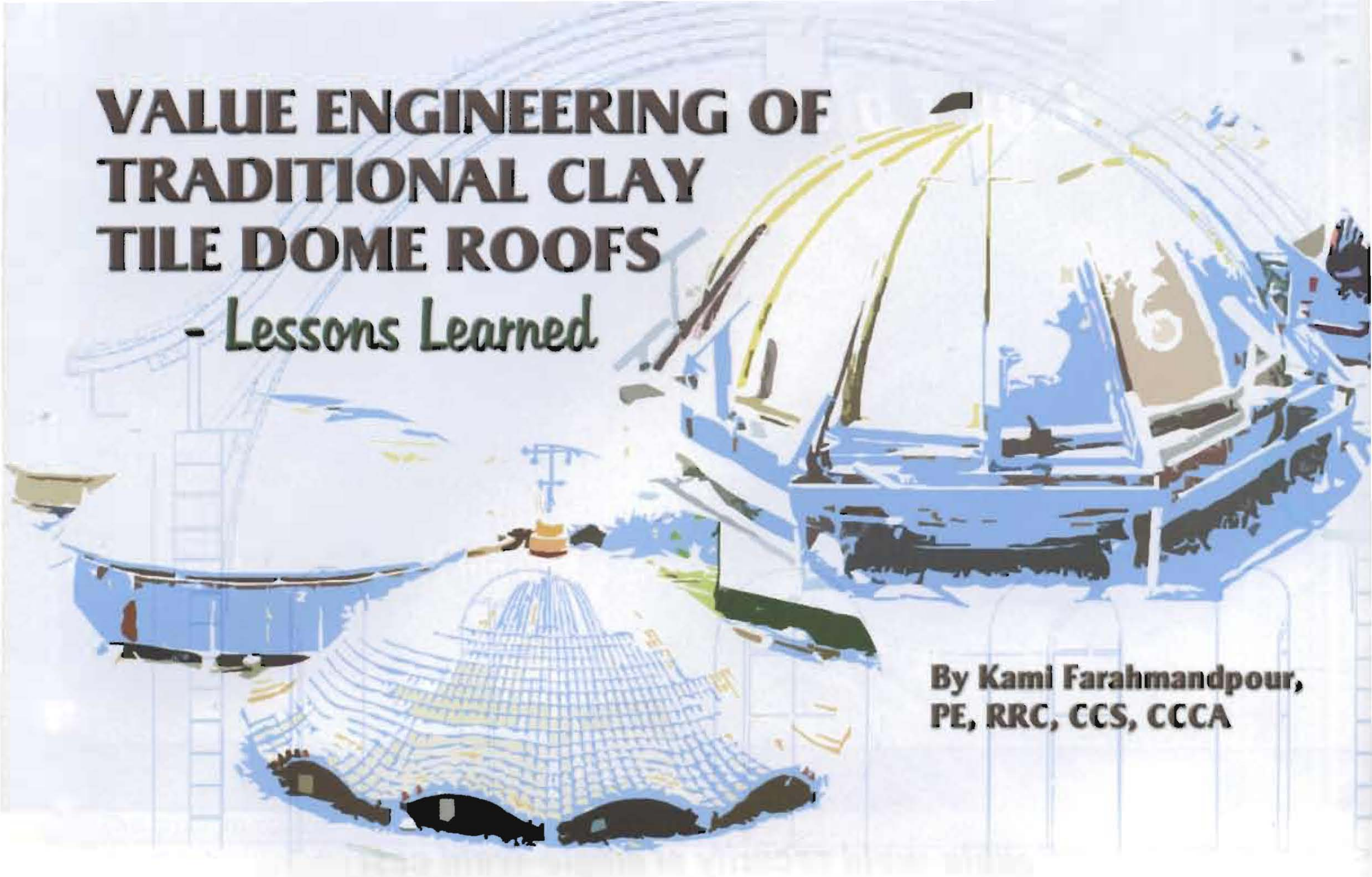
VALUE ENGINEERING OF TRADITIONAL CLAY TILE DOME ROOFS - Lessons Learned



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ABSTRACT

The design and construction of traditional dome roofs present several challenges. These challenges are intensified when the design criteria call for the use of clay tiles. This article discusses the design and construction of the roofing systems for the new buildings at St. John Chrysostomos Monastery in Kenosha, Wisconsin.

