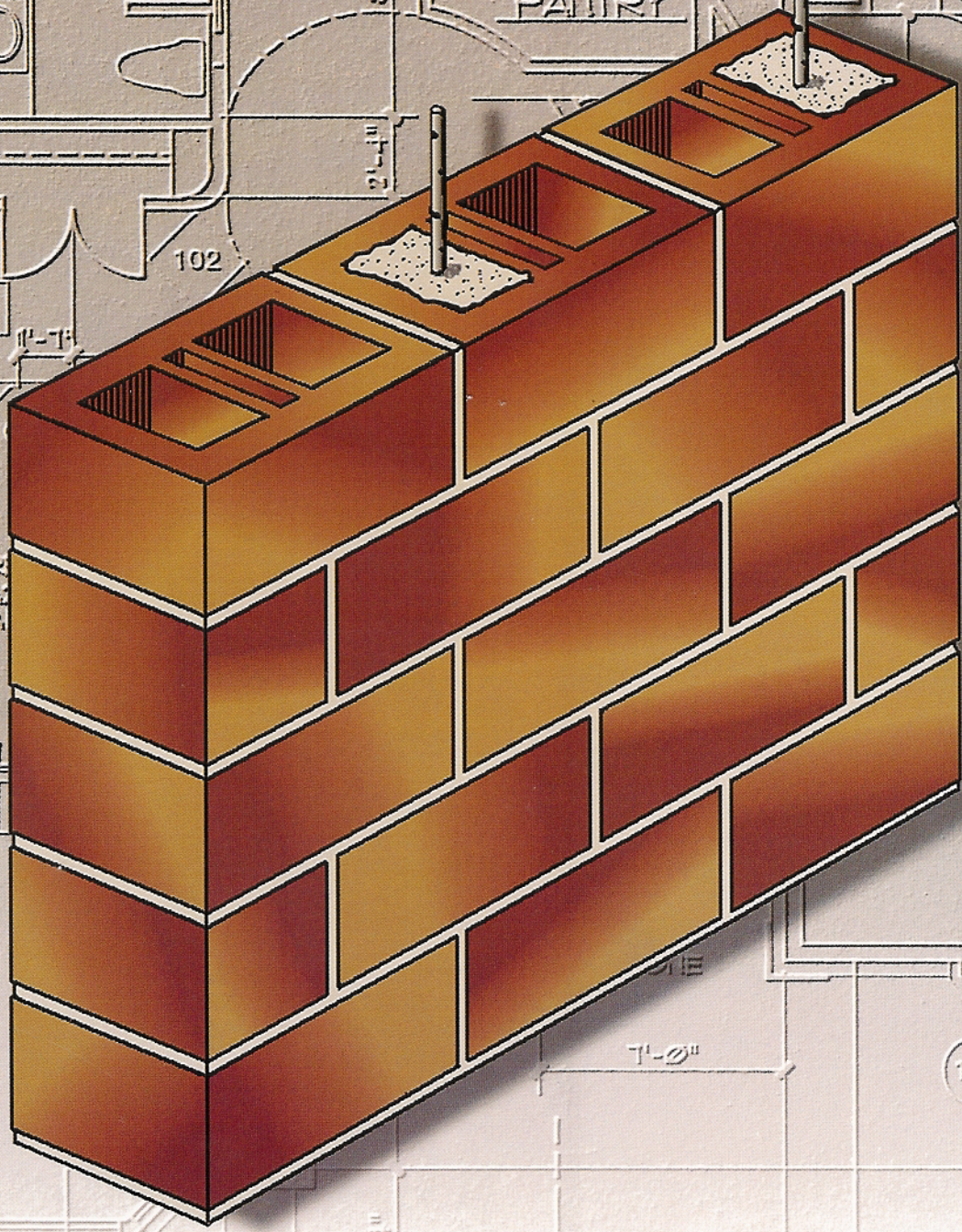


NOTES ON THE SELECTION, DESIGN AND CONSTRUCTION OF REINFORCED HOLLOW CLAY MASONRY



prepared for
Western States Clay Products Association
by
KPFF Consulting Engineers

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Prepared for

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PREFACE

Reinforced hollow clay masonry offers the building owner many advantages. These advantages are often overlooked by the structural engineer when selecting a structural system. Yet, reinforced hollow clay masonry has been successfully used for more than 40 years on many projects.

The structural engineer receives limited training in the design and construction of masonry. Many universities and colleges do not offer courses in masonry. Often the structural engineer's first exposure to the masonry is when the architect or owner requests it be used. When this happens, the engineer is faced with a requirement to quickly learn the subject.

Resources currently available are generally in textbook form and address the design of all forms of masonry. Few are directly applicable to reinforced hollow clay masonry design. And, most are more appropriate for academic study than for producing construction documents.

This lack of resources was discussed during a recent meeting of the Western States Clay Products Association. At that time it was agreed to produce a publication specifically for the structural engineer designing a reinforced hollow clay masonry project.

This document is the result of that decision and is a compilation of 20 years of experience. The content emphasizes the activities required to successfully complete a hollow clay masonry project and is presented sequentially beginning with the Schematic Design Phase and continuing through to the Construction Phase.

The material presented in this publication, including technical and engineering data, figures, drawings and tables is for general information only. It should not under any circumstances be used or relied upon for specific applications without independent evaluation by a licensed design professional familiar with the specific use and application. Anyone making use of this material does so at their own risk and assumes any and all liability resulting from such use.

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INTRODUCTION

Scope

This publication is about designing and building structures using reinforced hollow clay masonry. The most common shapes of hollow clay brick are shown in Figure 1-1.

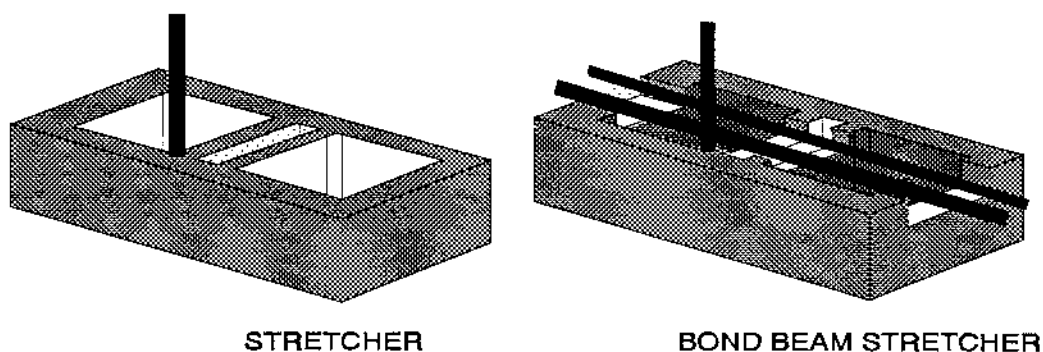


Figure 1-1. Typical Hollow Clay Units

Customary nominal thicknesses are 4-inch, 5-inch, 6-inch, 8-inch, 10-inch and 12-inch. The typical height is a nominal 4-inches and the typical length is either a nominal 12-inches or 16-inches. 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.

Allowable or working stress design is the common method for structural design. Strength design methods are also sometimes used, but a detailed discussion of structural design methods is not included in this publication. More detailed information on structural design methods can be found in numerous textbooks and other references.

This publication is based on the 1994 Uniform Building Code. However, most of the information presented is independent of the code selected.

This publication assumes the traditional design and construction project organization. In the traditional organization, the structural engineer contracts with and reports to the project architect as a special consultant. The architect typically contracts with and reports to the owner. The architect, structural engineer and other special consultants are referred to as the

design team. The contractor is selected after the design is completed and selection is based on the price to do the work. The contractor enters into an agreement with the owner and reports to the architect who serves as the owner's representative.

Other construction organizations and variations on this traditional method exist. However, for the purpose of this publication the traditional approach is assumed.

Organization

The publication is divided into four sections. Each section addresses a different phase of the design and construction process.

Section 1 presents issues regularly occurring during the schematic design phase. It contains information on the selection of hollow clay masonry as the structural system. It lists example projects where hollow clay masonry is frequently used. It briefly discusses the selection of materials, but defers a more detailed discussion until Section 2. The advantages and common objections raised over the selection of structural hollow clay masonry and choices for initial design criteria are presented. Finally, the section provides information about the relative costs and typical wall thickness.

Section 2 presents issues typically occurring during the design development phase. Methods for the preliminary sizing of walls, beams and reinforcement are presented. Methods for the selection of masonry strengths are presented. Masonry bond pattern and reinforcement layouts are discussed. Initial selection and specification of materials are recommended. Finally, designer's choices such as partial versus solid grouting; joint reinforcement versus reinforcing bars; high-lift versus low-lift grouting; special inspection versus no special inspection; working stress design versus strength design and other choices are considered.

Section 3 discusses the preparation of the contract documents. The section is divided into three parts. The first briefly presents methods for checking the strength of the design. References are provided for more detailed information. The second discusses the preparation of the drawings. Drawing layout, dimensioning and typical details are addressed. The third presents information on the preparation of specifications. An example set of structural notes is provided in an appendix.

Section 4 presents construction phase issues. The selection of qualified masonry contractors is discussed along with items for discussion at the pre-construction conference. The handling of submittals is addressed including a checklist for structural observation of reinforced hollow clay masonry construction. A troubleshooting table is also provided.

SCHEMATIC DESIGN

During the schematic design phase, the architect reviews the owner's program to ascertain the requirements of the project. Based on this understanding, the architect prepares schematic design documents consisting of drawings, outline specifications and other documents illustrating the scale and relationship of the project components.

Selection of the Structural System

During the schematic design phase, the structural engineer is expected to influence the selection of a structural system for a building. The owner expects a cost-effective structural design and it is appropriate for the structural engineer to offer alternative choices for the building structure.

One structural system often overlooked is reinforced hollow clay masonry.

The following are some typical examples where reinforced hollow clay masonry is used for the primary, secondary and other structural applications.

Primary Structure

Example 1 -- Commercial/Retail

One- and two-story commercial buildings in retail malls or other commercial developments can frequently benefit from using reinforced hollow clay masonry construction. As an alternative for concrete masonry (CMU), there is usually a small increase in initial cost for a major improvement in aesthetics and strength. As an alternative for a steel frame with metal stud walls, hollow clay masonry may be used as both a bearing wall and an enclosure wall providing structure and finish at the same time. Often, the initial cost is less. Moreover, because of the frequent long lead times for the fabrication of structural steel, construction of hollow clay masonry buildings can often be completed within a shorter construction period.

Example 2 -- Low-rise Residential

Hollow clay masonry is frequently substituted for wood frame construction in low-rise residential projects. Hollow clay masonry can be more economical than wood or other choices and offers better acoustical properties, less seismic or wind drift, more fire resistance, less maintenance and no insect damage.

Example 3 -- Mid-Rise Residential

Hollow clay masonry is used in medium-rise residential projects. Hollow clay masonry exhibits very high compressive strength. For buildings in the four-story to 12-story range, the full strength can be used with little or no increase in cost.

Example 4 -- Hotels

As in residential buildings, hollow clay masonry offers many opportunities for hotel construction in the two to 20-story range. The high strength can mean savings for most buildings using load-bearing construction and may offer an advantage over other forms of construction. The hollow clay masonry system is compatible with wood, precast, cast-in-place or prestressed floor systems. Besides aesthetics, the major advantage to hollow clay bearing wall construction is the sound separation provided by the mass of the masonry wall.

Example 5 -- 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 employed because they limit the flexibility of the interior space. However, high-strength hollow clay masonry shear walls can be substituted for steel braced frames or moment frames to resist lateral force. This is especially workable when shear walls become part of the exterior aesthetics of the building or permanent partitions.

Example 6 -- Schools

For many years, schools used load-bearing clay masonry for exterior walls. Interior walls were either hollow concrete masonry or hollow clay masonry. This traditional approach to the design of schools has yielded to lighter metal or lightweight cement-based wall systems. These systems appear more economical, but often have limited life spans. Their initial cost is low, but the life cycle cost may be high. If hollow clay load-bearing masonry is used instead of the traditional veneer to act as both the wall and the support structure, even the initial cost may be less.

Example 7 -- Institutional Facilities

For libraries, hospitals, fire stations, city halls and university buildings, brick is often the material of choice. In these situations, the use of hollow clay masonry offers an alternative to brick veneer. When designed to be load-bearing, hollow clay masonry performs double duty and may provide savings. Even if not designed to be load-bearing, a new system using reinforcing hollow clay units installed as a veneer offers better performance and longer life than traditional veneers.

Secondary Structure**Example 8 -- Reinforced Veneer**

Brick veneer on metal studs is a popular curtain wall system. An alternative system is reinforced veneer. Reinforced veneer is the same as conventional veneer except the brick is constructed with hollow units and reinforced. One way to view reinforced veneer is that the placement of reinforcement in the wall allows the veneer ties to be spaced farther apart. Typical brick veneers have ties every two square feet. Reinforced veneers have ties every 100 square feet. The ties or anchors carry more load, are constructed of thicker materials, offer simpler methods for isolation from the primary structure, and the cost of increased corrosion protection has a smaller impact on the cost of the wall.

Example 9 -- Brick Panels

A brick panel system is one popular use of hollow clay masonry. Brick panels are constructed of hollow clay units, reinforced, grouted solid 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 provides the designer with new opportunities not available with conventional masonry. The system has been used on many different sized buildings ranging from single-story branch banks to 50-story office buildings.

Other Applications

Example 10 -- Retaining Walls

Hollow clay masonry is often overlooked as a possible alternative for retaining walls. Because of the flexibility in wall geometry, it is often possible to design more efficient retaining walls from hollow clay masonry than from cast-in-place concrete. A hollow clay retaining wall can also be built from one side, often eliminating the considerable excavation required to provide adequate back slope to conform to safety requirements.

Example 11 -- Sound Walls

Hollow clay walls provide excellent opportunities for the construction of highway sound barrier walls. The flexibility of color and form offers both structural and aesthetic advantages.

Advantages of Hollow Clay Masonry

1. Strength

It is relatively easy to obtain high-strength hollow clay masonry. Design strengths (f'_m) to 5300 psi are common when using unit strengths between 10,000 psi and 16,000 psi. There is generally no cost premium for these higher strengths. In load-bearing applications, the higher strengths may offer an advantage over concrete masonry.

Tensile strengths of the hollow clay masonry units range between 700 and 1500 psi. Thus, visible cracking of a reinforced hollow clay masonry wall is uncommon.

2. Record of Performance

Hollow clay masonry has been used for nearly 40 years. It has a good record of structural performance.

3. Speed of Construction

Hollow clay units may be currently inventoried or rapidly produced by the brick manufacturer. Construction of the structural system can proceed as soon as the foundation is placed.

4. Flexibility of Design

SCHEMATIC DESIGN

Hollow clay masonry is laid one unit at a time; thus there is the flexibility of having articulated shapes for a small increase in cost. Flexibility of form can be used to achieve structural efficiency. A classic example of the relationship between form and structure is the serpentine retaining wall.

5. Low Maintenance Cost

Hollow clay masonry is relatively maintenance-free. Expected life is in excess of 50 years as compared to 20 or 30 years for metal and other light wall systems.

6. Water Resistance

Hollow clay masonry expands for as long as long as five years and the expansion does not reverse. In reinforced hollow clay masonry, this expansion places the brick in compression and the steel in tension. The result is reduced cracking and improved water penetration resistance.

7. Variety of Appearances

There are thousands of colors and textures from which to choose.

Common Objections to Choosing Hollow Clay Masonry

Hollow clay masonry is viewed as masonry in general. Consequently, it carries many of the objections often raised with masonry in general. The customary objections include the following:

"Hollow clay masonry is too expensive."

It is common during the design development phase to reject hollow clay masonry as an option because it is perceived as being too expensive. Often this is not the case and the potential savings available are lost before comparisons of initial and total costs are made. Costs need to include the total wall system and the life-cycle cost to make a comparison.

