FILLING IN THE FRAME It's Time for Masonry Again!

New software makes structural masonry wall system engineering and design quick, simple and cost effective

BY DAVID T BIGGS, PE

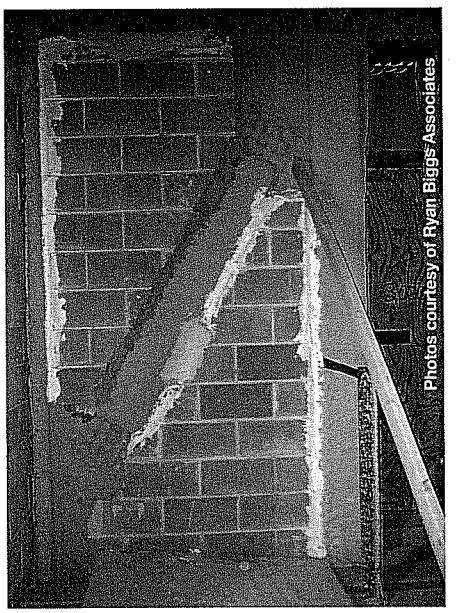
As an architect or engineer, have you ever had to detail a masonry wall to fit around steel bracing? As a contractor, have you ever had to cut the wall reinforcement to fit the concrete masonry units (CMU) around that structural steel? It's not pretty! Even more difficult can be determining if the actual construction meets the intent of the design and building code standards.

Photograph 1 shows a wall from a project where 8" CMU were cut and fit around diagonal bracing within a steel-framed building. In the lower triangular panel, the CMU is sitting on the floor slab. Joints at the underside of the diagonal brace and at the column on the right are soft joints, which allow steel movement without bearing on the CMU. These joints are filled with fire-safing insulation. There is one retainer clip visible on the underside of the diagonal that braces the wall section. The clip and the steel are covered with sprayed-on fireproofing.

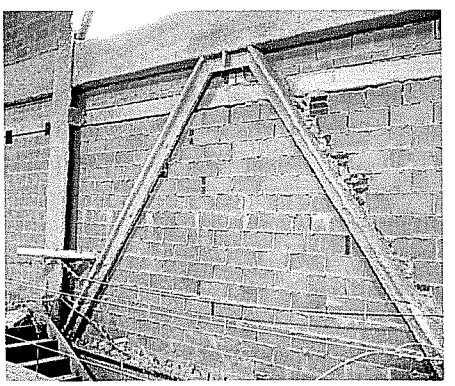
The upper CMU panel in Photograph 1 bears on and is anchored to the diagonal brace. The top and side of the CMU panel again have soft joints, and there is another retainer clip at the top of this panel. Imagine what happens to the reinforcement! Are these wall panels adequately installed and braced? The designer's intent was to isolate the masonry such that it rides with the framing but is not stressed by the movement of the structure. Making the system fire rated is difficult.

Photograph 2 shows another brace at an exterior wall as viewed from the interior. CMU is built around steel bracing without isolation. Clay units were used to infill some of the cut areas. This is an example of a common detailing mistake often created by the separation of design responsibility and lack of coordination. The architect detailed the exterior wall, but the engineer's steel design did not account for the masonry being built tight. The system will survive until the bracing is forced into service. Then, masonry will become a redundant system and act as hybrid masonry or it will crack.

For both of the examples shown, wouldn't it be more efficient if the CMU could provide the entire lateral strength and stiffness and there were no steel bracing to create interference?



Photograph 1. Masonry infill. What's wrong with this picture?



Photograph 2. Masonry infill. Common detailing mistake due to lack of coordinating.

Evolution of framed construction

Historically, the development of framed construction in the United States can be traced back to the late 1890s. Those structural frames were first encased with masonry for fireproofing and the exterior walls were also infilled with masonry. In addition, partitions in commercial buildings were generally masonry. It was common to design building frames for only gravity loads. The massive amount of masonry on the interior and the exterior provided lateral strength and stiffness to the frames as well as a very redundant system.

