Masonry and Steel

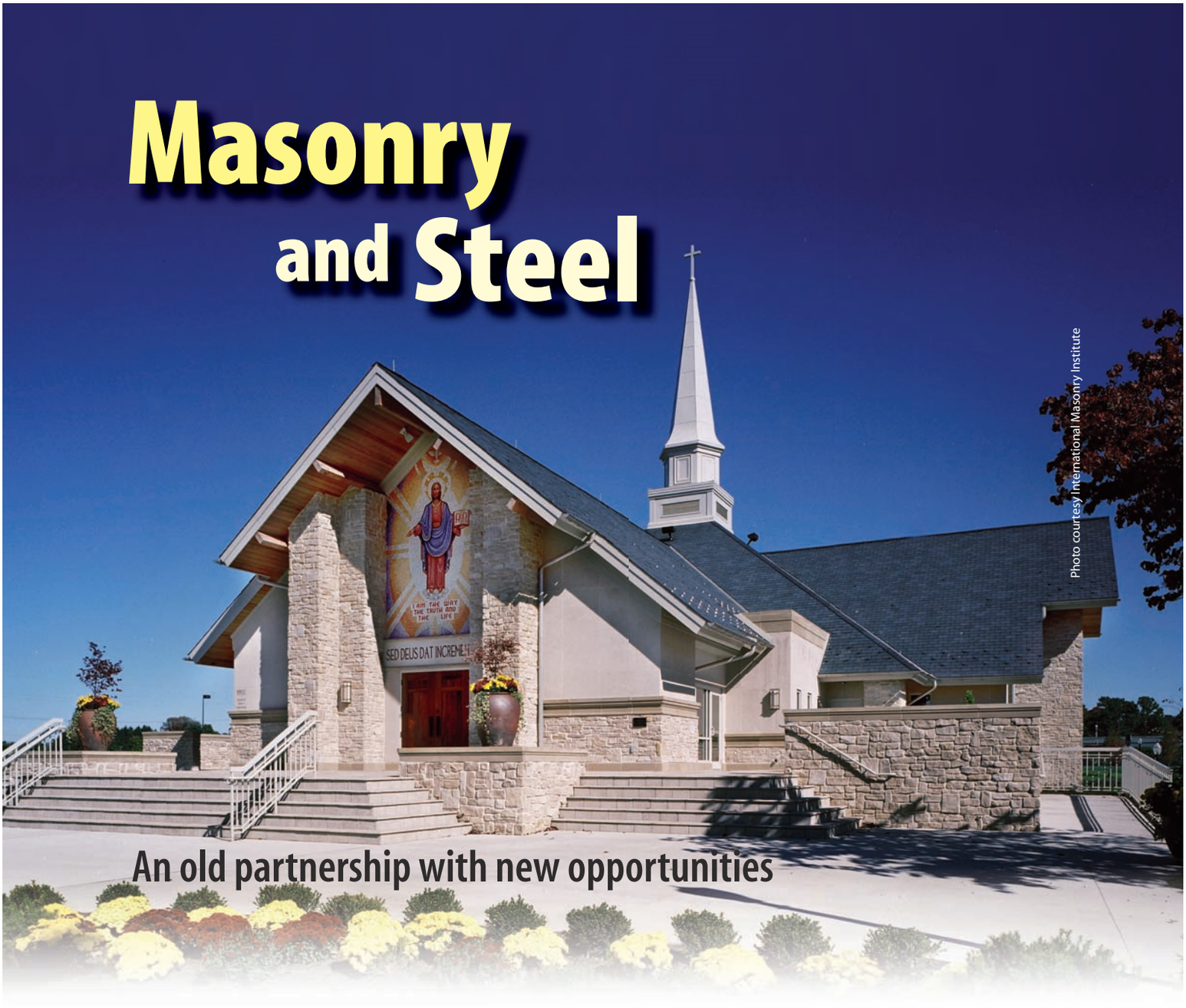


Photo courtesy International Masonry Institute

An old partnership with new opportunities

There are many options and benefits when combining masonry and steel. The Walsh University Chapel (North Canton, Ohio) uses load-bearing masonry with a structural steel roof. The project team included Thorson Baker & Associates, Peninsula Architects, Fred Olivieri Construction Co., GMR Builders, and Bricklayers and Allied Craftworkers Local 6 Ohio.

by Keith Lashway, PE, and Diane Throop, PE, MBA

Designers have long known masonry and steel make good partners. The former is great in compression; the latter in tension—combining the two attributes allows the creation of a versatile structural system.

Masonry is ubiquitous—reinforced masonry structures are a staple of the building market and masonry veneer can be backed up by cold-formed steel stud systems. However, the combination of masonry infill with structural steel frame construction is often overlooked. The masonry is usually considered a non-structural element and its contribution to the support system's behavior is not taken into account. This perception may change with the increasing focus on the structural role of masonry infills within the steel frames.