"Hollow clay masonry leaks."

Masonry is often perceived to leak more than other wall systems. This has proven to be inaccurate for reinforced hollow clay masonry. The expansion of the brick masonry against the reinforcement tends to significantly reduce cracking and thus, leakage. As with other wall systems, a secondary water control strategy is often required.

"Using masonry adds another subcontractor to the job."

General contractors often resist adding the masonry subcontractor to the job. One reason is the cost to administer the masonry work. Another reason may be that the general contractors perform their own concrete work. In this situation, the contractor will prefer concrete walls instead of masonry walls in order to keep a larger percentage of the project.

"The colors are never what is expected."

Many architects have experienced difficulty in obtaining the colors desired. Initial samples and production runs are often perceived as different. Often construction schedules do not leave sufficient time to resolve the problem. This situation can be mitigated by early selection of brick colors.

"The engineer is not familiar with the design methods."

There are many new resources available to assist with the design of reinforced hollow masonry. This publication is one. Additionally, references are contained at the end of the Design Document Section.

"Technical information from suppliers is inconsistent."

There are many different types of masonry. There are many different uses. Often communication between the masonry representatives and the designer is confused because of misunderstandings over intended use and terminology. The design and construction of veneer brick masonry does not match the design and construction of load-bearing brick masonry. The behavior of concrete masonry is different from the behavior of clay masonry. One example: It is often recommended to wet clay units before laying, whereas, it is not recommended to wet concrete units before laying.

"Standard details are not available."

While there are many standard details available, there are so many different types of masonry, methods and systems, no single set of standard details is sufficient to design a project.

"Prices are not predictable -- they vary considerably from job to job."

Unfortunately, it is difficult to predict the bid price of a masonry job. Since masonry is labor intensive, the masons' production is a key factor. Many variables come into play such as the complexity of bonding patterns and site conditions. The cost of the brick remains relatively predictable and can be obtained from the supplier. Cost estimates for a specific project can be obtained with the assistance of a qualified mason contractor. Additional pricing information is presented later in this section.

"The required "R" values exclude masonry."

Wall details are available to obtain the required "R" values. Check with local suppliers. The mass of the wall system is an important advantage in the overall energy analysis.

Selection of Materials

When hollow clay masonry is selected for consideration as the structural system, the next step is to select 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 have been shipped thousands of miles. Hollow clay masonry buildings have been built with custom colors and shapes which have never been used before and will never be used again.

A key structural consideration in the selection of the unit is the unit strength. The unit strength will establish the range of strengths available for the structural design of the masonry. The units can have compressive strength ranging between 4000 psi and 16000 psi. Generally light colored units have lower strengths than dark colored units.

Local suppliers can provide information on the strengths, common shapes and colors available from the manufacturers who are members of the Western States Clay Products Association. Custom colors and shapes are available upon request.

Initial Design Criteria

The design of structural hollow clay masonry typically follows Chapter 21 of the Uniform Building Code or the Building Code Requirements for Masonry Structures (ACI 530/ASCE 6/TMS 602). Associated loads are found in Chapter 16 of the Uniform Building Code or Minimum Design Loads for Buildings and Other Structures (ASCE 7). Chapter 14 of the Uniform Building Code on brick veneer does not apply.

Chapter 21 of the Uniform Building Code is divided into three design methods. They are Working Stress Design, Strength Design and Empirical Design. The Working Stress Design method is divided into two parts. They are Reinforced Masonry Design and Unreinforced Masonry Design. It is recommended that the Working Stress, Reinforced Design method be selected for design. This is the most common method used for reinforced hollow clay masonry. The applicable code sections include Section 2106, 2107.1 and 2107.2. The provisions of Unreinforced Design, Strength Design or Empirical Design must not be used in combination with Reinforced Design. There are many inconsistencies and gross errors could occur if the provisions are mixed.

Cost Comparisons

Cost is always a factor in the selection of the structural system. The cost of hollow clay masonry depends on the cost of the materials, the cost to lay the materials, job factors, and other considerations. Costs vary from region to region.

Approximate material costs are summarized in Table 1-1

Table 1-1
Approximate Material Cost
(1994 Pacific Northwest)

| Cost (per sq. foot) | 4" | 5" | 6" | 8" |
|------------------------------------|----------------------|----------------------|----------------------|----------------------|
| Units ¹ | \$1.80-\$2.70 | \$2.55-\$3.30 | \$2.70-\$3.60 | \$3.30-\$3.90 |
| Mortar ² | \$.06 | \$.06 | \$.07 | \$.07 |
| Grout ³ (assumed solid) | \$.29 | \$.41 | \$.45 | \$.66 |
| Reinforcement ⁴ | \$.08 | \$.10 | \$.11 | \$.15 |
| Total Materials | \$2.23-\$3.13 | \$3.12-\$3.87 | \$3.33-\$4.23 | \$4.18-\$4.78 |

1. Add between \$0.10 and \$0.25 for bond beam units. Add 30 to 50% for non-standard stretcher shapes shown in catalogs.
 2. Assumes \$90.00 per cubic yard with waste.
 3. Assumes \$80.00 per cubic yard hand-placed.
 4. Assumes \$0.24 per lb and minimum steel ratio of .002 times the cross-section of the wall.

The production of the mason is the primary factor involved in the cost of laying the material. The normal measure for comparison is the number of units laid per mason per day. The range for hollow brick is between 100 and 225 per day. The rate depends on many factors including:

1. The size of the project.

The size of the project will determine the optimum crew size. The most efficient crew is from six to 12 masons. For six masons, two laborers are added. For 12 masons, three laborers are added. If the project can only support one mason, then one laborer is still required and the cost per square foot greatly increases.

2. Dimensioning of the walls.

Dimensioning to match the brick module can significantly reduce the cost by increasing the speed with which units are laid.

3. The size of the unit.

The size of the unit affects cost. Generally, the larger the unit the more productive it is to lay. However, heavier units tend to slow production.

4. Special patterns.

Bonding patterns, angles, corbels, soldier courses, rusticated joints, or other special

features will increase the cost by slowing the production. Designing an exposed finished wall on both sides slows production. Units are not of a uniform thickness. The mason must take care to balance the non-uniformity on both sides of the wall.

5. Experience of the contractor.

The experience of the masons laying hollow units can also affect production and cost. The experience of the masons will also affect the quality of the wall.

6. Weather.

Weather must be considered. In climates where freezing is common, winter construction techniques will typically increase cost.

7. Reinforcement.

The quantity, size and spacing of reinforcement affects production. Generally, the further bars are spaced the better the production rate. The spacing of horizontal reinforcement can have a big impact if production is stopped at each bond beam in order to grout.

Other factors that influence the cost include:

1. Access to the project and scaffolding difficulties.
2. Lifting costs.
3. Availability of labor and union versus non-union labor.
4. Difficulty laying certain brick. Factors include the compatibility of the unit to normal mortars and the cost to clean the wall after construction.
5. Extra cost imposed by the contract documents or conditions imposed by the general contractor.

While the costs vary, Table 1-2 lists low and high labor costs for simple walls consisting mostly of common stretcher units with few corners. Table 1-3 lists low and high combined material and labor costs.

Table 1-2
 Cost of Labor^{5,6}
 (1994 Pacific Northwest)

| | Approx. Square Footage | 4" Wall | 6" Wall | 8" Wall |
|-------------------------|------------------------|----------------------|----------------------|----------------------|
| | | 225-100 ⁴ | 225-100 ⁴ | 200-100 ⁴ |
| Small Job ¹ | <2,000 SQ. FT. | \$8.00-\$14.67 | \$8.00-\$14.67 | \$8.67-\$14.67 |
| Medium Job ² | <10,000 SQ. FT. | \$4.12-\$9.12 | \$4.12-\$9.12 | \$4.62-\$9.12 |
| Large Job ³ | >10,000 SQ. FT. | \$3.37-\$7.53 | \$3.37-\$7.53 | \$3.78-\$7.53 |

1. One or two masons with a laborer. Two days for set-up and clean-up.
 2. Six masons with two laborers. Two days for set-up and clean-up.
 3. Twelve masons with three laborers. Two days for set-up and clean-up.
 4. Units per day, per mason.
 5. Cost per mason, per day range is assumed from \$337 per mason, per day for the large job to \$800 per mason, per day for a small job including laborers.
 6. Assumes units are 3.5" high.

Table 1-3
 Combined Material and Labor Cost¹
 (1994 Pacific Northwest)

| | Approx. Square Footage | 4" Wall | 6" Wall | 8" Wall |
|------------|------------------------|-----------------|-----------------|-----------------|
| | | 225-100 | 225-100 | 200-100 |
| Small Job | <2,000 SQ. FT. | \$12.28-\$21.36 | \$13.60-\$22.68 | \$15.42-\$23.34 |
| Medium Job | <10,000 SQ. FT. | \$7.62-\$14.70 | \$8.94-\$16.02 | \$10.56-\$16.68 |
| Large Job | >10,000 SQ. FT. | \$6.72-\$12.79 | \$8.04-\$14.11 | \$9.55-\$14.77 |

1. Includes cost of materials and labor from Tables 1-2 and 1-3 with a 20% markup for overhead and profit. Does not include scaffolding, cleaning, sealing or caulking.

The cost of scaffolding depends on the project requirements but typically ranges between \$.30 and \$.50 per square foot of wall. Cleaning typically costs between \$.40 and \$.50 per square foot of wall and sealing (usually required only in wet climates) costs between \$.35 and \$.50 per square foot of wall. In addition, the above costs are that of the masonry sub-contractor. The general contractor typically marks up the masonry sub-contractor's costs by 5%.

Typical Dimensions and Wall Thicknesses

SCHEMATIC DESIGN

The nominal dimension is the specified dimension plus one mortar joint thickness used to lay the unit. The typical thickness dimensions are presented in Table 1-4. The typical length and height dimensions are described in Figure 1-2.

Table 1-4
Thickness Dimensions

| Nominal Thickness | Specified Thickness |
|-------------------|---------------------|
| 4" | 3.5" |
| 5" | 4.5" |
| 6" | 5.5" |
| 8" | 7.5" |
| 10" | 9.5" |
| 12" | 11.5" |

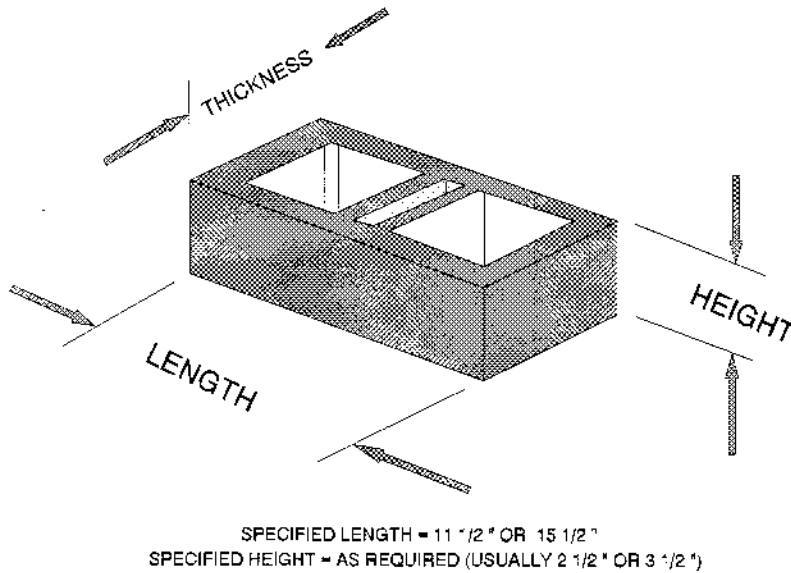


Figure 1-2. Typical Hollow Clay Dimensions

Table 1-5 presents the most common wall thickness for various typical buildings. Notice that

the out-of-plane loading usually controls the thickness of the wall.

Table 1-5
Typical Wall Thicknesses

| Use | Stories or Height (ft) | Nominal Wall Thicknesses | Controlling Direction of Bending |
|----------------------------------|------------------------|--------------------------|----------------------------------|
| Commercial | 1 or 2 Stories | 6" | Out-of-Plane |
| School | 1 or 2 Stories | 6" | Out-of-Plane |
| Warehouse | < 20 ft | 6" | Out-of-Plane |
| | > 20 ft | 8" | Out-of-Plane |
| Residential | < 2 Stories | 4" | Out-of-Plane |
| | < 4 Stories | 6" | Out-of-Plane |
| | < 12 Stories | 8" | In-Plane |
| Gymnasium | < 20 ft | 6" | Out-of-Plane |
| | > 20 ft | 8" | Out-of-Plane |
| Reinforced Veneer (story height) | < 12 ft | 4" | Out-of-Plane |
| | < 16 ft | 5" | Out-of-Plane |
| | < 24 ft | 6" | Out-of-Plane |

It is not unusual to use different thicknesses of walls on the same floor or change the wall thickness from floor to floor.

It is also not unusual to use different masonry design strengths on the same floor or change the wall strength from floor to floor. There are three methods for varying strength. The first is to change the unit strength, the second is to change the mortar or grout strength, and the third is to change the inspection requirements.

Changing the unit strength almost always means a change in brick color. Therefore, the architect usually controls the unit strength.

DESIGN DEVELOPMENT

During the design development phase, the architect prepares design development documents consisting of drawings and other documents to fix and describe the size and character of the entire project as to architectural, structural, mechanical and electrical systems, materials and such other elements as appropriate.

During this phase, the structural engineer identifies the space required for the structural portions of the project and those elements that will dictate the strength of the materials.

Initial Sizing of Members

Selection of the Design Strength

The design allowable stresses depends on the specified compressive strength, f'_m , and on the level of quality control used during construction. The determination of the specified compressive strength, f'_m , will be discussed in the next section. The effect of the level of quality control will be discussed in the section titled "Designers Choices".

For now, however, assume there are two levels of quality and there are only two choices to comply with the level of quality requirements. The highest level of quality requires full time inspection and prism testing during construction. The lower level of quality requires periodic inspection and does not require prism testing during construction.

If the highest level of quality is selected, then the designer can use the full allowable stresses that are based on f'_m . If the lower level of quality is selected, then the designer uses one half the allowable stresses that are based on f'_m , except for the modulus of elasticity.

For simplicity, in the next section discussing initial sizing of members, the specified compression strength of masonry is assumed to be 4000 psi. This is a common value used for hollow clay masonry. Full time inspection and prism testing during construction are also assumed.

Selection of Wall Thickness

Selecting the wall thickness is an important step in the structural design. The structural requirements often do not dictate the thickness. The wall thickness may be limited by fire code requirements, aesthetics, geometric requirements or energy code requirements. The architect will normally supply the required thickness.

Whether or not the architect has initially selected the wall thickness, the structural engineer will need to make a quick estimate of the thickness required to resist the loads. A good initial guess can save a lot of design effort. Table 2-1 presents typical wall thicknesses for walls controlled by out-of-plane loading. Wind is usually the controlling load.

Table 2-1
Typical Height Limits for Out-Of-Plane Load ^{1,6}

| Nominal Wall Thickness (in.) h = wall height (in.) | Height of Wall (ft.) | | | |
|---|------------------------------------|------------------------------------|-----------------------------------|---------------------------|
| | Normal Application ² | Common Application ³ | Extended Application ⁴ | Slender Wall ⁵ |
| | h/t = 24 | h/t = 30 | h/t = 36 | h/t = 48 |
| 4" | 8 | 10 | 12 | 16 |
| 5" | 10 | 12 | 15 | 20 |
| 6" | 12 | 15 | 18 | 24 |
| 8" | 16 | 20 | 24 | 32 |
| 10" | 20 | 25 | 30 | 40 |
| 12" | 24 | 30 | 36 | 48 |

1. Assumes f'_m equals 4000 psi.
2. Average reinforcement, without special inspection or prism testing during construction.
3. Average reinforcement, with special inspection and prism testing during construction.
4. For low wind loading, heavy reinforcement, with special inspection and prism testing during construction.
5. Strength design with special inspection and prism testing during construction.
6. Wall assumed pinned at the top and bottom.

