NOTES ON THE SELECTION, DESIGN AND CONSTRUCTION OF

REINFORCED HOLLOW CLAY MASONRY

WESTERN STATES CLAY
PRODUCTS ASSOCIATION

Acknowledgements

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Introduction

Reinforced Hollow Clay Masonry (RHCM), also known as "Structural Clay Brick" and "Reinforced Structural Clay Units," offers the building owner many advantages. Unfortunately, the structural engineer often overlooks these advantages. When the structural engineer offers the client alternative structural systems, steel, concrete, concrete masonry, brick veneer, concrete masonry, and wood are usually considered, but reinforced hollow brick masonry is often not.

Most structural engineers are familiar with steel, concrete, wood, and concrete masonry design. RHCM design is similar to concrete masonry design, but there are important differences.

Knowledge of RHCM structural design provides the structural engineer with a meaningful design niche.

Recognizing this lack of knowledge, the Western States Clay Products Association (WSCPA) agreed to produce this RHCM publication specifically for the structural engineer. The first edition was published in 1995, followed by a revision in 1997. This is the third edition.

The document emphasizes the information required to successfully complete a RHCM project, the first being to convince the owner, architect, and sometimes the contractor to consider the RHCM option.

The document begins with example projects followed by helpful information during the traditional project phases: Schematic Design, Design Development, Construction Documents, and Construction.

Cost is always a factor. Suggesting RHCM will usually result in the client saying: "How much does it cost?" Costs are difficult to predict. Here is one example. For the brick wall below* costs was developed by a general contractor and a mason contractor in the Pacific Northwest in August 2022.

Two options were considered; a brick veneer on steel studs and RHCM. The brick veneer required an 8-inch structural stud backing, while the RHCM required only interior partition (furring) studs. The brick veneer option costs $59.10 per square foot, and the RHCM option costs $57.33 per square foot.

This cost study only included the wall. Additional savings exist if the RHCM wall supports the roof and provides lateral resistance.

Analogous to unreinforced concrete, unreinforced brick masonry is not cost-effective. Adding reinforcement reduces cost. The purpose of this document is to provide the structural engineer with the knowledge to utilize the RHCM design niche.

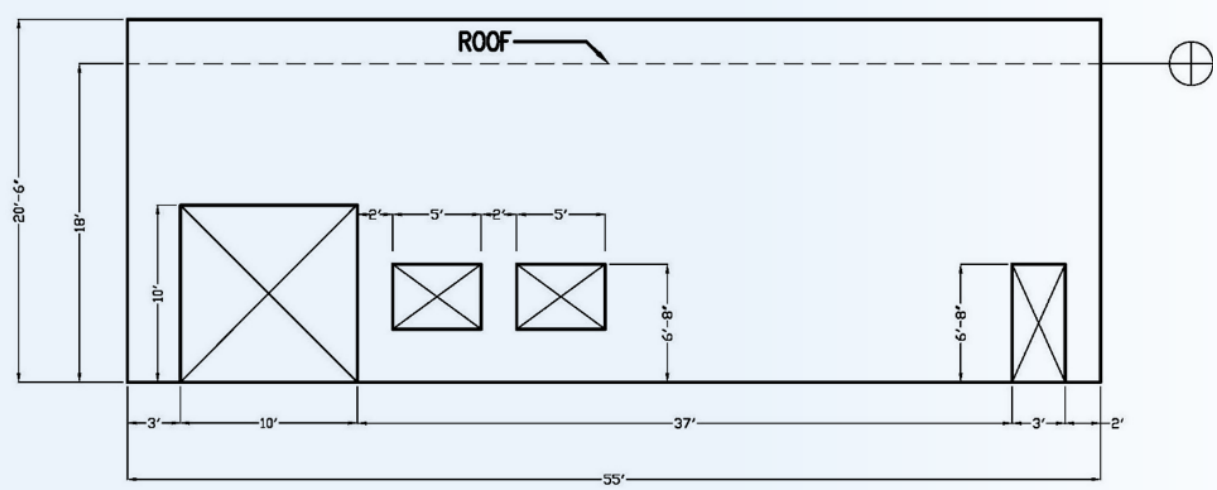


**Figure 1* Cost Comparison - Brick Veneer on Metal Studs versus Reinforced Hollow Clay Masonry

What is RHCM?

The most common shapes of hollow clay units (sometimes referred to as structural clay units) are shown below. There are many shapes and sizes available. Custom shapes may be designed, fabricated, and installed on larger, more geometrically complex projects.

Hollow clay units are produced by extruding a mixture of various clays that determine color, strength, water absorption, and saturation coefficient. Different clays are combined to a fine powder, water is added, and the mixture is extruded through a steel die. The extruded column of clay is then sliced perpendicular to the extruded column at the desired unit height. The units are then placed on carts and generally fired to temperatures above 2000 F degrees in a kiln.

Following firing in the kiln, units are placed on pallets for shipping. Units are transported from the manufacturing plant to the project by truck or rail.

Masons place the units in mortar, and reinforcement is placed in the cells and bond beams. The resulting wall is grouted to bind the units, grout, and reinforcement to form the structural wall. In some situations, insulation can be placed in the ungrouted cells to enhance the thermal properties of the wall.

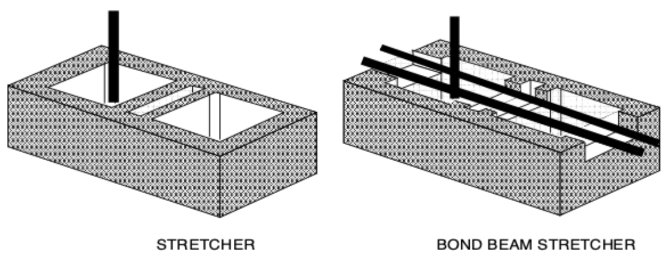


Figure 2 Typical Reinforced Hollow Clay Unit

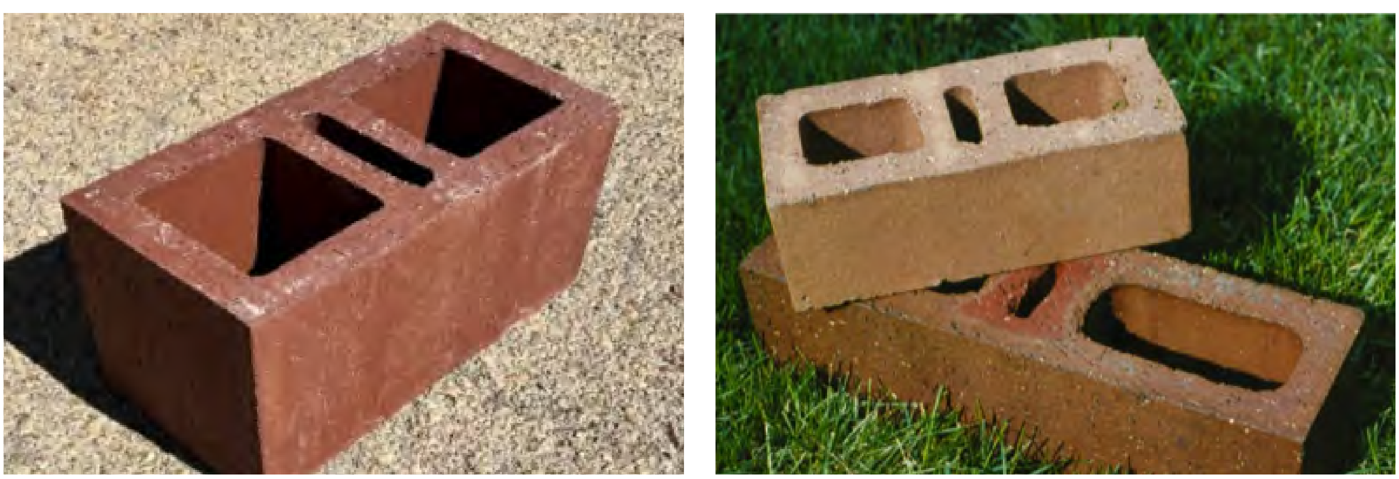


Figure 3 Hollow Clay Units (*Left:* 7 3/8″ x 7 3/8″ x 15 3/8″, *Right:* 3 1/2″ x 2 1/2″ x 7 1/2″, and 3 1/2″ x 3 1/2″ x 11 1/2″)

Document Scope

Detailed information about structural design methods is not included in this document. Instead, this document contains "rules of thumb" to assist in creating the design. More detailed information on structural design methods can be found in numerous textbooks and other references. Two resources available are the Reinforced Masonry Engineering Handbook and the Masonry Designers Guide. These resources contain example designs with example structural analysis. They can be found at The Masonry Society Library.

Design software is also available from many sources.

Mostly, the information is based on Building Code Requirements and Specifications for Masonry Structures, The Masonry Society 402/602. TMS 402/602 is adopted by reference in ASCE 7 and the IBC with minor overriding provisions.

It is intended that most of the information presented is independent of the code edition selected. Specific code references are not included as code provisions change with time and may be revised by the local jurisdiction. In this document, there are statements that a provision is required by code. This statement means that the provision has existed in the code for many years or may be new and is likely to continue being a code provision. But, the provision may or may not apply to your project and may not be current. The structural engineer must check current code provisions applicable to the project based on the jurisdiction having authority.

The traditional design and construction project delivery system (design-bid-build) are assumed. In the traditional project delivery system, the structural engineer contracts with and reports to the project architect as a specialty consultant. The architect typically contracts with and reports to the owner. The contractor is selected after the design is completed, and the selection is often based on price. The contractor enters into an agreement with the owner and reports to the architect serving as the owner's representative.

Other project delivery methods exist, such as the Construction Manager/General Contractor (CM/GC) and Design-Build. Because there is usually more interaction with contractors in these alternative methods, converting a project to RHCM may be easier. However, for this publication, the traditional approach is assumed.

Figure 4 Reinforced Hollow Clay Masonry Wall with Shear Keys for the Slab Connection

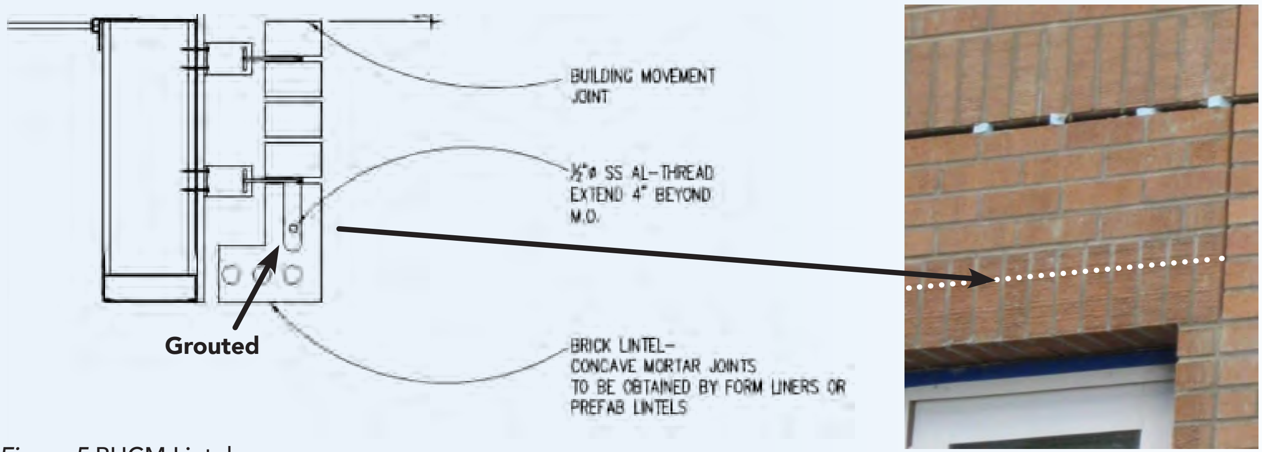


Figure 5 RHCM Lintel

Example Projects

Basic Applications

Reinforced Hollow Clay Masonry Header for Veneer

Brick veneer over various veneer backings is often used for a building's exterior wall. Above openings, the brick veneer is usually supported by steel angles called loose lintels prone to rusting. Observing the rusted angle above an opening makes it easy to determine that a wall is brick veneer. There is a better design.

Figure 6 Custom Lintel Unit for an Inset Window

Replace the steel loose lintel angle with a Reinforce Hollow Clay Masonry lintel. The simplest design is a half-hollow clay soldier. A horizontal reinforcing bar is placed in the cell, and the cell is grouted.

Because the reinforced lintel is typically exposed to water on both sides, it is recommended to use a stainless steel all-thread for the reinforcement. Stainless steel all-thread is much less expensive than stainless steel reinforcement and is readily available. For most applications, a 3/8-inch or ½-inch diameter all-thread is sufficient.

Construction is accomplished by shoring the opening, usually with wood framing. Some masons elect to prefabricate the lintel as a RHCM panel, either on-site or off-site, in a controlled environment.

Reinforced Hollow Clay Masonry Retaining Walls

Many retaining walls are constructed using concrete. Concrete forms often use brick pattern forms for the exposed surface. Why not use brick instead?

Typical hollow clay masonry design strengths (ranging between 2600 and 4000 psi) match that of concrete (higher strength than concrete masonry). Reinforcement requirements are comparable to concrete.

A significant cost advantage is the geometric flexibility of RHCM. Hollow clay masonry units are laid one unit at a time. There is flexibility to have articulated shapes for a small increase in cost.

Figure 7 Articulated Retaining Wall

The serpentine retaining wall is a classic example of the relationship between form and structure. The geometry of a RHCM retaining wall can significantly increase the structural capacity and is more economical. Varying the geometry of a concrete retaining wall is expensive. RHCM can be considered similar to reinforced concrete with the forming left in place.

Additionally, RHCM expands, and concrete and concrete masonry shrinks. In RHCM, the expansion puts the reinforcement in tension, reducing cracking and water penetration. Also, a brick retaining wall can be built from one side, often minimizing the expense of the back-side excavation.

Figure 8 RHCM Retaining Wall

RHCM Soffits, Sills, and Cantilevers

Brick veneer walls may include brick soffits, sills, and cantilevers. Instead of complicated veneer backing, RHCM can be used.

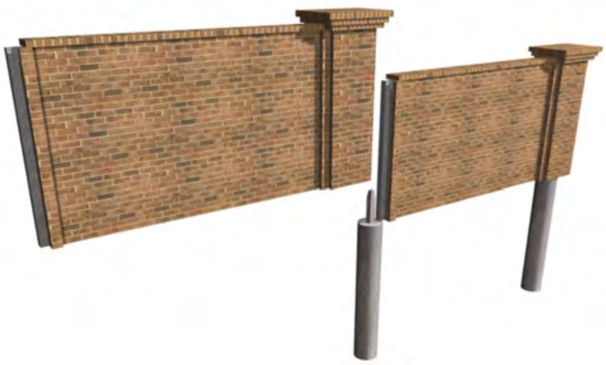
Spanning between connectors to the structure, the hollow clay masonry transforms the veneer into a structural element, eliminating the structural veneer backing. Some local building codes restrict the use of veneers on overhead horizontal surfaces. RHCM would be code compliant and solve the problem.

Figure 9 RHCM Cantilevered Exterior Wall

Reinforced Hollow Clay Masonry Sound Walls

RHCM sound barrier walls are cost-effective. In addition, the flexibility of color and form offers cost and aesthetic advantages.

Two schemes of sound walls are recognized, the cantilever wall and the pier and panel wall. The cantilever has a continuous footing, and the wall is designed to cantilever from the footing. The pier and panel wall has a foundation below the pier but does not require a continuous footing under the wall panels, a significant saving. The piers are designed to support the loading from the wall panel between the piers.



The Sound Transmission Class of a reinforced hollow clay wall is comparable to a concrete wall. The sound transmission class rating can be found in TMS Standard 0302-12 and Brick Industry Association Technical Note 45.

Figure 10 Pier and Panel Sound Wall

Advanced Applications

Schools

For aesthetic reasons, brick is often preferred for the exterior of a school. Often architects will opt for a brick veneer which they believe costs less. However, brick veneer has a limited life unless properly designed with items like stainless steel ties.

Additionally, school story heights add significant costs to the veneer backup system. When the veneer is converted to an RHCM structural system, the backup wall can remain inexpensive, and the brick wall can be part of the building's primary structure. There are many examples of the RHCM wall costing less than brick veneer walls.

Interior RHCM hall and classroom walls provide fire resistance and a long-lasting, durable surface that resists abuse and requires little maintenance.

Figure 11 RHCM School

Commercial/Retail

One- and two-story commercial buildings, retail malls, or other commercial developments can frequently benefit from RHCM construction. As an alternative to concrete masonry, there is an increase in initial cost for a significant improvement in aesthetics, strength, and durability.

As an alternative to a steel frame with metal stud infill walls, RHCM masonry can be used as both a bearing wall, shear wall, and enclosure wall providing structure and exterior finish simultaneously.

Long lead times for structural steel detailing and fabrication can increase the construction schedule. The construction of RHCM can usually begin shortly after the design is complete.

