

STRUCTURAL MASONRY

Done Right



By Diane B. Throop, PE, FASTM, FTMS

There is little debate over masonry's beauty; its warmth, variety, and handcrafted appeal have never gone out of style. However, beyond its good looks, this type of wall assembly has long been a staple in the structural building market.

Depending on the building's configuration and function, masonry can be the primary structural system (load-bearing achieved with bearing and shear walls) or integrated with a steel or reinforced concrete frame in the form of a hybrid masonry and frame system.

With the recent introduction of several commercially available whole-building, finite-element, structural engineering software programs that rapidly analyze load-bearing and hybrid buildings,¹ structural masonry is more viable than ever, even in complex configurations. Consequently, designers and specifiers need to ensure project documents include both architectural and engineering requirements for masonry.

A GOOD PLACE TO START

There are many resources for guidance on structural masonry, but two good starting points for any project are the *Building*

Code Requirements for Masonry Structures (i.e., TMS 402-08/ACI 530-08/ASCE 5-08) and the *Specification for Masonry Structures* (i.e., TMS 602-08/ACI 530.1-08/ASCE 6-08).² These documents are known collectively in the industry as the *Masonry Standards Joint Committee (MSJC) Code and Specification*. These editions are incorporated by reference into the 2009 International Building Code (IBC).

In addition to building codes, there are many ASTM standards for masonry, with more than 75 under the jurisdiction of the ASTM masonry committees—C12, *Mortars and Grouts for Unit Masonry*; and C15, *Manufactured Masonry Units*—and additional new ones at various stages of development. However, they can be narrowed down to a handful for the basic building blocks of structural masonry.

The following tips may help in designing and specifying structural masonry, although they may not be applicable for all projects. (These tips are also not intended to be inclusive of all items needed to design or specify masonry.)

Tip 1: Use the MSJC Checklists

While designers and specifiers must be familiar with both the *MSJC Code and*

Specification, two tools within these documents often go unnoticed: the MSJC checklists. They note items where, in the project specification, the architect/engineer (A/E) must (or may)

- Make choices of alternatives,
- Add provisions, or
- Take exception to the *MSJC Specification*.

Explanatory notes are also included with each entry.

The Mandatory Requirements Checklist contains items that must be included in project specifications. The required compressive strength for structural masonry (f'_m) is one example. The Optional Requirements Checklist, on the other hand, lists items the A/E may wish to include in project documents, such as specifying additional requirements for grout.

Tip 2: For ASD, Consider Using the 2011 MSJC Provisions

The 2011 MSJC Allowable Stress Design (ASD) provisions represent a substantial update over previous editions. There is a harmonization of ASD and Strength Design (SD) shear provisions, an extensive stress recalibration, the removal of the "1/3 stress



Creativity and structural masonry went together well at the International Union of Bricklayers and Allied Craftworkers/International Masonry Institute (BAC/IMI) John J. Flynn International Training Center in Maryland. The building was designed by Stanley Tigerman, FAIA. (Photo courtesy International Masonry Institute.)

increase” option, and more. These provisions are included in the 2012 IBC. Consider using these most current provisions when designing with ASD.

Concrete Masonry Units

Concrete masonry units (CMUs) are a common structural material and an important component of many buildings.

Tip 3: Start With the Correct and Most Current Standard

When designing structural concrete masonry buildings, one should specify ASTM C90-11, *Standard Specification for Load-Bearing Concrete Masonry Units*. As its name suggests, this standard covers load-bearing CMUs, setting minimum requirements for compliance. As with all ASTM standards, the “-11” indicates this is the 2011 edition. (If the edition is not included in the project specification, it defaults to the version referenced in the locally adopted building code—which may or may not have

significant differences.) Current ASTM standards are listed at www.astm.org.

Tip 4: Unit Compressive Strength Is Independent of Unit Density

Speaking from a structural viewpoint, it is worth noting the minimum compressive strength requirements in ASTM C90 are the same for all density classifications. In other words, “lightweight” units are required to meet the same compressive strength requirements as “medium-weight” and “normal-weight” units, and vice versa.