Initial sizing for in-plane loading is more difficult. Normally, the in-the-plane loads are due to seismic or wind lateral forces applied to the entire structure. For a regular geometry (the center of rigidity approximates the center of mass or the center of pressure), the first step is to calculate the base shear.

The base shear due to wind may be estimated as:

$$V_{base} = WA$$

Where "W" is the wind pressure and "A" is the building area exposed to the wind pressure.

The base shear due to seismic is also easy to estimate. Since hollow clay masonry buildings are normally box system that resists seismic forces with shear walls, the building period is typically less than .85 seconds. Thus, the base shear can be approximated as:

$$V_{base} = \begin{pmatrix} 0.183 \text{ ZONE 4} \\ 0.137 \text{ ZONE 3} \\ 0.092 \text{ ZONE 2} \end{pmatrix} \times W I$$

Where "W" is the building weight (including partitions and sometimes snow) and "I" is the importance factor.

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 rigid diaphragm buildings, the load is distributed to the walls in relationship to the relative rigidity of the wall. Rigid diaphragm buildings are constructed with floors of concrete, concrete plank or concrete over metal deck. For these buildings with wall height to length greater than 3, distribute the base shears in proportion to $(L/H)^3$. For walls with (H/L) less than 3, distribute the base shears to the walls in proportion to (L/H) . H is the height of the wall (not the story height) and L is the length of the wall.

For non-rigid diaphragm buildings, the base shear is distributed by the tributary area method. Non-rigid diaphragm buildings are constructed with floors of wood or metal deck without concrete topping. The tributary area method requires engineering judgement. The force in each floor diaphragm is distributed by dividing the floor into areas that split the distance between the walls. The thickness, length or height of the wall is not used.

Shear walls connected by beam elements at each floor or walls with punched window openings are sometimes designed as "coupled" shear walls. For rigid diaphragm buildings the length of the wall could be either the entire length of the wall or be divided into a series of separate piers. Where the coupling beam stiffness is comparable or greater than the pier stiffness, assume the wall is coupled; otherwise assume individual piers. If coupled, the coupling beam elements have a small influence on the distribution of the base shear to the wall elements. The coupling beams, however, have a significant effect on the overturning moment. More coupling results in less moment because the piers and coupling beams act as a frame. This effect can be important for sizing the amount of reinforcement at the end of the wall and selecting the masonry strength.

Once the load in the wall is estimated, the wall overturning moment can be estimated by assuming the following:

For wind, assume the load is applied at the mid-height of the wall.

For seismic, assume the load is applied at two-thirds of the height of the wall.

Once the shear and moment are estimated, Table 2-2 provides a guide for wall thickness when shear governs. This is usually the case when the H/L is less than 3.

Table 2-2
Wall Thickness for Shear

| WALL THICKNESS (NOMINAL) | APPROXIMATE SHEAR CAPACITY (LB/FT) ¹ | |
|-----------------------------|---|----------------------|
| | WIND | SEISMIC ² |
| 4" | 3780 | 2520 |
| 5" | 4860 | 3240 |
| 6" | 5940 | 3960 |
| 8" | 8100 | 5400 |

1. Assumes M/Vd less than or equal to 1.0, F_v = 75 psi., j = .9 and solid grout.
2. Values reduced by the requirement to increase the applied seismic shear by 50%.

When H/L is high, the overturning moment will often dominate the initial selection of the wall. The fastest check for adequacy is to use the unity equation. The unity equation evaluates the capacity of the wall for masonry compression stresses caused by bending and axial compression. It does not address the design of reinforcement.

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1.33 \quad (\text{wind or seismic})$$

To use the unity equation, there are four values to be determined. The first is to calculate the axial stress due to dead and live load on the wall. The tributary area method is most commonly used. Don't forget the wall weight and live-load reduction factors.

$$f_a = \frac{P_{DL} + P_{LL}}{AREA}$$

Next, determine the allowable compressive strength. As a first try, assume f'm equals 4,000 psi.

$$F_a = 0.25 f'_m \left[1 - \left(\frac{h}{40t} \right)^2 \right] \quad \text{for } \frac{h}{t} \leq 28$$

$$F_a = .25 f'_m \left(\frac{20t}{h} \right)^2 \quad \text{for } \frac{h}{t} > 28$$

Where, "t" is the specified dimension from Table 1-4 and "h" is the distance between the floors measured in inches. These equations are modified from the code but are conservative because the radius of gyration used in the code is replaced by .28 times the specified thickness and h is the distance between supports instead of effective height.

The third number is f_b . This value is the computed masonry compression stress due to bending alone. An estimate of f_b is obtained by assuming that the neutral axis is 30% of the distance from the extreme compression fiber to the centroid of the reinforcement and that the centroid of the reinforcement is at 80% of the wall length.

$$f_b = \frac{2M}{b(.8L)^2(0.3 \times 0.9)}$$

Where b is the wall thickness (same as "t" used for out-of-plane design). Finally the allowable bending compression stress is calculated as:

$$F_b = \frac{f'_m}{3} = \frac{4000}{3} = 1333 \text{ psi}$$

Substitution of the above values into the Unity Equation will yield a check for the adequacy of the selected wall thickness for overturning moment.

It often happens that one wall (or a small percentage of walls) will 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 to prove adequacy.

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 estimate the applied moment. Normally the maximum moment results from full dead and live loading applied. However, if the beam is a shear wall coupling beam, then combined dead load plus seismic load normally controls.

The best design occurs when the distance from the extreme compression fiber to the neutral axis is less than approximately 30% of the distance to the centroid of the reinforcement.

Using this assumption, the approximate beam depth can be obtained from the following equation:

$$d = 3 \sqrt{\frac{M}{bF_b}}$$

and the area of steel can be estimated as:

$$A_s = \frac{M}{0.9 d F_s}$$

Selection of Masonry Strength, f'_m

Comparable to concrete design, the engineer specifies the strength of masonry required to resist the loads for the member size selected in the design. The notation f'_m is analogous to f'_c . Like concrete the designer is limited in the choice of strength by the availability of materials. For hollow clay masonry, available design strengths reach 5000 psi. A typical value for design is 4000 psi. However, for some light colored brick (white) the maximum strengths can be as low as 2000 psi. The engineer should become familiar with available strengths, or call local suppliers.

Specified strengths, f'_m , in excess of 4000 psi should not be used unless the engineer has experience with the specific brick and other materials to be used.

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 strength of the system. This is not generally the case. It is common to have a combination of materials with a design strength of 4000 psi with a grout design strength of 2000 psi and a mortar design strength of 1800 psi. This is because the grout and mortar strengths are represented by laboratory or field tests. Laboratory or field-prepared grout and mortar tests are cured and tested 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.

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 variables such as weather, temperature, method of sampling, curing, handling, transportation and testing method.

For this reason, the Uniform Building Code relies mostly on the prism test as a measure of strength. The prism test is the accepted reference test for the strength of masonry.

Unfortunately, during the design development phase, it is uncommon to obtain prism test data. For hollow clay masonry, the unit strength method provides an alternative to prism testing.

Unit Strength Method

The unit strength method can be used with or without the selection of the brick by the architect. If the brick is not selected then the engineer must assume a strength. The value to be assumed should be the minimum value compatible with the design.

When assuming a strength, the structural engineer should notify the architect of the minimum acceptable value. And, notify the architect that if a brick is selected with strength less than the minimum value that a redesign extra service fee may be required.

Brick Selected

If the brick colors are selected before or during the design development phase, then the following method for establishing an upper limit on the design f'_m can be used.

The method conforms to the provisions of the code and will be sufficient for most circumstances. It is called the Unit Strength Method. Proceed as follows:

Step 1

Determine the brick strength from the manufacturer. Document the information. Using the unit strength, go to Uniform Building Code Table 21-C and find the appropriate unit strength rows. Assume Type S mortar.

Step 2

Interpolate between the values to find the limits on the design strength.

Step 3

If the project is small and you expect the stresses to be low, it may be possible to save money by not requiring special inspection and testing during construction. In this case, the allowable stresses based on f'_m are divided in half.

Example: The project is a shopping center (commercial) with a 14-foot tall wall. The brick selected is called "Rockeye" manufactured by XYZ Company

Step 1

Call XYZ Company and ask about the net area compressive strength of "Rockeye". The company responds with a net area compressive strength of 11,000 psi. Be sure that the company gives you net area strength. From Uniform Building Code Table 21-C with Type S mortar, the 12,000 psi unit strength corresponds to an f'_m of 4700 psi and the 10,000 psi unit strength corresponds to an f'_m of 4,000 psi.

Step 2

By interpolation the limit on the masonry strength is 4,350 psi.

Step 3

From the Table 1-5 on typical wall thicknesses, the 6-inch wall is common for one-story commercial projects. From the Table 2-1 on height of walls for different thicknesses, the 14-foot height is more than the normal application, but less than the extended application. Thus, the 6-inch wall with special inspection and with field testing will probably work. Specify 4,350 psi. If an 8-inch wall were used, then special inspection and field testing would probably not be required. Still specify 4,350 psi but design with one half the allowable stresses based on f'_m .

Brick Not Selected

If the brick is not selected early in the design, it is difficult to select a strength for design. However, this situation is not uncommon, and the structural engineer is forced to guess at a value for design.

Fortunately, it is unusual to find brick strengths in the western U.S. less than 6,000 psi. According to the unit strength method, this corresponds to a 2,700 psi design strength. Assume a 2,700 psi strength for special inspected and field testing.

In Seismic Zones 3 and 4 select 2600 psi. Special code requirements in Seismic Zones 3 and 4 make the assumption of 2600 psi. a better choice.

Pattern Walls

When the architect selects a brick wall with several brick colors placed in patterns, it is likely the strength of the masonry wall will vary in relationship to the strengths of the brick. Selecting the lowest strength brick as the basis of design is conservative and recommended whenever possible. However, for some strengths and patterns selecting the average strength may be appropriate. Selecting the strongest brick strength is generally not appropriate.

Bond Pattern

Figure 2-2 presents definitions for unit orientation.

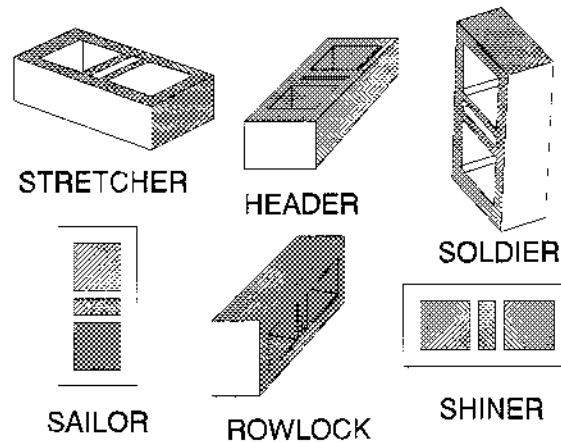


Figure 2-1 Unit Orientation

Typically, the architect will select the bonding pattern. Some choices can have an important impact on the structural design.

The bonding pattern may appear to create a wall which cannot be reinforced and grouted. However, there are usually methods available. Some typical methods include:

1. Use back-to-back bond beams for soldier courses.

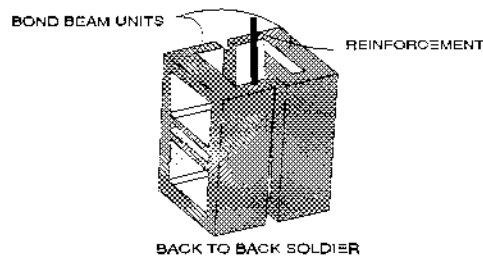


Figure 2-2 Soldier Reinforcement

2. Use precast concrete 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 look just like the adjacent mortar joints.

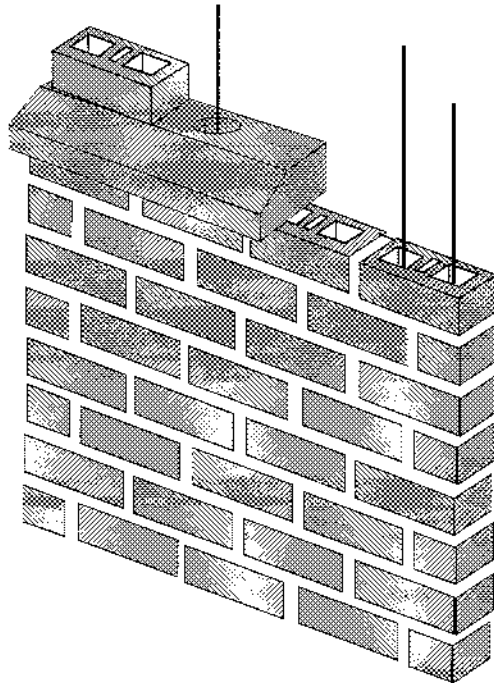


Figure 2-3 Precast and Brick

3. Use various brick thicknesses and special shapes.

It is common to use several thicknesses in the same wall to produce elegant walls. Flexibility is one of the most important advantages of reinforced hollow clay masonry. Rustication, quoins and cornices are examples of a few designs that can be easily produced using different thicknesses of hollow clay.

4. Use cut lintel blocks from the end of units for exposed sills and lintels.

5. Use prefabricated portions of the wall and connect these portions by welding, bolting or grouting.

Prefabricated reinforced hollow clay masonry is common in many locations. Prefabrication is simply building the brick masonry into a panel that can be lifted into place. Common

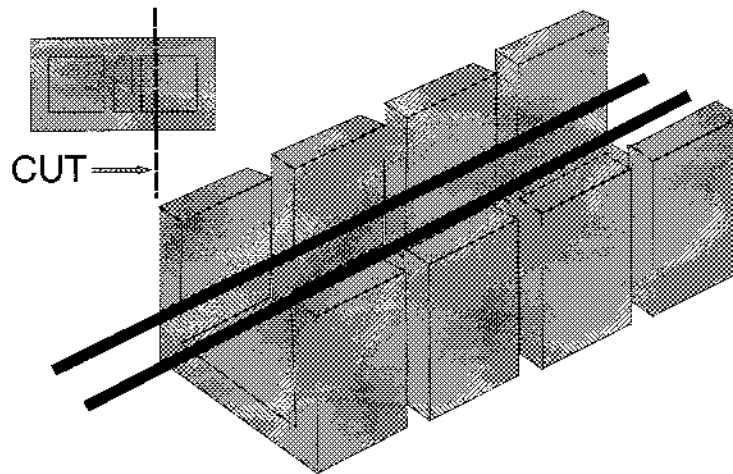


Figure 2-4 Typical Brick Lintel

applications include door and window head lintels (to eliminate construction shoring) and soffit panels where prefabrication may be the only practical method of construction.

6. Add horizontal reinforcement when concrete masonry units are used as part of the hollow clay brick wall.

It is common to have bands of CMU within a brick wall. It is important to consider that the CMU shrinks with age and that the brick masonry expands. To avoid aesthetic problems with cracks, extra horizontal reinforcement should be placed in the CMU to limit the size of the cracking.

Reinforcement

There are building code limitations on the sizes of reinforcement that typically affect the design. They include:

1. Maximum bar size.

The maximum bar size allowed is a Number 11. The maximum reinforcement in a cell is limited to 6 percent of the cell area or 12 percent with splices. The following table presents typical maximum bar size for the standard units. However, the cell areas vary somewhat from manufacturer to manufacturer and dimensions should be verified on each job.