Figure 12 RHCM Retail Center

Small Office Buildings

The typical office building requires column-free spaces to provide flexibility for interior design. These buildings often employ moment frames or braced frames to resist lateral loads. Load-bearing walls are typically not used because they limit the flexibility of the interior space. However, RHCM shear walls can be substituted for steel braced frames or moment frames to resist lateral force. Fire-rated stairs and fire-rated elevator shafts can utilize RHCM, providing up to four-hour fire resistance with an interior brick finish. This is especially desirable when shear walls become part of the exterior aesthetics of the building or permanent partitions.

Single-Family Residential

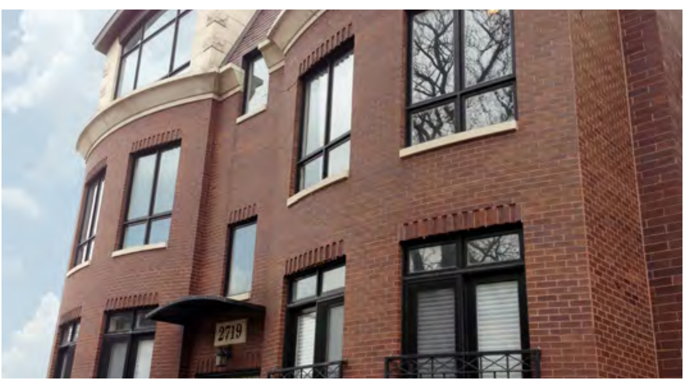


Figure 13 Brick House

RHCM can be substituted for wood frame construction in single-family residential projects. It offers better acoustical properties, less seismic or wind drift (deflection), better fire resistance, less maintenance, insect resistance, and hail resistance. Also, stiff masonry walls may provide better performance in expansive soil locations than flexible walls.

Multi-Story Residential/Hotels

RHCM is used in medium-rise residential projects, including hotels. RHCM exhibits high compressive strength. For buildings in the four-story to the 20-story range, the full strength can be used with little or no increase in cost.

Figure 13 RHCM Residential

The high strength can mean savings and offer an advantage over other forms of construction. The RHCM system is compatible with wood, precast, cast-in-place, or prestressed floor systems. Besides aesthetics, a primary benefit of RHCM bearing wall construction is the sound separation provided by the wall mass. RHCM dwelling unit dividing walls also provide reliable fire separation and thermal mass.

Figure 15 RHCM Hotel

Institutional Facilities

Brick is often the material of choice for libraries, hospitals, fire stations, city halls, and university buildings. In these situations, using RHCM offers an alternative to brick veneer. It can perform double duty when designed to be load-bearing and may provide savings.

Even if not designed to be load-bearing, RHCM offers better seismic isolation and longer life than traditional veneers. RHCM can be designed to isolate the wall from building movements in areas of high seismic exposure. This is difficult to accomplish with conventional brick veneer, particularly at the building corners.

Figure 16 RHCM University Building

Other Applications

Small Bridges

Figure 17 Small Bridge

Building a bridge can be limited by local conditions. A RHCM brick bridge can be built almost anywhere. The materials can be transported one brick at a time. Additionally, the flexible geometry allows for more efficient structural systems.

Blast Walls

Technical information about RHCM and brick blast walls is limited. At this time, it is not a typical application. ASCE/SEI Standard 59-11 Blast Protection of Buildings addresses material and design issues. Masonry is included and, except for minor differences, is equivalent to reinforced concrete. The referenced document addresses concrete masonry. Experience indicates that because of the significant increase in strength of hollow clay masonry units over concrete masonry units, brick blast-resistant walls will perform equal to or better than concrete masonry blast-resistant walls.

The Department of Defense and the ASCE/SEI 59-11 prohibit using unreinforced or partially grouted masonry for blast resistance. This is because fragmentation of the units causes airborne debris.

Storm Shelters

Test panels made of fully grouted RHCM, produced by Interstate Brick Company, have been tested for debris impact. The test objective was to ensure compliance with a high-performance standard to protect shelter occupants from wind-borne debris. Performance criteria include preventing the perforation of the shelter by the test missile and preventing damage that could cause injuries to the occupants.

The panels tested met the debris impact guidelines of FEMA 320/361 and ICC – 500 for a tornado shelter. Again, remember that the flexibility of wall geometry gives RHCM a significant cost advantage over reinforced concrete.

Curtainwall or Reinforced Veneer, or Structural Brick Veneer

Brick veneer on metal studs is a popular curtainwall system. An alternative system is an RHCM curtainwall or reinforced veneer. A reinforced veneer is similar to a conventional veneer, except the wall is constructed with RHCM. Typical closely spaced veneer ties are replaced with intermittent connectors spaced farther apart. A typical brick veneer has ties every two square feet. Reinforced veneers have connectors every 100 square feet. The connectors carry more load, are constructed of galvanized thicker materials, offer simpler methods for isolating the veneer from the primary structure, provide less thermal bridging, and are more corrosion-resistant.

A design guide for reinforced veneer or structural brick veneer is available at the Western States Clay Products website (www.brick-wscpa.org/technical-publications.php, Design Guide for Structural Brick Veneer, Third Addition).

A reinforced veneer is sometimes called "laid-in-place panels."

Figure 18 RHCM Reinforced Veneer Hospital Exterior Wall in a High Seismic Zone

Brick Panels

Brick panels are an application for RHCM. Brick panels are constructed of hollow clay units, reinforced, fully grouted, and attached to the building in a manner comparable to a precast concrete panel. The system can speed construction, eliminate the requirement for scaffolding, and provide the designer with new opportunities not available with conventional masonry. The system has been used on many buildings ranging from single-story branch banks to 50-story office buildings.

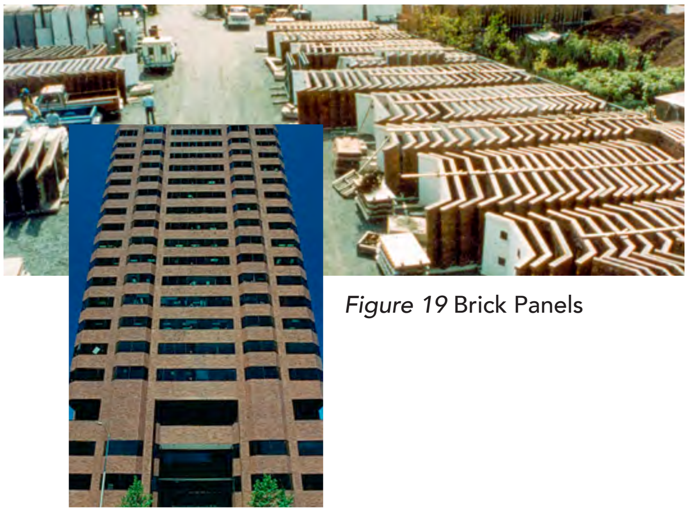


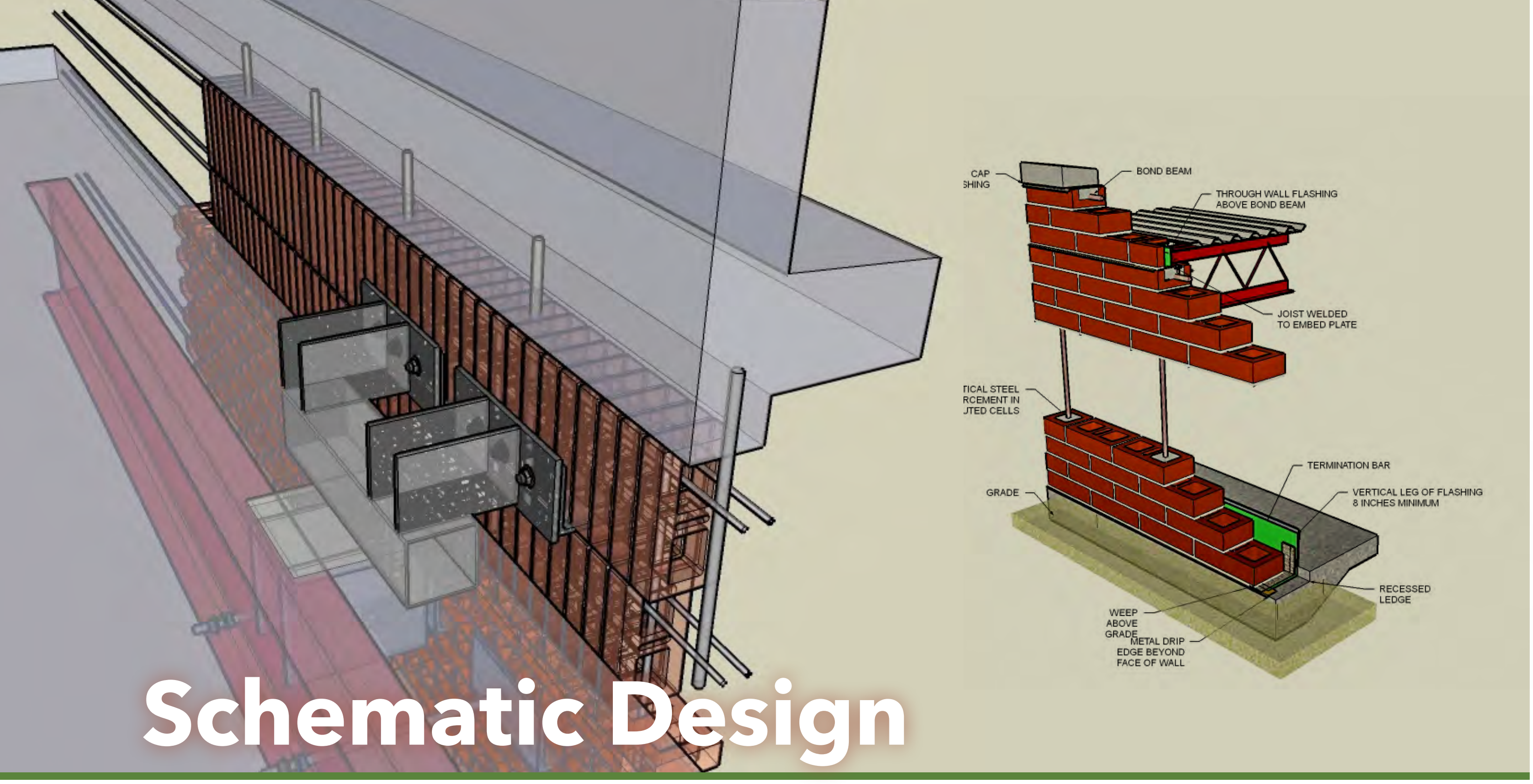
Figure 19 Brick Panels

Concrete Form

RHCM or, in some cases, unreinforced solid brick can be used as a form for concrete. When a brick exterior is desired, the brick can become the form for concrete structural columns and spandrels. In addition to increasing the element's capacity (the brick concrete form is structural and is not removed), the geometry flexibility offers interesting opportunities for unique designs.

Figure 20 RHCM Columns and Spandrels Used Both as a Form and for Structure

Figure 21 RHCM Used as the Finish Wall and Backing for Concrete Shotcrete (Gunite)



Schematic Design

Selection of the Structural System

During the schematic design phase, the architect evaluates the owner's needs and develops the project concept. Multiple design concepts are explored and developed during this phase. The structural engineer is expected to influence the selection of a structural system with choices that are cost effective for the owner.

The architect and owner will likely have defined a preliminary site plan and layout before the structural engineer's involvement. For example, if the site plan includes retaining walls, the structural engineer should include the retaining walls in the design scope, increasing the fee if possible, and suggest RHCM as a cost-saving option.

Suppose the exterior skin (curtainwall) has not been defined, and the building is of institutional quality or in a high seismic or hurricane zone. In that case, RHCM curtainwall (reinforced veneer) may be an option for significant cost reduction and enhanced performance. Reinforced veneer usually costs less than conventional brick veneer on steel studs if the story height is over 12 feet.

During the selection dialogue, the following advantages and objections could arise.

Advantages

Sustainability and Resilience

Unlike many modern construction materials, fired clay (bricks) lasts thousands of years in the environment. They are sustainable. Additionally, bricks can be recycled either by reuse or by adding ground-up bricks to clays for making new bricks.

Resilience can be developed through the geometric flexibility of RHCM. Adding intersecting walls and flanges to shear walls will increase resilience at a minimum cost.

Expansion Property

Brick masonry expands with time. This can take as long as five years. It is not reversible. In RHCM, this property places the brick in compression and the steel in tension. The result is reduced cracking and improved water penetration resistance. Expansion joints can be placed further apart or, in some cases, eliminated.

High Strength

It is relatively easy to obtain high-strength hollow clay masonry. Design strengths (f'_m) of 4,000 psi are recognized in TMS 602 Specification based on an 11,500 psi clay unit net area compressive strength. Typical unit strengths are between 10,000 and 15,000 psi. Higher unit strengths are common.

Darker colored bricks generally have higher strengths and lower absorption than lighter colored bricks. There is typically no cost premium for these higher strengths, although there may be local limitations on available colors. In load-bearing applications, the higher strengths offer an advantage over concrete masonry units.

The tensile strength of the brick masonry unit range between 700 and 1500 psi. Brick cracking in structural walls is less common than in concrete masonry (CMU).

Form and Structure

Structural capacity can be significantly increased by modifying geometry. For example, adding a pilaster to the wall. The cost to modify geometry is minimal when bricks are laid one at a time.

Speed of Construction

Most masonry materials, including hollow brick, are readily available on short notice. Therefore, it is not necessary to wait for steel fabrication.

Low Maintenance Cost

RHCM is relatively maintenance-free. Expected life far exceeds the life of metal and other light exterior wall systems. RHCM does not rot. Insects do not eat RHCM.

Aesthetic Flexibility

There are thousands of colors and textures from which to choose. The many brick placement orientations can create unique patterns that challenge the architect's creativity. Fewer expansion (or control) joints (if any) are required. Special shapes can be produced to further broaden the aesthetic possibilities.

Building a bridge can be limited by local conditions. A RHCM brick bridge can be built almost anywhere. The materials can be transported one brick at a time. Additionally, the flexible geometry allows for more efficient structural systems.

Objections

RHCM is viewed as masonry in general and carries many of the perceived negatives often associated with masonry.

Below are a few of the common objections. However, despite these objections, RHCM has been successfully used on many projects for the past 80 years and should continue to receive consideration in many projects.

Unfamiliarity with RHCM

Many designers, both architects, and engineers, are not familiar with RHCM. A simple solution is to consider RHCM as concrete masonry with the CMU units replaced with brick units.

Higher Cost

RHCM costs more than concrete masonry. But it may cost less than brick veneer on metal studs. When floor heights exceed 12 feet, many examples exist where an RHCM with only an interior partition costs less than a brick veneer with a structural steel stud backup system. This is because the backup structural steel stud wall cost exceeds the increased brick structural cost.

Water Penetration

Masonry is often perceived to leak more than other wall systems. This has proven to be inaccurate for RHCM, particularly when grouted solid. The expansion of the brick masonry against the reinforcement tends to reduce cracking and, thus, reduce leakage significantly.

Another Subcontractor

Adding the mason adds another subcontractor to the job. General contractors often resist adding a masonry subcontractor to the job. One reason is the cost of administering the masonry work. Another reason exists if the general contractor performs their own concrete work. In this situation, they will prefer concrete walls instead of masonry walls to keep a larger percentage of the project.

Unreliable Color

Colors are variable and sometimes not what was expected. Many architects have experienced difficulty in obtaining the colors desired. To a large degree, many of these problems don't exist today. More sophisticated manufacturing processes and adequate color mock-ups have nearly eliminated issues in this area.

Inexperienced with Design Methods

Many structural engineers are not familiar with masonry design methods. There are many new resources (literature and software) available. This document is one example.

Inconsistent Information

Sometimes technical answers obtained from suppliers appear inconsistent. There are many different types of masonry. There are many different uses. Communication between the masonry industry and the designer often needs clarification because of misunderstandings of intended use and terminology. Veneer brick masonry is not designed and constructed like load-bearing brick masonry. CMU masonry behaves very differently from fired clay masonry. One typical example: wetting clay units before laying is often recommended, while it is not recommended to wet CMU units before laying.

Inconsistent Standard Details

Many standard details are available, but the problem is similar to the apparent inconsistency of technical answers. Since there are so many different types of masonry, methods, and systems, a single set of standard details is not possible. Further, details vary by region. Most local masonry institutes have recommended details available.

Prices are not predictable.

Price varies from job to job. Unfortunately, it is difficult to predict the price of a masonry job. Since masonry work is labor intensive, the mason's production is a key factor. Many variables come into play. The cost of the bricks remains relatively predictable and can be obtained from the supplier.

Complicated Building Code

There are many different types of masonry and many different applications. Persistence in understanding the applicable provisions of the code is required. This document is intended to help.

Selection of Materials

When RHCM is selected for the structural system, the next step is to choose the specific type of units to be used. The choices of shape, color, texture, and pattern are almost unlimited.