During the 1940s, as the design of framed construction advanced, exterior wall systems changed. Lighter and less durable wall systems were introduced as a masonry substitute. When masonry was used, designers began to isolate it from the frame to the point where it started to take on a nonstructural role. Overall, the redundant stiffness of framed structures decreased.

More recently, masonry cavity walls

CONTINUING EDUCATION AIA

Learning Objectives

After reading this article, you should:

1. Understand what hybrid masonry means.
2. Understand how hybrid masonry can be used as wall bracing to provide redundancy and transfer axial and shear loads.
3. Expect masonry engineering benefits from forthcoming RAM Advanse software.

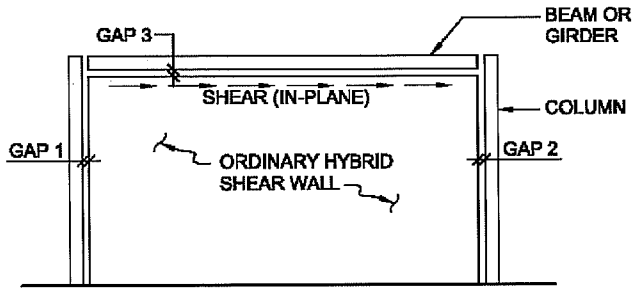
See insert for test and answer form.

Shear Wall Type	R	Ω_0	C_d
Ordinary Reinforced	3	2.5	2.25
Intermediate Reinforced	4	2.5	2.5
Special Reinforced	5.5	2.5	4

Table 1. Factors based upon shear wall type used with building frames

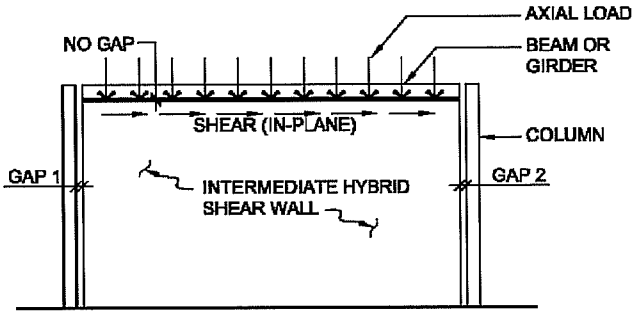
Masonry System	Axial Load	Shear at Beam/Girder	Shear at Column
Ordinary Hybrid Shear Wall	No	Yes	No
Intermediate Hybrid Shear Wall	Yes	Yes	No
Special Hybrid Shear Wall	Yes	Yes	Yes

Table 2. Masonry wall systems based upon performance



GAPS 1, 2: NO IN-PLANE LOAD TRANSFER (SOFT JOINTS)
GAP 3: TRANSFERS IN-PLANE SHEAR LOAD; NO AXIAL LOAD

Figure 1. Ordinary hybrid shear wall



GAPS 1, 2: NO IN-PLANE LOAD TRANSFER (SOFT JOINTS)
BEAM/GIRDER TRANSFERS IN-PLANE SHEAR LOAD AND AXIAL LOAD

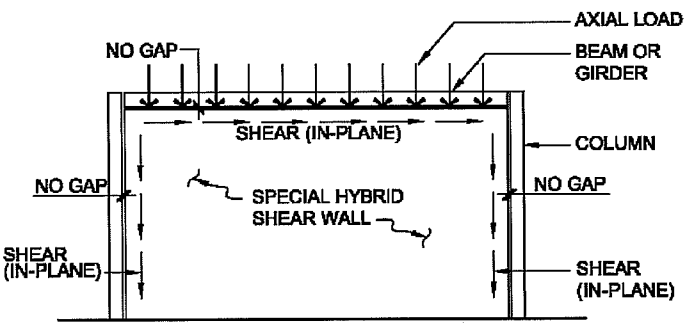
Figure 2. Intermediate hybrid shear wall

have been the standard wall system of choice. While it was first found in ancient Greek and Roman construction, the British are credited with reinventing the cavity wall in the early 19th century. The system did not appear in the United States until the late 19th century. Exterior masonry walls now primarily act as a veneer, and the structural backup supports the interior finish and provides fire protection for the frame. Initially, masonry backup was unreinforced, but now it is generally partially reinforced to accommodate wind or seismic loads.