Built between 1997 and 2003, the new monastery campus consists of several buildings, including the church building that was designed to replicate the old Greek Orthodox churches of the 16th century. The new church building included several domes, gable, hip, and arch barrel roofs. There were a total of eight domes on the proposed church building *(Figure 1)*.

The dome roofs included geometrically complex shapes that required extensive computer modeling. The domes ranged from less than 20 feet to over 40 feet in diameter. Several options were considered for roofing the domes. During the design process, clay tile roofing was deemed an essential element of the design tradition and was selected for the project. All other buildings throughout the new campus were also designed with traditional clay tile roofing systems.

Figure 1 - The architect's original rendering of the church building at St. John Chrysostomos Monastery. The dormitory building behind the church is not shown.

The original design of the dome roofing systems incorporated a waterproofing system and custom-shaped clay tiles secured in place with a wire fastening system. Due to the high cost of manufacturing the custom-shaped clay tiles, a value engineering alternative was proposed. This alternate design incorporated structural fiberglass inner and outer domes. The alternate was ultimately selected for its cost advantages and included an outer dome that was molded from reinforced fiberglass using silicone molds to replicate the shape and appearance of clay tiles. Due to concerns for cracking of the fiberglass outer domes, the alternate design incorporated a redundant waterproofing system. Subsequent to their construction, the fiberglass domes exhibited cracking and leakage through the outer domes, requiring remediation.

The gable and hip roofs on the remaining campus buildings were roofed with traditional clay tiles. The construction of these roofs also presented several challenges, such as the incorporation of a lightning arrest system at the ridges and providing appropriate ventilation of the roof decks.

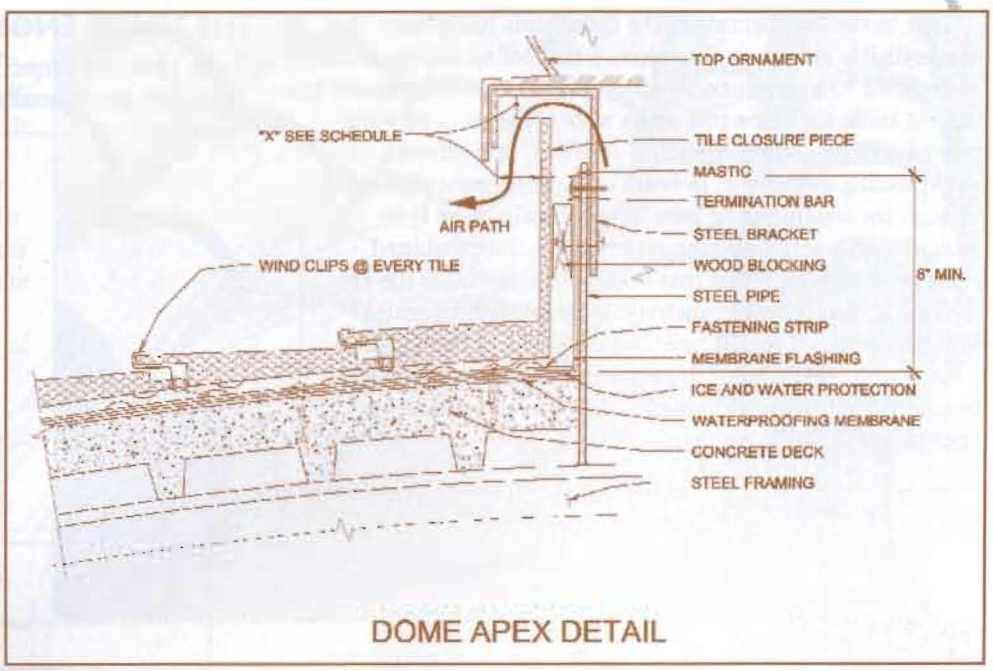


Figure 2 - Typical detail at dome apex.

THE ORIGINAL DESIGN OF THE DOME ROOFS

The design of the dome roofs posed many challenges. These challenges included the design of the structure (roof deck and its supporting structural members), design of the roofing system, and moisture/thermal control measures such as ventilation and insulation placement.