Thousands of colors exist. Almost any shape can be produced. Units can be shipped thousands of miles.

Local suppliers can provide information on the available strengths, shapes, and colors. The manufacturers who are members of the Western States Clay Products Association are listed in Appendix A.

Initial Design Criteria

The likely applicable code is The Masonry Society (TMS) 402/602 *Building Code Requirements and Specification for Masonry Structures*. It is adopted by reference in the International Building Code. Associated design loads are found in the *International Building Code* and the *American Society of Civil Engineers (ASCE 7) Minimum Design Loads for Buildings and Other Structures*.

TMS 402/602 includes two design methods: Allowable Stress Design and Strength Design. The Allowable Stress Design and Strength Design methods are divided into Reinforced Masonry Design and Unreinforced Masonry Design. Hollow clay masonry can be designed as reinforced masonry or unreinforced masonry using either Allowable Stress Design or Strength Design.

The code provisions for Unreinforced Design, Reinforced Design, Strength Design, and Allowable Stress Design may be used in combination. For many years ASCE 7 has restricted combining Allowable Stress Design and Strength Design. But the IBC has typically not adopted the ASCE 7 restriction. Before combining methods, the structural engineer must verify if the mixing of design methods is allowed within the project jurisdiction.

Dimensions

It is traditional to describe the masonry unit dimensions in the order of thickness, height, and length. For example, a 6 x 4 x 12 unit is a nominal 6-inch-thick, 4-inch high, and 12-inch long unit. Nominal dimensions are one mortar joint thickness larger than the specified brick dimensions. The typical mortar joint thickness for RHCM is either 3/8 inch or 1/2 inch, depending on the manufacturer (the typical mortar joint thickness for concrete masonry units is 3/8 inch). Thus, a nominal 4-inch height unit laid with a ½-inch mortar joint has a specified height dimension of 3 ½ inches

Standard nominal thicknesses are 4, 5, 6, and 8 inches. The availability of 10 and 12-inch thick units may be limited. The typical nominal height is 4 inches (other heights are available), and the nominal length is 12 inches or 16 inches. Smaller standard-size brick units (for example, 3 ½ x 2 ½ x 7 ½) can be manufactured with cells large enough to be reinforced.

Hollow clay units are produced in accordance with ASTM C 652 H60V, where the sum of the void area is greater than 40 percent but less than 60 percent of the gross cross-sectional area.

Hollow clay masonry units have cells and cores. A cell is different from a core. A cell's cross-section exceeds 1 ½ square inches. A core's cross-section is less than 1 ½ square inches. Cores do not need to be grouted for a wall to be classified as fully grouted, but all cells need to be grouted. Reinforcement is not generally placed in cores.

Hollow clay masonry units are easily reinforced, both vertically and horizontally. Vertical reinforcement is placed in the cells that align vertically. Horizontal reinforcement is placed in bond beams that align horizontally. Smaller standard-size units manufactured with cells can also be easily reinforced. Diagonal reinforcement is very difficult to construct and is almost never designed.

Special units can be manufactured for custom patterns. The additional cost for custom units, shapes, and colors on large projects is generally small. A project that offers the opportunity for custom units provides the architect and structural engineer with an opportunity for creative, sustainable, and resilient design. One example is the custom units used in a large hospital for a six-inch thick wall that visually projected a standard four-inch corner.

For analysis, the specified dimensions of the masonry are used, except the nominal dimensions are used for the following:

1. Effective flange width.
2. Reinforcement spacing.
3. Maximum size of reinforcement based on the thickness of the unit.
4. Height-to-thickness ratios for determining design compression strength.
5. Minimum dimensions (Example: Minimum side dimension of a column is eight nominal inches).

It is desirable, but not necessary, that the plan dimensions match the unit module. Cutting units is common but can significantly add to the wall's cost. Moreover, a wall or pier of limited length (say, 14 inches long) could pose a problem with aligning cells for reinforcement.

Generally, the masonry contractor can adjust dimensions by plus or minus 1/8 inch per stretcher. This can be accomplished by unit selection or by adjusting mortar joint widths. It should be recognized that units typically are not exactly the same thickness, height, or length. Variations in specified dimensions are addressed in ASTM C 652. The dimension of a darker unit will generally be smaller than the dimension of a lighter unit. Because the thickness varies, hollow clay walls are typically laid to line on one exposed face. When both sides of the wall are exposed and considered finished, additional costs may result, either because of the increased cost for more uniform units or the potential increased cost to lay the units.

A floor height that does not divide evenly by the brick height is not a big problem. Usually, the bed joints can be adjusted. Sometimes the brick is cut. Gabled walls are typically constructed by cutting the units at an angle.

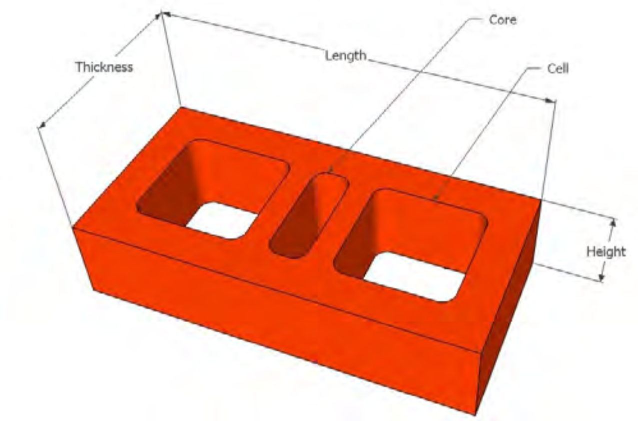
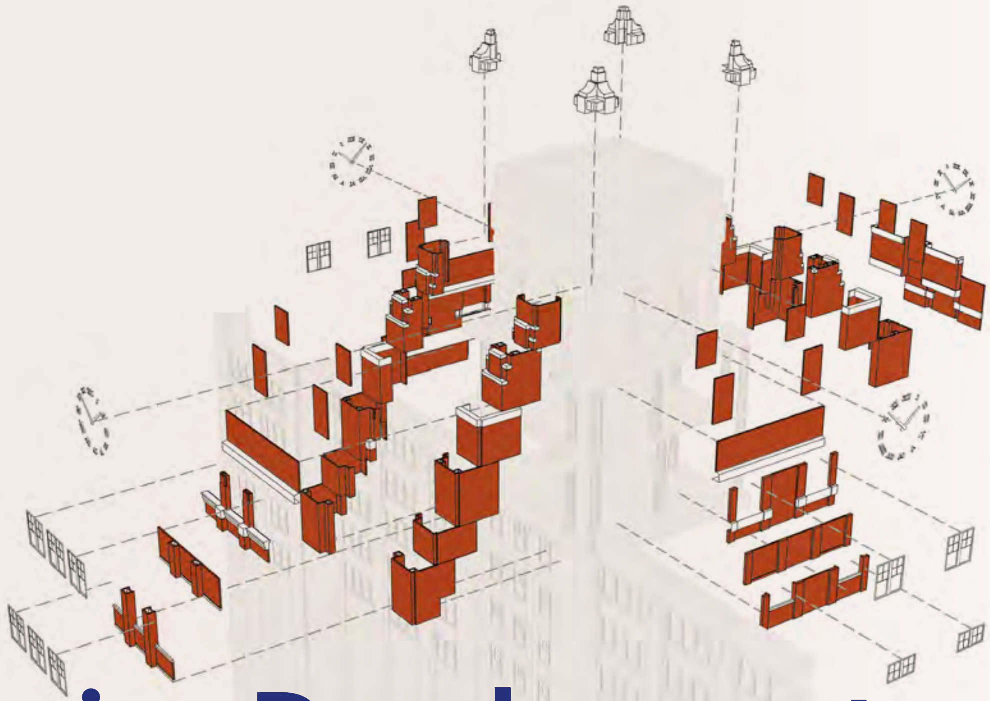


Figure 22 Dimension Order: Thickness, Height and Length

Figure 23 Custom Unit for a Four Inch Corner in a Six Inch Wall

Wall Thicknesses

It is common to use different thicknesses of walls on the same floor or to change the wall thickness from floor to floor.



Design Development

During the design development phase, the design team prepares documents consisting of drawings and specifications to fix and describe the size and character of the entire project.

During this phase, the structural engineer identifies the space required for the structural portions of the project and the elements of the structure that will control the required strength of the materials, in addition to a beginning draft of the specifications.

Bond Pattern

The building code recognizes only two bonding patterns, running bond and other than running bond (formerly defined as stack bond and that term to be used herein). For running bond, the units must overlap by more than one-quarter of the unit length. If the overlap is less than one-quarter, the pattern is classified as other than running bond for design purposes, or stack bond. The code has lower capacities for stack bond and includes prescriptive requirements for its use.

For RHCM and CMU masonry, the head joint is normally face shell bedded instead of full bedding. The structural engineer should assume that the face shell bedded head joint has no shear or tension capacity. In running bond, the head joints stair step in the wall. The code design capacities take this into account. In stack bond, the head joints line up in the wall, causing a structural discontinuity. The code provision limit capacity accordingly.

There are many bonding patterns other than stack and running bond. The orientation of the units provides the architect with many creative designs.

There are names for the orientation of units in a wall. The un-hatched face is the face exposed to view.

For unreinforced masonry, bed joint code capacities are higher than head joint code capacities. The code defines the bed joint as the horizontal layer of mortar on which the masonry is laid. The capacity is higher because of the compression on the joint during curing supplied by gravity. For example, for a soldier orientation of a unit, the head joint is the end web.

Typically, the architect will select the bonding pattern. Many designs have multiple bond patterns. Some patterns can have a significant impact on the structural design.

When the head joint limits the capacity required, using open-end units (units with the end webs removed) and fully grouting will solve the problem.

The bonding pattern may appear to create a wall that cannot be reinforced and grouted. However, there are usually methods available. Typical methods are:

- Use a single bond beam or back-to-back bond beams for vertical reinforcing in soldier courses.
- Use precast concrete or cast stone with holes (like brick cells) to pass vertical reinforcement. When using precast concrete, it is important to consider that concrete shrinks with age and that brick masonry expands. The precast should not be set until it is at least 28 days old, and the length of the precast should be limited to 10 feet with a soft caulk joint at the end. Placing sand on the surface of the caulk will make the caulk joint appear like the adjacent mortar joints.
- Use various brick thicknesses and special shapes to produce elegant walls. Flexibility is one of the most important advantages of RHCM. Rustication, quoins, and cornices are examples of a few designs that can be easily produced using different thicknesses of hollow clay.
- Work with the brick manufacturer to design custom extruded shapes.
- Use cut lintel blocks from the end of units for exposed sills and lintels.

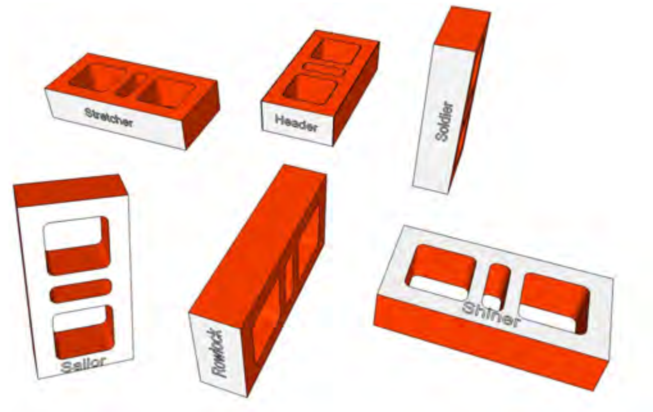


Figure 24 Unit Orientation Definitions

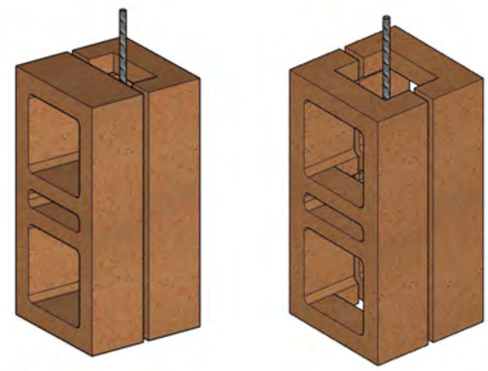


Figure 25 Soldier Reinforcement

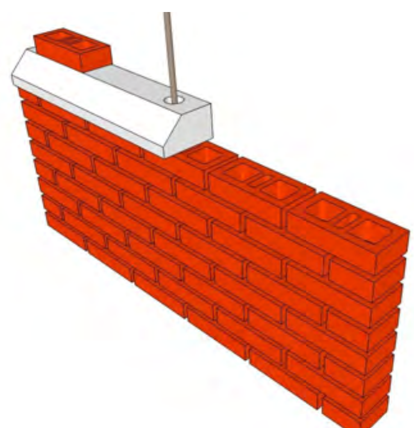


Figure 26 Precast and RHCM

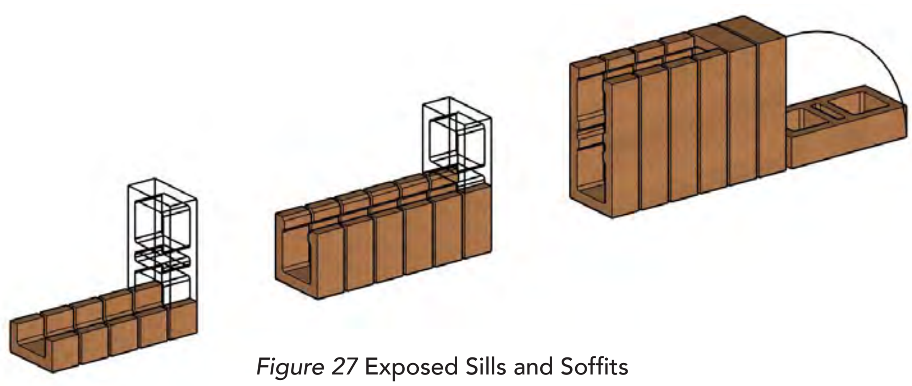


Figure 27 Exposed Sills and Soffits

Initial Sizing of Members

During meetings with the client, questions about member sizes will occur. Structural engineers tend to rely on their computer models, requiring additional time, instead of "back of the envelope" analysis on the spot. The following information will assist the engineer in quickly providing the client with the needed information.

Making money on the structural design directly correlates to the quality of the first guesses.

Designing a structure is an iterative process. It consists of guessing, checking, and resizing to meet code and performance expectations. Fortunately, whole numbers are used to select masonry member sizes, so the engineer doesn't need to run extensive analysis to get started.

Selection of the Design Strength

Masonry is composed of units, mortar, and grout. The f'_m specified is the required strength of the combination of these materials. A common incorrect assumption is that the weakest of the units, mortar or grout, determines the system's strength. This is not the case. It is common to have a combination of materials with a strength of 4000 psi, a grout strength of 2000 psi, and a mortar strength of 1800 psi. This is because laboratory or field tests, not in-the-wall tests, define the grout and mortar strengths. Laboratory and field-prepared grout and mortar test samples are cured in conditions quite different from those in the wall. The strengths in the wall are typically much higher.

Mortar and grout compression tests measure the water-to-cement ratio of the mix. In the wall, the units absorb much of the water from the grout and mortar, resulting in increased strength. Think of the unit as a sponge absorbing water. Accepted standards for the field tests of mortar and grout attempt to mimic this effect. The methods used are unreliable. Moreover, field tests of mortar and grout are sensitive to weather, temperature, sampling method, curing, handling, transportation, and testing method (Appendix D).

For this reason, the structural engineer should rely on the prism test as a measure of strength.

Unfortunately, it is rare to obtain prism test data during the design development phase. The masonry code unit strength method provides an alternative to prism testing and is recommended for the initial design.

In accordance with TMS 602, the specified strength of RHCM can be determined from the unit strength by the following equations.

$$f'_m = 0.3057 * (the\ net\ area\ strength\ of\ the\ unit) + 480.39$$
(Type M or S mortar)

$$f'_m = 0.2439 * (the\ net\ area\ strength\ of\ the\ unit) + 487.80$$
(Type N mortar)

For RHCM, the structural engineer can assume a design strength of 2,600 psi in most situations. Lower values for the hollow clay masonry are unlikely. Higher values can be obtained if required.

The modulus of elasticity for hollow clay masonry is 700 f'_m psi (for concrete masonry, it is 900 f'_m psi).

Commonly, one building element controls the required masonry strength. Reducing the strength of other elements not requiring the higher strength may or may not result in cost savings.

It is not unusual to change the wall strength or the unit thickness from floor to floor.

Changing the unit color may mean a change in the masonry strength. Consequently, the architect's choice of color may control the strength of the masonry.

Selection of Wall Thickness

Out-of-plane loads will likely control the exterior wall thickness, except for buildings over six stories, where the compression demand may control wall thickness, or in a high seismic zone, where the shear demand may control the wall thickness.

Out-of-Plane

Whether or not the architect has initially selected the wall thickness, the structural engineer will need to estimate the thickness required to resist the loads. A good initial guess can save a lot of design effort. The following table presents typical wall thicknesses for walls controlled by out-of-plane loading. Wind load is usually the controlling load (For 10-inch and thicker walls, seismic may control in high seismic areas).