Table 2-4
Maximum Bar Size

| Unit Thickness (Nominal) | 12" Long Units | | 16" Long Units | |
|--------------------------|----------------------------|-----------------|----------------------------|-----------------|
| | Cell Size (width x length) | Max. Bar Size # | Cell Size (width x length) | Max. Bar Size # |
| 4 INCH | 1 3/4 X 3 1/2 | 5 | 1 3/4 x 3 | 5 |
| 5 INCH | 2 1/2 X 3 1/2 | 6 | 2 x 5 | 7 |
| 6 INCH | 3 1/2 X 3 1/2 | 7 | 3 x 5 | 8 |
| 8 INCH | 5 X 3 1/2 | 9 | 5 x 5 | 11 |
| 10 INCH | 6 3/4 X 3 1/2 | 10 | 6.5 x 5 | 11 |
| 12 INCH | 8 1/2 X 3 1/2 | 11 | 8 x 5 | 11 |

2. Clearance between reinforcement and the unit.

The minimum clearance between the inside face of the cell and the bar is 1/4 inch when fine grout is used and 1/2 inch when coarse grout is used. The bars can touch the cross webs when set horizontally in a bond beam.

3. Clearance between bars.

The clear distance between bars in walls and beams should be at least the bar diameter or 1 inch, whichever is greater. In masonry columns the clear distance between bars should be at least 2.5 times the bar diameter. Bars can be in contact with each other at splices.

4. Adjacent cell dowels.

Dowels into walls do not necessarily need to match the cells containing the wall reinforcement. Placing dowels in adjacent cells is common.

5. Minimum reinforcement for seismic.

The code requires minimum amounts of reinforcement when the building is located in seismic Zones 2,3 or 4. The requirements in Zone 2 are prescriptive in terms of the size of bars and location. The requirements in Zones 3 and 4 are that the sum of the horizontal and vertical reinforcement ratios exceed .002 bt with not less than .0007 bt in either direction. The variable "b" is the spacing of the bars and "t" is the specified thickness of the wall.

The following table provides some example configurations that conform to minimum steel percentages required in seismic areas.

Table 2-5
Typical Minimum Reinforcement¹
Seismic Zones 3 and 4

| WALL NOMINAL THICKNESS | VERTICAL REINFORCEMENT | HORIZONTAL REINFORCEMENT |
|------------------------|------------------------|-----------------------------------|
| 4 | #4 @ 48 | 2-#3 @ 48 ² or #4 @ 48 |
| 5 | #5 @ 48 | 2-#3 @ 48 or #4 @ 48 |
| 6 | #5 @ 48 | 2-#4 @ 48 or #4 @ 48 |
| 8 | #6 @ 48 | 2-#4 @ 48 or #5 @ 48 |
| 10 | #7 @ 48 | 2-#4 @ 48 or #6 @ 48 |
| 12 | #7 @ 48 | 2-#5 @ 48 or #6 @ 48 |

1. Based on A_s greater than 0.0007 bt in the vertical or horizontal direction and A_s greater the 0.0020 bt for the sum of both directions.
2. (2) #3 @ 48 does not meet the requirement for a 1" spacing between the horizontal bars. With 3/4 inch brick face shells the spacing between the #3 bars is 3/4 inch instead of 1 inch.

Selection and Specification of Materials

Units

Specify units as conforming to ASTM C-652 or UBC Standard 21-1 with the strength determined by the design requirements.

Mortar

Specify mortar as Type S, portland cement-lime by proportions. Do not specify a mortar strength. Do not specify Type M mortar, masonry cement or mortar cement. Type M mortar is too hard and usually causes a crack between the unit and the mortar. Masonry cement and mortar cement are generally not acceptable for most jobs because it is difficult to determine if the material meets the design requirements. By code, masonry cement mortars are not allowed in Seismic Zones 3 and 4, but mortar cement mortars are allowed.

Grout

Specify grout in accordance with UBC Table 21-B. Do not specify grout by the minimum strength of 2,000 psi. The proportions of Table 21-B will result in strengths well in excess of 2,000 psi.

Note: Lime may be added to grout per UBC Table 21-B. This usually improves the grout properties by increasing flow and retention of water, resulting in improved placement and bonding to the unit.

Sand

Specify sand in accordance with 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 when compared to grouts with the sharper sands.

Cement

Specify cement to conform to ASTM C-150 or UBC Standard 19-1, Types I, II or III. Do not use air-entrained cement types IA, IIA or IIIA, etc. Low alkali cements reduce the tendency for the masonry to effloresce. If available, they are recommended.

Lime

Specify lime to conform to ASTM C-207 or UBC Standard 21-13. Do not use air-entrained lime.

Masonry Cement

Do not specify masonry cement.

Additives

Use Sika Grout-Aid, or equivalent, as a grout additive. Sika Grout-Aid contains a superplasticizer and expansion agents. Do not use additives in mortar, except colors in accordance with manufacturers recommendations.

Color

Color additives to mortar generally do not reduce mortar strength for bond or compression. Most color additives consist of mineral oxides except carbon black, which consists of finely ground carbon. The code limits the amount of carbon black (for grey mortars) to 3% of the weight of the cement. When using colored mortar, follow the recommendations of the color additive manufacturer.

Reinforcement

Grade 60 reinforcement is now almost universally used. When welding reinforcement, use ASTM A-706 bars.

Masonry

Specify the masonry required strength $f'm$.

Designer Choices

Solid Versus Partial Grouting

A solid grouted wall is a wall where all the cells are filled with grout. A cell is different from a core. A cell's cross section exceeds 1 1/2 square inches. A core's cross section is less than 1 1/2 square inches. Cores do not need to be grouted for a wall to be classified as a solidly grouted wall, but all cells do need to be grouted. Reinforcement is not placed in cores.

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 cost for grout material. Most contractors agree that when bars are spaced closer than 24 to 30 inches on center, it is less expensive to grout solid.

Energy considerations may require that some cells remain ungrouted and be filled with insulation.

Solid grouted walls perform better than partially grouted walls. The solidly grouted wall resists water penetration, cracking and loads better than the partially grouted wall. Sound transmission is less. The fire rating is higher. The wall is more able to resist freeze damage because there are fewer voids in the wall.

High-Lift Versus Low-Lift Grouting

Grout pours less than 5 feet are called Low-Lift grouting. High-lift grouting is when the grout pours exceed 5 feet. A grout pour is defined as the total height of the masonry wall to be grouted prior to the erection of additional masonry.

Methods for grouting may be considered as 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 therefore may be part of the designer's choice.

Uniform Building Code Table 21-H provides the maximum grout heights for various cell sizes. For standard hollow clay masonry, the grout height limits are as follows:

Table 2-5
Grout Pour Heights (feet) ¹

| Wall Nominal Thickness (inches) | Fine Grout | Coarse Grout |
|------------------------------------|------------|--------------|
| 4 | 12 | Do not use |
| 5 | 12 | 5 |
| 6 | 24 | 12 |
| 8 | Do not use | 24 |
| 10 | Do not use | 24 |
| 12 | Do not use | 24 |

1. The code allows higher grout pour heights if it can be demonstrated that the spaces to be grouted are properly filled

In hollow clay masonry it is advantageous to use high-lift grouting. Grout pours with heights in excess of 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 quality of the grout improves with the increased volume of placement. 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.

In order to verify the materials and procedures before construction, the engineer can recommend to the architect that he specify a grouting demonstration panel. This demonstration panel is a sample of the wall built before construction and often is also used as the visual mock-up. The architect, engineer, inspector, building official and general contractor should witness the grouting demonstration. Several days after the grouting the panel can be cut open to expose the grout cell and access the quality of materials and process.

For highly stressed walls where reinforcement and grout placement are important, it is recommended that the engineer specify the grout pour heights and the lap locations in the wall.

Conduct a grouting demonstration on a sample of wall prior to construction.

The use of mortar (slushing) is not an acceptable substitute for grouting.

Clean-outs

Clean-outs are access ports at the bottom of the cell for the purpose of removing mortar droppings. Mortar droppings can prevent the grout from bonding to the surface at the bottom of the cell. This mortar causes a weak plane for resisting shear forces.

If the shear stresses are low, the grout bond area may not be necessary to transfer the load. The mortar bed joint may be sufficient. This is often the case for long walls.

Where the in-plane shear is less than 15 psi assuming only the face shell area is effective, clean-outs may not be necessary. To eliminate the clean-out requirement, it will be necessary to ask for a building code variance (Section 104.2.8) from the building department. Otherwise, clean-outs are required for high lift grouting. With or without clean-outs, mortar droppings should be minimized through good construction practices.

When stresses require clean-outs or when a variance from the building department is not obtained, the use of low-lift grouting techniques may be less costly than using clean-outs.

Joint Steel Versus Bond Beams

When the horizontal reinforcement is required to resist shear forces, use bond beams. There is more confidence with the placement of bars in a bond beam than with the placement of joint steel in the bed joint. This is because it is not unusual 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 joint steel is a common practice in non-structural masonry and veneer. The mason may not understand the difference or importance.

When horizontal reinforcement is not required to resist shear forces, joint reinforcement may be satisfactory and could save cost. If used, joint reinforcement must be galvanized. This is because it is placed in the mortar joint with limited cover and must be protected from chemical attack and carbonation.

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 number four bar should be placed at each window and door jamb. This recommendation is for general good performance of the wall even when not required by code.

Vibration and Reconsolidation

The Uniform Building Code 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 placement of the grout to increase the flow and decrease the chance for grout voids. 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 grout is high (8 to 10 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.

Mechanical reconsolidation is the process of vibrating the grout sufficiently to collapse these voids. Often this requires placing a vibrator one foot or less into the top of the grout. When successfully done, the top of the grout will settle below its previous position, often settling 2 to

4 inches for low-lift grouting and 4 to 8 inches for high-lift grouting.

The mechanical vibration during placement (consolidation) of fluid fine grout is not necessary and a code modification should be requested under Uniform Building Code Section 104.2.8.

In some situations, mechanical reconsolidation of fine grout in small cells may not be necessary and a code modification under 104.2.8 may also be appropriate.

Working Stress Design versus Strength Design

Allowable stress or working stress design is the traditional design method for hollow clay masonry. New standards and codes are being introduced that employ ultimate strength or limit states design. However, at this time the designs using the new standards have limited field verification and many of the requirements are not in accordance with standard design and construction practice.

It is recommended that Working Stress Design methods be used.

With or Without Special Inspection

Uniform Building Code Section 1701.5.7 presents the requirements for special inspection of masonry. Provisions are dependant on whether or not open end units and solid grouting are chosen. Since it is very uncommon to use open end units in hollow clay masonry, the effect of the provisions can be ignored.

When specially inspected and the specified design strength, f'_m , exceeds 2600 psi, the special inspector must be on the job full time and inspect the following:

1. The placing of all masonry units.
2. The placement of reinforcement.
3. The space to be grouted.
4. The clean-out opening just prior to closing.
5. The grouting operation.
6. The preparation of test specimens.
7. The preparation of mortar.

When specially inspected and the specified design strength, f'_m , is less than 2600 psi, the special inspector need not be on the job full time to inspect the placing of all masonry units, reinforcement and creation of the grout space. Instead the inspector must:

1. Inspect the placing of units at the start of construction.
2. Inspect the reinforcement after placement.
3. Inspect the place to be grouted prior to grouting.
4. Inspect clean-out openings just prior to closing.
5. Inspect the grouting operation.
6. Inspect the preparation of test specimens.
7. Inspect the preparation of mortar.

To simplify these requirements, it is recommended that the engineer ignore the 2600 psi separation of the requirements and use the first inspection list with inspection full time.

It can be argued that the specified strength should be unrelated to the inspection requirements and thus the construction quality. Instead, only the design allowable should be related to the construction quality. The specified strength should only be related to the materials used (brick, mortar and grout).

It is recommended that the engineer using full allowable stresses, specify special inspection in accordance with UBC Section 1701.5.7.1 without the exception.

It is recommended that the engineer using one half the allowable stresses, not specify special inspection in accordance with UBC Section 1701.5.7.1 or 2. This conforms to the exception of UBC Section 1701.5.7.2.

Field Testing versus No Field Testing

Field testing includes testing of the materials and masonry to be used prior to the start of construction. It also includes testing during construction.

The selection of the allowable design stresses as either full or one half values determines the level of quality control testing required prior to and during construction. When using the unit strength method and full allowable stresses, the code requires the following minimum quality control tests:

1. Units shall be tested prior to construction and for each 5000 square foot of wall placed.
2. Mortar shall be verified to comply with that used in the Unit Strength Method (UBC Table 21-D).
3. Grout shall be verified to comply with UBC Table 21-B.

When using the unit strength method and one half the allowable stresses, the code allows the following minimum quality control:

1. A letter of certification shall be provided by the manufacturer stating that the units meet the required strength used for the Unit Strength Method (UBC Table 21-D).
2. A letter of certification shall be provided from the grout supplier stating that the grout complies with the requirements of Table 21-B.

To simplify these requirements and provide adequate assurances for the structural engineer, it is recommended to ignore the substitution of unit tests for prism tests.

It is recommended when using the unit strength method and full allowable stresses, that prism tests be conducted prior to construction and for each 5000 square foot of masonry placed. Mortar and grout should be verified in the field by checking that the proper proportions are used.

It is recommended when using the unit strength method and one half the allowable stresses, that unit strength certification be obtained prior to construction. Mortar and grout should be verified

in the field by checking that the proper proportions are used.

Summary /Strength, Inspection and Testing

The selection of a masonry design strength, f_m , allowable stresses, inspection requirements and testing can be confusing. In an effort to summarize the above recommendations, the following table is offered.

Table 2-6
Summary
Strength, Inspection and Testing¹

| | Design Allowable Stresses ¹ | |
|---|---|--|
| | Full Allowable Stress Design | Half Allowable Stress Design |
| Determination of f_m | Unit Strength Method | Unit Strength Method |
| Verification of f_m | Prism tests prior to construction | Certification of the unit by the manufacturer and verification of mortar and grout proportions prior to construction |
| Verification of Construction Quality | 1. Full time Special Inspection. 2. Prism tests each 5000 square foot of wall. | No Special Inspection required. |
| 1. For any specified strength (above or below 2600 psi). | | |

CONSTRUCTION DOCUMENTS

During the construction document phase, the architect prepares construction documents consisting of drawings and specifications setting forth in detail the requirements for the construction of the project.

During the construction document phase, the structural engineer prepares the structural design of the primary structural system. The primary structural system is defined in the National Practice Guidelines for the Structural Engineer of Record, prepared by the Coalition of American Structural Engineers, November 1989 as:

"The completed combination of elements which serve to support the Building's self weight, the applicable live load which is based upon the occupancy and use of the space, the environment loads such as wind and thermal, plus the seismic loading. Curtain wall members, non load bearing walls or exterior facade, to name a few items are not part of the Primary Structural System."

The process of preparing construction documents includes structural analysis, drawing preparation and writing or reviewing of specifications. Each part of this process proceeds simultaneously and they are interrelated. However, for the purpose of simplifying the description, the parts are separated in this section.

Structural Analysis

Following the preliminary sizing of the primary structural elements, the global loads applied to the building can be distributed to the elements. The loads are distributed to each element by methods that have become customary to structural engineering. For example, it is common practice to distribute vertical loads using the tributary area assumption instead of elastic stiffness. It is common practice to ignore the effects of cracked sections for elastic distribution of lateral loads.

Once the loads on the elements are known, the elements can be checked to assure 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.

A detailed discussion of the structural analysis procedures is contained in many excellent references. Several recommended references are included at the end of this chapter. The following paragraphs present issues commonly encountered during the structural analysis of hollow clay masonry structures.

Distribution of Loads

Vertical loads are normally distributed to the walls using the tributary area method. Stiffness methods are not appropriate because the actual distribution depends on the sequence of construction more than stiffness. The tributary area method splits floor dead and live loads to the walls by splitting the distance between the walls.

Lateral loads are distributed to the walls by the tributary area method for buildings with flexible diaphragms or the stiffness method for rigid diaphragms. The stiffness method can be accomplished either by using hand calculations or by finite element computer analysis. Reference 5 presents example calculations for three typical buildings.

