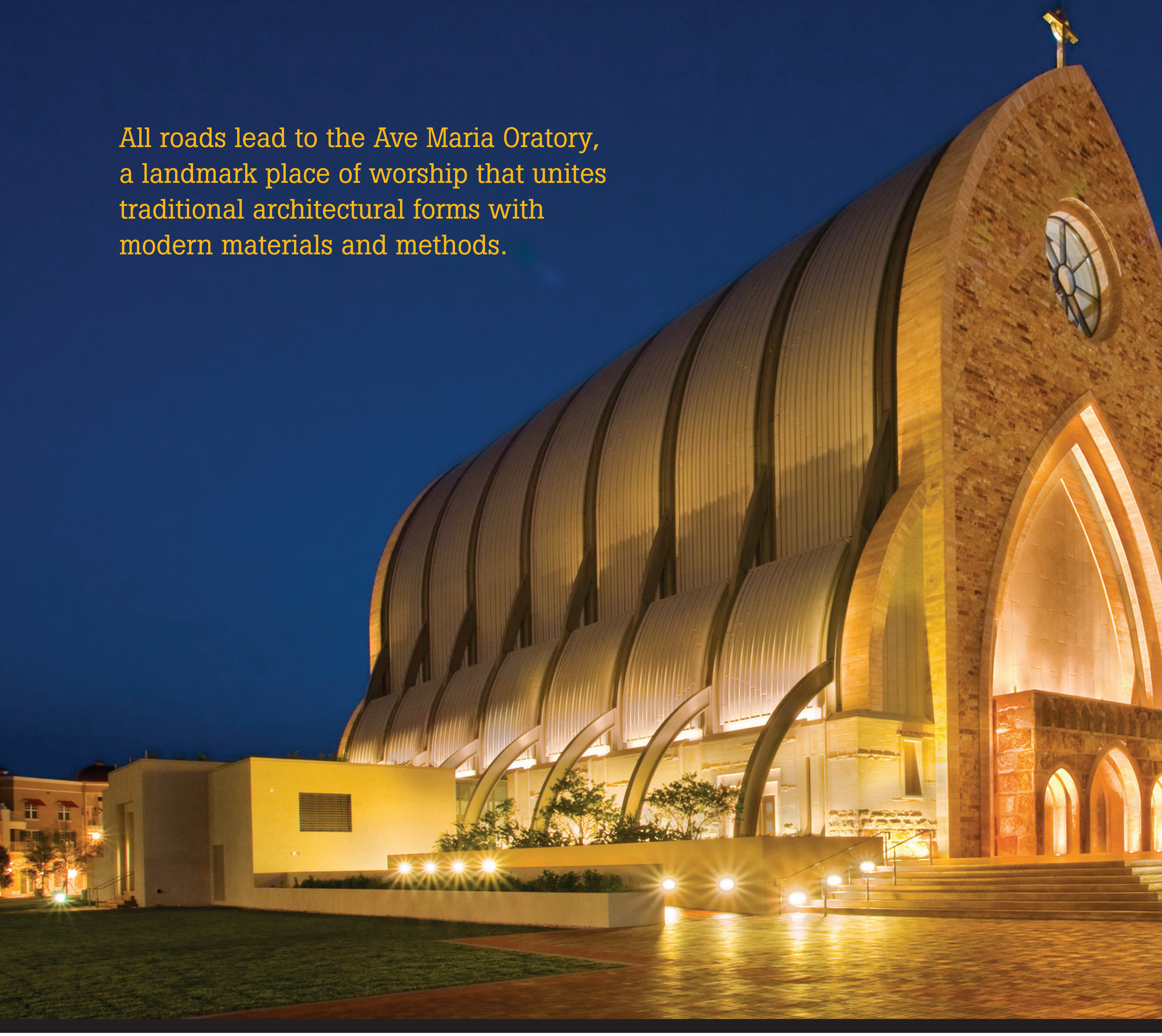


All roads lead to the Ave Maria Oratory, a landmark place of worship that unites traditional architectural forms with modern materials and methods.