Typical Height Limits for Out-of-Plane Loading

Nominal Wall Thickness (in.)[3]	Height of Wall (ft.)1.2		
	Normal Application h/t = 24	Common Application h/t = 30	Extended Application h/t = 36
4"	8	10	12
5"	10	12	15
6"	12	15	18
8"	16	20	24
10"	20	25	30
12"	24	30	36

1. h = effective height, t = nominal thickness
2. Wind loading 45 psf with .0025 net area vertical reinforcement. (f'_m = 2600 psi)
3. 10 and12-inch thick units may not be available – check with the manufacturer.

For walls with h/t ratios less than 24, there is significant capacity for compression (load bearing). Moment magnification resulting from out-of-plane deflection (small deflections) will have little or no effect on the design.

For walls with h/t ratios between 24 and 30, the compression capacity is reduced but still significant in most applications. Generally, the moment magnification factor will need to be considered in the design but will have a small effect.

For walls with h/t ratios between 30 and 36, the compression capacity is reduced, and it is necessary to consider moment magnification in the design. Walls in this category often have roof loads accumulating to a point along the wall (roof trusses). In these circumstances, the structural engineer should consider using pilasters (protruding inside, outside, or both) and span the masonry horizontally between pilasters.

Compression

Compression in the wall results from the dead load, live load, snow load, and overturning due to lateral wind or seismic forces.

The compression from dead, live, and snow loads can be easily determined by the tributary area method. The tributary area method requires engineering judgment. The dead and live load from each floor and the dead load, live load, and snow load on the roof are distributed by dividing the floor and roof into the areas between the walls (except in high snow load locations). Live load reduction should be used, and partition loads should be added if required by the code. Don't forget to include the weight of the wall.

Lateral Forces

Initial sizing for in-plane lateral loading is more complicated. Usually, the in-plane loads are due to wind or lateral seismic forces applied to the entire structure (main lateral force resisting system). For a regular geometry (the center of rigidity approximates the center of mass or the center of pressure), the first step is calculating the base shear. For irregular geometry, the first step is to educate the architect about the performance advantages of regular geometry, then determine the base shear.

Wind Base Shear

The base shear due to wind may be estimated as:

$$V_{base} = WA$$

Where W is the estimated average wind pressure on the building (generally, direct pressure on the windward elevation and plus suction on the leeward elevation) and A is the building area exposed to the wind pressure.

Seismic Base Shear

The layout of shear walls for resistance to seismic loads is important. Maintain the symmetry of shear walls. Getting the architect to add a shear wall to provide symmetry can significantly reduce the required design time. It will also improve the resilience of the building. Methods for seismic design of asymmetric geometry are available but require additional effort. Perhaps you should request an additional design fee if symmetry is not approximated.

For Seismic Design Category C and above, TMS 402 requires that along any line of lateral resistance, not more than 20 percent of the lateral resistance can be provided by columns unless the base shear is determined using a response modification factor (R) of 1.5 (not recognized by ASCE 7 or the IBC but the exception is likely within the normal standard of structural engineering care).

The base shear due to seismic can be estimated. Since Reinforced Hollow Clay Masonry buildings normally have a box system that resists seismic forces with shear walls, the estimating procedure is not very complicated. It can be estimated with hand calculations.

The base shear is:

$$V_{base} = C_s W$$

Where W is the seismic weight of the building (including partitions and sometimes snow. See ASCE 7 for the definition of seismic weight).

The value of Cs is determined by:

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I_e}\right)}$$

Where S_{DS} is the short period design spectral response acceleration parameter, I_e is the Importance Factor, and *R* is the Response Modification Coefficient.

R = 5.0 for specially reinforced masonry shear walls (Seismic Design Category A, B, C, D, E, F)

R = 3.5 for intermediate reinforced masonry shear walls (Seismic Design Category A, B, C)

R = 2.0 for ordinary reinforced masonry shear walls (Seismic Design Category A, B, C)

C_s need not exceed:

$$C_s < \frac{S_{D1}}{T\left(\frac{R}{I_e}\right)}$$

Where S_{D1} is the design spectral response acceleration parameter at a period of 1 second.

The building period can be estimated as follows:

$$T_a = .02h_n^{.75}$$

Where h_n is the height of the building, in feet.

And C_s must be greater than:

$$C_s = 0.044 S_{DS} I_e \geq 0.01$$

And, if S_1 is equal to or greater than 0.6, then C_s shall be greater than:

$$C_s = \frac{0.5 S_1}{\left(\frac{R}{I_e}\right)}$$

Where S_1 is the 5% damped mapped maximum considered earthquake spectral response acceleration parameter at a period of 1 second.

Distribution of Base Shear

The base shear, either wind or seismic, is resisted by the in-plane forces in the building walls. The amount of load in each wall can be estimated as follows.

For flexible diaphragm buildings, the base shear is distributed by the tributary area method. Flexible diaphragm buildings are constructed with wood or metal deck without concrete topping floors and roof. The tributary area method requires engineering judgment. The force in each floor diaphragm is distributed by dividing the floor into areas that split the distance between the walls. The stiffness (rigidity) of the wall is not used.

For rigid diaphragm buildings, the load is distributed to the walls in relation to the relative rigidity of the wall. Rigid diaphragm buildings are constructed with concrete, concrete plank, or concrete over metal deck floors and roof. For these buildings with wall height to length greater than 3, distribute the base shears in proportion to $(H/L)^3$. The stiffness of these walls is dominated by flexure. For walls with (H/L) less than 3, distribute the base shears to the walls in proportion to (H/L). The stiffness of these walls is dominated by shear. The value of H in the equations is the height from the base to the floor being considered.

Shear walls connected by beam elements at each floor or walls with punched window openings are sometimes designed as "coupled" shear walls. If coupled, for rigid diaphragm buildings, the length of the wall can be approximated as the sum of the walls adjacent to the coupling beam element.

Where the coupling beam stiffness is comparable to or greater than the wall stiffness, assume the wall is coupled; otherwise, assume individual walls. If coupled, the coupling beam elements have a small influence on the base shear distribution to the wall elements. The coupling beams, however, significantly affect the overturning moment. More coupling results in a lower moment because the piers and coupling beams act as a frame. This effect can be important for sizing the amount of vertical reinforcement in the wall and selecting the masonry strength.

In high seismic areas, coupling beams over interior and exterior doorways can be a problem. Distortion of the coupling beams prevents the doors from opening and traps the resident in their unit and the building.

Once the axial and shear loads are estimated, the building overturning moment can be estimated by assuming for wind that the lateral load is applied at the mid-height of the wall and for seismic that the lateral load is applied at two-thirds of the height of the wall.

Once the shear and moment are estimated, the following provides a guide for wall thickness when shear governs. This is usually the case when the H/L is less than 3. The values are conservative.

Wall Thickness for Shear

Nominal Wall Thickness (in.)[4]	Approximate Shear Capacity (lb/ft)[3]	
	Wind[1]	Seismic[2]
4"	4,000	2,500
5"	5,000	3,300
6"	6,000	4,000
8"	8,000	5,300
10"	10,000	6,600
12"	12,000	8,000

1. Approximately $2\sqrt{2600}$
2. Approximately $2\sqrt{2600}/1.5$
   (Factor to increase flexural dominance of a wall)
3. Strength level and fully grouted construction
4. 10 and 12-inch thick units may not be available – check with the manufacturer.

When H/L is high, the overturning moment will often dominate the initial design of the wall. Before developing the finite element model to distribute loads to the wall, an estimate of the wall thickness is needed. One method is to assume the wall consists of two piers, each with 20 percent of the wall length.

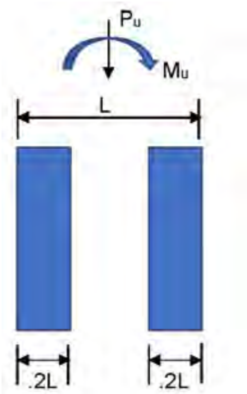


Figure 28 Model for Estimating the Design of a Wall

The axial load is divided between the two piers, and the moment is modeled as a coupled axial load on each pier. Assuming 60,000 psi reinforcement, the tension load is calculated as follows:

$$P_t = \frac{M_u}{.8L} - \frac{P_u}{2}$$

The required reinforcement is estimated as follows:

$$A_s = \frac{P_t}{60{,}000}$$

High strength reinforcement exceeding 60,000 psi yield is currently not allowed for masonry design. The area of reinforcement should appear reasonable for the wall. If not, the wall may need to be longer or more walls are needed.

The thickness of the wall will depend on the compression zone. An estimate of the compression stress can be obtained using the same model.

$$P_c = \frac{M_u}{.8L} + \frac{P_u}{2}$$

$$f_c = \frac{P_c}{.2t_{sp}L}$$

Where t_{sp} is the specified thickness of the wall, and L is the length of the wall. If the compression stress exceeds .64 f''_m , the wall needs to be increased in thickness and/or length.

One wall (or a small percentage of walls) will often not comply using the above initial method. Judgment must be employed to determine if the selected wall thickness is adequate. The above method is usually conservative, and with experience, the degree of conservatism can be readily estimated.

A more refined analysis is required during the construction document phase.

Selection of Beam or Lintel Size

An estimate of a beam or lintel size can also easily be obtained. These elements usually occur over wall openings. To estimate the beam or lintel requirements, first, calculate the applied moment. Normally the maximum moment results from full dead and live to load. If the beam is a shear wall coupling beam, then combined dead load plus seismic load normally controls.

The area of steel can be estimated as follows:

$$A_s = \frac{M_u}{.9F_y d}$$

It is best to use the same size bars in the beam or lintel as those bars used in the wall. Contractors sometimes take bars from the wrong pile. It is good practice to minimize the number of different bar sizes to simplify procurement, job site storage, and reinforcement handling.

Specifications

Specification of Materials

Units

Specify units to conform to ASTM C 652 with the minimum unit net area compression strength determined by the design requirements. ASTM C 652 requires a gross area compressive strength, not a net area compressive strength.

Mortar

Specify mortar as Type S, Portland cement-lime by proportions per ASTM C 270. Do not specify a mortar strength. Do not specify Type M mortar because Type M mortar is too hard and usually causes a crack between the unit and the mortar. For most jobs, masonry cement or mortar cement mortars are allowed by code, but local masonry preferences need to be investigated.

Preblended mortars (proportions of the ingredients are blended by the supplier with water added at the site) are specified per ASTM C 1714/C 1714M. They meet the requirements of ASTM C 270.

Do not use additives in mortar, except colors in accordance with manufacturers' recommendations.

Color additives to mortar generally do not reduce mortar bond strength or compression strength. Most color additives consist of mineral oxides except carbon black, which consists of finely ground carbon. Carbon black (for grey mortars) should be limited to 2% of the weight of the cement. When using colored mortar, follow the recommendations of the color additive manufacturer.

Grout

Specify grout per ASTM C 476 for regular or self-consolidating grout. Specify grout strength (f'g) equal to f'_m but not less than 2,000 psi (required by code). The ASTM C 476 proportions will result in strengths well in excess of 2,000 psi. Lime may be added to the grout. This usually improves the grout properties by increasing the flow and retention of water, resulting in improved placement and bonding to the unit.

Grout is normally placed at a slump of 8 to 11 inches. The high-water content is permitted because the masonry units absorb the water like a sponge before the grout sets.

Figure 29 Fluid Grout

Consolidation and Re-Consolidation

TMS 402/602 requires mechanical vibration of the grout during placement (consolidation) and, at a later time, mechanical vibration to reconsolidate.

Like concrete, mechanical vibration is used during the grout placement to increase the flow and decrease the chance of grout voids. For fluid fine grout, mechanical vibration during placement (consolidation) is likely unnecessary, and a code modification may be requested if performance is demonstrated with a grout demonstration panel.

Reconsolidation is unique to masonry. After the grout is placed in the unit, the unit absorbs water from the grout. Since the water content of the grout is high (8 to 11-inch slump or more), the volume of water removed results in voids in the grout. These voids occur somewhere between 5 minutes and forty-five minutes after the grout is placed. The amount of time depends on many factors, including the absorption of the units, the grout mix, the weather, and the height of the pour.

Reconsolidation is accomplished by placing a vibrator one foot or less into the top of the grout column for each grouted cell. When successfully done, the top of the grout will settle below its previous position, often settling 2 to 4 inches for a single lift and 4 to 8 inches for multiple lift grouting.

In some situations, mechanical reconsolidation of fine grout in small cells may not be necessary. A code modification may be appropriate if performance is demonstrated with a grout demonstration panel.

Self-consolidating grout mixed to a slump flow of 24 to 30 inches, measured in conformance to ASTM C 1611/C 1611M, may be used. For self-consolidating grout, consolidation, and re-consolidation are not required.

Sand

Specify sand per ASTM C 144. Use mortar sand for fine grout. Mortar sand is finer and produces grout that flows better, particularly in 4-inch and 5-inch hollow units. Some sands are composed of rounded granules instead of sharp granules. The rounded sands can be used in grout with less cement and water to obtain equivalent flow compared to grouts with sharper sands. Use only clean, washed sand.

Coarse aggregate for grout

Specify coarse aggregate per ASTM C404. Use only clean, washed aggregate. Coarse aggregate is not allowed in fine grout; either fine regular grout or fine self-consolidating grout.

Cement

Specify cement to conform to ASTM C 150, Types I, II, or III. Do not use air-entrained cement types IA, IIA or IIIA, etc. Low alkali cement reduces the tendency for the masonry to effloresce. If available, they are recommended.

Lime

Specify lime to conform to ASTM C 207. Do not use air entrained lime, as it will reduce the bond strength between the unit and mortar.

Reinforcement

ASTM A 615 Grade 60 reinforcement is normally used. When welding reinforcement, use ASTM A 706 bars. High strength reinforcing with specified yield strengths in excess of 60,000 psi is not currently allowed for reinforced masonry design.

Quality Assurance

IBC and TMS 402 require a minimum level of quality assurance to be included in the contract documents. It is recommended that the minimum quality assurance requirements be included in both the structural notes and the project specifications. The quality assurance program itemizes the requirements for verifying conformance with the specified materials, material storage and handling, and construction execution. It shall also set forth the procedures for reporting and review and include procedures for the resolution of non-compliance.

TMS 402/602 presents three levels of quality assurance. Level 1 is for prescriptive design methods such as veneers, glass block, and partition walls. Level 2 and Level 3 are for engineered masonry design methods that include RHCM. Level 2 is for Risk Categories I, II, or III. Level 3 is for Risk Category IV. Risk categories are defined by ASCE/SEI 7.

The primary difference between Level 2 and Level 3 quality control is that Level 2 allows more periodic inspections or less continuous inspections. The following table summarizes the quality assurance program code requirements with additional recommendations for RHCM. R means required by code. NR means not required by code but may be required for the project. P means periodic inspection. C means continuous inspection.

Quality Assurance Program

		Level 2	Level 3
Before construction			
	Verify masonry strength by prism test or the unit strength method.	R	R
	Verify compliance with mortar and grout specifications.	R	R
	Verify compliance with submittal requirements.	R	R
	Verify the grade and size of reinforcement, connectors, and anchor bolts.	R	R
	Verify and observe the construction of the sample panel, if required.	R	R
	Require a sample grout panel.	Recommended	Recommended
	Require a pre-construction meeting with the mason contractor and others.	Recommended	Recommended
During construction			
	Require verification of masonry strength every 5000 square feet of the wall.	NR	R
	Require verification that preblended mortar and grout meet specifications and submittals.	NR	R
	Require inspection of site-prepared mortar and grout.	P	P
	If self-consolidating grout, verification of conformance to the required slump flow and visual stability index is required.	R	R
	Require inspection of the grade and size of reinforcement, connectors, and anchor bolts to verify conformance to the design.	P	P
	Require inspection to verify the proper placement of masonry units and mortar joint construction.	P	P
	Require inspection to verify the size and location of structural members.	P	P
	Require inspection of the welding of reinforcement	C	C
	Require inspection to verify the type, size, and location of anchors, including other details of anchorage of masonry to structural members, frames, or other construction.	P	P
	Require inspection for protection of masonry for hot and cold weather construction.	P	P
	Require inspection of the preparation of prisms and, if required, the preparation of mortar and grout specimens.	P	C
Prior to and during grouting			
	Require inspection and verification that the size of the grout space meets the specification.	P	C
	Require inspection of the size and placement of reinforcement, connections, and anchor bolts to verify conformance to the design.	P	C
	Require inspection during the placement of grout.	C	C

In addition, the quality assurance program shall also define the qualifications for testing laboratories and inspection agencies. ASTM C 1093 defines the duties and responsibilities of testing agency personnel and the technical requirements for equipment used to test masonry materials. Testing agencies qualified to test masonry are accredited or inspected for conformance to the requirements of ASTM C 1093 by a recognized evaluation authority.