Tip 5: Remember That ASTM C90 Includes Minimum Requirements

Another point of structural interest goes back to the term “minimum requirements.” There is a minimum compressive strength listed in Table 2 of ASTM C90, but there is no maximum compressive strength limit prescribed. This permits the engineer to specify higher strength units than the minimum, which in turn leads to higher design

compressive strengths for the masonry assembly. Of course, the upper bound of unit compressive strength is not unlimited; nevertheless, it is certainly quite practical in most markets to purchase CMUs of higher compressive strength than the ASTM minimum.

Tip 6: Consider Specifying Above the ASTM Minimum for Unit Compressive Strength

Economics, material efficiency, and the potential for thinner walls or less reinforcement make it important for an engineer to know higher strength CMUs can be specified (once local availability is confirmed). Manufacturers often produce units that routinely have higher compressive strengths than the ASTM minimum—if the standard bricks or blocks have higher compressive strength, it makes good sense to use that strength in the design. The project documents must reflect this higher unit strength requirement; material test reports

would verify compliance.

For example, both the IBC and the *MSJC Code and Specification* permit the establishment of masonry assembly compressive strength (f'_m) by either the Prism Test Method or the Unit Strength Method (the latter being the easier, less expensive, and more common option).

With the Unit Strength Method, the engineer uses a table published in the *MSJC Code and Specification* to determine the assembly's compressive strength based on the specified compressive strength of the units and the specified type of mortar. The Prism Test Method requires the project materials be tested per ASTM C1314, *Standard Test Method for Compressive Strength of Masonry Prisms*, to establish the compressive strength of the assembly.

Here is an example based on an actual test report for a typical production unit. The unit's average compressive strength is 3,067 psi (i.e., about 21,146 kPa), which is much higher than the ASTM C90 minimum of 1,900 psi (i.e., about 13,100 kPa).³ Assuming Type S mortar is specified, the 3,067-psi average unit strength is put into the MSJC

Unit Strength Method

Net area compressive strength of concrete masonry units, psi (MPa)		Net area compressive strength of masonry, psi ¹ (MPa)
Type M or S mortar	Type N mortar	
1900 (13.10)	1900 (13.10)	1350 (8.96)
2800 (19.31)	2150 (14.82)	1500 (10.34)
3750 (25.86)	3050 (21.03)	2000 (13.79)
4800 (33.10)	4050 (27.92)	2500 (17.24)
	5250 (36.20)	3000 (20.69)

ASTM C90 Minimum unit strength → 1900 (13.10)

Average unit compressive strength from testing report → 3067

→ 2140 (15.00)

Figure 1 – Unit strength method, from MSJC Specification (TMS 602/ACI 530/ASCE 6).

table and tracked across to the net area compressive strength column to find the compressive strength for the wall is 2,140 psi (i.e., about 16,761 kPa). This should be contrasted with the 1,500 psi (i.e., about 10,342 kPa) that would have resulted if the

1,900 psi minimum unit strength (from ASTM C90) had been assumed (Figure 1).

It is important to remember there is no cost premium for this added structural capacity—these were the standard production units.

The key to our Garden Roof® is our Monolithic Membrane 6125®, a seamless rubberized asphalt membrane with a 45+ year track record for critical waterproofing and roofing applications world-wide.

From concept to completion

American Hydrotech's Garden Roof® Assembly has set the standard by which all other green roofs are measured. Our Total Assembly Warranty provides owners with single source responsibility from the deck up. This is peace of mind that only American Hydrotech can offer.

To learn more about the American Hydrotech Garden Roof Assembly, please call 800.877.6125 or visit us online at www.hydrotechusa.com.

American Hydrotech, Inc. | 303 East Ohio | Chicago, IL 60611 | 800.877.6125 | www.hydrotechusa.com

© 2012 Garden Roof is a registered trademark of American Hydrotech, Inc.



Chicago's Orozco Fine Arts & Sciences Elementary School received strength and beauty from masonry that offers a smart investment. (Photo courtesy International Masonry Institute.)