Checking the Strength of Masonry Elements

Typically, the vertical and lateral loads are distributed to the elements as separate loading conditions. The building code specifies the combination of these separate load cases to be used for designing the element. With the combined loads defined, the following assumptions are used to check the adequacy of a hollow clay masonry element:

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 that they work together as a homogeneous material in the range of working stresses.

Additionally, the following assumptions are made for the area of masonry to be used in resisting the loads:

1. For ungrouted hollow clay, the design area is the face shell area of the unit.
2. For solidly grouted masonry, the design area is the gross cross-sectional area of the masonry. The area of cores is included even though it is not grouted.

Also, the following assumptions are recommended:

1. For partially grouted masonry, the design area is the face shell area. It is not recommended to include the area of the grout since the mechanism for transferring load to the grouted cell is questionable.
2. For beams with compression on the head joint, the design area is the face shell area. This is because the head joint is filled to the depth of the face shell, not the complete thickness of the unit. If bond beams or open-end units are used, then the design area would be the full thickness of the unit.

For working stress design, it is assumed that the stress in the masonry is proportional to the strain in the masonry. For strength design, it is assumed that the maximum compression strain is a specific value. At this time the Uniform Building Code uses a value of .003 and the Masonry Standards Joint Committee uses a value of .0025. In either case the actual distribution of compression stress is replaced by a rectangular stress block (see Reference 7). For the remainder of this section the working stress design assumption is used.

Bending

In masonry working stress design, there are allowable stresses for both the masonry in

compression and the reinforcement in tension. The analysis needs to verify the adequacy of the section for both. It is recommended that this be accomplished by using separate moment capacities based on the following equations:

$$M_c = \frac{bd^2}{2}kjF_b$$

$$M_t = A_sjdF_s$$

where M_c is the moment capacity limited by the compression allowable in the masonry and M_t is the moment capacity limited by the tension allowable in the reinforcement. It is customary in masonry for the allowable stress notation to be capitalized and the computed stresses to be lower case. The following defines the terms in the above equations:

$F_b = f'_m/3$ (times 1.33 for wind or seismic)

$F_s = 24,000$ psi (times 1.33 for wind or seismic)

$E_m = 750 f'_m$ less than 3,000,000 psi

$A_s =$ The area of tension reinforcement (in²)

$d =$ The distance from the extreme compression fiber to the centroid of the reinforcement

$b =$ The width of the masonry (in)

For out-of-plane bending, "b" is the lesser of:

1. The distance between bars.
2. In running bond, six times specified thickness.
3. In stack bond, the unit width.
4. In stack bond, three times the specified thickness when grouted solid.

For in-plane bending, "b" is the thickness of the wall if grouted solid. If partially grouted, the compression length of the wall (kd) needs to be compared to the number of cells grouted at the end of the wall. Often, the compression length is less than the length where all of the cells are grouted. If this occurs, then b is the wall thickness. If not, then it is conservative to assume that b is the sum of the face shell thicknesses.

The values of k and j can be determined by:

$$np = \frac{E_s A_s}{E_m bd}$$

$$k = \sqrt{(np)^2 + 2np} - np$$

$$j = 1 - \frac{k}{3}$$

These equations apply for in-plane or out-of-plane loading.

Some additional comments are:

1. The equation for the value of E_m has fluctuated from code to code. Be sure to use the applicable code for the project. When using computer software, the value of E_m is often programmed incorrectly and should be verified. Testing for the modulus of elasticity is uncommon even when deflection is important to the design. This is because the test results are unreliable and the methods for performing a cracked section deflection analysis are questionable.
2. The value of F_s and F_b can be increased by one-third for seismic or wind loading conditions.
3. Bending is usually accompanied by axial load due to dead load. Using the principles of mechanics methods for bending plus axial will normally result in significantly less tension reinforcement, (see Appendix A).

Deflection

Deflection calculations are approximate. This is the result of 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, the methods presented in the building code give some indication of the deflection magnitude.

Bending Plus Axial

There are many methods for checking a section loaded by bending with compression. Some of the approaches neglect the beneficial effect of dead load. Dead load reduces the required area of reinforcement when an element is limited by the tensile moment capacity.

An interaction diagram is helpful for a detailed analysis. Unfortunately, interaction diagrams are not as readily available in masonry. Thus, easier approximate methods are commonly employed. The Unity Equation is an example.

The Unity Equation

The code allows the use of the Unity Equation. This equation checks only the masonry for compression not the reinforcement for tension. It neglects the beneficial effects of dead load. The bending ratio f_b/F_b in the unity equation, assumes no axial load is applied. The normal controlling design load combination is full dead, plus reduced live load, plus wind or earthquake.

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1.00 \text{ (or 1.33 for wind or seismic)}$$

$$f_a = \frac{P}{A} \quad A = \text{net area}$$

$$F_a = .25 f'_m \left[1 - \left(\frac{h}{40t} \right)^2 \right] \quad \text{for } \frac{h}{t} \leq 28$$

$$F_a = .25 f'_m \left(\frac{20t}{h} \right)^2 \quad \text{for } \frac{h}{t} > 28$$

$$f_b = \frac{2M}{bd^2kj}$$

$$F_b = \frac{f'_m}{3} \leq 2000 \text{ psi}$$

The terms in these equations have been previously defined. The equation for F_a is conservative because the radius of gyration used in the Uniform Building Code is replaced by .28 times the specified thickness. And, although the code allows the use of effective height (h'), it is recommended that a pin-pin condition be assumed. Or, if the wall is cantilevered use twice the height.

The Unity Equation is for the compression capacity of the element. The tension capacity, or required steel, can be determined by the following. The normal controlling design load combination is 85% of dead load plus wind or seismic (see UBC Section 1631.1).

$$A_s = \frac{M}{jdF_s}$$

Where F_s may be increased by one-third for wind or seismic loads.

If the quantity of tension steel is large, there may be savings by using the principles of mechanics to relieve the tension stresses. A method is presented in Appendix A.

Axial Compression

Wall elements are typically designed for the combination of axial load and bending. Column elements are also normally designed for combination of axial load and bending. The ACI 530

code requires a 10% eccentricity for axial load in column design thus forcing the combination of loading analysis. However, for columns the allowable compression stress, F_a , is slightly higher than it is for walls.

It is recommended for simplicity that the allowable stress for walls be used for columns.

The minimum nominal column dimension for masonry in Seismic Zones 3 or 4 is 12 inches unless half allowable stresses are used. With half allowable stresses the minimum nominal column dimension is 8 inches.

In Seismic Zones 3 and 4, the minimum nominal bearing wall thickness is 6 unless the brick exceeds 8000 psi. With the high strength brick, the minimum nominal wall thickness is 4 inches, see UBC 2107.1.3.1.

Shear

Masonry design for shear is not analogous to concrete design for shear capacity. In concrete, the capacity of the concrete is added to the capacity of the reinforcement. In masonry, if the capacity of the masonry is exceeded, then its contribution is neglected and all of the capacity is provided by the reinforcement.

The shear design of flexural elements is distinct from the shear design of shear walls. The shear wall allowable stress is lower because the consequence of a failure is considered more serious.

Beam Elements

For beam elements, the computed or applied shear stress is determined by:

$$f_v = \frac{V}{bjd}$$

The allowable without shear reinforcement is:

$$F_v = 1.0\sqrt{f'_m} \leq 50 \text{ psi}$$

and with shear reinforcement is:

$$F_v = 3.0\sqrt{f'_m} \leq 150 \text{ psi}$$

Where the required shear reinforcement is:

$$A_v = \frac{Vs}{F_s d}$$

where s is the spacing of the steel. The spacing of shear reinforcement must not exceed $d/2$.

Shear Walls

The applied shear stress is determined by:

$$f_v = \frac{V}{bjd}$$

If the shear force V is due to seismic loading, then $V = 1.5 V_{\text{applied}}$ in the above equation.

Without shear reinforcement (flexural reinforcement only) and for $M/Vd < 1.0$, the allowable shear stress is:

$$F_v = \frac{1}{3} \left(4 - \frac{M}{Vd} \right) \sqrt{f'_m} \leq \left(80 - 45 \frac{M}{Vd} \right)$$

and for $M/Vd \geq 1.0$ is:

$$F_v = 1.0 \sqrt{f'_m} \leq 35 \text{ psi}$$

With shear reinforcement and for $M/Vd < 1.0$, the allowable shear stress is:

$$F_v = \frac{1}{2} \left(4 - \frac{M}{Vd} \right) \sqrt{f'_m} \leq \left(120 - 45 \frac{M}{Vd} \right)$$

and for $M/Vd \geq 1.0$ is:

$$F_v = 1.5 \sqrt{f'_m} \leq 75 \text{ psi}$$

F_v and the maximums for F_v are increased by one third for wind or seismic. M is the bending moment occurring in the element where V occurs. V is not increased by the 1.5 factor in M/Vd for seismic loading.

F_v and the maximum values are divided by two for masonry without special inspection.

Bearing

Typically, the smaller code allowable of 0.26 f'm for bearing will be sufficient. Use embedded plates with welded-on bars to distribute loads. Use ASTM A 706 weldable bar and design the welds for half the nominal allowable.

Bolts

The UBC and other codes provide a method for design.

Shear Friction

In many situations, particularly for the design of connections such as beam seats, the shear capacity of the masonry perpendicular to the reinforcement is required. In these cases, the use of the shear friction concept is recommended. The code is silent on this subject but there is reason to believe that reinforced masonry acts the same as reinforced concrete in these conditions. Thus, the quantity of shear friction reinforcement can be calculated as:

$$A_v = \frac{V_u}{\phi F_y}$$

The codes provide no guidance as to the appropriate values. The following values are recommended:

$$V_u = 2.0 \text{ (applied shear)}$$

$$\phi = .40$$

$$F_y = \text{steel yield stress}$$

Bar Laps

It has been traditional to use 48 bar diameters for tension laps and 36 bar diameters for compression laps for grade 60 reinforcement.

Whenever possible, it is recommended that laps do not occur where the stress in the bar approaches the allowable stress. If the stress in the bar exceeds 80% of the allowable stress (19,200 psi for grade 60 bars), then increase the lap length to 72 diameters. If the one third increase in allowable stress has been used for wind or seismic loading (32,000 psi for grade 60 bars) and the applied stress exceeds 80% (25,600 psi for grade 60 bars) then use 96 bar diameters.

Where laps exceed the 48 bar diameters, it may be more economical to change the location of the splice or increase the bar size to reduce the design stress.

Embedments

Use 48 bar diameters for design stresses less than 80% of the allowable increased to 64 bar

diameters for wind or seismic. Use 72 bar diameters for design stresses over 80% of the allowable when the allowable has not been increased by 1/3 and 96 bar diameters when the allowable stress is increased by the 1/3 factor.

Maximum Bar Size

The maximum bar size is No. 11. Additionally the bar cannot exceed 6% of the cell area (12% for splices).

Two bars placed side by side in a bond beam with one vertical is a common method of reinforcement. Using two horizontal bars can act as positioners for vertical steel and also provides the opportunity to stagger laps. However, two bars will decrease the available space for the flow of grout. Voids may result if contractors in the area are not skilled at grout placement. Local capabilities should be investigated for each design.

Drawing Preparation

Layout

Figure 3-1 presents a typical layout of the structural drawings for a building project.

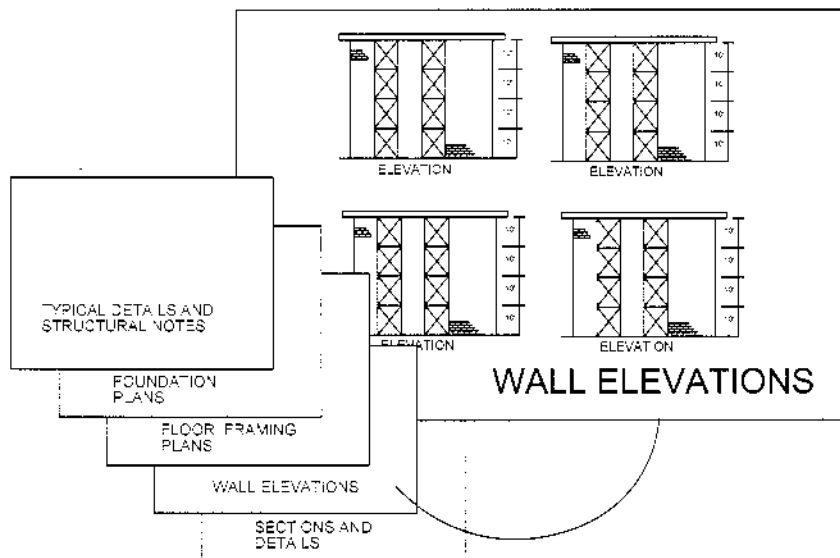


Figure 3-1 Drawing Layout

When reinforced hollow clay masonry 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. All bars should be shown or called out on these elevation drawings. Tabulation of reinforcement requirements has not proven to be a very successful method of communicating the design to the mason.

Structural Notes

The structural notes are placed on the drawings to define 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 user.

The notes typically take precedent over the specifications. Appendix B presents sample structural notes.

Dimensions

The length of hollow clay masonry units is based on a 6-inch module. Thus, bars should be spaced at 6 inches, 12 inches, 18 inches, etc. on center. However, 16 inch units with an 8-inch module are available from some manufacturers. In this situation bars should be spaced at 8 inches, 16 inches, 24 inches, etc. on center.

The height of hollow clay units is normally based on the 4-inch (3-1/2 inch for the unit, plus 1/2 inch for the joint) module. However, other height units can be obtained. Typically, the cost per square foot rises in proportion to the number of units required to be laid per square foot.

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

Generally, the masonry contractor can adjust 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, length or height. The dimension of a darker unit will normally 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 cost will result either because of the increased cost for more uniform units or the 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.

Special unit designs for custom patterns can be accomplished with adequate planning and budget. The additional cost for custom units, shapes and colors on large projects is generally small.

Details

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

Hollow clay masonry 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 masonry is supported on a concrete floor or slab, it is often desirable to recess the concrete.

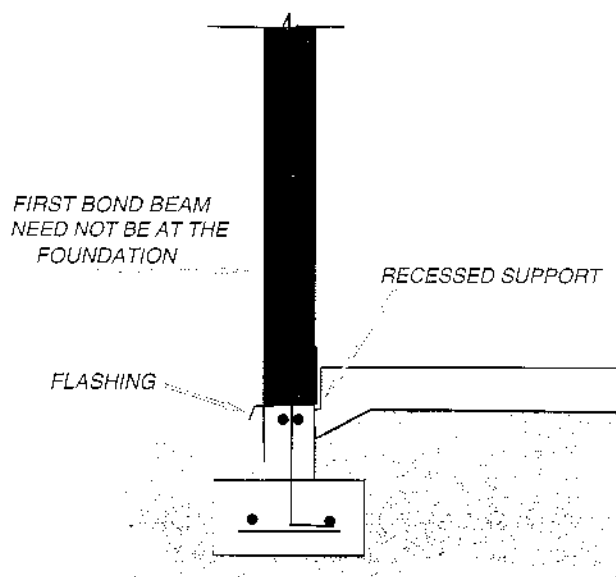


Figure 3-2 Wall to Foundation Detail

Water and Flashing

Water seldom completely penetrates a reinforced hollow clay wall. Instead, it enters the wall and travels downward through open cells or small voids in the grout and mortar. 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 the bottom of the masonry and therefore requires flashing. A drift joint (horizontal joint between building floor elevations to accommodate in-plane movement of one floor relative to the adjacent floor) is typically a bottom for the masonry and therefore requires flashing.

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 (Reference 8). 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. Nevertheless, additional dowels may be appropriate in Seismic Zone 3 and 4 in order to assure that the walls and foundation remain connected in an earthquake.

Connections/Windows

Wall and roof connections or intersections with masonry can take many forms. References 4 and 5 provide excellent typical details.

Windows are typically connected to the structural hollow clay masonry. The engineer should provide typical details for this connection or specifically require the contractor to provide the design and so indicate on the drawings and in the specifications.

