EVALUATING THE COMPRESSIVE STRENGTH OF CONCRETE MASONRY

INTRODUCTION

Structural performance of concrete masonry is largely dependent upon three key criteria:

• the engineering rationale forming the basis of the structure's design;

• the physical characteristics of the materials used in the construction (i.e., the masonry units, grout, mortar, and reinforcement); and

• the quality of the construction used in assembling these components.

The first step in the design of any engineered masonry structure is determining anticipated service loads. Once these loads are established, the required strength of the masonry can be determined. The designation f'_m, indicates the specified compressive strength of masonry. It is used throughout the design and, in accordance with the appropriate code, to predict the strength and behavior of the masonry assembly and thus to size masonry elements. It should be stressed that the specified compressive strength of the masonry is related to but not always equal to the tested compressive strength of the masonry.

To ensure that a safe and functional structure is being constructed that will meet or exceed the intended service life, measures must be taken to verify that the compressive strength of the assembled materials (including masonry units, mortar and grout if used) meet or exceed the specified compressive strength of the masonry.

Compliance with the specified compressive strength is verified by one of three methods: the unit strength method, the prism test method, or by removing units from existing construction. These methods are referenced in masonry design codes (refs. 1, 3, 4, 6), specifications (ref. 2, 4), and standards (ref. 5) as rational procedures for verifying masonry compressive strength.

UNIT STRENGTH METHOD

The unit strength method is often considered the least expensive and most convenient of the two methods. However, the unit strength method also tends to yield more conservative masonry strengths when compared to the prism test method.

Compliance with f'_m by the unit strength method is based on the net area compressive strength of the units and the type of mortar used. The compressive strength of the concrete masonry assemblage is then established in accordance with Table 1 for concrete masonry designed in accordance with the 2013 Specifications for masonry Structures (MSJC) (ref. 2), and Table 2 for concrete masonry designed in accordance with the 2016 Specifications of Masonry Structures (TMS 402) (ref. 4). Use of the unit strength method requires the following:

• Concrete masonry units must be sampled and tested in accordance with ASTM C140, *Standard Test Method for Sampling and Testing Concrete Masonry Units* and Related Units (ref. 7) and meet the requirements of ASTM C90, *Standard Specification for Loadbearing Concrete Masonry Units* (ref. 8). (Note that ASTM C140 allows the test of

Table 1—Compressive Strength of Masonry Based on the Compressive Strength of Concrete Masonry Units and Type of Mortar Used in Construction (ref. 2)

Net area compressive strength of masonry[A], psi (MPa)	Net area compressive strength of concrete masonry units, psi (MPa)	
	Type M or S mortar	Type N mortar
1,700 (11.72)	----	1,900 (13.10)
1,900 (13.10)	1,900 (13.10)	2,350 (14.82)
2,000 (13.79)	2,000 (13.79)	2,650 (18.27)
2,250 (15.51)	2,600 (17.93)	3,400 (23.44)
2,500 (17.24)	3,250 (22.41)	4,350 (28.96)
2,750 (18.96)	3,900 (26.89)	----
3,000 (20.69)	4,500 (31.03)	----

[A] For units less than 4 in. (102 mm) in height, 85% of the values listed.

Net Area Compressive Strength of Concrete Masonry, psi (Mpa)	Net Area Compressive Strength of ASTM C90 Concrete Masonry Units, Psi (Mpa)	
	Type M or S mortar	Type N mortar
1,700 (11.72)	----	2,000 (13.79)
2,000 (13.79)	2,000 (13.79)	2,650 (18.27)
2,250 (15.51)	2,600 (17.93)	3,400 (23.44)
2,500 (17.24)	3,250 (22.41)	4,350 (28.96)
2,750 (18.96)	3,900 (26.89)	----
3,000 (20.69)	4,500 (31.03)	----

A For units less than 4 in. (102 mm) in height, 85% of the values listed.

one set of units to be applied to any number of concrete masonry units or related units of any configuration or dimension manufactured by the producer using the same materials, concrete mix design, manufacturing process, and curing method.)

- Mortar bed joints used in construction must not exceed 5/8 in. thickness (15.9 mm).

- If grouted masonry is used in construction, the grout must meet either the proportion or the property specification of ASTM C476, *Standard Specification for Grout for Masonry* (ref. 9), and the 28-day compressive strength of the grout must equal or exceed f'_m but not be less than 2,000 psi (14 MPa). When property specifications are used, the compressive strength of the grout is determined in accordance with ASTM C1019, *Standard Test Method for Sampling and Testing Grout* (ref. 10).

- Mortar must comply with requirements of ASTM C270, *Standard Specification for Mortar for Unit Masonry* (ref. 11).

In addition to this TEK, CMHA has generated a spreadsheet that calculates the specified compressive strength (f'_m) for masonry based on the compressive strength of the concrete masonry unit and the type of mortar used. Additionally, the spreadsheet also calculates the required strength of a unit to obtain a specific value of f'_m. See CMU-XLS-004-19, *CMU Unit Strength Calculator* (ref. 17).

Using either Table 1 or Table 2 for example, for concrete masonry units with a compressive strength of 2,600 (17.93 MPa), the maximum f'_m used in design would be 2,250 (15.51 MPa) if Type M or S mortar were used. Note that per footnote A of Table 1 and Table 2, compressive strength of masonry values must be multiplied by 85% when the unit strength is established on units less than 4 in. (102 mm) in nominal height.