Masonry Mortar

The mortar specified affects masonry wall assemblies on a structural level. Often thought of more for its role in bonding units than its effect on compressive strength, mortar choice still has significant impact.

Tip 7: Mortar Type Matters

In the example given in Figure 1, Type S mortar was assumed. However, if a Type N mortar were used, the permissible net area compressive strength of the wall would be less—about 2,000 psi (i.e., 13,790 kPa)—instead of the 2,140 psi (i.e., 16,761 kPa) allowed with Type S mortar.

The cost difference between these two mortars is very small (as little as one to three cents per sq. ft. of wall), so with everything else being equal—and assuming compatibility with the other design criteria—the former offers higher compressive strengths for the wall than Type N, essentially for free.

Tip 8: Watch What Is Specified for Field QA for Mortar

The first consideration should be whether field-testing of the mortar is necessary. Many projects do not require mortar

testing, but if it is needed or desired, one should specify ASTM C780, *Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry*.

The ASTM standard offers several test methods. The most applicable quality assurance test for site-mixed mortar is the Mortar Aggregate Test in Annex 4. This provides quick results and information on the mortar proportions—exactly what is needed to verify compliance. While it might be tempting to specify compressive strength testing, this procedure has a long turn-around time and will not provide information on what proportion of each mortar ingredient was in the sampled mortar. Without that data, there is no guidance on what to adjust if the sample tests low in compressive strength.

It is important to remember this is a very short discussion of a complex subject. There are several additional sources for further information on the use of ASTM C780 and ASTM C270, *Standard Specification for Mortar for Unit Masonry*, which leads to Tip 9.

Tip 9: Be Familiar With ASTM C1586

Not one of the more well-known ASTM masonry standards—ASTM C1586, *Standard Guide for Quality Assurance of Mor-*



For the Yale School of Forestry and Environmental Studies' Kroon Hall, high-strength autoclaved aerated concrete (AAC) was chosen for the reinforced backup. (Photo courtesy International Masonry Institute.)

A GREAT OPENING ACT: PRECAST MASONRY LINTELS

The Illinois District Council Training Center (DCTC) in Addison provides training to members of the International Union of Bricklayers and Allied Craftworkers (BAC), along with educational programs for Chicago-area architects, engineers, and builders. Recently, the building underwent a 1,022-m² (11,000-sq.-ft.) addition. While it naturally featured masonry, the engineers still called for steel lintels. The masons, however, decided to try precast masonry lintels.

Right there in the parking lot, DCTC staff created the lintels with concrete block bond beam units, two #5 rebars, and grout. This eliminated the need to worry about differential movement between the steel and concrete masonry over the larger openings (except for small pieces supporting the brick over the openings). That was true even with some openings as large as 6 m (20 ft.) or walls with numerous windows. The concrete masonry lintels also matched the appearance of the rest of the wall—a nice finishing touch to the building's appearance.

It certainly helped that this project had the on-site expertise of professional masons with access to plenty of materials and tools. However, the approach could easily be duplicated, says Robert Arnold, DCTC's director. "There is always downtime on a job; we just worked on these in the parking lot," he explains. "Besides, it's a lot simpler, it does a better job, and it's cheaper."

The experience went so well that they used the lintels for all the interior masonry walls.



*Photos courtesy
International Masonry Institute.*

tars—discusses proper use of ASTM C270 and ASTM C780 for mortars produced in the laboratory and at the construction site. It should be very helpful to designers and users in evaluating project needs for both specifying and testing masonry mortar.

Masonry Grout

Grout and reinforcement enhance the structural capabilities of masonry assemblies, increasing the strength and allowing construction of taller, thinner walls. With grouted, reinforced masonry, structures can be engineered to be suitable for high-wind and seismic zones. Achieving these structural goals, however, depends on careful detailing and proper construction practices in the field.

Tip 10: Specify Grout Strength Appropriately

The minimum grout compressive strength permitted by the *MSJC Code and Specification*, IBC, and ASTM C476, *Standard Specification for Grout for Masonry*, is 2,000 psi (i.e., 14 MPa). For many structures, no change in the mini-

mum strength requirement is needed. However, if higher strengths are desired, a good practice is to specify grout strength approximately equal to the unit strength to produce a structurally compatible wall.