Movement Joints

Movement joints are always a challenging design item. In addition to normal thermal expansion and contraction, brick expands with moisture. The expansion is called moisture expansion, but is different from moisture expansion of concrete. Moisture expansion of brick occurs only once.

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 clay of the brick expands. The amount of expansion depends on the clay. The length of time required depends on the clay and exposure. The time required for the process is between one and five years. The amount of expansion depends on the type of clay, but can be as large as .0004 inch per inch or 1/2 inch in 100 feet.

Movement joints in clay brick are called expansion joints. Expansion joints are important to the performance of unreinforced clay masonry. For reinforced hollow clay masonry, expansion joints are not as 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, it is common practice to place expansion joints at 100 feet or less.

If the length of the wall exceeds 20 feet, expansion joints should also be placed on one side

of a 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, probably causing a crack.

Another requirement for expansion joints occurs when brick becomes confined by another material. Figure 3-3 shows an example where hollow clay is confined in a concrete frame.

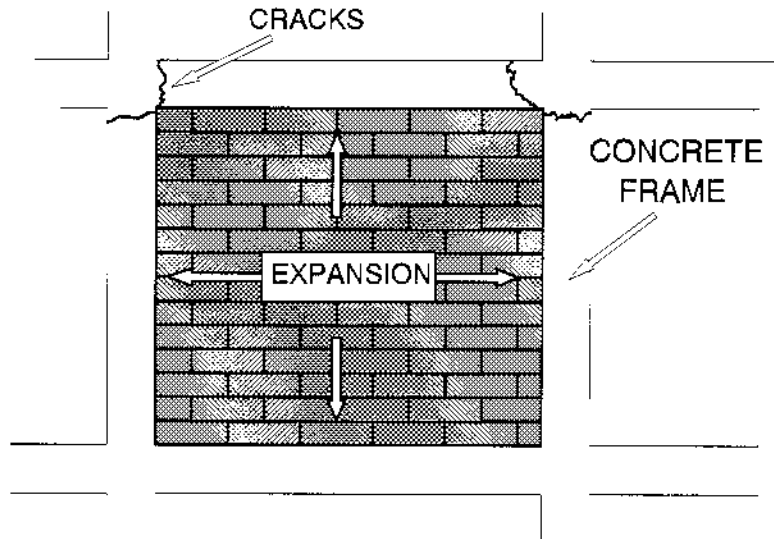


Figure 3-3 Confined Brick Masonry

Specifications

Specifications are normally prepared by the architect and reviewed by the structural engineer. Appendix C provides a checklist for the hollow clay masonry sections of the typical specifications. Additional considerations may include:

1. Require the mason subcontractor to prepare or oversee the preparation of reinforcing shop drawings. The shop drawing preparer should be familiar with the design and construction of reinforced hollow clay masonry. 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 responsibility in the event of problems.
3. On a large project, require a grout placement 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 reinforced hollow clay masonry. 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 selection:

- (a) Require the contractor to employ experienced labor.
- (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 on the contractor's qualifications or to provide a list of qualified bidders.
- (c) Require prior experience with the construction of hollow clay masonry on projects similar to the one being designed and built.

- 5. Require a preconstruction conference.
- 6. Require methods other than shovel count to control proportions for mortar and grout.
- 7. 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.

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. In the Northwest, with intense winter rains followed by a sudden freeze, masonry has been damaged by freezing after fourteen days of curing.
- 9. Require inspection prior to grouting and during grouting even when stresses do not require special inspection.
- 10. Require Sika Grout-Aid, or equivalent be used as an additive to the grout. This additive improves flow (contains a plastizer) and helps fill the voids left by the absorption of water by the units (contains an expansion agent).
- 11. Require mechanical vibration for placement and reconsolidation of grout. However, mechanical vibration and reconsolidation may not be necessary in all conditions; see the Designers Choices Section of this publication. When not required, obtain a building code variance in accordance with UBC Section 104.2.8.
- 12. 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.
- 13. Require the mason contractor to submit a written quality control program for the masonry construction.

References

1. Drysdale, R.G., Hamid A.A., Baker, L.R., *Masonry Structures, Behavior and Design*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1994.
2. Schneider, R.L., Dickey, W.L., *Reinforced Masonry Design*, Prentice-Hall, Inc., Englewood Cliffs, NJ, Second Edition, 1987.
3. Abrams, D.P., *A Set of Classnotes for a Course in: Masonry Structures*, The Masonry Society, Boulder, CO, 1991.
4. Beall, C., *Masonry Design And Detailing For Architects, Engineers, and Builders*, McGraw-Hill Book Company, New York, 1987.
5. Amrhein, J.E., *Reinforced Masonry Engineering Handbook*, Masonry Institute of America, Fifth Edition, 1992.
6. *Masonry Designers' Guide*, The Masonry Society, 2619 Spruce Street, Boulder CO., 1993
7. Tawresey, J.G., *Strength Design Stress Factors Determined From the Masonry Stress-Strain Relationship*, Proceedings of The Sixth North American Masonry Conference, June 6-9, 1993 Philadelphia, PA.
8. McGinley, W.M. and Borchelt, J.G., *Friction at Supports of Clay Brick Wall*, Proceedings of The Fifth North American Masonry Conference, June 3-6, 1990 Urbana-Champaign Illinois

CONSTRUCTION

The construction phase of the project begins with the award of the Contract for Construction. During the construction document phase, the architect is the representative of the owner 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 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 assure 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 and summarizes the construction process.

Bidding and Award

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

The structural drawings show the design concept for the project. They are not the 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. It is supplied by the general contractor. 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 normally prepare shop drawings for reinforcement. Thus, the responsibility for providing an adequate set of shop drawings can become lost in the process of bidding. 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. This method is assumed in the sample specifications and structural notes. However, some mason contractors may bid high or even not bid at all as a result of 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 steel detailer. Unfortunately, the detailer may have limited experience with masonry (the expertise is concrete) and the drawings are often full of errors or items that cannot be constructed.

Pre-Construction

Once the general contractor and the mason subcontractor have been selected, the engineer should verify his qualifications with the local masonry institute and the local material suppliers. This information will be helpful for determining the amount of time and effort that will be needed during construction.

At an appropriate time, usually at least two months 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 engineer.
7. The owner's representative.
8. The brick supplier.

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 , then mortar, grout and prism testing prior to construction are not required. However, prism tests prior to construction are recommended when full allowable stresses were used in the design.

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 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:

If the project was designed using full allowable stresses, then prism testing is recommended for each 5,000 square feet of wall. During construction three prisms constitute a test. Prior to construction five 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.

If prism tests are conducted, grout and mortar tests are usually not required.

If the project was designed using one half allowable stresses, then prism testing is not required.

4. Inspection:

When the project was designed using full allowable stresses, it is recommended that the inspector be on site full time. The inspector should regularly check the batching of mortar and grout to assure proper proportions and the laying of units to ensure proper workmanship. The inspector should verify and ensure full compliance with the contract documents for the placement of reinforcement, grouting and reconsolidation and the protection of the masonry from rain, dirt, cold and/or hot weather.

When the project was designed using one half allowable, it does not mean that there is no inspection required. It is still required that the building department inspect the project on a periodic basis to confirm that the project is proceeding in accordance with the code and contract documents. Unit strengths, mortar proportions and grout proportions are required to be verified.

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

7. Submittals:

Verify that the required project submittals have been approved or are in the process of being approved.

8. Cleaning and Sealing:

The procedures to be used to clean and seal the masonry 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, the method and materials to be used should also be verified with the brick manufacturer.

Proper sealers do not seal the wall. Masonry must breath. 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.

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 (ASTM C 270).

2. Grout proportions:

For batch-provided grout, the proportions are normally described by weight. The weight proportions should be converted to volume proportions for comparison with UBC Table 21-B or ASTM C 476. An example calculation follows:

Table 4-1
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. | 7.0 | 1 |
| Lime | 50 | 40 ₂ | 7.5 | .18 |
| Sand | 2143 | 80 ₃ | 26.8 | 3.8 |
| Aggregate | 1009 | 105 ₂ | 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 to Uniform Building Code Table 21-B or ASTM C 476 is given in Table 4-2. The mix design does not comply.

Table 4-2
Comparison to UBC Table 21-B

| Item | UBC Table 21-B | 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 the cement and lime | | |

3. Unit certifications:

If the Unit Strength Method was used to establish f'_m and the design used one half the allowable stresses, then the structural engineer should request a letter from the brick supplier 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. Though review of the submittal is necessary to verify that the contractor has the correct understanding of the design. If enough time is available, re-submittal is possible without costly delays.

5. Miscellaneous iron 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:

When required by the specification, the 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.

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 construction observation. It is defined in AIA C141 Section 2.6.3 as:

"The consultant shall visit the site at intervals appropriate to the stage of construction for This Part of the Project, or as otherwise agreed with the Architect in writing, to become generally familiar with the progress and quality of the Work completed for This Part of the Project and to determine in general if the Work is being performed in a manner indicating that the Work, when completed, will be in accordance with the Contract Documents. However, the consultant shall not be required to make exhaustive or continuous on-site inspections to check the quality or quantity of the Work for This Part of the Project. On the basis of such on-site observations as a consultant, the consultant shall keep the Architect informed of the progress of the Work for This Part of the Project and shall endeavor to guard the Owner against defects and deficiencies in such work. (*More extensive site representation may be agreed to as an Additional Service, as described in Paragraph 3.2*)"

An example site observation form and checklist is provided in Appendix D.

Non-Conforming Quality Control Tests

Unit Compression Strength

If the Unit Strength Method for establishing and verifying the specified compression strength, f'_m , and full stresses are used in the design, then unit compression tests may be substituted for the recommended prism tests prior to and during construction. (This is allowed by the 1994 Uniform Building Code but not recommended). If the unit test prior to construction does not comply with the required strength, then another brick may be required, or the project may have to be redesigned for a lower strength.

When units are tested prior to construction and conform to the requirements but do not conform to the requirements when tested during construction, the problem probably is with the manufacturing of the units or with a change in the testing procedures. The units should be retested. If the units still do not comply, the code allows prism testing to verify strength. Construct prism and test to verify the strength.

If the prism strengths do not comply, a redesign or change in the brick unit may be required. Non-conforming walls will likely require removal.

Mortar Compression

It is recommended that field testing of mortar not be required. Prism testing every 5000 square foot of wall is recommended when full allowable stresses are used and field testing should not be required when half allowable stresses are used. However, the requirement for mortar testing often is not within the control of the structural engineer, and on many projects mortar testing becomes a requirement.

The field sampling and testing for mortar compression strength is highly variable. Figure 4-1 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%.

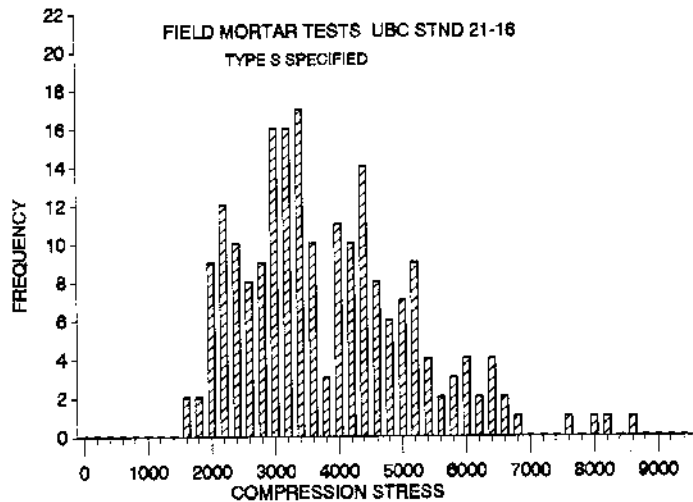


Figure 4-1 Field Mortar Test Frequency Distribution

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 UBC Standard 21-16.
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 strengths 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. Figure 4-2 presents the relationship for the same projects.

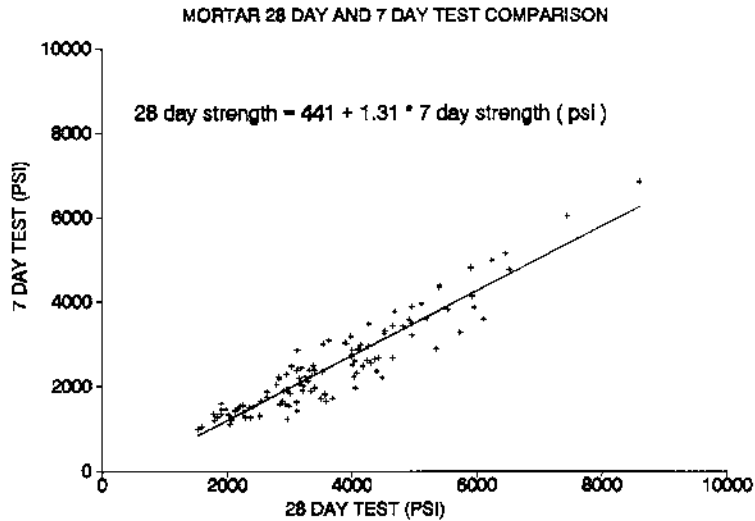


Figure 4-2 Comparison, 7 and 28 Day Mortar Compression Tests

Grout Compression

It is recommended that field testing of grout not be required. Prism testing for every 5000 square foot of wall is recommended when full allowable stresses are used and prism testing should not be required when half allowable stresses are used. However, the requirement for grout testing often is not within the control of the structural engineer, and on many projects grout testing becomes a requirement.

The field sampling and testing for grout compression strength is highly variable. Figure 4-3 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%.

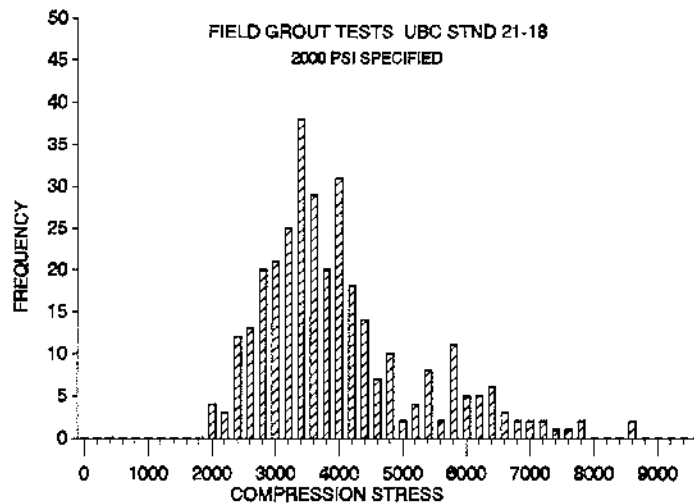


Figure 4-3 Field Grout Test Frequency Distribution

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 UBC Standard 21-18.
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.

The relationship between 7 day grout strength and 28 day grout strengths 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. Figure 4-4 presents the relationship for the same projects.

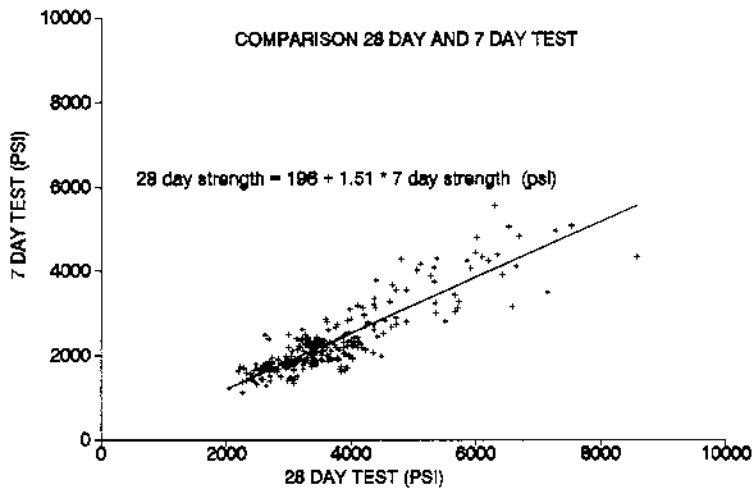


Figure 4-4 Comparison, 7 and 28 Day Grout Compression Tests

Prism Tests

The prism test is not required when using the unit strength method under the 1994 UBC. However, the prism test is an alternative to unit testing and grout quality checking. It is recommended that on large projects (more than 20,000 square feet of masonry) that prism testing be used.