It is recommended that the following be required before construction to conform to code requirements.:

1. A letter of certification provided by the unit manufacturer stating that the units meet the required strength.
2. When the mortar is not site prepared, a letter of certification provided by the mortar supplier stating that the mortar complies with the requirements.
3. When the grout is not site prepared, a letter of certification provided by the grout supplier stating that the grout complies with the requirements.
4. Prism tests per ASTM C 1314

It is recommended that prism tests be conducted during construction and for every 5000 square feet of masonry placed. Mortar and grout should be verified in the field by checking that the proper proportions are used.

Field mortar and grout tests should not be specified. They are unreliable and too variable due to the difficulty in controlling water content.

Designer Choices

Allowable Stress Design versus Strength Design

Allowable stress or working stress design was the traditional design method for hollow clay masonry. Standards and codes are now available for strength design. For some projects, the use of allowable stress design provides some advantages, or the use of strength design provides other advantages. For example, in the current codes, the maximum shear wall flexural reinforcement in ASD is less restrictive than in SD, while ASD does not have the slender wall provisions contained in SD. Care must be exercised when combining the two design methods on the same project.

Fully Grouted Versus Partial Grouted

A fully grouted wall means that all the cells are filled with grout.

Fully grouted walls perform better than partially grouted walls. Fully grouted walls resist water penetration and cracking. Sound transmission is less in fully grouted walls, a property of the wall's mass. The wall is more able to resist freeze damage because there are fewer voids in the wall.

Partial grouting requires blocking the flow of grout into the areas not intended for grout. This adds cost to the wall. However, there is an offsetting decrease in the cost of the grout material. Most contractors agree that it is less expensive to fully grout when vertical bars are spaced closer than 24 to 30 inches on center.

It is easier, and therefore takes less time, to analyze a fully grouted wall than a partially grouted wall.

Multiple Lift Versus Single Lift Grouting

Grout pours equal to or less than 5 feet 4 inches are called Low-Lift grouting. Grout pours that exceed 5 feet 4 inches are called High-Lift grouting. A grout pour is defined as the total height of masonry to be grouted before the installation of additional masonry. A grout pour consists of one or more grout lifts.

Grouting methods may be considered the contractor's means and methods and not part of the design. However, grouting methods may impact the cost and performance of a masonry wall and may be part of the designer's choice.

In hollow clay masonry, it is advantageous to use High-Lift grouting. When demonstrated with a grout demonstration panel, grout pours with heights exceeding 30 feet have been successfully accomplished. High-Lift grouting will typically have fewer voids. The reinforcement requires fewer or no splices and therefore costs less. Generally, the grout quality improves with the increased placement volume. For these reasons, it may be appropriate for the engineer to specify High-Lift grouting methods. Otherwise, the decision can be left to the contractor.

For highly stressed walls where reinforcement and grout placement are important, it is recommended that the structural engineer specify the grout pour heights and the lap locations in the wall. Where congestion of reinforcing is a concern, staggered laps and/or mechanical splices may be specified by the designer.

To verify the materials and procedures before construction, the structural engineer can recommend to the client that they specify a grouting demonstration panel. This demonstration panel is a sample of the wall built before construction and is often used as the visual mock-up. The architect, engineer, inspector, building official, owner's representative, and the general contractor should witness the grouting demonstration. Several days after the grouting, the panel can be cut open to expose the grouted cells and assess the quality of the materials and the process.

Clean-outs

Clean-outs are access ports at the bottom cell of the grout pour for access to removing mortar droppings. Mortar droppings can prevent the grout from bonding to the surface at the bottom of the grout pour. The mortar droppings cause a weak plane to resist shear forces. For partially grouted walls, clean-outs are installed at each reinforced cell. For fully grouted walls, clean-outs are spaced not less than 32" on center.

The Code requires clean-outs if the grout pour exceeds 5 feet 4 inches.

Where the in-plane or out-of-plane shear stress is less than 15 psi when using only the face shell area, clean-outs may not be necessary. The grouted cell area is not required to transfer the load. This is often the case for long walls.

To eliminate the clean-out requirement, it will be required to ask for a building code variance from the building department.

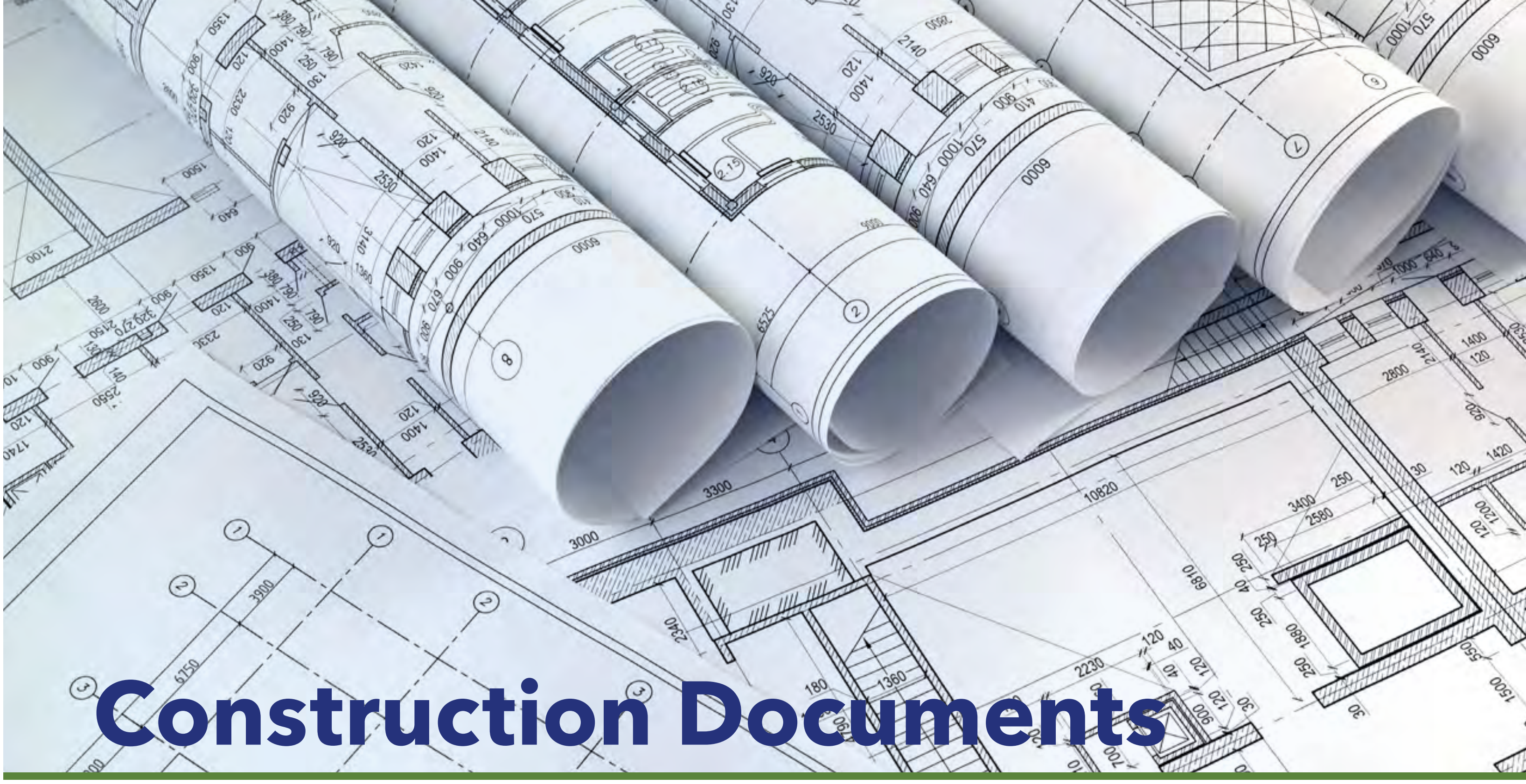
With or without clean-outs, mortar droppings should be minimized through good construction practices. Contractors can reduce droppings at the bottom of the wall by placing sponges in the cells and pulling them up as the wall is constructed. The sponges collect the mortar droppings that would otherwise need to be cleaned out at the bottom of the wall.

Horizontal Joint Reinforcement Versus Bond Beams

When horizontal reinforcement is required to resist shear forces, use bond beams. There is more confidence in the placement of bars in a bond beam than with the placement of horizontal joint reinforcement in the bed joint. This is because it is common for the joint reinforcement to be laid on the unit before the bed joint mortar is placed. The result is a void underneath the wire. It is also not unusual for the wires to be placed without lapping (butted ends). The result is incomplete embedment and development of the steel. The "butting" of horizontal joint reinforcement is a common practice in non-structural masonry and veneer. The mason may not understand the difference or importance. If joint reinforcement is used, it is recommended to require full-time inspection for its placement.

When horizontal reinforcement is not required to resist shear forces, horizontal joint reinforcement may be satisfactory and could save cost. If used, joint reinforcement must be galvanized. It is placed in the mortar joint with limited cover and must be protected from chemical attack and carbonation. Flattened or oval wire used in horizontal joint reinforcement is available in some markets. It is used to help satisfy the code wire size limitations (the wire diameter, height, cannot exceed half the bed joint height).

It is recommended that horizontal reinforcement be placed in bond beams continuously at the window sill, window and door head, and at each floor. Additionally, at least one No. 4 bar should be placed at each window and door jamb. This recommendation is for the generally good performance of the wall even when not required by code.



Construction Documents

During the construction document phase, the architect prepares the contract documents consisting of drawings and specifications set forth the detailed requirements for the construction of the project.

During the construction document phase, the structural engineer prepares the contract documents for the primary structural system consisting of drawings, including structural notes and sometimes the structural portion of the specifications.

Preparing construction documents includes structural design, analysis, drawing preparation, and writing or reviewing specifications. Each part of this process proceeds simultaneously, and they are interrelated.

Structural Analysis

Following the preliminary sizing of the primary structural elements, the global loads applied to the building are distributed to the primary structural elements. The loads are distributed to each element by methods that have become customary in structural engineering. There are several commonly used software programs available for this purpose. Stairs and ramps that are not isolated, while seldom constructed of masonry, resist wind and lateral seismic loads and must be included in the model accordingly.

For RHCM shear wall buildings, if the finite element model is used, wall expansion joints, if any, need to be modeled. If there are intersecting walls, the structural engineer needs to recognize that due to warping effects, the structural elements will have axial loads and moments resulting from torsion on the system. The design may be simplified by not connecting intersecting walls in the model. Reinforcing details can be simplified, but the overall resilience of the building is reduced. For seismic design, if the mass of the walls is included with the floors or roof, then diaphragm loads will be overestimated.

Once the loads on the walls, columns, and elements are known, the elements can be checked to ensure conformance with acceptable standards. The building code is a minimum acceptable standard. The design may or may not require a higher standard than the building code. The structural engineer should communicate options for increasing the resilience above the code minimum to the architect and owner.

A detailed discussion of the structural analysis procedures is contained in many excellent references. The following paragraphs present information commonly encountered during the structural analysis and design of RHCM structures. Appendix B provides a checklist for the design of RHCM.

Design Assumptions

The analysis for determining the strength of RHCM elements is very similar to that used to check the strength of reinforced concrete elements. Standard assumptions for strength design are:

1. Plane sections before bending remain plane after bending.
2. Masonry components (units, mortar, and grout) combine to form a homogeneous member.
3. Masonry carries no tensile stresses.
4. Reinforcement is completely surrounded by grout and bonded to the masonry materials, so they work compositely as a homogeneous material in the range of working stresses.
5. The building code limits the yield strength of reinforcement to 60,000 psi.
6. The maximum usable strain in clay masonry is 0.0035 (It is 0.0025 for concrete masonry).
7. The compression stress block height is 0.80 f'_m for a distance of 0.80 times the distance from the extreme compression fiber to the neutral axis.

Additionally, for ease of design, the following recommendations are made for the area of masonry to be used in resisting the loads.

1. For partially grouted RHCM walls, it is recommended and conservative to use the face shell area of the unit as the shear design area. For partially grouted RHCM, the code allows shear areas to be increased by counting the grouted cells, but the advantage is usually small. Also, for partially grouted walls, the nominal shear capacity is reduced by a factor of 0.70.
2. For fully grouted (sometimes referred to as solidly grouted) RHCM walls in running bond, the design area is the gross cross-sectional area of the masonry. The area of cores (most hollow clay masonry units have cores) or the void at the head joint when the masonry is laid with only face shell bedding is not subtracted from the gross area.
3. For beams with compression on the head joint and the requirement of full bedding of the head joint is not made, the design area is the face shell area for shear and flexure. This is because the head joint is filled to the face shell's depth, not the unit's full thickness. If bond beams or open-end units are used, then the design area would be the full thickness of the unit.

General

There are provisions of the code limiting the design:

1. Vertical conduits, pipes, or sleeves shall not exceed 2 percent of the net design area.
2. Pipes or conduits containing liquids, gas, or vapors at temperatures above 150 degrees Fahrenheit, pressure greater than 55 psi, or water or other liquids subject to freezing shall not be placed in the masonry.

Walls

For out-of-plane bending, the effective width "b" of the compression block is the lesser of:

1. The distance between bars.
2. In running bond, six times the nominal thickness.
3. In stack bond, the unit width.

If partially grouted, the compression area of the wall (distance to the neutral axis) needs to exclude cells not grouted. This can lead to a more complicated analysis to determine capacity.

For in-plane bending, "b" is the thickness of the wall if fully grouted. If partially grouted, the face shell area is recommended to be used. Using b as the two-face shell thicknesses is conservative.

For in-plane bending, the effective width of intersecting walls differs for compression and tension. For compression, the code allows the flange width to be 6 times the nominal thickness on each side of the intersecting wall; for tension, the maximum is 0.75 times the floor-to-floor height.

Walls Flexure Plus Compression

Flexure plus compression occurs for walls resisting lateral forces from wind or seismic loads. Software is available for checking a wall loaded with combined flexure and compression. Or, create your own. Dead load reduces the required reinforcement area when the tensile moment capacity limits an element. When intersecting walls occur, analysis can be complicated. Don't forget to include the dead load of the wall in your analysis.

For walls with a height to a nominal thickness greater than 24, second order or moment magnification effects should be considered.

Shear Walls

For shear walls resisting seismic forces, there are code-specified reinforcement requirements. For RHCM, the choices of shear wall types are Detailed Plain, Ordinary Reinforced, Intermediate Reinforced, and Special Reinforced.

The minimum reinforcement required for a Detailed Plain shear wall is shown below. Detailed Plain shear walls are only allowed in Seismic Design Categories A and B and are designed as unreinforced masonry.

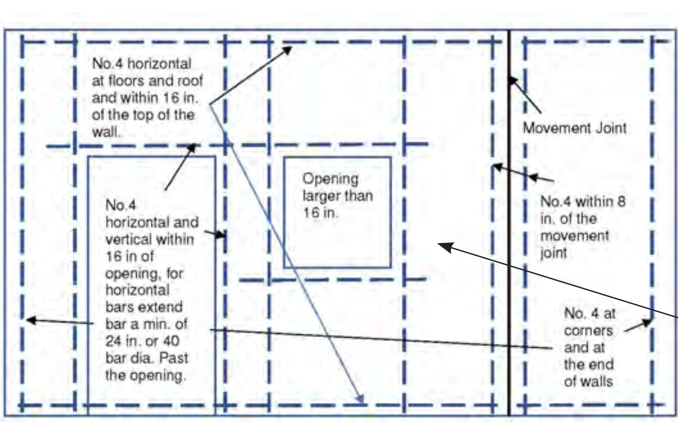


Figure 30 Minimum Reinforcement for RHCM

If your project is a Seismic Design Category C project, then Ordinary Reinforced shear walls, Reinforced Intermediate shear walls, or Special Reinforced shear walls are required. Ordinary Reinforced shear walls have the following additional requirements.

Ordinary Reinforced Shear Wall:

1. Reinforced masonry design is required.
2. Maximum spacing of vertical reinforcement is 120 inches.
3. Maximum spacing of horizontal reinforcement is 120 inches.

Intermediate Reinforced Shear Walls has the following additional requirement:

1. Maximum spacing of vertical reinforcement is 48 inches.

If your project is a Seismic Design Category D, E, or F, then Special Reinforced shear walls are required. Special Reinforced Shear Walls have the following additional requirements:

1. The maximum spacing of vertical reinforcement is smaller than 1/3 the height of the wall or 1/3 the length of the wall or 48 inches. For stacked bond masonry (less than ¼ the length of the unit overlapping), the maximum spacing is 24 inches.
2. The maximum spacing of horizontal shear reinforcement must not exceed 1/3 the height or length of the wall. For walls of short length, this can present a problem. For example, a wall consisting of a single stretcher (12-inch length) between windows will require horizontal reinforcement at 4 inches on center, or for 4-inch height units, every unit is a bond beam. In this situation, it may be best to isolate the element from the seismic resisting system. Another possible solution is a displacement compatibility analysis to demonstrate that the element can withstand the required displacements.
3. Maximum spacing of horizontal reinforcement for running bond is 48 inches and 24 inches for stack bond.