Tip 11: Understand Grout Pours and Lifts

A grout lift is the amount of grout placed in a single, continuous operation. A grout pour, on the other hand, is the entire height of masonry to be grouted before more courses are constructed. A grout pour can consist of one or more lifts placed in succession. Engineers and specifiers may have reason to limit grout pour or lift heights, but it typically is the contractor's decision whether to use pours with cleanouts (i.e., often called "high-lift grouting") or without them (i.e., "low-lift grouting").

Grout pour height is limited by the *MSJC Code and Specification* and is a function of the grout type (i.e., fine or coarse) and space dimensions. Grout lift heights used to be restricted to 5 ft. (1.5 m) unless cleanouts were employed. Starting with the 2005 edition of the *MSJC Code and*

Specification, lifts up to 12 ft., 8 in. (3.9 m) are permitted under the following conditions:

- Masonry has cured for at least four hours,
- Grout has a slump of 10 to 11 in. (254 to 279 mm), and
- No intermediate horizontal reinforced bond beams are between the top and bottom of the pour height.

Tip 12: Give the Mason Contractor Some Latitude

Take advantage of contractor expertise in both technical and constructability considerations. Unless there are engineering considerations that override specific means and methods, giving the mason contractor the latitude to select fine or coarse grout, determine the lift and pour heights, and the use of self-consolidating grout can result in savings in both cost and time.

Masonry Innovations

Innovative ideas, products, and construction techniques are popping up routinely within the masonry industry.

Building Envelope

Technology Symposium 2012



Sheraton Phoenix Downtown | Phoenix, AZ October 22-23

Technical Education for Building Envelope Professionals

The Symposium on Building Envelope Technology is a two-day educational program offering cutting-edge information regarding design, construction, maintenance, and repair of modern and older building envelopes.

The event's open, inclusive environment encourages attendees to ask questions and stimulates dialogue. Speakers offer relevant solutions by referencing real-world examples and specific case histories.

Call For Abstracts

The Building Envelope Committee is soliciting abstracts for 2012 presentations.

Download the Call For Abstracts document.

Submission deadline:
April 30, 2012



www.rci-online.org/symposium.html

RCI, Inc. 800-828-1902

www.rci-online.org/symposium.html

Material options in units, techniques for easier and faster grout installation, and sustainable products are just some of the new options available.

Tip 13: Embrace New Technology by Considering Self-Consolidating Grout

A recent innovation in masonry construction is the development and acceptance of self-consolidating grout (SCG), a highly fluid mixture of cement, water, fine and coarse aggregates, and plasticizing admixtures, which is placed without consolidation.

Like conventional grout, it is used to fill selected spaces in masonry walls and, after it hardens, to transfer loads to embedded reinforcement. Self-consolidating grout can save time, but specifiers and contractors need to understand how its differences affect a project. For example, field proportioning of SCG is prohibited, and a knowledgeable producer must supply the material.

Further, unlike conventional grout, SCG needs neither rodding nor vibration for consolidation. In fact, the requirements in the *MSJC Code and Specification* prohibit con-



This close-up photo shows the corner of a heavily reinforced structural brick masonry wall. (Photo courtesy International Masonry Institute.)

solidation of SCG. Additionally, grout lift height is often permitted to be higher than that for conventional grout.

The testing procedures for SCG are also different than for conventional grout (although the compressive strength test is similar and is included in ASTM C1019, *Standard Test Method for Sampling and Testing Grout*). Slump flow rather than slump cone testing is done, as well as a test for Visual Stability Index (VSI). SCG must have a slump flow of 610 to 762 mm (24 to 30 in.), and a VSI less than or equal to 1. Both of these properties are determined by ASTM C1611, *Standard Test Method for Slump Flow of Self-Consolidating Concrete*. Earlier this year, ASTM included provisions for SCG within ASTM C476; this is the edition that should be specified when self-consolidating grout is permitted on a project.