The masonry infill—reinforced to carry in-plane and out-of-plane loads at the designer's option—is used to brace the steel frame, resulting in an efficient use of both materials. The system can potentially eliminate the need for moment connections in the steel frame or steel cross bracing, simplifying the installation of both the masonry and the structural steel. This system is suitable for any building—however, projects with masonry veneer or many cladding materials can benefit the most as the masonry backup wall

serves both as anchorage for the veneer or cladding and will be reinforced to provide lateral resistance to structural steel frame construction.

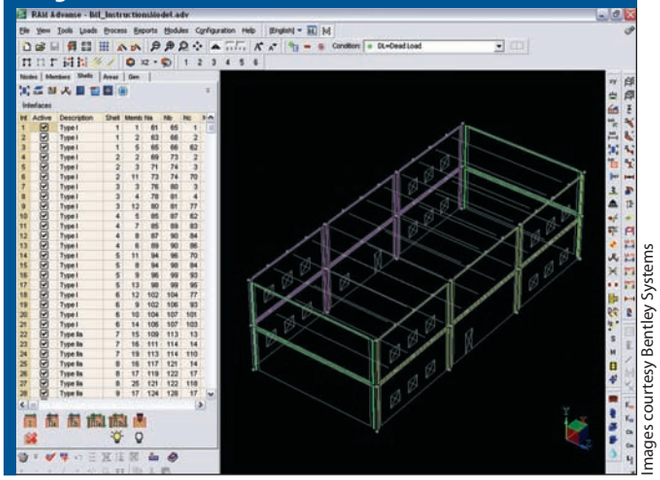
Newest role for masonry with steel

The 2011 Masonry Standards Joint Committee (MSJC)—the group responsible for *Building Code Requirements for Masonry Structures*—is developing provisions for masonry infills, based on research, to define the masonry's interaction with the steel (and also concrete) frames.[1] The new code provisions will aid engineers who wish to factor the interaction between frame and masonry infill into their designs.

Another development this year is the release of software for designing 'hybrid' masonry and steel structures (*i.e.* buildings with reinforced masonry infill and steel frames), allowing them to be analyzed as an integrated structural system. The genesis for the software was a paper authored by David T. Biggs, PE, of Ryan-Biggs Associates.[2]

Currently, Biggs and other engineers who wish to use reinforced masonry infill as bracing for steel frames need to do the analysis by hand—a laborious task. The desire for software that would engineer both masonry and steel in an integrated package prompted Biggs to approach the International Masonry Institute (IMI) and the National Concrete Masonry Association (NCMA) to underwrite a project to develop such a program.

Figure 1



Images courtesy Bentley Systems

The first step is to model the steel frame system.

The objective of this collective effort—carefully reviewed by a group of practicing structural engineers—was to produce a new hybrid masonry and steel analysis option that made it

Photo courtesy International Masonry Institute

Structural masonry walls are strengthened with steel reinforcement.

easier to account for the effect of the reinforced masonry infill and the steel frame, treating both as structural elements that work hand-in-hand as an economical and efficient structural system that also provides redundancy.

The development work has resulted in a program that is finite-element-based but nevertheless works in a fairly intuitive manner. This way, engineers not well versed in finite element method (FEM) analysis can still be able to follow the procedure.

First, the steel frame structure is modeled (Figure 1, page 77); once that geometry is set, the masonry infill walls are identified (Figure 2). Openings within the masonry walls can be included and may be different for each infill panel. There are also options allowing the user to define the type of interaction between the steel frame and the masonry infill—axial, in-plane, and out-of-plane load transfer.

The model is then ready for analysis with multiple options for load cases, output, 2- or 3-D analyses (Figure 3), and more. The program report provides complete information on the steel and masonry, including the prescriptive reinforcement requirements for the latter (Figure 4, page 80). The program will make it easier for structural engineers to design these 'hybrid' masonry and steel structures and enjoy the resulting economies.

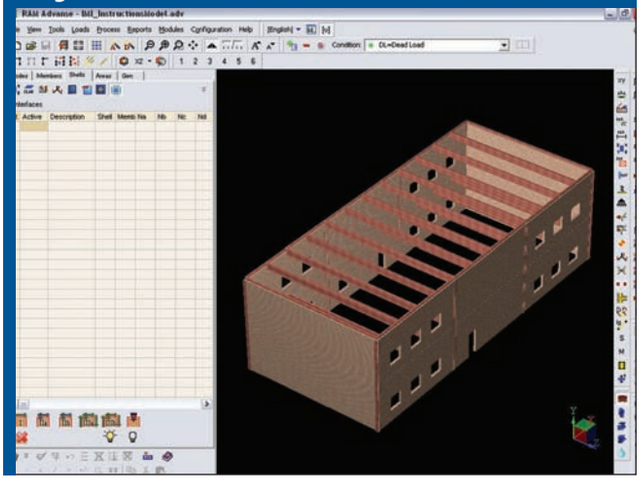
History of masonry and steel

The hybrid concept is the latest step in a long path traveled together by masonry and steel. From the Roman Colosseum and the Cathedral of Notre Dame to the Old State House in Philadelphia and modern applications, masonrywork has evolved. Earlier structures were designed and built with thick masonry walls without additional reinforcing steel or structural steel frames. These walls functioned as bearing systems and were the primary means of load transfer; their thickness provided ample mass to stabilize against lateral forces.