Along with the advent of cavity walls, relief angles were added. While the backup was supported directly by the floor structure, the veneer was supported by the frame using relief angles which allowed the veneer to accommodate frame movement. This was to isolate the masonry to prevent distress in the veneer.

So where does that leave masonry now? Generally, buildings have steel frames designed by structural engineers and wall systems detailed by architects. Based upon this separation of design responsibility, there are numerous examples of conflicts on projects where the wall bracing interferes with the masonry backup. There are detailing challenges to provide soft joints so that the building frame does not bear on the masonry and cause distress.

"Wouldn't it be more efficient if the CMU could provide the entire lateral strength and stiffness and there were no steel bracing to create interference?"



NO GAPS AT COLUMNS. COLUMN TRANSFERS IN-PLANE SHEAR LOAD
BEAM/GIRDER TRANSFERS IN-PLANE SHEAR LOAD AND AXIAL LOAD

Figure 3. Special hybrid shear wall

The future with hybrid masonry

What does the future hold? A return to the original concept of framed structures and infill the exterior walls with masonry is one option. Rather than just infilling masonry, this generation of buildings can be designed so that masonry is an integral part of the structure. Infill can be designed and detailed to provide both in-plane lateral stiffness and out-of-plane strength for exterior walls. This new generation of structural masonry is termed *hybrid masonry*. While hybrid masonry systems can be applied to either concrete or steel-framed structures, the emphasis is being directed to steel frames.

The concept of hybrid masonry has been included in the International Building Code (IBC) since its inception. The 2003 IBC has factors for R (response modification coefficient), Ω_0 (system over-strength factor), and C_d (deflection amplification factor) applicable to building frames with infilled masonry walls. Factors vary based upon the type of shear walls used with the frame. These factors are given in Table 1.

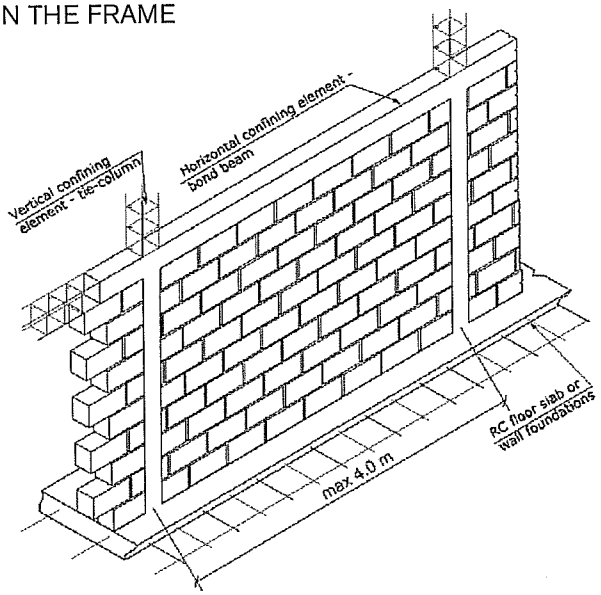


Figure 4. Masonry for high velocity hurricane zone

Ordinary reinforced shear walls are only permitted in Seismic Design Categories (SDC) A, B and C. Building height is unlimited for SDC A and B and limited to 160′ (48.8 m) for SDC C.

Intermediate reinforced shear walls are also only permitted in SDC A, B and C. Building height is unlimited.

Special reinforced shear walls are permitted in all seismic design categories. Building height is unlimited for SDC A, B and C; limited to 160′ (48.8 m) for SDC D and E; and limited to 100′ (30.5 m) for SDC F.