Prism tests are less variable than either mortar or grout testing and provide the engineer with a higher level of confidence that the masonry system has the strength desired.

When prism tests do not conform, verify that the materials used (units, mortar and grout) conform to the specifications. If they do conform, then either the prism was improperly constructed or the testing procedures were not in compliance with UBC Standard 21-17.

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 and not providing a thick enough loading platen to distribute the test machine load evenly to the prism. Another common problem is that the prism is not centered in the testing machine when loaded.

Troubleshooting

**TABLE 4-3
TROUBLESHOOTING TABLE
FOR
THE DESIGN STRUCTURAL ENGINEER**

| PROBLEM | CAUSE | SOLUTION |
|---|--|---|
| Prisms fail to reach the design strength. | <ol style="list-style-type: none"> 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. | <ol style="list-style-type: none"> 1. Instruct the lab to retest being careful to follow the ASTM C 448 OR UBC Standard 21-17 procedures. 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. | <ol style="list-style-type: none"> 1. Incorrect proportions. 2. Incorrect testing. | <ol style="list-style-type: none"> 1. Check mortar quality control procedures. 2. Mortar tests are unreliable. Forget about testing mortar. The code doesn't require it. |
| Colors do not meet expectations. | <ol style="list-style-type: none"> 1. Bricks were not blended. 2. Sample panel has different sealer. 3. The brick production run is different from the sample run. | <ol style="list-style-type: none"> 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. | Architect was checking on your advice. Architects should do this, so don't get mad. | Explain to the architect how the reinforcement reduces the need for most of the expansion joints. |
| The mason tells the general who tells everyone that the cells are too small to be grouted with all the congested steel. | <ol style="list-style-type: none"> 1. The mason contractor does not have experience with 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. | <ol style="list-style-type: none"> 1. Prepare and grout a test panel. Be sure to invite everyone concerned. 2. Re-design the wall. |

| PROBLEM | CAUSE | SOLUTION |
|--|--|--|
| Welded bars are breaking off. | ASTM A 706 bars were not used. Inspect bars. A "W" symbol indicates type A 706. | Use the correct bars. |
| Contractor is not protecting his materials or work. | Sometimes the responsibility for protecting the work is left with the general contractor. He is saving money. Sometimes the responsibility is not well defined. | Write a letter to your client. Explain the consequences. Send a copy to the brick manufacturer. |
| Cracks in the mortar joints. | <ol style="list-style-type: none"> 1. Shrinkage of the mortar joint. 2. Movement of the supporting structure. 3. Overloading. 4. Too rapid drying. | <ol style="list-style-type: none"> 1. Suggest the contractor decrease the cement content of the mortar and increase the lime. 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. |
| 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 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 high-lift grout with lifts larger than 6' | The code restricts the grout lift to 6' even though the grout pour might be higher. | 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. |
| 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, see the Design Development Section. |

| PROBLEM | CAUSE | SOLUTION |
|---|---|---|
| <p>The dowels out of the concrete foundation interfere with the unit cross webs. They miss the cells.</p> | <p>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.</p> | <p>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.</p> |
| <p>The brick masonry is cracked, with cracks extending through the units.</p> | <ol style="list-style-type: none"> 1. A great deal of force is required for this condition to exist. Frozen grout, foundation movement, or thermal movement from adjacent structure are a few examples. 2. The bricks may have been manufactured with the cracks. 3. Foundation cracks extend into brick wall. | <ol style="list-style-type: none"> 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 not coordinated with the masonry expansion joints. |
| <p>Contractor doesn't cover the walls at the end of the day.</p> | <ol style="list-style-type: none"> 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. | <ol style="list-style-type: none"> 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. |
| <p>Corrosion of the joint reinforcement.</p> | <ol style="list-style-type: none"> 1. Too strong of an acid cleaning without pre-wetting of the wall. 2. Ungalvanized joint reinforcement. | <ol style="list-style-type: none"> 1. Pre-wet the wall and use industry cleaners as recommended by the manufacturer of the units. 2. Use galvanized joint reinforcement. |

| PROBLEM | CAUSE | SOLUTION |
|---------------------------------|---|---|
| Leaking Walls | <ol style="list-style-type: none"> 1. Improper flashing installation. 2. Improper flashing design. 3. Poor workmanship. 4. Improper grouting. 5. Raked joints or other unprotected horizontal surfaces. 6. Unsealed wall. | <ol style="list-style-type: none"> 1. Correct flashing. 2. Correct flashing. 3. Repair mortar joints. 4. Pressure epoxy grout. 5. Fill joints. Cover horizontal surfaces. 6. Seal wall. |
| Dome shaped voids in the grout. | Loss of water to the unit. | <ol style="list-style-type: none"> 1. Use proper reconsolidation techniques. 2. Use Grout-Aid or equal. 3. Add lime to maximum allowed. |
| River voids in fine grout. | Loss of water to the unit. | <ol style="list-style-type: none"> 1. This is normal provided they are approximately 1/4 inch in width. 2. Use Grout-Aid or equal. 3. Add lime to the maximum allowed. 4. Reduce water in mix. |
| Efflorescence on the wall. | <ol style="list-style-type: none"> 1. Precipitation of salts at the wall surface. 2. Wall was uncovered during construction and excessive water entered. | <ol style="list-style-type: none"> 1. Clean the wall and then keep water from entering the wall by fixing leaks and sealing. Be sure the wall is dry before sealing. 2. Cover wall during construction. |

APPENDIX A

Flexure with Axial Load, Working Stress Design

Two methods for the structural analysis of wall or column elements are presented. These methods account for the effects of axial load to reduce the required tension reinforcement. The first method is a simple approximate approach to preparing an interaction diagram. The second method provides a set of equations that satisfy the assumptions of working stress design. This method is not approximate and requires iteration of equations which converge provided the neutral axis location is less than about 80% of the distance from the extreme compression fiber to the centroid of the reinforcement.

Figure A-1 presents the commonly used symbols for flexural analysis. The masonry width or thickness is usually symbolized by the letter "b". The depth is usually symbolized by the letter "d". The location of the neutral axis is normally designated "kd" where k is the ratio of the distance from the extreme compression fiber to the neutral axis location divided by the depth "d". The distance " Δd " is the distance from the centroid of the tension steel to the line of action of the axial load.

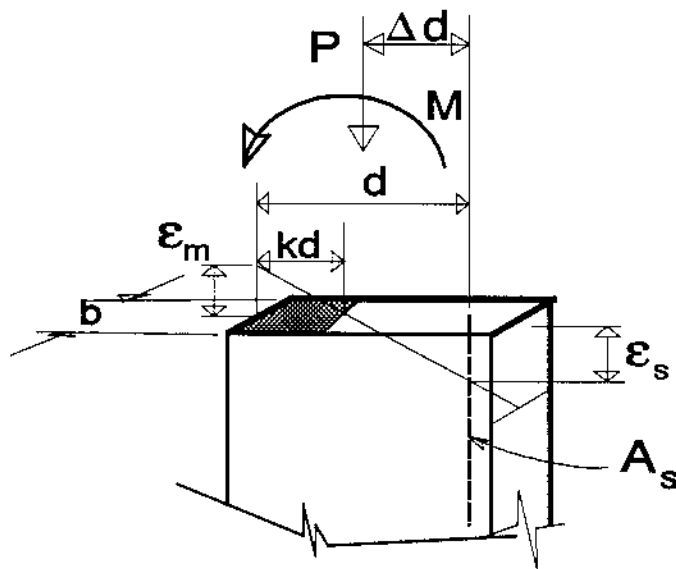


Figure A-1 Axial Load Plus Flexure

Approximate Interaction Diagrams

Several points on the interaction diagram can be obtained easily. Straight line interpolation

between them provides an approximate interaction diagram. The approximate interaction diagram is presented in Figure A-2.

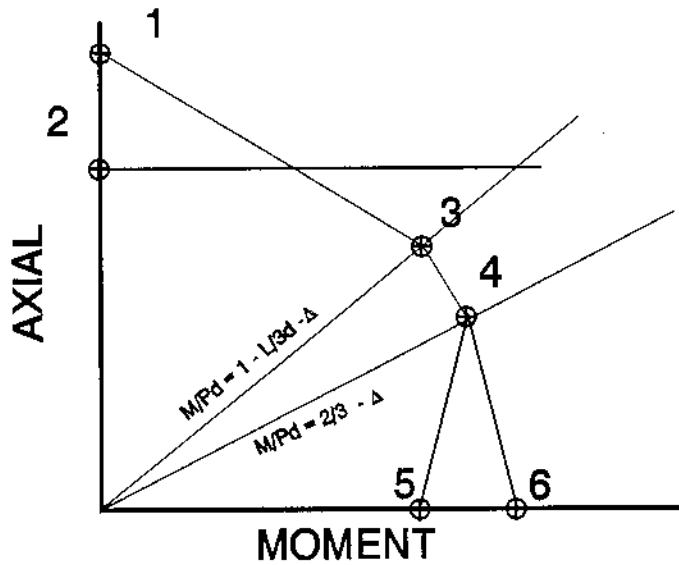


Figure A-2 Simple Interaction Diagram

The following equations define each point.

POINT 1

$$P = F_b b L \quad M = 0 \quad 1$$

POINT 2

$$P = F_a b L \quad , \quad M = 0 \quad 2$$

POINT 3

$$\frac{M}{Pd} = \left(1 - \frac{L}{3d} - \Delta \right) , \quad P = \frac{F_b b L}{2} \quad , \quad M = P \left(1 - \frac{L}{3d} - \Delta \right) d \quad 3$$

POINT 4

$$\frac{M}{Pd} = \left(\frac{2}{3} - \Delta \right), \quad P = \frac{F_b b d^2}{2}, \quad M = P \left(\frac{2}{3} - \Delta \right) d \quad 4$$

POINT 5

$$P = 0, \quad M_t = A_s j d F_s \quad 5$$

POINT 6

$$P = 0, \quad M_o = \frac{b d}{2} k j F_b \quad 6$$

The location of points 5 and 6 on the moment axis may interchange depending on whether the section is controlled by tension in the reinforcement or compression in the masonry.

Iterative Method

Using the assumption that plane sections remain plane, the following equation results:

$$\epsilon_m = \frac{y}{R} \quad 1$$

where ϵ_m is the strain in the masonry at a distance "y" from the neutral axis and "R" is the radius of curvature of the flexural element. The relationship between the curvature and the applied moment can be expressed by the following:

$$\frac{1}{R} = \frac{M}{E_m I} \quad 2$$

Where E_m is the modulus of elasticity of the masonry and I is the second moment of inertia. Substitution of Equation (2) into Equation (1) results in the following:

$$\epsilon_m = \frac{My}{E_m I} \quad 3$$

Using the assumption that stress is proportional to strain or:

$$\sigma_m = E_m \epsilon_m \quad \sigma_s = E_s \epsilon_s \quad 4$$

The stress in the masonry may be determined as:

$$\sigma_m = \frac{My}{I} \quad 5$$

For unreinforced masonry (masonry designed allowing tension), Equation (5) is commonly used with the applied moment limited by the allowable tensile stress in the masonry. This assumes that the allowable tensile stress is less than the allowable compression stress. When axial load is also applied, the compression allowable stress may limit the applied moment.

For masonry design not allowing tension in the masonry, the tensile stresses are assumed to be resisted by the tensile reinforcement with the masonry cracked when subjected to tension. Thus, the crack extends from the edge of the masonry to the neutral axis (kd from the extreme compression fiber). The depth of the section " d " is now defined as the distance from the extreme compression fiber to the centroid of the tensile force in the reinforcement. Using plane sections remain plane assumption and similar triangles, the strain in the masonry and reinforcement are related as follows:

$$\frac{\epsilon_m}{\epsilon_s} = \frac{k}{(1-k)} \quad 6$$

where ϵ_m is the strain in the masonry and ϵ_s is the strain in the reinforcement. Neglecting the effects of compression reinforcement and summing forces along the axis of the beam results in the following equation:

$$\sigma_m \frac{kbd}{2} - A_s \sigma_s = P \quad 7$$

where σ_s is the stress in the reinforcement and A_s is the area of the tension reinforcement. Substitution of Equation (4) into Equation (7) results in:

$$E_m \epsilon_m \frac{kbd}{2} - A_s E_s \epsilon_s = P \quad 8$$

Defining two new terms, the first is the reinforcement ratio and the second the modular ratio as follows:

$$\rho = \frac{A_s}{bd} \quad n = \frac{E_s}{E_m} \quad 9$$

substituting into Equation (8) and dividing by $E_m b d \epsilon_s$ results in the following:

$$\frac{\epsilon_m}{\epsilon_s} k - 2n\rho = \frac{2P}{E_m b d \epsilon_s} \quad 10$$

and using Equation (6) results in:

$$\frac{k^2}{(1-k)} - 2n\rho = \frac{2P}{E_m b d \epsilon_s} \quad 11$$

Defining a new term as ϵ_{m0} as follows:

$$\epsilon_{m0} = \frac{P}{E_m b d} \quad 12$$

Equation 11 can be rearranged to:

$$\frac{k^2}{1-k} = 2(np - \frac{\epsilon_{m0}}{\epsilon_s}) \quad 13$$

Which can be rearranged to:

$$k^2 - 2k(np - \frac{\epsilon_{m0}}{\epsilon_s}) - 2(np - \frac{\epsilon_{m0}}{\epsilon_s}) = 0 \quad 14$$

solving the Quadratic Equation results in the following expression for k:

$$k = \sqrt{(np - \frac{\epsilon_{m0}}{\epsilon_s})^2 + 2(np - \frac{\epsilon_{m0}}{\epsilon_s})} - (np - \frac{\epsilon_{m0}}{\epsilon_s}) \quad 15$$

For a given structure A_s, b, d, E_m and E_s are known terms. The unknown terms are ϵ_{m0}/ϵ_s and k .

To find the two terms an additional equation is required. Summing moments about the centroid of the compression force acting at $1/3$ the distance from the extreme compression fiber to the neutral axis, results in:

$$\frac{A_s F_s}{P} (d - \frac{kd}{3}) - P(d - \frac{kd}{3} - \Delta) = \frac{M}{Pd} \quad 16$$

Using the definition of ϵ_{m0} to define the axial load P and substituting into Equation 16 results in the following expression for ϵ_{m0}/ϵ_s :

$$\frac{\epsilon_{m0}}{\epsilon_s} = \frac{np(1 - \frac{k}{3})}{\frac{M}{Pd} - (1 - \frac{k}{3} - \Delta)} \quad 17$$

Summing moments about the centroid of the tension force results in an expression of the applied moment limited by the allowable bending compression stress in the masonry.

$$M_c = \frac{bd^2}{2} k j F_m - P\Delta d \quad 18$$

Summing moments about the centroid of the compression force results in an expression for the applied moment limited by the tension stress in the reinforcement:

$$M_t = A_s j d F_s - P (j - \Delta) \quad 19$$

Equations 15, 17, 18 and 19 provide the basis for the design of walls with flexural and axial compression, neglecting the effects of compression reinforcement and when the reinforcement is in tension. They are applicable to rectangular sections.

The limiting condition of the steel in tension can be evaluated by consideration of Equation 15. The parameter ϵ_{m0}/ϵ_s becomes infinite when ϵ_s goes to zero and the quantity M/Pd equals $(1 - k/3 - \Delta)$. But since at this condition, by definition $k = 1.0$, the limit occurs when:

$$\frac{M}{Pd} = (2/3 - \Delta) \quad 20$$

For M/Pd greater than this quantity, the section is cracked, the reinforcement is in tension and Equations 15, 17, 18 and 19 apply.