4. The sum of vertical and horizontal reinforcement must exceed .002 times the gross cross-section using specified wall dimensions, with a minimum vertical or horizontal reinforcement equal to .0007 times the gross cross-section using specified dimensions. The minimum horizontal reinforcement required for stack bond masonry is .0015 times the gross cross-section using specified dimensions.

5. Stack bond masonry must be fully grouted and use open-end units. Open-end units only need to be open on one head joint for the grout to bond to the next unit.

6. If the shear demand to only the masonry shear capacity ratio (not including the reinforcement capacity) is more than 0.40, 180-degree hooks around the vertical reinforcement at the end of the wall are required. Engineering judgment is required, and a rule of thumb is that if the shear walls' height-to-length ratio is less than 1, hooks will likely not be required.

7. The design shear capacity shall exceed a shear corresponding to 1.25 times the nominal flexural capacity but not exceed 2.0 times the factored shear demand. This provision is intended to enhance flexural ductility by increasing the wall's shear capacity.

Also, in E and F, there is an additional reinforcement requirement for walls that are not shear walls or non-participating walls.

For more detailed information on the design of Special Reinforced Masonry Shear Walls, see *Seismic design of specially reinforced masonry shear walls: A guide for practicing engineers*, NIST GCR 14-917-31, prepared by the Applied Technology Council for the National Institute of Standards and Technology, Gaithersburg, MD.

Columns

There are special code provisions for columns:

1. The distance between lateral supports of a column cannot exceed 99 times the radius of gyration of the column in the direction of support.

2. The minimum side dimension cannot be less than a nominal 8 inches.

3. The minimum number of longitudinal reinforcement bars is 4.

4. Columns must be fully grouted.

5. The area of vertical reinforcement must be greater than 0.0025 times the net area of the column and not more than 0.04 times the net area of the column.

6. The effective height of a column can be taken as the distance between inflection points. But it is recommended to use the unsupported height. For cantilevered columns, use twice the unsupported height.

7. Lateral ties of at least ¼ inch diameter shall enclose the vertical reinforcement. Spacing shall not exceed 16 longitudinal bar diameters, 48 tie diameters, or the least cross-sectional dimension of the column.

8. If allowable stress design is used, the code requires a 10% eccentricity axial load in the column. For strength design, the eccentricity is accounted for in the code equations.

9. In seismic design category C and above, when anchor bolts are used at the top of a column to connect to horizontal elements, adding two No. 4 ties within 5 inches of the top of the column is required.

10. In seismic design category D and above, lateral ties must be spaced at less than 8 inches on center and be 3/8 inch in diameter or greater.

11. In seismic design category C and above, along a line of lateral force resistance, not more than 20 percent of the resistance may be provided by masonry columns. This requirement is overly restrictive and without justification for buildings such as a single-story firehouse where one of four walls has garage door openings separated by columns. There is no reason that the columns property detailed cannot exhibit adequate ductility to accommodate seismic displacements.

    The masonry code offers an exception, but only if designed for an R of 1.5. ASCE/SEI 7 does not recognize this exception. It is not addressed in the IBC. If it is not clear which code applies, check with the authority having jurisdiction.

Placing a bearing pad, allowing lateral displacement while supporting the axial load, could be an option. Another option is to use a concrete or steel column and a brick veneer or a reinforced veneer surround.

Another possible solution is a displacement compatibility analysis demonstrating that the element can withstand the required displacements.

Fortunately, in seismic design categories A, B, and C, the code provides an exception to these restrictive column requirements for lightly loaded columns. Lightly loaded columns are defined as columns with an axial load not exceeding 2000 lbs. The requirements are only an 8-inch minimum dimension, fully grouted, more than 0.2 square inches of reinforcement, and not to exceed a height of 12 feet.

Pilasters

The code definition of a pilaster is a vertical member built integrally with a wall, with a portion of its cross-section typically projecting from one or both faces of the wall. The word typically is inserted in the definition because, in some applications, a pilaster is contained within the wall, not projecting from either side.

For the intersecting wall to be considered part of the pilaster, it needs to be connected to the pilaster element by one of the following.

1. At least 50 percent of the masonry units interlock.
2. Walls need to be anchored by steel connectors.
3. Intersecting reinforced bond beams spaced less than 48 inches on center.

The effective width for compression will depend on the pilaster's geometry and the moment's direction. The effective width is generally the same as that for intersecting walls. For compression, the code allows 6 times the nominal thickness of the intersecting wall; for tension, the maximum is 0.75 times the floor-to-floor height. When the pilaster projects from one side of the wall or unevenly on both sides of the wall, the effective width, if any, will be different depending on the direction of the moment.

When the height divided by the radius of gyration (generally equal to .288 times the thickness) exceeds 99, second-order or moment magnification effects need to be considered. This will need to be considered for both moment directions.

Bar laps and Embedment

The Code provides methods for the design of bar laps.

Alternatively, use 48 bar diameters for grade 60 reinforcement. This is conservative for RHCM units of nominal 8 inches or less for number 6 bars or less and placed at the center of the wall. For number 7 bars in 8-inch units, it is unconservative by about 10 percent.

Whenever possible, it is recommended that laps do not occur where the stress in the bar approaches the yield stress. If the stress in the bar exceeds 80% of the yield stress (48,000 psi for grade 60 bars), it is recommended to increase the lap length to 72 diameters, although not required by code.

Deflection

Deflection calculations are approximate. This results from the uncertainty about the value of the elastic modulus and the distribution and depth of cracking throughout the section. Fortunately, it is uncommon for a masonry element to be limited or sized based on the expected deflection. When deflection calculations are required, such as when height-to-thickness ratios are high, the methods presented in the building code give some indication of the deflection magnitude. The IBC provides deflection limits for exterior and interior walls with various surface finishes.

Maximum Bar Size

There are building code limitations on the sizes of reinforcement. No. 11 bar was recently allowed, but some previous codes limited the size to a No. 9. The nominal bar diameter cannot exceed one-eighth the nominal unit thickness. The maximum reinforcement in a cell is limited to 4 percent of the cell area or 8 percent with splices. The maximum diameter of the reinforcement shall not exceed one-third of the minimum dimension of the gross grout space. Additionally, there are minimum grout cover requirements for the space between the edge of rebar to the edge of the grout cell of ½" and ¼", for coarse grout and fine grout, respectively. The following table presents the typical maximum bar size for the hollow clay units. However, the cell areas vary somewhat from manufacturer to manufacturer, and dimensions should be verified on each job.

Maximum Bar Size by Cell Size

Unit Thickness (Nominal)[2]	12” Long Units		16” Long Units	
	Cell Size (Width x Length)	Max. Bar Size #	Cell Size (Width x Length)	Max. Bar Size #
4"	1 3/4 X 3 1/2	4[1]	1 3/4 x 3	4[1]
5"	2 1/2 X 3 1/2	5[1]	2 x 5	5[1]
6"	3 1/2 X 3 1/2	6[1]	3 x 5	6[1]
8"	5 X 3 1/2	8[1]	5 x 5	8[1]
10"	6 3/4 X 3 1/2	10[1]	6.5 x 5	10[1]
12"	8 1/2 X 3 1/2	11	8 x 5	11

1. Controlled by one eight of the nominal unit thickness.
2. 10 and 12-inch thick units may not be available – check with the manufacturer.

Retaining Walls

Failure of retaining walls constructed of concrete, masonry, and other materials occurs frequently. Carefully analyze the soil information (have a soil report, if not, then require one), and use proper analysis methods (it can get complicated). It is recommended to place the reinforcement in the center of the cell, not offset. Many failures are traceable to the contractor placing the bars on the wrong face of the wall. The added reinforcement costs are usually small.

Bearing, Bolts, and Shear Friction

The Code provides a design method.

Drawing Preparation

Layout

The following figure presents a typical layout of the structural drawings for a building project.

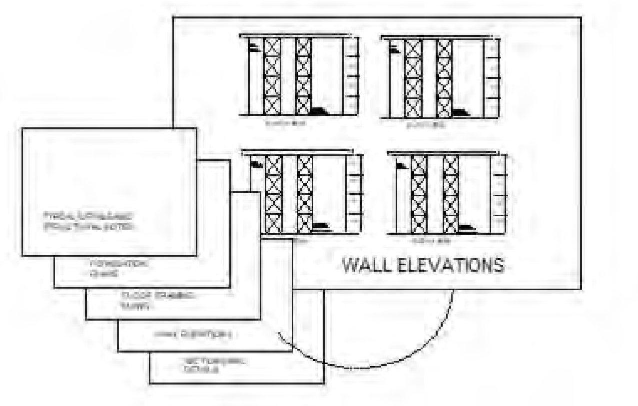


Figure 31 Recommended Drawing Layout

When RHCM is used, it is normal to prepare elevations of each wall. This may appear to be an unnecessary level of drawing detail, but experience indicates that it saves time and effort in the long run. Wall openings, expansion or movement joint locations, and reinforcing should be shown or called out on these elevation drawings. Tabulating reinforcement requirements has not proven to be a very successful method of communicating the design to the mason.

Provide a detail that shows the hollow clay unit dimensions so that the reinforcement detailers have the information to lay out the reinforcement. Additionally, expansion joints should be shown and coordinated with the architect's drawings.

Structural Notes

The structural notes are placed on the drawings to define applicable codes, loads, design assumptions, materials, and inspection requirements. Often this information is redundant to the project specifications. However, the project specifications often become lost with time. The structural notes will stay with the drawings and become useful information for some future users.

In some states, the structural notes take precedence over the specifications. In other states, the reverse is true. The architect's specification and the structural notes should state which takes precedence over the other.

The structural engineer should check the architectural specification to eliminate conflicts with the structural notes.

Details

RHCM can generally be treated like reinforced concrete, except the bond strength between the mortar and a unit is a plane of weak tension capacity. The head joints are particularly susceptible to low tension and shear capacity, and it is appropriate for the designer to assume zero tension and shear capacity for the head joint. This is important for the design of masonry connections. It is recommended that larger scale or more frequent connections be made than are typically used in reinforced concrete.

Unit dimensions restrict reinforcement spacing. Vertical bars need to be spaced to match the cell spacing, and horizontal bars need to be spaced at dimensions matching the unit height. Diagonal bars should not be used. Placing vertical bars that are 16 inches on center for a 12-inch hollow clay brick, with cells at 6 inches on center, will be generally viewed as a design error.

RHCM is normally supported on concrete or steel. The detail of the connection between the concrete or steel and the masonry is affected by the control of water and the transfer of forces. Where the exterior masonry is supported on a concrete floor or slab, it is often desirable to recess the concrete.

Water and Flashing

Water seldom completely penetrates a reinforced hollow clay wall. Instead, it enters the face of the wall and travels downward through open cells or small voids in the grout and mortar. Fully grouted walls are less susceptible to water penetration. The inside face of the wall may become damp; however, it is unusual for water to disengage from the brick or flow on the inside surface.

For this reason, the base or bottom of a wall requires flashing or another method to direct water to the exterior. The water traveling downward through the brick should be intercepted and directed outside the building. A lintel over the top of a window or door is considered a bottom of the masonry and therefore requires flashing or appropriate window head design.

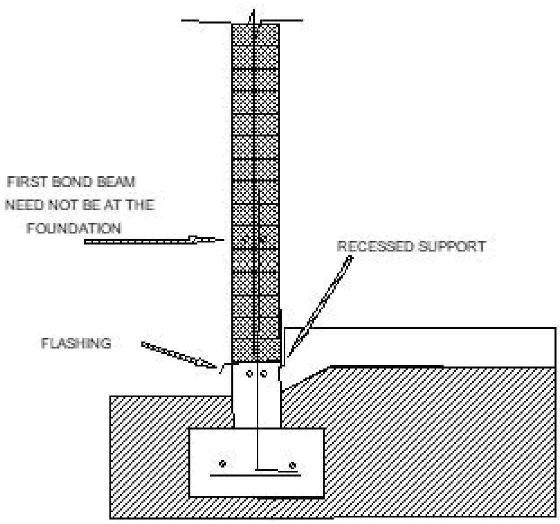


Figure 32 Wall to Foundation Detail

There are many acceptable flashing materials available. The architect should select the flashing. For the structural design, all commonly used flashing materials provide sufficient friction capacity to transfer shear loading. However, dowels will need to penetrate the flashing to transfer the shear load. Shear transfer tests indicate that the organic flashing materials transfer load better than the metal materials. This is probably because the organic materials mold to the roughness of the concrete and mortar more than the rigid material.

The code provides a method to analyze the capacity using shear friction.

Connections

Floor and roof connections to walls can take many forms. They are similar to connections to concrete walls, except the designer has more flexibility because the units are laid one at a time. Consider using embeds to connect ledgers.

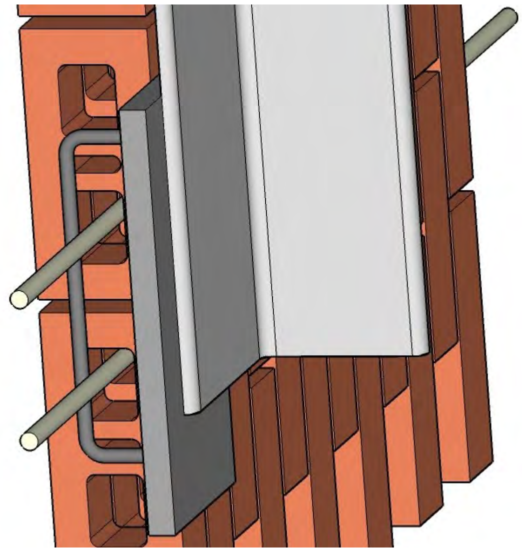


Figure 33 Embed Plate for a Ledger Connection

Movement Joints

Movement joints are challenging design item. In addition to normal thermal expansion and contraction, brick expands permanently with moisture. This permanent volumetric change is called irreversible moisture expansion and differs from concrete or CMU irreversible shrinkage and cyclic moisture expansion and contraction. Irreversible moisture expansion of brick occurs only once over an extended period of time. It does not reverse.

After the brick is fired, there is no moisture in the brick. When placed in the environment, the brick absorbs moisture through exposure to the atmosphere containing humidity or by direct contact with water. As the brick absorbs moisture, the brick irreversibly expands. The amount of permanent, irreversible expansion depends on the type of clay. The length of time required depends on the clay and exposure. The vast majority of the permanent expansion occurs between one and five years after production. TMS 402 provides a value of 0.0003 inches per inch or 3/8 inches per 100 feet for irreversible moisture expansion. This value is typically used for design. Movement joints related to the inherent expansion of the clay brick are called expansion joints. Expansion joints are important to the performance of unreinforced clay masonry. For reinforced hollow clay masonry with horizontal reinforcement, expansion joints are less important and often are not required. As the brick expands, the reinforcement resists the expansion. The result is that the reinforcement is placed in tension, and the brick is placed in compression. The consequence is less cracking. Nevertheless, placing expansion joints at 100 feet or less is common practice.

If the wall length exceeds 20 feet, expansion joints should also be placed on one side of a corner, near the corner. Without a corner expansion joint, the expansion of the brick in the wall results in flexural stresses in the brick on the other side of the corner and may cause a crack.

Movement joints other than expansion joints may be needed to accommodate differential movement at interfaces between dissimilar materials or systems, or changes in supports or steps in foundations, or at wall intersections, depending on the design assumptions related to load transfer between walls.

Another requirement for expansion joints occurs when a brick becomes confined by another material. The following figure shows an example of hollow clay confined in a concrete frame.

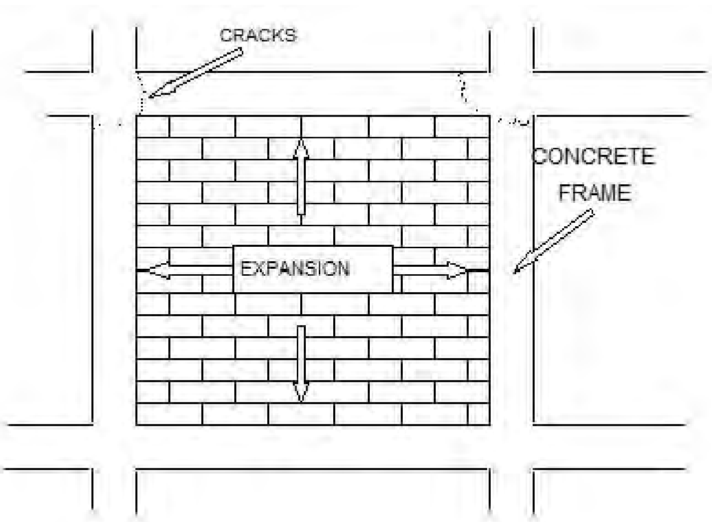


Figure 34 Brick Masonry in a Concrete Frame

Specifications

Specifications are normally prepared by the architect and reviewed by the structural engineer.