Tip 14: “Green” Your Grout With Fly Ash

Fly ash is a mineral byproduct of coal combustion that is often used to supplement the portland cement in masonry grout. (Consequently, it can contribute toward points for use of recycled materials under the Leadership in Energy and Environmental Design [LEED®] program.) It may be called for specifically as part of the grout mix or included in blended cement. ASTM C476 permits the use of cement meeting ASTM C595, *Standard Specification for Blended Hydraulic Cements*, which allows 15% to 40% fly ash by weight of portland cement as a cement replacement. This means fly ash can be substituted for port-

WANTED

[PHOTOS OF]

CONSULTANTS AT WORK

RCI is looking for photography of consultants in action:

- On ladders and roofs
- Using technology: IR tools, wind-uplift chambers, computers, etc.
- Performing inspections: roofs, walls, and waterproofing

Selected photos will be used in publication, in advertising, on Web sites, and in e-mails. Photo credit will be given to the photographer or company.

Please submit high-resolution digital photos as well as photographer information and a short caption to wmyers@rci-online.org.




Once submitted, copyright is owned by RCI, Inc. Contact William Myers, director of marketing communications, at 919-389-1088 or wmyers@rci-online.org for more information.

land cement up to these limits per ASTM C476.

Besides adding strength, the fine spherical particles of fly ash enhance the important grout properties of flow and pumpability. Grout containing fly ash generally reaches at least a similar compressive strength as grout with just portland cement. However, most fly ash grout has slower early compressive strength gain. This should be investigated in situations where the early strength of a grouted wall is critical, such as when setting planks or floor joists on newly built masonry or in cold weather.

Tip 15: Consider Structural Brick

The engineering requirements for structural brick masonry are included in the IBC and *MSJC Code and Specification*. While not used as often as CMU, brick can be employed as a structural material. Steel reinforcement is placed either within cells of the brick units or within a grout space formed between two wythes of brick units.

ASTM C652-11, *Standard Specification for Hollow Brick (Hollow Masonry Units*

Made From Clay or Shale), is the most common standard used when steel reinforcement is to be installed within the cells of the units. It offers options for units cored up to 60%. When steel reinforcement is placed and grouted between two brick wythes, any clay brick standard included within the *MSJC Code and Specification* and the IBC can be employed.

Tip 16: Consider AAC Masonry

Autoclaved aerated concrete (AAC) masonry is a lightweight cellular concrete formed by a chemical reaction among lime, portland cement, aluminum powder, aggregate, and water.⁴ Once produced, the large cakes of material are cut into blocks or panels for installation with thin-set mortar. Lightweight and easily cut on site, AAC masonry can be used for the structural support system in most areas of the United States, but it is important to know local requirements.

The *MSJC Code and Specification* and the IBC include provisions for its use. ASTM has several material, installation, and testing standards.