In the 1800s, iron hangers threaded through brick were early attempts at ductility. 'Thru-building' bolts at floor joist level might have been used to prevent buildings from bowing under axial loads. By the late 19th century, steel straps, ties, and anchors were employed in place of iron. The combination of masonry and steel was born.

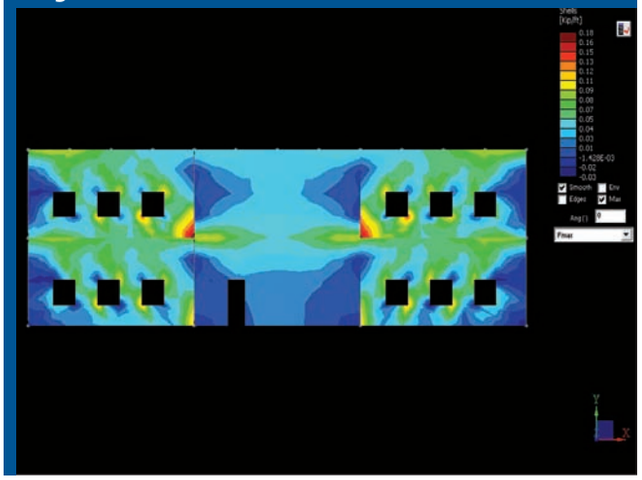
Around this time, frame construction debuted in the U.S. commercial industry. Structural frames were encased with structural clay tile masonry for wall infill and fireproofing.

Figure 2



Once geometry is set, masonry infill walls are added.

Figure 3



Visual results as output shown in 2-D for analysis.

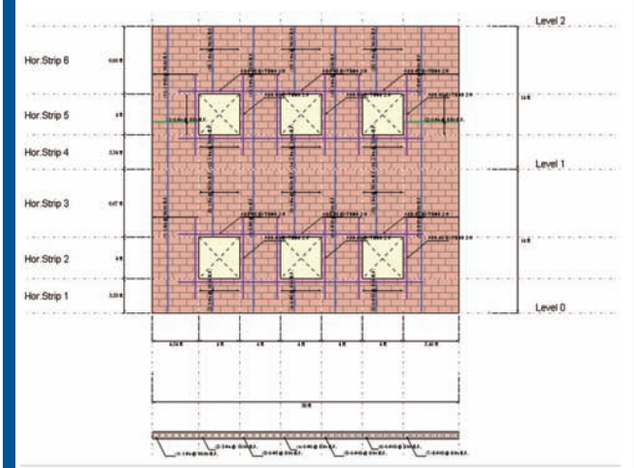
These building frames were generally designed only for gravity loads, while the clay masonry provided redundancy for lateral load support.

Prior to the 1890s, most major buildings used load-bearing masonry walls for multi-story construction. These walls were thick at ground level, and gradually thinned as additional floors were added. During the early 1900s, concrete masonry units (CMUs) were introduced. Along with clay units such as brick and structural tile, CMUs became a popular choice for foundations, bearing walls, and partitions, as well as infill in frame buildings. Unreinforced masonry continued to be the structural system of choice for many design professionals, particularly in low- to moderate-rise structures.

A defining moment in the history of masonry and steel construction was the Long Beach, California, earthquake of 1933. This seismic event, with an estimated 6.25 Ms, caused significant damage in many masonry buildings constructed with unreinforced walls. Engineered buildings and reinforced concrete structures, on the other hand, performed well under these conditions and sustained little damage. One conclusion drawn from studies of the building failures was the unreinforced masonry structures of the day were not built to resist the lateral forces imposed by earthquakes.[3]

However, since the reinforced concrete structures generally performed well, the masonry industry embarked on a path to study steel reinforced masonry structures. This effort produced significant advances in design and construction procedures to ensure reinforced masonry structures could compete as ductile structural systems capable of resisting

Figure 4



Output showing both calculated and prescriptive reinforcements.

gravity and lateral forces dictated by updated building codes and nature. This path has continued, resulting in modern reinforced masonry buildings with demonstrated excellence in seismic resistance.