Masonry design is based upon the Masonry Standard Joint Committee (MSJC) standard (ACI 530/ASCE 5/TMS 402) for reinforced masonry using allowable stress design. The analysis results in a linear elastic design. As strength design procedures gain acceptance, load factor design with nonlinear elastic evaluation of the masonry will be possible.

Infill walls as we have known them have not transferred axial load or shear. They only supported out-of-plane forces. Hybrid masonry participates with the steel frame.

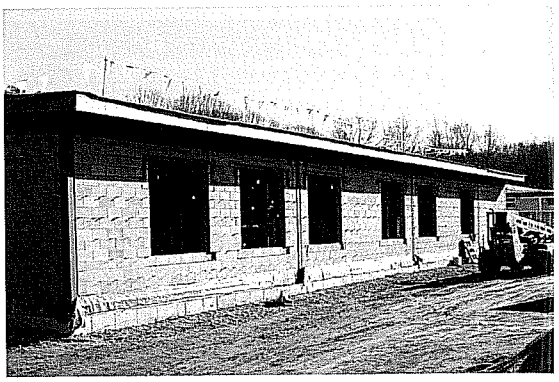
Hybrid walls are defined by how the masonry is connected to the frame and thus how masonry performs in the system. Walls have the ability to potentially transfer axial loads from the beam/girder of the frame as well as transfer shear from the beam/girder or the columns. Wall systems are defined in Table 2. All wall systems listed address backup for cavity wall construction. If a veneer is used, it is constructed with relief angles and is isolated for differential movement as with conventional cavity wall construction.

Remember, infill walls as we have known them have not transferred axial load or shear. They only supported out-of-plane forces. Hybrid masonry participates with the steel frame.

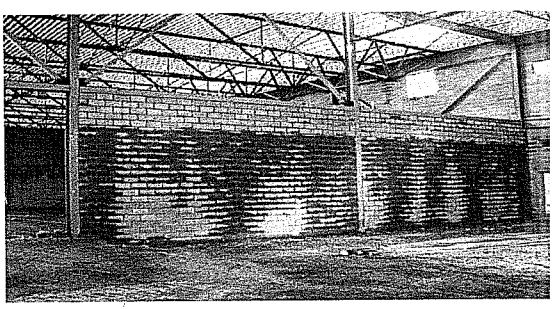
Figures 1, 2 and 3 graphically show the three hybrid masonry walls. Gaps noted are often referred to as soft joints. Where there is no gap indicated, soft joints are eliminated.

For each type of hybrid wall, the designer has the option of using ordinary reinforced, intermediate reinforced or special reinforced masonry. That selection will affect detailing the masonry and the R, Ω_o, and C_d factors.

Currently, MSJC covers the design of ordinary hybrid and intermediate hybrid walls. However, there are no current standards in the United States that govern the design of special hybrid walls. The closest thing to code standards for special hybrid walls in the US is found in the building codes of various states with high-wind concerns. For example, Florida's building code has a structural system for high-velocity hurricane zones which confines masonry between concrete columns and tie beams (Figure 4). System detailing is highly prescriptive and size limitations are restrictive.



Photograph 3. Ordinary hybrid wall



Photograph 4. Intermediate hybrid wall

Photograph 5. Completed building with hybrid walls

If IBC has criteria for designing hybrid masonry and MSJC governs masonry design, why don't engineers use hybrid masonry for bracing buildings?

They are being used, but by too few engineers and architects. Photographs 3 and 4 show two examples where hybrid