The next condition occurs when the steel is in compression and the masonry is cracked. This condition is most important for out-of-plane bending of walls with reinforcement at the center of the wall. The limit to this condition occurs when the masonry first becomes cracked. At this point the value of k is equal to L/d , a value greater than 1. At this condition, summing forces along the axis of the member results in:

$$P = \frac{F_b b L}{2} \quad 21$$

And summing moments results in:

$$\frac{M}{Pd} = (1 - \frac{L}{3d} - \Delta) \quad 22$$

If the quantity M/Pd is less than $(2/3 - \Delta)$ but greater than $(1 - L/3d - \Delta)$ then the moment is limited by the compression allowable and is given by:

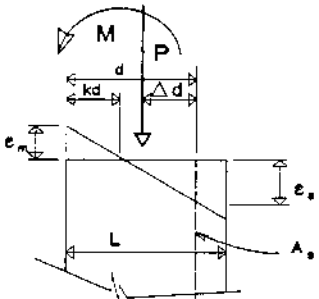
$$M_c = P(1-\Delta)d - \frac{2}{3} \frac{P^2}{F_b b} \quad 23$$

If the quantity M/Pd is less than $(1-L/3d-\Delta)$, then the entire section is in compression. The moment is also limited by the compression allowable and is given by:

$$M_c = \frac{bL^2}{6} F_b - \frac{PL}{6} \quad 24$$

The following table summarizes the design equations for flexure plus compression:

TABLE A-1
DESIGN EQUATIONS FOR BENDING PLUS COMPRESSION

| REGION | LIMITING CONDITION | EQUATIONS |
|--------|---|---|
| 1 | $M/Pd > (2/3 - \Delta)$  | $\frac{\epsilon_{m0}}{\epsilon_s} = \frac{np(1 - \frac{k}{3})}{\frac{M}{Pd} - (1 - \frac{k}{3} - \Delta)}$ $k = \sqrt{(np + \frac{\epsilon_{m0}}{\epsilon_s})^2 + 2(np + \frac{\epsilon_{m0}}{\epsilon_s})} - (np + \frac{\epsilon_{m0}}{\epsilon_s})$ $M_t = A_s j d F_s - P(j - \Delta) d$ $M_c = \frac{bd^2}{2} k j F_m - P \Delta d$ |
| 2 | $(2/3 - \Delta) > M/Pd$ and $M/Pd > (1 - L/3d - \Delta)$ | $M_c = P(1 - \Delta) d - \frac{2 P^2}{3 F_b b}$ |
| 3 | $M/Pd < (1 - L/3d - \Delta)$ | $M_c = \frac{bL^2}{6} F_b - \frac{PL}{6}$ |

APPENDIX B

Sample Structural Notes

The following paragraphs are a sample of the type of information that can be added to the structural drawings when reinforced masonry is used. They are not intended to be used without review and modification by a licensed structural engineer for the specific application. These sample notes apply only to masonry.

MASONRY STRUCTURAL NOTES

GENERAL

In addition to the design shown on these plans and the architectural specifications, the Contractor shall comply with the following:

CONFLICTS

These drawings are for the structural design concept of the masonry system. They are not intended to be, nor do they take the place of comprehensive detailed shop drawings to be prepared by the Contractor. Where conflicts, inconsistencies, interferences, omissions or errors in the specification or in the drawings occur, it is the responsibility of the Contractor to identify the conflict, inconsistency, interference, omission or error to the Architect or Engineer prior to fabrication and erection. Unless otherwise directed, when conflicts exist, the Contractor shall assume the more stringent (expensive) interpretation shall apply.

PURPOSE OF DESIGN DRAWINGS

The information shown on these drawings is for the structural design of the masonry system. Where the construction requires modifications to the structural systems shown on these drawings, the Contractor shall submit to the Architect or Engineer the proposed modification for review and approval prior to fabrication, erection or testing. Connection locations, dynamic joint locations, exterior and interior architectural profiles and dimensions exposed to view are to be maintained as shown on these drawings unless otherwise approved.

IN-PLACE DESIGN

The design shown on these drawings is for the finished structure. The contractor is responsible for the means and methods employed to achieve the final construction. Thus, the contractor shall provide adequate shoring and bracing of all members during construction.

APPLICABLE CODES

All design and construction shall conform to the requirements of the Uniform Building Code, _____ Edition, as amended by _____. Unless otherwise specified, all standards, codes and specifications used herein are to be the latest edition.

SUBMITTALS

Shop drawings shall be submitted to the Architect and Engineer prior to any fabrication or construction for masonry reinforcement, precast or prestressed concrete items, embedded steel items and structural steel items supporting masonry.

If the shop drawings differ from or add to the design of the structural drawings, they shall bear the seal and signature of the Registered Structural Engineer who is responsible for the design.

Design drawings and calculations or shop drawings, for the design and fabrication of items that are designed by others such as precast concrete, shall bear the seal and signature of the Registered Structural Engineer who is responsible for the design and shall be submitted to the Architect or Engineer for review prior to fabrication. Submitted calculations are for information only and will not be stamped or returned.

PRISM TESTS

When prism tests are required prior to construction, prisms shall be constructed and tested as follows:

1. For each strength of masonry specified.
2. For partially grouted walls, both solidly grouted prisms and ungrouted prisms.
3. For each thickness of masonry.

It is not necessary to construct and test prisms for the following:

1. Varying bond patterns.
2. Varying face shell textures.
3. Varying unit colors.

MATERIALS

WATER

Water used in mortar, grout and other purposes shall be clean and free of deleterious amounts of acid, alkalies, organic matter or other harmful substances.

Cement

Cement shall conform to Uniform Building Code Standard No. 19-1, Type I,II or III.

Lime

Lime shall conform to Uniform Building Code Standard No. 21-13 without air entraining.

SAND

Mortar and grout sand shall conform to the requirements of ASTM C 144.

AGGREGATES FOR GROUT

Aggregates for grout shall conform to ASTM C 404.

ADDITIVES

No additives are allowed in mortar, grout or masonry without approval of the Architect and Engineer.

MORTAR

All masonry mortar shall conform to Uniform Building Code Standard 21-15, Type S in accordance with the "Proportion Specifications". The proportions of sand, cement and lime shall be controlled. Shovel counts shall not be used. Masonry cement mortars shall not be used. Dry mix or ready mix mortars may be used if approved by the Architect and Engineer prior to construction.

MASONRY GROUT

All masonry grout shall conform to Uniform Building Code Standard Table 21-B. Grout shall be proportioned by laboratory or field experience to obtain the required masonry assemblage strength f'_m given above. Grout proportions shall be submitted for approval prior to construction. Grout shall have compressive strength equal to or greater than 2000 psi or f'_m , when tested in accordance with Uniform Building Code Standard 21-19. Sufficient water shall be added to the grout before placement to assure filling of all cells to be grouted. Grout slump at the time of grouting shall exceed 8 inches.

Sika Grout Aid Type II or equal shall be used in accordance with the manufacturers recommendations. No other additives or other chemicals are to be added to the grout without approval of the Architect and Engineer.

MASONRY REINFORCING

Reinforcing, when not welded, shall conform to ASTM A 615 grade 60, $F_y = 60,000$ psi. Reinforcing shall, when welded, conform to ASTM A 706 grade 60, $F_y = 60,000$ psi.

CONSTRUCTIONLAYING OF UNITS

Units shall be mortar bedded the full thickness of the face shell. Cross webs need not be bedded, except the first course of masonry shall be full bedded, including webs. The thickness of the first bed joint shall not be less than 1/4 inch nor more than 1 inch. Joints shall be 1/2 inch plus or minus 1/8 inch. Mortar fins shall be less than 1/2 inch and prevented from separating and falling into the cell.

REINFORCEMENT PLACEMENT

Reinforcing shall be secured against displacement prior to grouting by wire positioners or other suitable devices at intervals not exceeding 200 bar diameters. Unless otherwise noted on the plans, the minimum wall reinforcement shall be as follows:

Typical Minimum Reinforcement

| WALL NOMINAL THICKNESS | VERTICAL REINFORCEMENT | HORIZONTAL REINFORCEMENT |
|------------------------|------------------------|--------------------------|
| 4 | #4@48 | #4@48 |
| 5 | #5@48 | (2)#3@48 or #4@48 |
| 6 | #5@48 | (2)#4@48 or #4@48 |
| 8 | #6@48 | (2)#4@48 or #5@48 |
| 10 | #7@48 | (2)#4@48 or #6@48 |
| 12 | #7@48 | (2)#5@48 or #6@48 |

Bond beams with horizontal bar or bars shall be provided at all floor and roof lines and at the top of the wall. Provide a bond beam with (2) horizontal bars of same size as typical horizontal bars over all openings, and extend these bars 2'-0" past the opening at each side, or as far as possible, and hook. Provide two vertical bars of same size as typical vertical bars for the full height of the wall at each side of openings, wall ends and intersections. Dowels to masonry walls shall be embedded a minimum of 1'-6" or hooked into the supporting structure and be of the same size and spacing as wall reinforcing. Provide corner bars to match the horizontal wall reinforcing at wall intersections. Lap all bars ___ diameters, but not less than 1'-6" minimum unless noted on the plans.

Reinforcement shall be placed within the tolerances given in the following table:

| Reinforcement | Direction | Tolerance |
|---|--|---------------|
| Vertical | Horizontal Position Perpendicular to the wall face | $\pm 1/2$ " |
| Horizontal over openings | Vertical Position, lintel depth < 24" | ± 1 " |
| | Vertical Position, lintel depth > 24" | $\pm 1 1/4$ " |
| Other horizontal bars | Vertical Position | ± 2 " |
| All reinforcement not otherwise given above | All Directions | ± 2 " |

Grout Placement

All cells containing vertical bars and all bond beams shall be filled with grout.

Grout pours shall be to the height shown on the plans. Grout lifts shall be less than 6'-0" unless approved by the building official.

Grout shall be consolidated by mechanical vibration during placing before loss of plasticity in a manner to fill the grout space. Grout shall be reconsolidated by mechanical vibration to minimize voids due to water loss. Any exceptions to these mechanical vibration requirements require approval from the Building Official.

WEATHER

At all times, masonry units, cement, lime and sand are to be protected from rain and dust. Completed masonry shall not be constructed during rain unless complete coverage of work is provided for at least one day after placement. At the close of work, completed masonry shall be covered.

Anti-freeze or other agents in mortar for cold weather construction shall not be used.

CLEANING OF MASONRY

Methods for cleaning masonry shall be submitted to the Architect and Engineer for approval.

SEALANT AND OTHER

Contractor shall be responsible for the selection and performance of primers, sealants, gaskets, baffles, setting blocks, edge blocks and other items. Mason contractor and window wall contractor shall coordinate the selection and use of primers and sealants to assure compatibility between systems.

Sealants and primers shall be tested for compatibility with materials in contact with sealants and primers.

Methods for sealing masonry, if any, shall be submitted to the Architect and Engineer for approval.

TOLERANCES

The edge of slab, steel embeds and wide flange columns supporting masonry may deviate from correct position by the tolerances given in the referenced specifications. The contractor shall account for tolerances in construction.

The Contractor shall verify all dimensions in the field.

NOTE TO ENGINEER: Use one of the following two paragraphs and modify it to suit the project. These cases represent the two extremes of special inspection with field testing and minimum inspection without field testing. If the project involves some walls that require special inspection and field testing and some walls that need no special inspection or field testing, then a combined note is required as well as indications on the drawings.

MASONRY INSPECTION

Masonry shall be specially inspected and tested in accordance with Uniform Building Code Sections 1701.5.7 and 2105. Prism tests of the masonry wall are required per Uniform Building Code Section 2105 prior to and during construction to confirm that the strength of masonry assemblies is as specified in the design.

Masonry shall have continuous inspection by special inspectors as specified in Uniform Building Code Section 1701.5.7 unless periodic or non-continuous special inspection is approved by the building official.

MASONRY INSPECTION

Unless otherwise noted, special inspection is not required. Inspection is required in accordance with Uniform Building Code Section 2105. This inspection shall include:

1. Prior to construction:
 - a. A letter of certification from the masonry unit supplier that the units conform to the specification.
 - b. A letter of certification from the grout supplier that the grout conforms to the specification.

- c. In Seismic Zones 3 or 4 when the design strength of the masonry assembly, f'_m , is greater than 1500 psi., tests are required of the units and grout or as an alternative, 5 prism tests.

2. During construction in Seismic Zones 3 or 4:

- a. A letter of certification from the manufacturer of the units is required at the time of, or prior to, delivery of the units to the job site.
- b. A letter of certification from the supplier of the grout is required at the time of, or prior to, delivery of the units to the job site.

OTHER INSPECTION

All welding is to be inspected, except for welding done in an approved fabricator's shop. Inspection shall conform to AWS D1.1 and AWS D1.4 which includes visual inspection of each weld for size, length and location in addition to the quality of the weld.

APPENDIX C

Design Check List

| No. | Item | Checked |
|-----|--|---------|
| 1.0 | STRUCTURAL NOTES | |
| | Applicable code specified (city and date). | |
| | 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.) | |
| | Is Type S mortar specified? | |
| | Is high or low lift grouting specified? | |
| | Can clean-outs be installed? (code variation ?) | |
| | Is special inspection required? Are prism tests required? | |
| | Have full allowable stresses been used in the design? | |
| 2.0 | DESIGN | |
| | Is h/t less than 30? If not, verify calculations. | |
| | Is the wall laterally supported with straps or other methods capable of resisting at least 200 lb/ft? | |
| | Does the bar fit in the cell? (see Table 2-4) | |
| | Are locations of laps shown (Min. 48 dia.)? Are they in locations where stresses are less than 80% of the allowable? | |
| | Are dowel laps sufficient (Min. 48 dia.)? | |
| | Is there continuous horizontal reinforcement at the window and door head? | |
| | 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? | |
| | Are provisions made in connections to accommodate thermal movement? (Steel roof rigidly attached at a masonry corner.) | |

| No. | Item | Checked |
|------------|---|---------|
| | Is the brick masonry confined between other materials without expansion joints? | |
| 3.0 | SPECIFICATIONS | |
| | Is a color, pattern, and workmanship panel required? | |
| | Is a grouting demonstration panel required? | |
| | Are materials specified in accordance with the correct standards? | |
| | Brick? Is the Hollow clay brick of sufficient strength? | |
| | Cement? | |
| | Lime? | |
| | Sand? | |
| | Grout? | |
| | Mortar? Is the mortar specified by proportions? | |
| | Reinforcement? Is weldable steel required? | |
| | Are there requirements for handling and storage of materials? | |
| | Is there a requirement for a preconstruction meeting? | |
| | Are shop drawings required? | |
| | Are control joint size and materials specified? | |
| | Are sealant compatibility tests required? | |
| | Are the cleaning methods included? | |
| | Does the specification require 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 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? | |

| | | |
|--|--|--|
| | Are prism test requirements included both prior to construction and during construction? | |
| | | |
| | | |

APPENDIX D

Construction Site 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. | |
| | 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 on mixing? (10 minutes maximum.) | |
| | Are the grout proportions being controlled? | |
| | Is Grout-Aid or equivalent being used? | |
| 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? | |
| | | |
| | | |

| No. | Item | Checked |
|-----|--|---------|
| | Are the joints uniform in thickness and full? | |
| | Is the reinforcement being placed within tolerance? Is reinforcement secured against displacement? | |
| | 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 | |
| | Are prisms being constructed plumb and on a flat surface? | |
| | Are the materials being used for the prism the same as used in the wall? | |
| | Are prisms being properly cured and handled? | |
| | Is the prism grout being reconsolidated? | |
| | Is the frequency and quantity of testing in accordance with the contract documents? | |

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