As the 20th century continued, the design of framed construction advanced and options other than masonry infill walls were developed and heavily marketed. When used in framed construction, brick and CMUs started to take on non-structural roles, becoming part of a non-structural backup system or simply used as veneer.

The most common masonry backup replacement of the late 20th century was the brick veneer/steel stud system. Light-gage steel studs replaced the more typical concrete masonry as backing for the brick veneer. Initially touted as a low-cost, high R-value, substitution for masonry backup, the initial pairing of masonry and steel studs was less than ideal.

The first stud design guidelines did not account for the stiffness of the masonry veneer, resulting in stud deflections incompatible with the masonry. At times, that led to significant cracking, leaks, and, in extreme cases, premature

Further Education

Over the next few months, a seminar series from the International Masonry Institute (IMI) and the National Concrete Masonry Association (NCMA) will educate engineers on the new structural software system to design reinforced masonry infill and the structural steel frame as an integral system. For more, visit www.imiweb.org or www.ncma.org.

Additional Information

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Abstract

Masonry and steel have enjoyed a long-term relationship since the late 19th century when steel straps, ties, and anchors were threaded through brick to prevent buildings from bowing under loads. The duo has evolved since then, presenting various combinations of masonry and steel in building construction. Masonry infill with structural steel frame construction is an option, one in which masonry plays a structural role. With the release of new software for designing such 'hybrid' masonry and steel structures, this partnership has a future of structural solutions.

deterioration of the thin-gage corrugated metal ties attaching the veneer to the stud backup.

Fortunately, those early failures paved the way for further improvement. Current published guidelines limit stud deflection, and recommend heavier gage studs plus tie systems with increased redundancy over the first-used corrugated metal ties. Additional study of thermal performance also resulted in adjusted R-values for the system as reflected in building codes and other standards such as American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) 90.1, *Energy Efficient Design of New Buildings Except Low-rise Residential Buildings.*

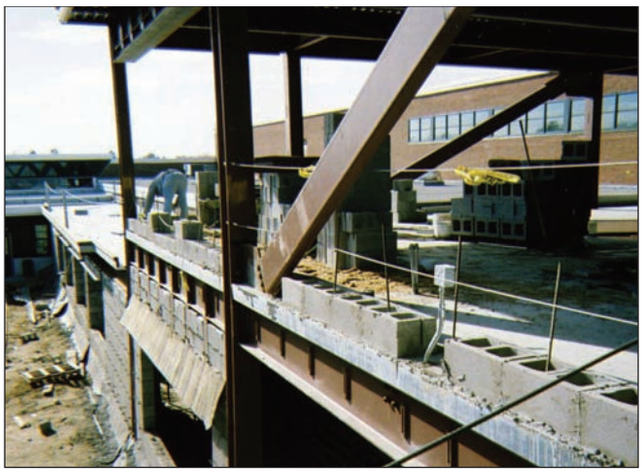

Photo courtesy Ryan-Biggs Associates, Inc.

Installation difficulties arise when steel cross bracing and masonry infill backup are used in the same bay. Hybrid masonry structures eliminate the need for the steel cross bracing and rely on the masonry to provide lateral resistance for the structure.

The partnership continues to evolve

Knowledge of masonry products and systems has improved immensely over time. Reinforced masonry structures can be constructed that compete with frame systems in terms of structural integrity and cost, partly due to the flexibility reinforced masonry offers. New techniques for grouting steel reinforcement in masonry, including greater pour and lift heights and new grout materials (*e.g.* self-consolidating products) continue to make such systems more economical and speed construction.

Creative designers have many options, including pre-stressed masonry with steel prestressing strands, and prefabricated masonry panels that can be hung on steel frames. The forthcoming hybrid masonry and steel structural software promises even more creative opportunities.

The tried and true system of reinforced masonry continues to be a construction workhorse but is not the only blending of steel and masonry. From the almost overlooked world of anchors, ties, and connectors, to the exciting new hybrid system, masonry and steel's partnership promises to provide the construction community with a variety of structural solutions far into the future.

Notes

[1] The code is also known as The Masonry Society (TMS) 402/American Concrete Institute (ACI) 530/American Society of Civil Engineers (ASCE) 5 (*i.e.* TMS 402/ACI 530/ASCE 5).

[2] See David Biggs' "Hybrid Masonry Structures," *Proceedings of Tenth North American Masonry Conference*, St. Louis, Missouri, The Masonry Society (2007). For more on Biggs' masonry work, see his article, "Brick Nogging—Historical investigation and contemporary repair," in the April 2006 issue of *The Construction Specifier.*

[3] See Susan Fatemi and Charles James', "The Long Beach Earthquake of 1933," National Information Service for Earthquake Engineering (NISEE) at University of California, Berkley. Visit nisee.berkeley.edu/long_beach/long_beach.html.