Options for Splicing Steel Reinforcement

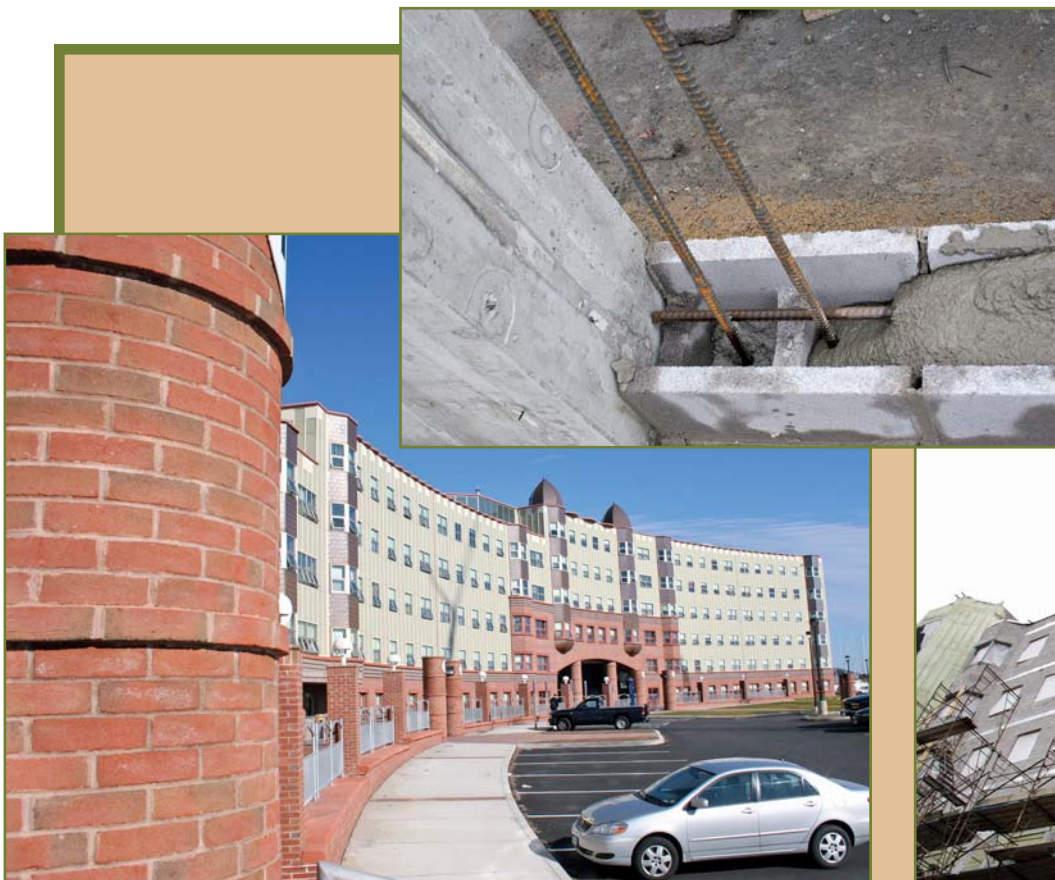
Placed vertically (and possibly horizontally) and firmly embedded in grout, steel reinforcement helps masonry resist seismic forces, wind, and other lateral loads. Where issues of availability or constructability make it impractical to install a single continuous steel bar for the full length that is required, lap splicing provides the needed continuity.

Tip 17: Include Reinforcing Splice Lengths in Project Documents

It is important for designers to consult the applicable requirements and show lap lengths and locations in the project documents. There can be structural implications that influence the lap lengths and locations. Contractors should not assume the responsibility for determining appropriate lap lengths.

Tip 18: Reduce Lap Splice Lengths When Necessary

Lap splice lengths are generally longer for larger-diameter bars, assemblies with



DESIGN
OUTSIDE
THE
BOX

less cover, multiple bars in a cell, and lower-strength masonry units. Options that may reduce lap splice lengths include

- Using smaller-diameter reinforcing bars spaced more closely together,
- Increasing the masonry compressive strength by employing higher-strength units, and
- Minimizing splices needed by utilizing higher grout pours.

Tip 19: Use the 2011 MSJC Splice Provisions

There are two changes in the 2011 MSJC that may help reduce splice lengths. Since the 2011 MSJC Code and Specification is adopted into the 2012 IBC, using these provisions may be easily accepted by reviewing authorities and will offer reduced laps. The two changes are

- The beneficial effect of larger cover for computing development and lap length has been changed from 5 bar diameters (d_b) to 9 d_b for both ASD and SD.
- A new transverse steel option uses

horizontal reinforcement within the splice to reduce the lap in the vertical steel reinforcement.

Tip 20: Consider Other Splicing Options

In addition to lap splicing, the MSJC Code and Specification and the IBC permit reinforcement spliced with mechanical couplers or welding. Typically, the mechanical couplers add some cost to a project but may still be cost-effective if in lieu of long lap lengths. Welding of steel reinforcement is difficult and requires certified welders and weldable bar reinforcement. Therefore, while the code permits this option, it is rarely used.

Tip 21: Think Joint Reinforcement, Not Bond Beams, When Possible


Both joint reinforcement and bond beams can be used in most regions of the country to meet horizontal reinforcement requirements; however, joint reinforcement is a much more cost-effective solution if it meets the structural criteria of the project. Bond beams can provide more steel area

and can also be used in combination with or without joint reinforcement to meet structural and crack control considerations.