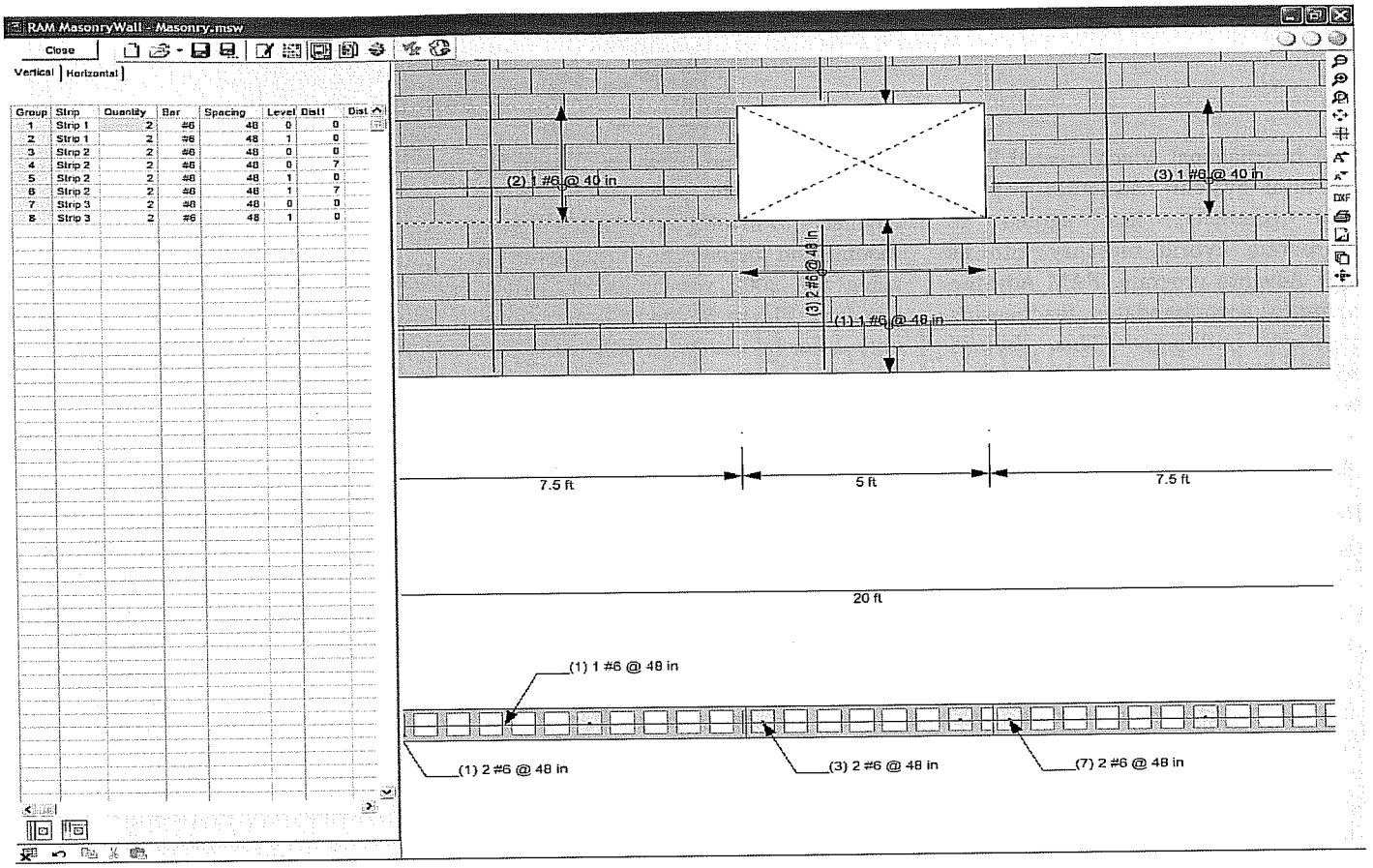


Figure 5. Sample masonry module output

walls have been used in buildings as bracing for steel frames, both exterior and interior. Photograph 3 is an exterior view taken prior to installation of the insulation, air barrier and veneer. Photograph 4 shows interior walls under construction that will be used as bracing. Photograph 5 shows a building with hybrid walls with the veneer of exterior walls completed.

Numerous Advantages to Using Hybrid Masonry

ECONOMICS, DESIGN AND CONSTRUCTION SIMPLICITY, SCHEDULE ENHANCING

There are several reasons for advancing the development of hybrid masonry systems. The primary reason is based upon the constant search for finding means to make construction more economical and efficient.