Design of the Roof Deck

To have a roof, one needs a roof deck. To construct a roof deck that conformed to the contours of the domes using modern materials was a challenge in itself. While not an easy task, supporting the roof deck on a structural framing system was somewhat less complicated.

The design team considered many options, including wood planks supported on glue-laminated and curved beams, steel deck supported on curved steel beams, and a cast-in-place or precast concrete deck. Each of these options had its advantages and disadvantages. The final design of the dome structures included curved steel beams supporting a cast-in-place concrete deck. A structural steel deck roughly conforming to the contours of the dome's surfaces was to be used as a forming surface for the cast-in-place concrete deck. All team members realized that constructing the cast-in-place concrete deck, particularly at its high sloped areas, would require unusually skilled workers.

Roofing System Options

The design team also considered several roofing system options. The system options included spray polyurethane foam (SPF), flat-lock copper, titanium, etc. Of course, each option had potential advantages and drawbacks and presented its own challenges in the design.

Despite the presented options, the owners' criteria called for traditional clay tile. Therefore, the design team set out to design a tile roofing system for the entire project. Tile was to be placed on all of the roofs (except a few small low-slope roofs) on the project. These included the domes, the barrel vault roofs, half domes, gable roofs, and hip roofs.

Design of the Roofing System

In order to provide for proper moisture and thermal control, all roofs were designed with a ventilated cavity below the decks. At the domes, the ventilated cavity was located between the plaster ceiling and the roof deck. Air was to move through soffit vents and exit at the apex of the dome through a ventilation shaft (see *Figures 2* and *3*).

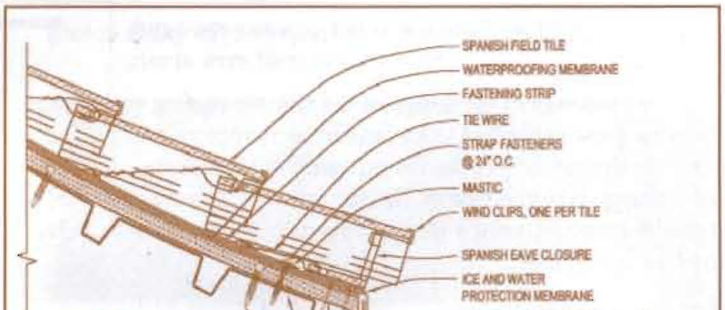


Figure 3 - Typical roof configuration at eaves.

Due to their configuration, the dome roofs had a slope that was negligible at the top. Therefore, a tile roofing system could not be designed as a conventional water-shedding or hydrokinetic system. As such, the dome roof decks were designed to be waterproofed with two layers of an SBS-modified, self-adhering waterproofing membrane. In order to minimize penetrations through the waterproofing membrane, the tiles were to be secured with a wire fastening system. This system utilized stainless steel hook strips that were to be attached to the concrete deck. The fastener penetrations would each be sealed with SBS-modified mastic prior to installation of the fasteners. A spray water test of each dome after installation of the wire fastening hook strips was specified to locate potential leaks prior to installing the clay tiles.

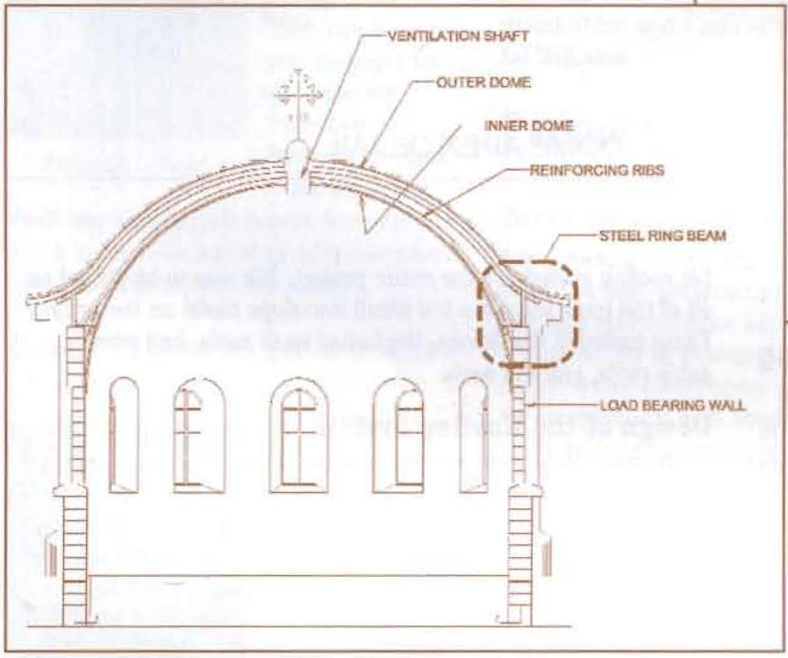


Figure 4 - Typical configuration of the proposed fiberglass domes.