Tip 22: Cleanout Options May Lead to Higher Pour Heights

Cleanouts are required for “high-lift” grout installation. Designers need not view cleanouts as an aesthetic reason to limit the use of higher pour heights. The full-face shell does not have to be removed to meet the code-mandated minimum opening of 3 in., and options exist to conceal the cleanout in the finished wall.

BUILDING THE BOTTOM LINE

Finally, structural masonry is environmentally sound. Masonry materials are produced locally and installed by local labor. Their inherent properties provide fire protection, blast resistance, and acoustical control, thereby serving many functions efficiently. Masonry’s durability is proven. For so many reasons, structural masonry is the right choice. 

Load-bearing masonry does not mean boxy design, as this Quinnipiac University project shows. Crescent Residence Hall, a multistory York Hill Campus building in Hamden, Connecticut, ranges from seven to nine stories and encloses 37,190 m² (400,305 sq. ft.). The project uses more than 1 million bricks, 500,000 concrete masonry units (CMUs), and 5,000 pieces of ornamental precast concrete.

The unique design by Centerbrook Architects puts most of the bearing walls on a radius. Using CMU blocks allowed the designers to have the bearing walls conform to the curve they wanted. The structural engineer was Gilsanz Murray Steficek LLP, with mason contracting firm B.W. Dexter II Inc.



Photos courtesy Centerbrook Architects and Planners and IMI.



The Hotchkiss School dormitory (also shown on page 15) demonstrates the versatility of load-bearing CMUs. They support the structure and form the backup for the brick veneer. (Photo courtesy DeStefano Associates.)

The information in this article is an updated version of an article that originally appeared in the October 2009 issue (Volume 62, No. 10) of The Construction Specifier, the official magazine of the Construction Specifications Institute. For more information, visit www.constructionspecifier.com.

FOOTNOTES

1. With Keith Lashway, PE, this author coauthored an article, "Masonry and Steel: An Old Partnership With New Opportunities," which appeared in the August 2008 issue of *The Construction Specifier*. Visit www.constructionspecifier.com and select "Archives."
2. The Masonry Standards Joint Committee is charged with developing and maintaining the *MSJC Code and Specification*. The group is under the sponsorship of The Masonry Society (TMS), the American Concrete Institute (ACI), and the Structural Engineering Institute of the American Society of Civil Engineers (SEI/ASCE).
3. As *MSJC Code and Specification*

uses the U.S. customary system (i.e., "English" units), this article places the approximate metric conversions in parentheses.

4. For more on AAC, see the July 2008 issue of *The Construction Specifier*

for "Designing With Autoclaved Aerated Concrete: New Provisions and Sustainable Properties," by William D. Palmer Jr., PE. Visit www.constructionspecifier.com and select "Archives."

Diane B. Throop, PE, FASTM, FTMS

Diane B. Throop, PE, FASTM, FTMS, is the director of engineering for the International Masonry Institute. She currently serves as chair of the 2013 Masonry Standards Joint Committee (MSJC), the group charged with writing the national masonry code and specification (TMS 402/ASCE 530/ASCE5 and TMS 602/ACI 530.1/ASCE 6). Previously, she served as chair of the 2011 MSJC Committee and chair of the MSJC Construction Requirements Subcommittee during the 2005 and 2008 cycles. She is also a former director of The Masonry Society (TMS). She was named a Fellow of the TMS (FTMS) in 2009. Throop is past chair of ASTM Committee C15 on Manufactured Masonry Units and past chairman of ASTM C12.03 on Specifications for Masonry Mortars. She was cochair of the ASTM Tenth Symposium on Masonry and coeditor of the resulting published volume of papers. Throop was recognized in June 2004 with an Award of Merit from ASTM for her work on the masonry committees. The award is the highest recognition from ASTM and carries the title of Fellow. Throop has a BS in civil engineering and an MA in business administration, both from the University of Toledo. She is a registered professional engineer in both Ohio and Michigan.

