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DESIGN AND CONSTRUCTION WITH **GROUTED REINFORCED MASONRY**

Gain the skills to specify architecturally dynamic, strong, non-combustible masonry structures

By Jennifer G. Prokopy

Air Rescue and Fire Fighting Station at Phoenix Sky Harbor Int'l Airport. *Photo: Courtesy of National Concrete Masonry Association* (For complete photo description, see online material).

CONTINUING EDUCATION AIA

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To take the quiz and earn one AIA/CES Learning Unit (LU), go to www.architectmagazine.com, and click on "Design and Construction With Grouted Reinforced Masonry". You must answer 70% of the questions correctly to receive credit for this course. This course requires online reading in addition to the following article in order to be able to take the quiz. See page ?? for details.

Masonry construction boasts a long tradition of strong, durable, aesthetically flexible design. Through the years, architects have taken advantage of its thermal mass to increase energy efficiency, its acoustical properties to create quiet retreats, and its fire resistance to keep occupants safe. The materials used to craft masonry structures are friendly neither to mold, nor to vandals, and they offer design possibilities from classic to contemporary.

Grouted reinforced masonry offers expanded structural possibilities in masonry design. Used in the U.S. since the mid-1800s, it is most common in single-story and low-rise construction, but can also be employed in high-rise design. The concept is simple: Masonry walls are constructed, horizontal and vertical steel reinforcing bars are placed in some of the cores, and grout is poured in to fill the voids.

Though traditional unreinforced masonry is strong, reinforced masonry walls are even stronger, allowing for the construction of taller, thinner walls. The versatility of the technique allows architects to design masonry structures in every location, even in high-wind and seismic zones. Grouted reinforced masonry can create strong, safe, and beautiful churches, hospitals, hotels, schools, prisons, warehouses, condominiums, and other residences...the possibilities are endless.

CHOOSING AND SPECIFYING MATERIALS

There are several key standard specifications and codes that designers should use to correctly specify components of grouted reinforced masonry, plus a

LEARNING**OBJECTIVES**

By reviewing the content of this article and the supplemental online reading, architects and engineers will gain the skills to specify dynamic, strong, non-combustible masonry structures. Key points include:

- **Learn the benefits and design possibilities of grouted reinforced masonry construction**
- **Possess a greater knowledge of component materials**
- **Gain the skills needed to successfully choose and specify project materials**

number of useful supplementary documents. Each is described in detail in the supplemental online reading material.

Concrete masonry units – In addition to standard sizes and shapes, concrete masonry units (CMUs) are available in a variety of shapes and configurations that accommodate reinforcing steel, and can function as either – or both – structure and skin. These include "A" and "H" shapes; pilaster, lintel, and open core units; and bond beam units with reduced or "knock-out" webs that are removed before placement. Use ASTM C 90 Standard Specification for Loadbearing Concrete Masonry Units to specify CMUs.

Clay masonry units – Clay units can also be made in a variety of shapes and sizes to accommodate reinforcement. ASTM C 652 Standard Specification for Hollow Brick (Hollow Masonry Units Made From Clay or Shale) covers hollow building brick and hollow facing brick made from clay, shale, fire clay, or mixtures thereof, fired in a kiln to form hard units. Like their C 90 counterparts, when reinforced and grouted, clay masonry units can be used for structure, skin, or both.

Mortar – Conventional mortars for masonry are made with cementitious materials, sand, and water, and are specified using ASTM C 270 Specification for Mortar for Unit Masonry. Cementitious materials can include masonry cements, mortar cements, portland cement, blended cements, and lime. Mortars (which can be Type N, S, or M) should be specified using either proportion specifications or property specifications—not both.

Grout – Specification of grout is covered under ASTM C 476 Standard Specification for Grout for Masonry. Grout is a very fluid combination of water, aggregates, portland cement, blended cements (as specified under ASTM C 595 and ASTM C 1157), and sometimes fly ash and admixtures. Depending on the size of aggregates used, grout is classified as either fine (using only fine aggregates) or coarse (using a combination of both fine and coarse aggregates). Selection is based on the size of the space to be grouted.

Grout is specified using either proportion specifications or strength requirements. When using proportion specifications, material volumes should be measured throughout the job to ensure consistency. When using strength requirements, the minimum compressive strength is 2,000 psi (about 14 MPa).

To ensure the proper consistency, grout should be mechanically mixed for at least 5 minutes, and have a slump of between 8 and 11 inches (about 200 to 280 mm).

Admixtures may be used with care, but those with chlorides can cause steel corrosion and are not recommended. Plasticizing admixtures may be used to add fluidity to the grout mix.

Reinforcement – The two key types of reinforcement used in grouted reinforced masonry are deformed steel bars and horizontal joint reinforcement. There are multiple specifications that address steel reinforcement materials; the standard most commonly used is ASTM A 615/A 615M Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement.

For the best success in specifying grouted reinforced masonry, architects should have a working knowledge of pertinent standards and codes, and should familiarize themselves with the appropriate masonry "TEK" design briefs offered at no charge online by the National Concrete Masonry Association (www.ncma.org).