Consider including:

1. Require the mason subcontractor to prepare or oversee the preparation of reinforcing shop drawings. The shop drawing preparer should be familiar with reinforced hollow clay masonry design and construction. Concrete reinforcement detailers generally do not have an appreciation for the construction sequencing and dimensional constraints for masonry.
2. Require the water repellent to be the responsibility of the mason subcontractor. This provides a single source of responsibility in the event of problems.
3. On a large project, require a grout placement demonstration test on a sample panel prior to construction. With adequate planning, the visual mock-up panel can be used for this purpose.
4. Limit the choice of mason contractors to those experienced with the construction of RHCM. Reserve the ability to disqualify the contractor based on past performance.

The designer can influence the selection of the mason contractor through the specifications. It is recommended that the following criteria be considered in the section:

(a) Require the contractor to employ experienced masons.

(b) If available, require the mason contractor to be a member of a local masonry institute. Call the institute or the material supplier to check the contractor's qualifications or provide a list of qualified bidders.

(c) If possible and where available, require the mason to have appropriate training and be certified by the local masonry institute or council or association.

(d) Require masons who have been trained by the International Masonry Training and Education Program, of the International Masonry Institute.

5. Require a preconstruction conference.
6. Require methods other than shovel count to control proportions for mortar and grout.

7. If site mixed mortar is used, require the sand pile to be protected from rain, snow, and dust. Require the walls to be protected from rain, snow, and freezing for a minimum of 7 days after construction.

   The best practice may be to require preblended, pre-bagged mortar to maintain uniformity of material properties and color.

   Require the mason contractor to cover the wall at the end of the day. The purpose is to prevent rainwater from entering the masonry and developing water paths through the fresh mortar and grout. If not covered, the likely result is a wall that leaks and effloresces.

8. Require hot and cold weather protection. Code provisions may not be adequate. For example, in the Pacific Northwest, winter rain followed by a sudden freeze may damage the masonry.
9. Require inspection prior to grouting and during grouting.
10. Consider requiring self-consolidating grout.
11. Place a table of tolerances on the plans or include one in the structural notes. The code defines placement tolerances for reinforcement in terms of the design parameter “d”. Unfortunately, the mason contractor has no idea what “d” is.
12. Require the mason contractor to submit a written quality control program for the masonry construction.
13. For the installation of foundation dowels, provide an option to use post-installed anchors.

Construction

The project's construction phase begins with the publication of the construction contract for bidding. During the construction phase, the architect is the owner's representative and advises and consults with the owner. Instructions to the contractor are forwarded through the architect.

During the construction phase, the structural engineer advises and consults with the architect as necessary and when requested. The structural engineer responds to bidders' questions about the design. Once the contract is awarded, the structural engineer reviews submittals by the contractor of items designed by the engineer or other items affecting the engineer's design. The engineer makes periodic site observations to ensure that the contractor is in general conformance with the intent of the structural design.

A reinforced hollow clay masonry project requires about the same effort during the construction phase as other structural systems. However, there are a few unique situations. This section describes some of these situations.

Bidding and Award

The mason contractor is normally a subcontractor to the general contractor. During bidding, the general contractor will typically take bids or cost estimates from more than one mason subcontractor. During this period, the engineer will likely receive requests to clarify the contract documents.

The structural drawings show the design concept for the project. They are not detailed construction drawings. It is likely that during the bidding process, the contractor will find some missing information or contradictory information on the drawings. This is normal, and it is normal to receive questions about the design during the bidding period.

Often the mason contractor does not supply the reinforcement for the project. Instead, the general contractor supplies it. The engineer should become aware of who will supply the reinforcement. It will have some influence on how the project proceeds.

Moreover, most mason contractors do not prepare shop drawings for reinforcement. Thus, the responsibility for providing an adequate set of shop drawings can become lost in the bidding process. The general contractor thinks the mason will prepare the shop drawings and the mason thinks the general contractor will prepare the shop drawings.

Experience has shown that the best performance occurs if the mason contractor purchases the reinforcement and supplies the shop drawings. However, some mason contractors may bid high or even not bid at all due to this requirement. The resulting cost pressure may require the engineer to be flexible about the requirement for shop drawings and their preparation.

Sometimes the general contractor will supply the shop drawings using his concrete reinforcing detailer. Unfortunately, the detailer may have limited experience with masonry (their expertise is concrete), and the drawings are often full of errors or items that cannot be constructed. An example is when the shop drawing shows bars spaced at 8 inches on center for a RHCM unit with a 6-inch module.

Submittal Review

Items submitted for review include the following:

1. Mortar proportions and laboratory test:

   The mortar submittal is usually submitted by Type (Type M, S, or N). This is satisfactory, provided the proportions are used to define the type, not strength.

   The contractor may submit by strength. In this case, laboratory tests should be performed to verify the strength of the mortar.

   Preblended dry mix mortars require submittal to verify conformance with ASTM C1714.

2. Grout proportions:

   The grout submittal is usually submitted by Type (fine or course). This is satisfactory, provided the proportions are used to define the type, not strength.

   If the design f'_m exceeds 2,000 psi, laboratory testing is required by the most recent TMS 602 to verify that the grout strength equals or exceeds f'_m. Testing is in accordance with ASTM C 1019.

   For batch-provided grout, the proportions are normally described by weight. The weight proportions should be converted to volume proportions for comparison with ASTM C 476. An example calculation of an actual grout submittal on a project follows:

Example Calculation of Volume Proportions from Weights

Item	Batch Weight (Lbs)	Conversion to Volume (Lbs/cu. ft)	Volume (cu. ft)	Proportions (by volume)
Cement	658 or 7 sacks	94[1]	7.0	1
Lime	50	40[2]	1.25	.18
Sand	2143	80[3]	26.8	3.8
Aggregate	1009	105[4]	9.6	1.37
Water	260	62.4	4.17	.6

1. 94 lbs per bag
2. One 50 lbs bag is 1 1/4 cu. ft
3. ASTM C-476 specifies 80 lbs per cu. ft for loose, damp sand (5% moisture). Dry sand weighs approximately 100 lbs per cu. ft.
4. Dry-rodded unit weight obtained from the supplier

A comparison ASTM C 476 is given in the following table.

Comparison to ASTM C 476

Item	ASTM 476	Mix
Cement	1	1
Lime	.1	.18
Sand	2.5-3.3	3.22[1]
Aggregate	1.1-2.2	1.16[1]
1. Proportions of cementitious material include both cement and lime		

The sample mix design does not comply. However, the mix design was accepted on this project because of past experience with the proportions where the additional lime in the mix improved flow while maintaining strength. ASTM C 476 allows proportions of the grout ingredients to be determined by laboratory testing or field experience if a satisfactory history of the grout mix performance is available.

3. Unit certifications:

   If the Unit Strength Method was used to establish f'_m, the structural engineer should specify that the brick supplier submits a letter stating that the bricks meet the required compressive strength.

4. Reinforcement shop drawings:

   These should be scheduled to provide sufficient time for review and resubmittal prior to construction. However, reviewing the submittal is necessary to verify that the contractor understands the design correctly. If enough time is available, re-submittal is possible without costly delays.

5. Miscellaneous metal shop drawings:

   Where miscellaneous steel connections and embedded items are included in the design, shop drawings need to be submitted with sufficient time for review.

6. Quality control program:

   TMS 402-22 requires the construction documents to include a written quality control program. A conforming quality control program should be written by the mason contractor and submitted in time for review and discussion with all involved including the inspector and general contractor.

Pre-Construction

Once the general contractor and the mason subcontractor have been selected, the engineer may verify their qualifications with the local masonry institute and material suppliers. This information will help determine the time and effort needed during construction.

At an appropriate time, usually, at least two weeks before the start of masonry construction, arrange for a preconstruction conference to discuss the masonry construction. Attendees should include:

1. The mason contractor and foreman.
2. The general contractor and superintendent.
3. The building official.
4. The architect.
5. The special inspector, when required.
6. The structural engineer.
7. The owner's representative.
8. The brick supplier or designated representative.

Subjects for discussion include:

1. Brick:

   Determine the availability and delivery schedule of the selected brick. If the unit strength method is used, verify that the brick will meet the required strength.

2. Initial testing:

   If the unit strength method was used to establish the design strength f'_m, mortar, grout, and prism testing prior to construction are not required. However, prism tests prior to construction are recommended.

   As a minimum, unit testing or manufacturer's certification is required. If a grouting test panel is to be used, define the schedule. The engineer, building official, and the special inspector should be present for the grouting demonstration. Often the grouting demonstration panel can also be used by the architect as a color and quality control panel.

3. Testing during construction:

   For risk category I, II, and III buildings, prism testing is recommended, but not required by code, for every 5,000 square feet of wall. For risk category IV buildings, prism testing is required for every 5,000 square feet of wall. Prior to construction, five prisms constitute a test. During construction, three prisms constitute a test. However, five are recommended during construction. Test the first one at seven days, the next three at 28 days, and hold the final sample for testing in case of a problem.

4. Inspection:

   The inspector should regularly check the batching of mortar and grout to ensure proper proportions or that the supplied preblended dry mortar mix meets the specifications and that the proper amount of water is added. The inspector should regularly check the laying of units to ensure proper workmanship. Continuous inspection during the placement of grout is required. The inspector should verify and ensure full compliance with the contract documents for the placement of reinforcement, grouting, consolidation, reconsolidation, top of the wall shear key, and the protection of the masonry from rain, dirt, and cold and hot weather.

5. Observation:

   Inform all participants that, from time to time, the engineer will visit the site to ensure general compliance with the contract documents.

6. Inspection Reports:

   Normally, special inspection and test reports and inspection reports go to the general contractor and the architect and then to the engineer. Deviations from this normal procedure should be discussed, defined, and documented.

7. Submittals:

   Verify that the contractor is using the approved project submittals.

8. Cleaning and Sealing:

   The procedures to clean and seal the masonry with water repellant should be discussed. It is important that the mason contractor verify the cleaning method with the unit manufacturer. If the wall is to be sealed with a water repellant, the method and materials to be used should also be verified with the brick manufacturer.

   Proper sealers do not seal the wall. The masonry must breathe. The sealers are actually only water repellents.

9. Construction Sequence and Schedule:

   Discuss the schedule for inspection and testing. Discuss coordination issues. One usually missed item is the coordination with the window and door supplier. The design of the connections should be discussed.

Site Visits

The structural engineer should make site visits to check on the progress and quality of the work. This part of the engineer's scope of services is called structural observation. Structural observation is required for most projects by the IBC and is defined as follows:

"The visual observation of the structural system by a registered design professional for general conformance to the approved construction documents."

Structural observation does not include or waive the responsibility for the inspection required by other code sections.

Masonry walls failing during construction, particularly those employing high lift grouting, happen more frequently than they should. While it is not the structural engineer's responsibility to evaluate the contractor's means and methods, if the shoring of the wall does not look adequate, the structural engineer should inform the contractor and document that the information was given.

An example site observation form and checklist are provided in Appendix C.

Non-Conforming Quality Control Tests

Prism Compression Strength – Prior to Construction

If the prism test prior to construction does not comply with the required strength, there are many possible reasons. Often, and particularly for larger units (8 inches and above) with a specified compression strength exceeding 2,600 psi, the problem is often the testing method. It is not uncommon for the platen used to be too thin or the prism surface to be not flat. The brick may not be strong enough, or the mortar and grout may not be the appropriate mix.

Prism Compression Strength – During Construction

When prism tests do not conform, verify that the materials used (units, mortar, and grout) conform to the specifications. If they do conform, either the prism was improperly constructed, or the testing procedures did not comply with ASTM C 1314.

Prism construction errors include not constructing the prism true and plumb. It is very important that the top and bottom planes of the prism are parallel. Another common problem for large cell units (8" units and larger) is that the grout is not properly reconsolidated. Without proper reconsolidation, a dome-shaped void will often form at the mortar joint and render the area of grout ineffective for resisting compression.

Common testing errors include not properly capping the prism so that the top and bottom planes are level and parallel, not providing a thick enough loading platen to distribute the test machine load evenly to the prism, and the prism is not centered in the testing machine when loaded.

When confronted with a non-conforming wall (a low prism test for the wall), the first step is to recalculate the structural design to verify that the strength specified is required. If this does not work, the next step is to cut a prism from the wall and test it. Usually, prisms taken from the wall will test with higher compression than the sample prism. If this fails, the wall will likely need to be removed, materials changed to meet the required strength, and the wall reconstructed.

Mortar Compression

It is recommended that field testing of mortar not be required. However, the requirement for mortar testing often is outside the structural engineer's control, and on some projects, mortar testing becomes a requirement (See Appendix D for more information).

Grout Compression

It is recommended that field testing of grout not be required. However, when f'_m exceeds 2,000 psi, TMS 602-22 Section 2.2 B (Specifications for Masonry Structures) requires verification of grout strength by testing in accordance with ASTM 1019 (See Appendix D for more information). This requirement is interpreted as prior to construction rather than verification during construction.

APPENDIX A: WSCPA Members

Western States Clay Products Association
website: www.wscpa.us

Manufacturing Members

Inerstate Brick Company
9780 South 5200 West
West Jordan, UT 84081-5625
Phone: (801) 280-5200
https://interstatebrick.com

McNear Brick & Block
1 McNear Brickyard Rd.
San Rafael, CA 94901-8310
Phone: (415) 453-7702
https://www.mcnear.com

H. C. Muddox/Gladding McBean
4875 Bradshaw Road
Sacramento, CA 95827
Phone: (801) 280-5200
https://www.gladdingmcbean.com

Mutual Materials Company
605 - 119th NE
Bellevue, WA 98005
Phone: (425) 452-2300
https://www.mutualmaterials.com

Summit Brick Company
601 E. 13th Street
Pueblo, CO 81001-2942
Phone: (719) 542-8278
https://www.summitbrick.com

Allied Associates Contacts

Arizona Masonry Council
3133 West Frye Road Suite 101
Chandler, AZ 85226
Phone: (602) 265-5999
https://www.azmasonry.org

Masonry Institute of America
1315 Storm Parkway
Torrance, CA 90501-5041
Phone: (310) 257-9000
https://www.masonryinstitute.org

Masonry Institute of Washington
11900 NE 1st Street, Ste 300
Bellevue, WA 98005-3049
Phone: (425) 214-7476
www.masonryinstitute.com

Rocky Mountain Masonry Institute
6145 Broadway Suite 44
Denver, CO 80216
Phone: (303) 893-3838
https://rmmi.org

Utah Masonry Council
4001 South 700 East #500
Salt Lake City, UT 84107-2177
Phone: (801) 264-6651
https://utahmasonrycouncil.org

APPENDIX B: Drawing Checklist

No.	Item	Checked
1.0	STRUCTURAL NOTES	
	Is the applicable code specified (city and date)?	
	Are the applied loads shown, including wind, seismic, and live loads?	
	Is the masonry strength f'_m specified?	
	Is the method to verify the f'_m specified? (Unit strength method.)	
	Are the units specified in accordance with ASTM C 652 with sufficient compressive strength to meet the f'_m specified?	
	Is cement specified in accordance with ASTM C 150 types I, II, or III? Is low alkaline cement available?	
	Is lime specified in accordance with ASTM C 207?	
	Is sand specified in accordance with ASTM C 144?	
	Is the mortar specified by proportions in accordance with ASTM C 270?	
	Is the grout specified in accordance with ASTM C 476?	
	Is self-consolidating grout specified in accordance with ASTM C 1611/C1611M?	
	Is high or low lift grouting specified?	
	For high lift grouting, are clean-outs to be eliminated with a code variation?	
	Is reinforcement specified in accordance with ASTM C 615 grade 60?	
	Is ASTM A 706 reinforcement specified when welded?	
	Is the quality assurance program included? (Required by code)	
	Is a grouting demonstration panel required?	
	Is there a requirement for a preconstruction meeting?	
	Are reinforcement shop drawings required?	
2.0	DESIGN	
	Is h/t less than 30? If not, verify the design includes analysis for moment magnification.	
	Are the walls at floors and roof laterally supported with straps or other methods capable of resisting at least 400 lb/ft?	
	Do the bars fit in the cells?	
	Are locations and length of laps shown? Are there locations where stresses are more than 80% of the allowable?	
	Are dowel laps sufficient?	
	Is there continuous horizontal reinforcement at the window and door head and jambs?	
	Is there continuous horizontal reinforcement at the floor?	
	Are window and door connections designed and shown on the drawings?	
	Are there expansion joints at the corners, and are they at or near the corners?	
	Are provisions made in connections to accommodate thermal and moisture expansion movement?	
	Is the brick masonry confined between other materials without expansion joints?	

No.	Item	Checked
3.0	SPECIFICATIONS (Additional items not typically in the structural notes)	
	Are the structural notes and specifications consistent?	
	Are control joint size, size, and materials specified?	
	Are control joint sealant compatibility tests required?	
	Are the cleaning methods included?	
	Does the specification allow wetting of the brick?	
	Are the joint finishes specified? If raked joints are used, is this in the analysis?	
	Are weep holes and fill materials specified?	
	Are the sealing, water repellant, procedures, and materials specified?	
	Are cold weather and hot weather construction provisions included?	
	Are requirements for protecting the work included?	
	Is it required to verify dimensions prior to laying the masonry?	
	Is a written quality control procedure required?	
	Is a color, pattern, and workmanship panel required?	