One challenge in the design of the clay tile roofing system was that each row of tile had to be tapered as it approached the dome apex. In the meantime, the tile exposure at each course would also change to accommodate the varying cord lengths of the tile rows. This necessitated a large number of custom fabricated clay tiles for each dome.

THE VALUE ENGINEERING SOLUTION

In 1999, the project was issued for bid. The bid results indicated that an unusually large percentage of the project cost would be devoted to the clay tile roofing system. Based on interviews with the contractors and tile manufacturer, it became evident that a significant portion of the cost was associated with fabrication and installation of the custom-tapered clay tiles on the domes. Combined with budget limitations, this triggered the investigation of other options for the dome roofs.

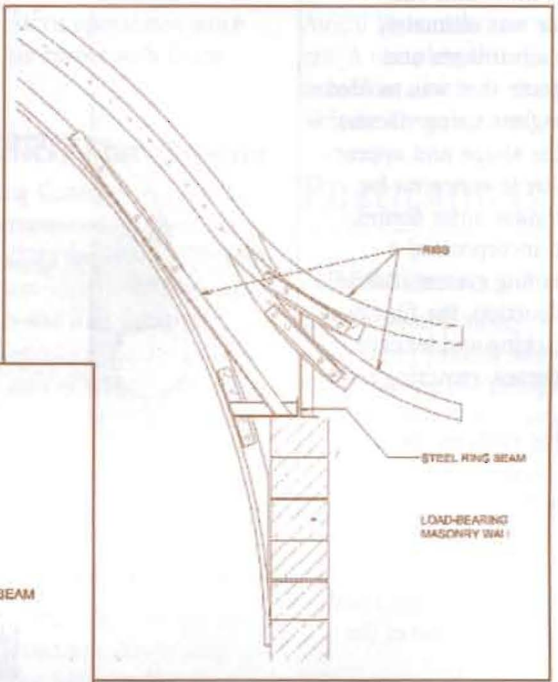


Figure 5 - Configuration of structural members and ring beam.

One value-engineering proposal was to construct the domes entirely of fiberglass. The proposed system called for constructing an inner dome that served as the finished ceiling inside the church building, and an outer dome that would be molded to replicate the appearance of clay tiles *(Figure 4)*. The cavity between the inner and outer domes would then be ventilated. The two domes would each be constructed with reinforcing ribs and supported on a steel ring beam *(Figure 5)*. As such, there would be no need for any other structural members for the domes. The entire structure, including the inner and outer domes, would be engineered and fabricated by the manufacturer. The outer dome surface would also be completely seamless and watertight.

Due to the significant cost savings offered by this approach, the proposed value engineering system was accepted. However, the design team expressed several concerns:

1. Since the domes were to be integrated into a larger building with many conventional clay tile roofs (the hip, gable, and barrel roofs), there was a concern regarding the color stability of the fiberglass and durability of the color coating on the fiberglass surfaces. To address these concerns, the fiberglass dome manufacturer incorporated color pigments in the fiberglass resin.
2. In order to replicate the appearance of the clay tile, the outer fiberglass domes were to have many crevices, making it difficult to mold the dome segments (*Figure 6*). To address this concern, the fiberglass manufacturer used a silicone mold process so that these crevices could be replicated by the molds.
3. The proposed fiberglass outer domes were designed with no expansion joints or provision for thermal movement. The design team expressed its concerns regarding the potential for thermal cracking of the domes. However, relying on its vast prior experience, the fiberglass dome manufacturer assured the owners and the design team that cracking would not occur. Since the domes were to be designed and fabricated by the fiberglass dome manufacturer, the design team had no control over the details, as long as the design criteria were met. However, the design team insisted on constructing a redundant waterproofing system on the inner domes. This system is depicted in *Figure 7*, and consisted of a spray polyurethane foam roofing system that was installed over the inner domes. The perimeters of the inner domes were then modified to provide a drainage trough and several drains. These drains would direct any water that would leak through the outer domes to the outside via flexible drain tubes. Spray polyurethane foam was selected for the system due to its flexibility for application around the structural steel members that penetrated through it.