DESIGN AND CONSTRUCTION

Reinforced masonry enables the designer to optimize the properties of masonry (strong in compression) and steel (strong in tension) in combination with one another. Structural engineers who design grouted reinforced masonry use one of two methods: Allowable Stress Design or Strength Design (see sidebar below). Either method is acceptable, and criteria for both are included in the MSJC Code (see online reading material).

Good construction technique starts when materials are delivered to the job site—CMUs, cementitious materials, aggregate stockpiles, and other materials should always be properly stored and protected from the elements. Once construction begins, correct alignment of CMUs is a must to ensure proper placement of reinforcement and good grout flow. When grout pour heights exceed 5 feet (1.5 m), cleanout openings are required so excess material can be removed from cavities to be grouted. Mortar protrusions may need to be removed to avoid interference with grout flow.

When installing vertical reinforcement, bars can be placed before the CMUs, or can be positioned afterward. Horizontal steel is laid in the appropriate course of masonry before additional courses are placed above. Once

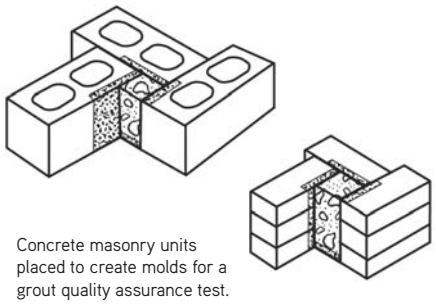
ALLOWABLE STRESS AND STRENGTH DESIGN: ALTERNATE PATHS TO DESIGN SOLUTIONS

Two equally acceptable approaches used for masonry design are Allowable Stress Design and Strength Design. Differences in the two design methodologies include the following:

ALLOWABLE STRESS DESIGN	STRENGTH DESIGN
Use service (actual) loads to determine stress in element	Use factored loads to determine required strength of element
Compare computed stress to an allowable stress	Compare design strength to required strength
Allowable stresses are a fraction of specified strength to provide conservative factors of safety in design	Design strength is nominal strength (actual capacity) reduced by strength reduction factor to ensure acceptable performance

Allowable stress and strength design procedures enable the designer to efficiently design safe masonry structures. While allowable stress has a longer history of use in the design of masonry structures, strength design may be more familiar to some engineers and architects because it is also used in concrete construction. The choice of either design methodology may be based on personal preference, or in some instances, a designer may try both methods and choose the one that results in the most efficient design.

DESIGN AND CONSTRUCTION WITH **GROUTED REINFORCED MASONRY**



Concrete masonry units placed to create molds for a grout quality assurance test.

GROUT QUALITY ASSURANCE

ACI 530-05/ASCE 5-05/TMS 402-05, Building Code Requirements for Masonry Structures (Reported by the Masonry Standards Joint Committee), offers guidance on crafting a solid quality assurance program. There are two kinds of field tests routinely used to evaluate conventional grout: slump and compressive strength. Grout samples should always be taken by a qualified technician, who will ensure the correct amount is collected, transported, and examined according to appropriate standards.

Slump – A slump test determines the consistency, or stiffness, of grout. This test is the same as a conventional concrete slump test, but results should be higher, typically between 8 and 11 inches (about 200 to 280 mm). Follow ASTM C 143, Standard Test Method for Slump of Hydraulic Cement Concrete.

Compressive Strength – In a compressive strength test for grout, 4 concrete masonry units like those used on the job site are placed in a "pinwheel" to form a rectangular mold, in which grout is placed and allowed to set for 24 to 48 hours. A pervious bond breaker is included between the grout and the absorptive masonry units to allow for water absorption and for ease of sample removal. The resulting samples are then tested for strength following ASTM C 1019, Standard Test Method for Sampling and Testing Grout.

reinforcement and units are in place and the mortar has cured for at least 4 hours, grouting can begin, using low-lift or high-lift grouting methods, described below. Following grouting, vertically reinforced cores with grout are called columns, and courses containing horizontal reinforcement are called bond beams.

GROUTING TECHNIQUES

Grout placement is measured in lifts (the amount of grout placed in a single continuous operation) and pours (the entire height of masonry to be grouted prior to the construction of additional masonry). A pour may be one lift, or several successively placed grout lifts.

In low-lift grouting, masonry height is limited to 5 feet (1.5 m) before grout is placed. Hand buckets, pumps, or concrete buckets with spouts can be used to deliver the grout, which must also be consolidated by vibrating or puddling each lift.

High-lift grouting is suited to larger projects; masonry walls are built to story-height (or the full wall height) and then grout is placed. Lifts are limited to a maximum of 12.67 feet (3.86 m) as long as three conditions are met: masonry has cured for at least 4 hours; grout slump is 10 to 11 inches (254 to 279 mm); and there are no reinforced bond beams between the top and bottom of the pour height. Otherwise the lift height can't exceed 5 feet (1.52 m). Alternate grout placement strategies – taller lift heights and other consolidation methods – can be approved through the use of successful demonstration panels. Grout can be transit-mixed and, as in low-lift grouting, delivered quickly through pumps or spouted concrete buckets. Cleanout openings are required at the base of the wall for any vertical core including reinforcement.