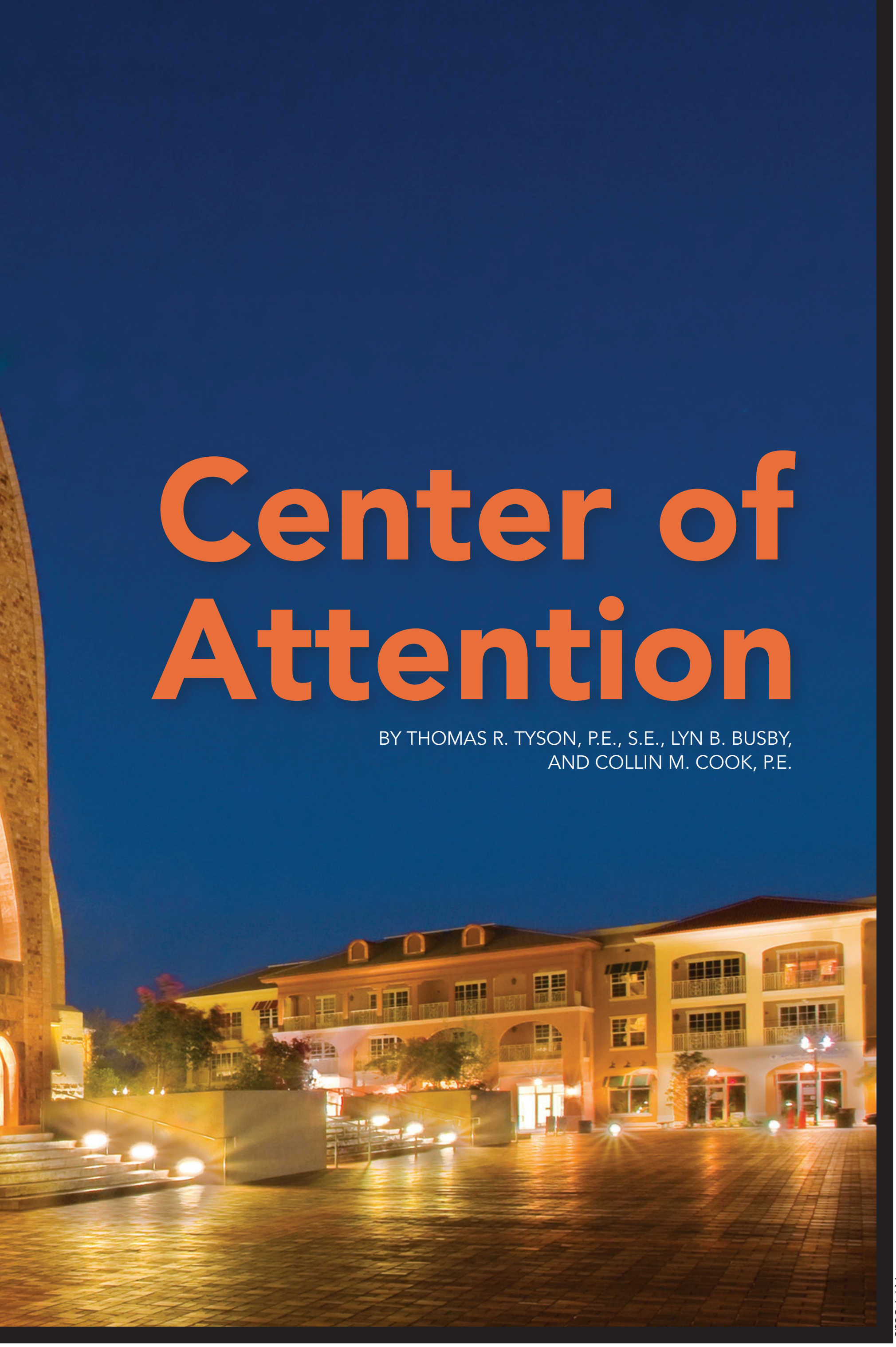
THE TOWN OF AVE MARIA SITS just northeast of Naples in southern Florida. While a brand-new community even by American standards, it adopts a decidedly old-world approach to layout by putting a church at its center.