Hybrid combines the strength of masonry with steel-framed structures, thereby simplifying the construction of masonry within framed buildings to avoid conflict with steel bracing. That simplification reduces construction conflicts and construction costs.

Further economy can also be derived by using intermediate hybrid or special hybrid walls to support some of the axial load. This can reduce the size of some of the structural steel framing and foundations while enhancing construction scheduling.

STRUCTURAL REDUNDANCY LIMITS PROGRESSIVE COLLAPSE

The second reason is to develop a system that could provide structural redundancy which can be utilized to limit progressive collapse. Although not necessary for all buildings, providing resistance to progressive collapse is becoming an important feature for public and private buildings.

In the public sector, the Unified Facilities Criteria of the Department of Defense has criteria for steel-framed buildings and separate criteria for loadbearing masonry buildings for limiting progressive collapse. Using hybrid masonry creates an alternative load path for gravity loads that provide redundancy. The resulting system can be more efficient than either a frame or a bearing wall system alone when subjected to progressive collapse design conditions. If a column is damaged in a hybrid masonry frame, gravity loads are transferred to the masonry. If the masonry is damaged, the gravity load transfers to the frame.

SOFTWARE REDUCES ANALYSIS, DESIGN AND CALCULATION TIME

The third reason involves analytical techniques available to structural engineers. Most framed structures are analyzed and designed using computer software. However, incorporating hybrid masonry takes extra effort, which usually involves significant hand calculations. Therefore, few engineers take advantage of myriad benefits of hybrid wall systems. Recognizing that the extra effort is a disincentive to many engineers for using masonry as bracing, the masonry industry, initiated by the Masonry Institute of Michigan (MIM) and led by the International Masonry Institute (IMI) and the National Concrete Masonry Association (NCMA), has embarked upon a major effort to modify computer software for steel-framed structures using hybrid masonry. Bentley Systems, Inc., the parent company of

RAM International which created RAM Structural System and other popular RAM products, has agreed to incorporate hybrid masonry into its RAM Advanse program. RAM Advanse currently accommodates loadbearing masonry buildings. This hybrid modification will provide further masonry options for designers.

Alternative designs can be evaluated using various bracing options to achieve efficiency and economy of both framing and masonry.

Once engineers have tools such as RAM Advanse to incorporate hybrid masonry, the designer of a steel frame will have many more options for bracing: steel braces, moment frames, hybrid masonry or a combination of these. Alternative designs can be evaluated using various bracing options to achieve efficiency and economy of both framing and masonry. The RAM Advanse program will further allow engineers to invoke the masonry design module and prepare the masonry design using the 2002 version of the MSJC standard. Figure 5 shows the graphical output for a masonry wall using the RAM Advanse masonry module. Other output screens provide calculations and interaction diagrams for in-plane and out-of-plane loadings.

While all loadings can be input into the RAM Advanse module, they can also be generated using RAM Structural System and RAM Frame. The generated loadings can be imported into RAM Advanse. Most engineers will recognize there can be significant time savings achieved by generating loadings rather than using hand calculations.

The masonry module is already available within RAM Advanse. The hybrid masonry feature is expected to be released in 2008.

The state of masonry software design and the future of hybrid masonry are definitely changing!

For more information, see *Hybrid Masonry Structures* in the 10th North American Masonry Conference Proceedings dated June 2007 and distributed by The Masonry Society (www.masonrysociety.org).

The author acknowledges the encouragement and support of Dan Zechmeister, PE, executive director of the MIM.

David T. Biggs, PE, is a principal with Ryan-Biggs Associates, structural engineering firm in New York and Pennsylvania. He specializes in the design, evaluation and restoration of masonry structures, forensic engineering and the development of new masonry products. He is an honorary member of ASCE and serves as a consultant to the masonry industry for software development. 518-272-6266 x 323 dbiggs@ryanbiggs.com