APPENDIX C: Construction Observation Checklist

No.	Item	Checked
1.0	MATERIALS	
	Are the bricks stored above ground and covered?	
	Are the bricks sound? Bang them together to see if they ring. If a thud, the bricks may need to be rejected or prism tests conducted to prove that f'_m is met.	
	Is the cement properly stored?	
	Is the lime properly stored?	
	Is the sand pile covered?	
	Does the sand appear well graded and sound?	
	Is the sand dirty?	
	Is there a method for controlling the sand proportions? Shovel count methods are not sufficiently accurate.	
	Does the person mixing the mortar know the proportions?	
	Are there any additives being added to the mortar?	
	Does the person mixing the mortar know the time limits for mixing? (10 minutes maximum.)	
	Are the grout proportions being controlled?	

No.	Item	Checked
2.0	CONSTRUCTION	
	Is the mortar dropping into the cells?	
	Are mortar fins being controlled? Are the cells clean?	
	Is the mortar being strung out too far on the bed joints?	
	Does the contractor understand cold (hot) weather construction requirements?	
	Are the walls being covered at the end of the day?	
	Is inspection being properly done?	
	Does the shoring of the masonry walls look about right?	
	Are the joints uniform in thickness and full?	
	Is the reinforcement being placed within tolerance? Is reinforcement secured against displacement? Are lap lengths correct?	
	Is the grout of sufficient slump to be placed?	
	Is the grout being vibrated during placement?	
	Is the grout being reconsolidated?	
3.0	DESIGN	
	Is the proper issue of design drawings on site?	
	Are the proper shop drawings on site?	
	Does the contractor understand the structural intent?	
	Is the inspector performing his duties properly?	
4.0	TESTING AND INSPECTION	
	Are prisms being constructed plumb and on a flat surface?	
	Are the materials being used for the prism the same as those used in the wall?	
	Are prisms being properly cured, handled, stored, and transported?	
	Is the prism grout being reconsolidated?	
	Is the frequency and quantity of testing in accordance with the contract documents?	

APPENDIX D: Field Test Data for Mortar and Grout

Field Mortar and Grout Test Data

The field sampling and testing for mortar compression strength are highly variable. Figure 1 is a frequency distribution of Type S mortar compression tests taken in the field during actual projects in California, Oregon, and Washington. There are a total of 205 mortar tests. The coefficient of variation is 36%.

With this amount of variability, it should not be surprising to get periodic non-conforming compression mortar tests. If the non-conformance occurs regularly, then the following steps are recommended:

1. Request that the mason identify the proportions being used. Go to the site and observe the mixing of the mortar.
2. Assess the method being used to control proportions. Check that the correct materials are being used.
3. Verify that the testing lab is using the procedures of ASTM C 270.
4. Visit the site and observe the mortar in the joint. Scratch the mortar with a key. If a white scratch results and the sand does not separate from the mortar, the strength of the mortar is probably acceptable. However, if the masonry is highly stressed (above 1200 psi), it may be necessary to remove a prism from the wall for testing.

The relationship between 7-day mortar strength and 28-day mortar strength is not as variable as the compression strength. It is useful to know the 7-day test results since it provides the engineer with an early indication of the 28-day results. The following figure presents the relationship for the same projects.

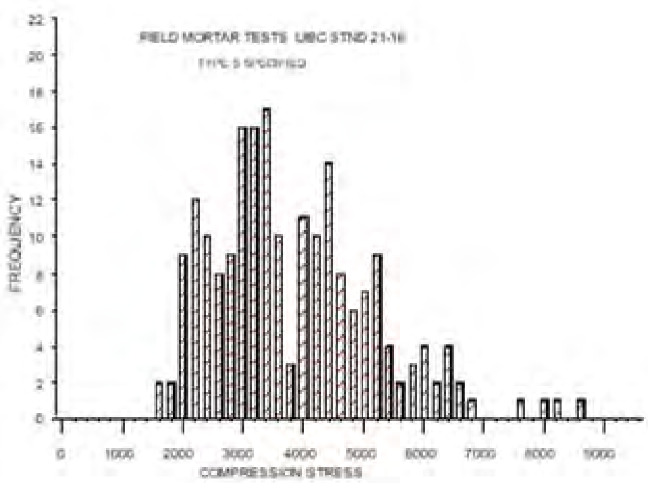


Figure 1 Field Mortar Tests

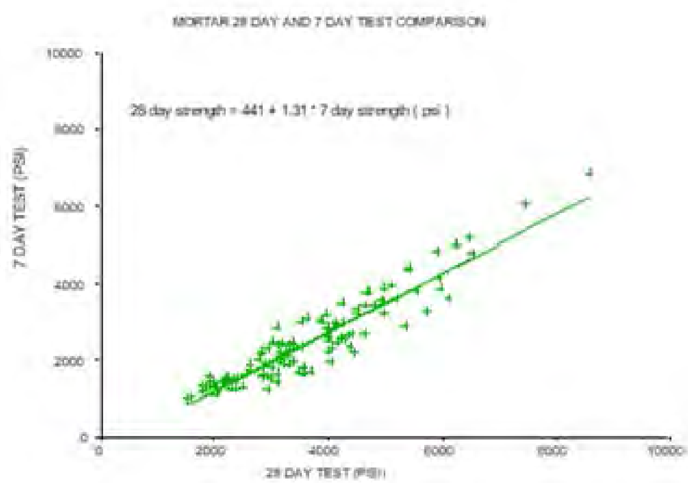


Figure 2 Comparison of 7 and 28 Day Mortar Tests

Grout Compression

It is recommended that field testing of grout not be required. However, when f'_m exceeds 2,000 psi, TMS 602-22 Section 2.2 B (Specifications for Masonry Structures) requires verification of grout strength by testing in accordance with ASTM 1019. This requirement is interpreted as prior to construction and not verification during construction.

The field sampling and testing for grout compression strength are highly variable. The following figure is a frequency distribution of field grout compression tests taken from actual projects in California, Oregon, and Washington. There are a total of 323 grout tests. The coefficient of variation is 32%.

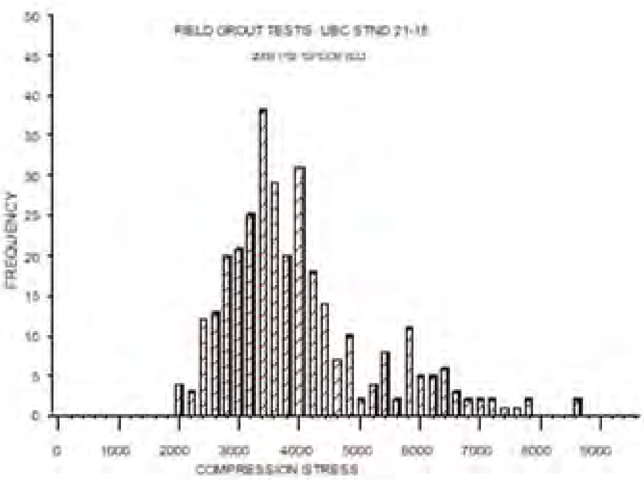


Figure 3 Field Grout Tests

With this amount of variability, it should not be surprising to get periodic non-conforming compression grout tests. If the non-conformance occurs regularly, then the following steps are recommended:

1. Request that the mason identify the proportions being used.
2. Assess the method being used to control proportions.
3. Verify that the testing lab is using the procedures of ASTM 1019.
4. If the cause of the low break is not identified, then taking core samples and testing them may be required.
5. The structural engineer should also consider the reason for requiring a specific grout strength. Often, the purpose of the grout is only to connect the reinforcement to the units. Even low-strength grouts (1500 psi) are probably capable of making the connection. Because of the high strength of the brick, the compression contribution of the grout can often be ignored in the analysis. If grout strength is less than f'_m, then lap lengths should be based on the grout strength and not f'_m.

The relationship between 7-day grout strength and 28-day grout strength is not as variable as the compressive strength. It is useful to know the 7-day test results since it provides the engineer with an early indication of the 28-day results. The following figure presents the relationship for the same projects.

Figure 4 Comparison of 7 and 28 Day Grout Tests

APPENDIX E: Troubleshooting Table

Troubleshooting Table for the Design Structural Engineer

Problem	Cause	Solution
Prisms fail to reach the design strength.	1. The testing lab has incorrectly tested the prism, usually by not placing the prism correctly in the machine or using a loading platen that is too thin. Or the specimens may have been damaged during transportation. 2. The bricks are below the specified strength. 3. The mortar is under specified strength. 4. Lab reported gross area stress instead of net area stress.	1. Instruct the lab to retest, being careful to follow the ASTM C 1314. 2. Request that the contractor have a lab test the brick. 3. Check mortar proportions. Retest the prisms. 4. Have the lab correct the report.
Mortar doesn't reach strength.	1. Incorrect proportions. 2. Incorrect testing.	1. Check mortar quality control procedures. 2. Mortar tests are unreliable. Forget about testing mortar. The code doesn't require it.
The grout mix does not meet ASTM C 476	Wrong mix	Change the mix to conform to ASTM C 476
For f'_m exceeding 2,000 psi, the tested grout strength is less than f'_m.	1. Tested during construction 2. Incorrect testing. 3. Wrong design mix	1. Grout tests are unreliable. Forget about testing grout during construction. The code doesn't require it. 2. ASTM C 1019 is not reliable. Repeat the test using different liners. 3. Change the design mix.
The colors do not meet expectations.	1. Bricks were not blended. 2. Sample panel has a different water repellant. 3. The brick production run is different from the sample run.	1. This is a problem for the architect and brick supplier. 2. Use the sample panel sealer. 3. Approve the production run before beginning construction.
The architect calls and says more expansion joints are required.	The architect was checking on your advice. Architects should do this, so don't get mad. The architect's experience may be with concrete masonry units that require closer spaced control joints for shrinkage and is not experienced with structural reinforced hollow clay masonry.	Explain to the architect how the reinforcement reduces the need for most of the expansion joints.
The mason tells the general contractor, who tells everyone that the cells are too small to be grouted with all the congested steel.	1. The mason contractor does not have experience with the grouting of reinforced hollow brick. He doesn't understand that he can make the grout with an 8 to 11-inch slump. 2. The cell is too small.	1. Prepare and grout a test panel. Be sure to invite everyone concerned. 2. Verify that the units conform to ASTM C 652 or re-design the wall with smaller diameter reinforcement, or use mechanical connectors
Welded bars are breaking off.	ASTM A 706 bars were not used. Inspect the bars. A "W" symbol indicates type A 706. Verify that bars were properly cooled and not quenched with water after welding.	Use the correct bars.
The contractor is not protecting his materials or work.	Sometimes the responsibility for protecting the work is left to the general contractor. He is saving money. Sometimes the responsibility is not well defined.	Request your client to set up a meeting with the general contractor and the masonry contractor to address the issue.

Problem	Cause	Solution
Cracks in the mortar joints.	1. Shrinkage of the mortar joint. 2. Movement of the supporting structure. 3. Overloading. 4. Too rapid drying.	1. Suggest the contractor decrease the cement content of the mortar and increase the lime, provided it still is in conformance with ASTM C 270. 2. Check supports. 3. Check loading the timing of the loading and shoring removal. 4. Pre-wet the units. Wet the wall during curing. Add lime to the mortar. Tooling of joints may not be done at the proper time, or joints are not properly tooled.
Shop drawings are not prepared.	The requirement was missed or "value engineered away."	Write a letter to your client explaining the requirement. If the project is underway, require an engineer familiar with the design to be on site full time.
The grout strength is specified at a minimum of 2000 psi; how can I get a prism of 4000 psi?	This is normal.	Explain that the prism does not fail in accordance with the weak link theory. See the Design Development section "Selection of Masonry Strength, f'_m."
The contractor wants to grout pours to exceed the 5 feet 4-inch lift height and not provide clean-outs.	The code restricts the grout lift to 5 feet 4 inches even though the grout pour might be higher. If the lift is over the 5 feet 4-inch then it is high lift grouting.	The problem is blow-outs of mortar joints and the ability to reconsolidate. In hollow clay, these problems are unlikely. Have the contractor demonstrate the procedure to you and the inspector using a grouting demonstration panel.
The contractor doesn't want clean-outs. You want high-lift grouting.	Code requires clean-outs for high-lift in order to remove the mortar droppings.	If the shear stresses are low, it may be possible to waive the clean-out requirement. The purpose of the clean-out is for shear transfer at the bottom of the cell. If shear stresses are low, this may not be necessary, and a code exception will be necessary.
The dowels out of the concrete foundation interfere with the unit cross webs. They miss the cells.	Improper placement of the dowels. However, it is often very difficult to get them in the right place. This situation is more common than not.	Cut the unit cross webs to allow the dowel to pass or drill in new dowels. Verify that all the dowels are required to meet strength requirements. If not, allow a certain % of them to be removed. It is common to allow the dowels to be bent slightly. A 1:6 slope ratio is a commonly used maximum.
The brick masonry is cracked, with cracks extending through the units.	1. A great deal of force is required for this condition to exist. Frozen grout, foundation movement, or thermal movement from an adjacent structure are a few examples. 2. The bricks may have been manufactured with cracks. 3. Foundation cracks extend into the brick wall.	1. Find the reason for the cracking. It is likely something needs to be corrected. Likely candidates include freezing, foundation settlement, overloading and thermal movement. 2. Verify the integrity of the units before use. A quick check is to bang the bricks together; if a ringing sound results instead of a thud, then the bricks are sound. 3. Foundation control joints are not coordinated with the masonry expansion joints. It may require rework or adding a control joint.

Problem	Cause	Solution
The contractor doesn't cover the walls at the end of the day.	1. The contractor is attempting to save money. 2. The responsibility for the masonry protection may have been left with the general contractor or, worse, left out of all the contracts. 3. The contractor may not be aware of the requirements of TMS 602 to cover walls at the end of the shift.	1. Insist on covering the walls. 2. Write a letter stating that the contractor is not in conformance with the likely result being efflorescence and other wall damage.
Corrosion of the joint reinforcement.	1. Too strong of an acid cleaning without pre-wetting the wall. 2. Ungalvanized joint reinforcement.	1. Pre-wet the wall and use industry cleaners as recommended by the manufacturer of the units. 2. Use galvanized joint reinforcement.
Leaking Walls	1. Improper flashing installation. 2. Improper flashing design. 3. Poor workmanship. 4. Improper grouting. 5. Raked joints or other unprotected horizontal surfaces. 6. Water repellant not applied.	1. Correct flashing. 2. Correct flashing. 3. Repair mortar joints. 4. Pressure epoxy grout. 5. Fill joints. Cover horizontal surfaces. 6. Apply water repellant wall.
Dome shaped voids in the grout.	1. Loss of water to the unit. 2. Improper or no vibration of the grout 3. No reconsolidation	1. Use proper reconsolidation techniques. 2. Use Grout-Aid or equal. 3. Add lime to the maximum allowed. Use self-consolidating grout.
River voids in fine grout.	Loss of water to the unit.	1. This is normal, provided they are less than approximately 1/4 inch in width. 2. Use Grout-Aid or equal. 3. Add lime to the maximum allowed. 4. Reduce water in the mix.
Efflorescence on the wall.	1. Precipitation of salts at the wall surface. 2. Wall was uncovered during construction, and excessive water entered. 3. Flashing not properly detailed, not installed, or not properly installed	1. Clean the wall and then keep water from entering the wall by fixing leaks and sealing it with a water repellant. 2. Cover the wall during construction. 3. Rework the flashing

Notes on the Selection, Design and Construction of

Reinforced Hollow Clay Masonary

Is also available from Western States Clay Products Association at
http://www.brick-wscpa.org

Other technical documents are also available

Design Guide for Anchored Brick Veneer Over Steel Studs

and

Design Guide for Structural Brick Veneer

Strengths of RHCM are usually greater than the 2600 psi used in this document.

- Increasing the f'_m increases the capacity of the masonry. RHCM design strengths far exceed those available for concrete masonry. The assumed starting value of 2,600 psi is conservative. Some engineers start with a value of 3,500 psi. However, it is recommended to specify the lowest value necessary to meet the project demand strength requirements especially for schematic design.

- Using the higher design strength can reduce or eliminate horizontal shear reinforcing in shear walls, and shear reinforcing (stirrups) in beams, in some cases.

- For specially designed shear walls, the structural engineer may be able to eliminate the transverse reinforcement hooks at the end of the wall if the following condition is satisfied.

$$V_u/(\theta V_{nm}) \leq 0.4$$

- For intermediate and special shear walls, the ductility requirements can be mitigated by increasing f'_m to allow additional tension reinforcement. This will only occur in multi-story load-bearing applications.

- For beams with high moment demand, the limits on tension reinforcement can be increased by increasing f'_m.

- In some situations, increasing f'_m can eliminate the requirement to do a moment magnification analysis.