The Ave Maria Oratory (a 2008 IDEAS^2 Award winner—5/08, p. 31) is at the convergence of major roadways and pedestrian paths leading from the surrounding residential communities and Ave Maria University. From a distance, the profile of the 120-ft-tall structure evokes images of a traditional cathedral. Moving closer, the clear distinction of a contemporary structure of glass, steel, and stone is revealed in greater detail. Entering the building, the soaring height of the nave is compressed by the choir mezzanine above and then dramatically expands upon entering the nave proper. The eye is drawn up to the light penetrating through the lattice of steel above, creating a "sense of mystery," the owner's primary design goal.

This design intent, not to mention the building's unique geometry, presented the team with a series of challenges. The Oratory's overall height, combined with a lack of interior floors, warranted careful attention to constructability considerations. The curved nature of the structure required complex connections that would remain visible. And, the final design needed to address the interface of stone and steel. Basically, it would need to orchestrate materials, assemblies, and aesthetics in a manner that would honor the spiritual significance of the Oratory.

All Together Now

From the very start, it was clear that the design effort could not be separate from



NY Focus

Center of Attention

BY THOMAS R. TYSON, P.E., S.E., LYN B. BUSBY, AND COLLIN M. COOK, P.E.

the fabrication and erection considerations that would prove critical to the project. The team took the unusual step of selecting the steel contractor during the schematic design. Under this arrangement, designers could work with the general contractor and steel contractor to develop connections for the steel frame that were not only functionally sound, but that also blended well with the architect's vision for the structure.

Several concepts were considered. The first design concept for connection used all field-bolted connections, but this method was eventually discarded, since many of the lower connections were very close to eye level, where the architect preferred smoother lines. While using all field-welded connections would resolve this issue, cost and schedule considerations ruled it out. The team eventually decided on a combination of the two methods, where the connections in the lower portions were field-welded and the upper connections were field-bolted where practical.

Due to the complexity of the structure, the fabricator chose a select group of subcontractors to assist in the Oratory's construction. The project detailer was selected early and worked closely with the design and fabrication teams during the connection design period by providing 3D models of the different connection concepts. Once fabrication began, the detailer was also able to provide multiple services for the shop, such as rolling diagrams for the curved members, actual-size templates for the complex skew cuts on the beam ends, and 3D images of the more complicated connections to aid the fitters and inspectors in visualizing the end product.

The structure consists of 10 main uprights, which were field-assembled to the greatest extent possible on skids prior to erection. Once each upright was hoisted into place, a secondary crane was used to erect the infill steel for stability. Originally, the erection schedule called for 25 weeks. However, the erector was able to complete the work more than a month ahead of schedule due to better-than-anticipated fit-up resulting from tight adherence to tolerances by the detailing shop, bender-roller, and fabricator.

Going Wide

Early in the process, a critical design decision was made to use wide-flange shapes in lieu of hollow structural sections for the main members of the uprights, based on architectural considerations as well as fabrication and erection concerns. Fourteen-inch wide-flange shapes were selected as the interior structural members of the uprights because of their stoutness, which provided significant weak-axis stiffness and stability. In addition, the W14s also permitted the flexibility to select elements for loading and stiffness criteria while maintaining compatible depths, which directly affected the architectural appearance. Lateral stability in the transverse direction is provided by a series of latticed structural steel uprights, while stability in the longitudinal direction is provided by bracing along the perimeter of the building. The longitudinal bracing was also intended to express the design intent of interlacing the Gothic arch lines of the transverse uprights.

Steel buttresses were designed as free-standing exposed elements that penetrate the outer skin, hinting at the latticed uprights forming the basis of the overall structure. In this building, structure *is* architecture. For example, analysis showed that the buttresses—originally ornamental only—

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provide significant additional stiffness to the structure and help transfer the lateral load to the foundation.

Rolling Along

The overall structure consisted of 1,270 tons of fabricated structural steel, and more than 70% of the pieces had to be rolled to various radiuses prior to the start of fabrication. In order to roll the members to the required radii and within AISC tolerances, the fabricator chose a rolling shop based on its ability to roll the very large shapes with heat induction equipment.