Above: Figure 6 - The crevices between the tiles were difficult to mold.

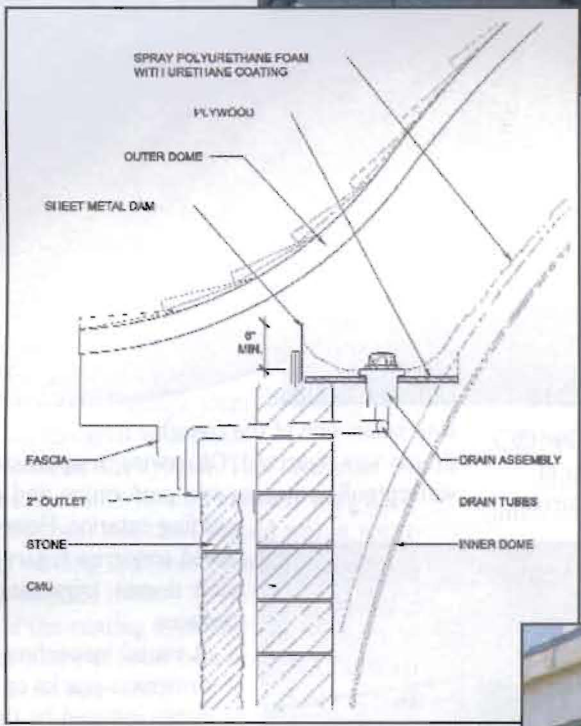


Figure 7 - Configuration of the redundant waterproofing system.

CONSTRUCTION OF THE DOMES

The domes were fabricated at the manufacturer's facility and brought to the site in pie-shaped segments (*Figure 8*). Depending on its size, each inner and outer dome was constructed of two to 12 segments. The segments were then joined in the field on the pre-fabricat-

Figure 8 - Outer domes were fabricated and delivered to the site in pie-shaped segments.

Above: *Figure 9 - An inner dome being assembled on the structural steel skeleton.*

Below: Figure 10 - Sealing of the pie-shaped segment joints with pigmented resin.

ed structural steel skeleton *(Figure 9)*. The seams between the pie segments were also sealed with fiberglass resin *(Figure 10)*.

Once the inner domes were constructed, the spray polyurethane foam system was applied, and the perimeter drainage trough was constructed *(Figure 11)*. The entire assembly was water tested on the ground and then lifted and installed onto the structure. The perimeter trough drains were directed to the building exterior using flexible tubing *(Figure 12)*.

SUBSEQUENT PROBLEMS AND EVALUATION

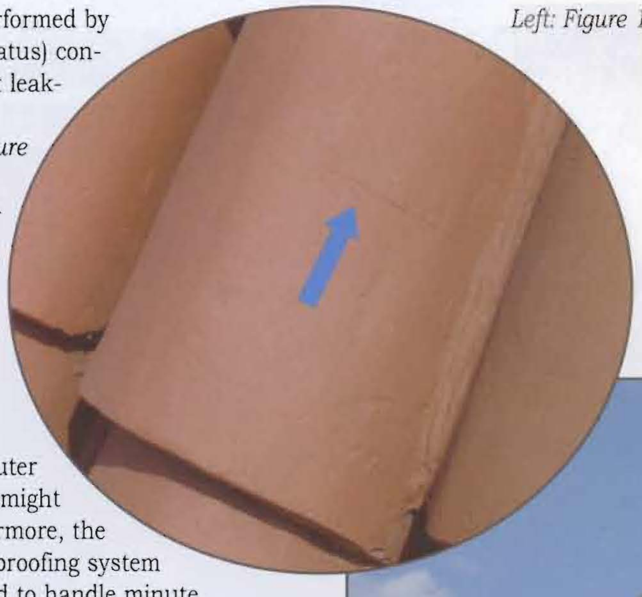
The fiberglass domes were installed in late 2001. Initially, no evidence of leakage was observed. However, after the winter of 2002, the owners observed water leaking through the perimeter trough system. Only one localized leak below one of the trough drains was observed. Otherwise, it appeared that the redundant waterproofing system was performing and directing water to the building exterior. However, these observations raised concerns regarding the integrity of the outer domes, triggering an evaluation of their surfaces.