Conventional grout must be placed within 90 minutes of introducing water to the mix, but extended set grout—containing admixtures that delay the onset of hydration—can remain in the mixer for longer periods of time, a useful option for out-of-the-way jobsites.

RISING STAR: SELF-CONSOLIDATING GROUT

In recent years, self-consolidating concrete advancements have led to the development of self-consolidating grout (SCG). While conventional grouts contain large amounts of water to provide flowability during placement, SCGs have lower water contents, instead taking advantage of superplasticizing admixtures, called polycarboxylates, to increase workability. SCGs have the same basic ingredients as self-consolidating concretes, but with slightly smaller coarse aggregate size.

Self-consolidating grout (SCG) moves freely in tight spaces, as seen through the clear plastic face on this demonstration panel.

SCGs offer some clear benefits: They provide excellent workability and flowability, filling the tiniest crevices without needing any vibration or consolidation. Smaller crews can place the material faster than conventional grout, saving time and allowing workers to focus on other tasks.

When working with SCGs, it is important to quantify both fresh and hardened properties. Instead of an in-field slump test, ready-mix producers will perform a slump flow (or spread) test before sending the material to the site; spread should be 22 to 30 inches (about 560 to 760 mm). Also, the mix must demonstrate that it is cohesive and free from segregation. Compressive strength testing on the mix should also be performed, with a minimum of 2,000 psi (about 14 MPa) at 28 days.

The following quiz includes questions derived from online material not included in this printed article. You are required to read the additional online material in order to take the quiz and complete this continuing education unit. Please go to www.architectmagazine.com, click on "Design and Construction With Grouted Reinforced Masonry" for the additional information.

TEST QUESTIONS

1. When using self-consolidating grout, which test results are desirable?
a. Slump flow (or spread) of 22 to 30 inches (about 560 to 760 mm)
b. Slump of 8 to 11 inches (about 200 to 280 mm)
c. Compressive strength of at least 1,000 psi (7 MPa) at 28 days
d. Slump flow (or spread) of 8 to 11 inches (about 200 to 280 mm)

2. Grouted reinforced masonry walls can be:
a. Stronger than traditional masonry walls
b. Designed for high wind and seismic zones
c. Taller and thinner than unreinforced masonry
d. All of the above

3. Which of these statements is true?
a. In traditional high-lift grouting, speed of placement is slower than in low-lift grouting
b. When using self-consolidating grout, larger crews are needed
c. Consolidation is required when using traditional low-lift grouting
d. Extended set grouts are best suited to small volume grouting jobs

4. Allowable stress design uses:
a. Service (actual loads)
b. Specified compressive strength of masonry
c. Comparison of computed stress to an allowable stress
d. All of the above

5. In ASTM C 476 Standard Specification for Grout for Masonry, grout is classified as:
a. Fine (containing mostly fine aggregates) or coarse (containing mostly coarse aggregates)
b. Fine (containing only fine aggregates) or coarse (containing both fine and coarse aggregates)
c. Fine (containing only fine aggregates) or coarse (containing only coarse aggregates)
d. None of the above

6. Cleanout openings are required when:
a. Self-consolidating grout is used
b. On every grouting job
c. When grout pour heights exceed 5 feet (1.5 m)
d. Only when performing low-lift grouting

7. Which is true of concrete masonry units used in grouted reinforced masonry?
a. They are available in a variety of shapes and sizes, and some styles have reduced or "knock-out" webs
b. Many styles come in "I" and "F" shapes
c. Pilaster, lintel, and open core shapes are available
d. Both a and c are correct

8. ACI 530-05/ASCE 5-05/TMS 402-05 is a:
a. Building code requirement examining masonry design and construction
b. Essential document for designers specifying masonry construction
c. Both
d. Neither

9. Grout:
a. Is specified using either proportion specifications or strength requirements
b. Can include any type of admixture, including those containing chlorides
c. Is specified using both proportion specifications and strength requirements
d. Should never include admixtures, all of which can cause corrosion

10. Which statement is true?
a. ASTM C 595 examines only performance of blended hydraulic cements
b. ASTM A 615 is the only standard used to specify steel reinforcement for concrete
c. Neither are true
d. Both are true

Design and Construction with Grouted Reinforced Masonry
Successful completion of this test (a score of 70% or higher) will earn 1 AIA/CES LU hour of health, safety, and welfare. Non-members will receive a certificate of completion upon request.

To take the test, go to www.architectmagazine.com and click on "Design and Construction with Grouted Reinforced Masonry" to download a PDF of this unit, supplemental information and register to take the test online.

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Since its founding in 1916, the Portland Cement Association has had the same mission: "Improve and expand the uses of portland cement and concrete." Where cement and concrete are concerned, so is the Portland Cement Association: in manufacturing, in raising the quality of construction, in improving our product and its uses, in contributing to a better environment. In practice, this mandate means well-rounded programs of market development, education, research, technical services, and government affairs on behalf of PCA members-cement companies in the United States and Canada.