While cold rolling applications were appropriate for some of the lighter members, heat induction rolling was required not only for the large shapes with tight radii, but also for control of accurate tangent points to reduce shop splices. Over 400 tons (153 pieces) were rolled through the heat induction process.

As might be expected, the largest steel sections on the project needed to be rolled to the tightest radius. The W24×207 outer buttress elements of the uprights were rolled to a 24-ft, 8-in. centerline radius. Control of the tangent point for the W24×207 elements following the main line of the exterior wall was critical, as it aligned with the most complicated connections of multiple elements, some at highly acute angles. The ability to accurately hold these tangent points eliminated a shop splice, reducing complications in a highly complex connection.

Heat induction bending was especially important for the curved elements that crossed diagonally from one upright to the next, following the line of an imaginary cylinder defined by elements in the plane of the upright. The line of these elements was approximated by determining three different radii along the length of the member, changing at two different intermediate tangent points. The heat induction process permitted these elements to be rolled as single pieces without the need for shop splices and accompanying ultrasonic testing inspections. Both the architect and owner were pleased with the level of control achieved on the rolling of the steel, since the uprights align visually and variations in the curvature would be obvious.

Updated Analysis Approach

The structure's lateral loads are transferred to the 3-ft-thick mat foundation via a combination of flexural bending and arching action of the curved steel members. The design of these members was governed by serviceability and stability concerns rather than strength design criteria. Stability analysis of the lateral framing was complicated by the members' curved geometry and unique connections, which made traditional effective-length and slenderness procedures ineffective.

Top: The end wall upright being lifted into place at the start of erection.

Middle: The full elevation of the uprights can be seen during erection.

Bottom: Longitudinal bracing in the plane of the side walls compliment the curves of the upright frames.

Fortunately, while the design of the Oratory was underway, AISC revised the *Specification for Structural Steel Buildings*, introducing new methods for performing stability analysis and design. In lieu of effective-length concepts, the Direct Analysis Method requires the user to perform a second-order analysis considering both local and global P-Delta effects to determine member forces and amplified deflections. In this analysis method, stability is verified by applying an out-of-plane notional load that provides the members with an initial out-of-plane geometry that is then amplified by the second-order analysis using reduced stiffness. Stability is verified by convergence of the P-Delta analysis.

Since the gravity loads for the Oratory are relatively small, the normally recommended notional load was not sufficient to provide the necessary distortion to perform the second-order analysis. Therefore, a notional load was amplified to produce the desired 1/500 initial out-of-plumbness. This load was applied at the upright lattice nodes of the main structural members.

Stormy Weather

The wind loads for the Oratory, sited in hurricane-prone south Florida, were determined by wind tunnel studies on a scale model. Since there are no diaphragms in the building, the dynamic response of the structure to the wind loads was an especially important design consideration.

For the apse of the Oratory, the structure is designed as a half-shell that frames into a D-ring-shaped member that functions similar to an oculus. The D-ring is supported in the vertical direction from the end wall upright, which controls the deflection of the half-shell. Internal stability for the apse is provided by a network of diagonal bracing that helps tie the individual arched ribs together so that they function as a shell-type structure. The interface between the apse and the end wall of the Oratory was designed as a soft joint to accommodate the difference in stiffness between the various components.

Support of the stone masonry end walls was another challenge addressed by the design team. The stone masonry façade was an important element of the architectural image, suggesting the traditional basilica. Since the geometry was clearly not conducive to self-supporting masonry, the stonework needed to be suspended from the steel frame. To provide an appropriate backup system for the stone, a series of site-cast concrete panels were suspended from the end wall uprights, providing adequate out-of-plane stiffness to transfer the hurricane wind forces to a longitudinal bracing system located in the side walls. These panels had a complex geometry with 5-ft returns on the outer edges, as well as complicated returns on the inner edges where the wall systems arch over both the entrance on the west and the apse opening on the east.

The integration of engineering, architecture, and construction is raised to an art form with the Ave Maria Oratory, as all systems unite to define and enrich the space. The final design is rooted in a combination of historic church forms, rendered with contemporary structure, materials, and technology. MSC

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Structural Design Software
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Tekla Structures