A visual inspection revealed the presence of numerous cracks on the outer domes, probably induced by thermal movement *(Figure 13)*. Water

Above: Figure 11 - Assembled inner and outer dome. Note the gray spray polyurethane foam system and the perimeter drain pipes (red arrow).

Right: Figure 12 - A flexible drain tube carried the water from the inner dome's perimeter drainage system to outside of the exterior walls.

spray testing (performed by fire-fighting aparatus) confirmed significant leakage through the outer domes (*Figure 14*). While the redundant waterproofing system appeared to control the leakage, the owners and the design team were concerned that the cracking of the outer fiberglass domes might continue. Furthermore, the redundant waterproofing system was only designed to handle minute amounts of water, not the amount that was revealed during the water testing.



Left: Figure 13 - Typical cracking of the outer dome surfaces.

Below: Figure 14 - Water testing of the outer dome surfaces using fire fighting apparatus. The nozzle at the top of the ladder delivered 1000 gallons of water per minute.

THE RETROFIT SOLUTION

Several options were considered for remediation of the outer domes. The most practical and cost effective solution was to apply an elastomeric coating over the dome surfaces. However, due to the presence of numerous crevices on the outer dome surfaces, such coating application would be challenging.

After consultation with a reputable elastomeric coating manufacturer, the design team specified a urethane-based material with paste consistency as the base coat for the system. This base coat was to be applied using brushes to ensure that all crevices were filled with the material. The base coat was then topped with a spray-applied elastomeric color coating that was formulated to match the color of the adjacent clay tile roofs.

Prior to application of the coating system, tests were performed to ensure the adequacy of bond between the fiberglass surfaces and the elastomeric base coat.

The application of the coating system also posed several challenges. Ensuring that all the surfaces and crevices were well coated was tedious work, performed from a large articulating boom (*Figure 15*). After completion of the coating application, no further evidence of water leakage was reported.

OTHER PROJECT CHALLENGES

Aside from difficulties encountered with the fiberglass domes, remaining portions of the tile system on the hip, gable, and barrel roofs also proved challenging. Several details, including the ventilated ridges and attachment of lightning arrest system rods to the tile roofs, proved difficult and required special attention (*Figures 16* and *17*). Exacerbating some of these problems were construction tolerance issues that resulted in deviations from the original design details.

CONCLUSIONS

While most designers and building owners avoid the use of innovative systems that have little or no track record, some will be courageous enough to specify innovative systems. If such innovations prove unsuccessful in building envelope applications, they

Figure 15 - Application of the elastomeric base coat in all the crevices with a brush.

Figure 16 - Roof ridge configuration with ventilation provisions and a lightning arrest rod.

Below: Figure 17 - Roof ridge detail after installation of ridge cap tiles.

can produce catastrophic results that are expensive to correct. Therefore, it is the author's opinion that while the use of innovative systems should not be discouraged, implementation of innovative solutions to complex building envelope problems requires careful attention to details and a thorough analysis of potential problems. Providing redundant systems to account for potential problems is one way to ensure a successful application.

In the St. John Monastery project, the cost of implementing the redundant waterproofing system for the domes was a small fraction of the total roofing cost. Yet, its implementation was deemed unnecessary and was resisted by some. In the end, if it were not for the presence of the redundant waterproofing system, the application of the elastomeric roof coating may not have been considered a reliable long-term solution for the dome cracking issues, and more extensive remediation would have likely been needed. ■

About the Author

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Kami Farahmandpour is the principal of Building Technology Consultants, PC, in Arlington Heights, Illinois. Over his 19-year-career, he has managed over 250 projects involving the evaluation and repair of building components. Farahmandpour is the president of the Chicago Area Chapter of RCI, chairman of its Building Envelope Committee, and a member of RCI's Building Codes and Standards Committee. He serves on NRCA's Education Resource Committee. Kami is active in several other professional organizations such as the American Society for Testing and Materials, International Concrete Repair Institute, and American Concrete Association.