When higher strength masonry materials are specified, it may be more cost effective to utilize the prism test method to

demonstrate compliance with f'_m due to the level of conservatism inherent in the unit strength method; i.e., the costs of prism testing may be offset by the construction savings resulting from a more economical design that takes advantage of using a higher compressive strength for the same specified materials.

Note that the unit strength values in the 2013 and 2016 *Specification for Masonry Structures* (i.e., those in Table and Table 2) are less conservative than values in previous editions. Note that in Table 2 the minimum compressive strength allowed or Type M or S mortar and Type N mortar is set to 2,000 psi (13.79 MPa) versus the 1900 psi (13.10 MPa) listed in Table 1. This change is as a result of changes made in ASTM C90 which sets the minimum compressive strengths of both Type M or S mortar, and Type N mortar, to 2000 psi (13.79). The historical conservatism was due to two primary reasons:

1) The original database of tested compressive strengths was based on the testing procedures and equipment that were considerably less refined than they are today. Current ASTM C1314, *Standard Test Method for Compressive Strength of Masonry Prisms* (ref. 3), requirements produce more consistent and repeatable compressive strengths, particularly the requirements for more stable bearing platens on the compression testing equipment.

2) Historical testing procedures did not strictly control the construction, curing, and testing of the masonry prisms.

As a result, a single set of materials could produce variousprism test results depending the construction, curing and testing procedures used.

The database of compressive strength values used to generate the values in Table 1 and Table 2 was compiled using modern concrete masonry materials, modern test equipment, and current ASTM test procedures, providing a more realistic estimate of masonry compressive strength.

PRISM TEST METHOD

ASTM C1314 contains provisions for determining the compressive strength of a masonry prism: an assemblage made of representative units, mortar and grout (for grouted masonry construction). Although constructed using materials used in the project, the prism is not intended to be a reduced-scale version of the wall, but rather a quality assurance instrument to demonstrate how the masonry components work together. For this reason, prisms are typically constructed in stack bond ith a full mortar bed joint, regardless of the wall construction. The tested compressive strength of the prism is corrected to account for different permissible height to thickness ratios of the prisms. This corrected strength must equal or exceed f'_m. Understandably, prism testing should be undertaken before construction begins to verify that the compressive strength of the assembled materials is not less than the specified compressive strength used in the design.

Prisms should be tested at an age not greater than 28 days to document compliance with f'_m, When prisms are tested as part of an inspection program periodically during the

course of construction, an earlier age, such as 3 or 7 days, is often referred. To confidently interpret the results of these earlier age prism tests, the relationship between prism age and strength evelopment should be determined using the materials, onstruction methods and testing procedures to be used throughout the job. Only when this strength/time curve is generated can early age test results be extrapolated to predict the 28-day strength.

Prism Construction

Masonry prisms are constructed using units representative of those being used in the construction. One set of prisms (containing three individual prisms) is constructed for each combination of materials and each testing age for which the compressive strength is to be determined. Note that for concrete masonry units of different configuration but from the same production lot, separate prisms are not required for each configuration. For example, if a project uses 8-in. (203-mm) and 12-in. (305-mm) units from the same lot, prisms need only be tested using either the 8-in. (203-mm) or the 12-in. (305-mm) units, but not both. ASTM C140 (ref. 7) defines a 'lot' as any number of concrete masonry units of any configuration or dimension manufactured by the producer using the same materials, concrete mix design, manufacturing process, and curing method. For multi-wythe masonry construction, with different units or mortar in each wythe, separate prisms should be built representative of each wythe, and tested separately. Prisms should be constructed on a flat and level location where they can remain undisturbed until they are transported for testing, at least 48 hours.

All units used to construct the prisms must be of the same configuration and oriented in the same way so that webs and face shells are aligned one on top of the other. Units are laid in stack bond on a full mortar bed using mortar representative of that used in the corresponding construction. Mortar joints are cut flush regardless of the type of mortar joint tooling used in

the construction. Prisms composed of units that contain closed cells must have at least one complete cell with one fullwidth cross web on either end. Various prism configurations are shown in Figure 1.

Since masonry prisms can be heavy, especially grouted prisms, it often proves effective to construct prisms using halflength units. The criteria for constructing prisms of reducedsized units are (also see Figure 2):

- that hollow units contain fully closed cells,
- that the cross section is as symmetrical as possible, and
- that the length is not less than 4 in. (102 mm).

As a result, handling, transporting, capping, and testing the reduced sized prisms is easier, resulting in less potential for damage to the prisms. Using reduced length prisms also reduces the required plate thicknesses for compression machines and typically result in higher and more accurate assessments of masonry strengths.

Immediately following construction of the prisms, each prism is sealed in a moisture-tight bag, as shown in Figure 3. The prism test method requires prisms to be cured in sealed plastic bags to ensure uniform hydration of the mortar and the grout if used. Under actual field conditions, it may require longer periods for hydration and the corresponding strengths to be achieved. Curing prisms in sealed plastic bags results in measured strengths which are representative of those exhibited by the masonry throughout the life of the structure. Bag curing also provides a uniform and repeatable testing procedure.

Where the corresponding construction is to be grouted solid, each prism is grouted solid using grout representative of that being used in the corresponding construction. When prisms are used for field quality control or assurance, prisms must be constructed at the same time as the corresponding construction and grouted when the construction is being grouted. When prisms are used for other purposes, such as preconstruction
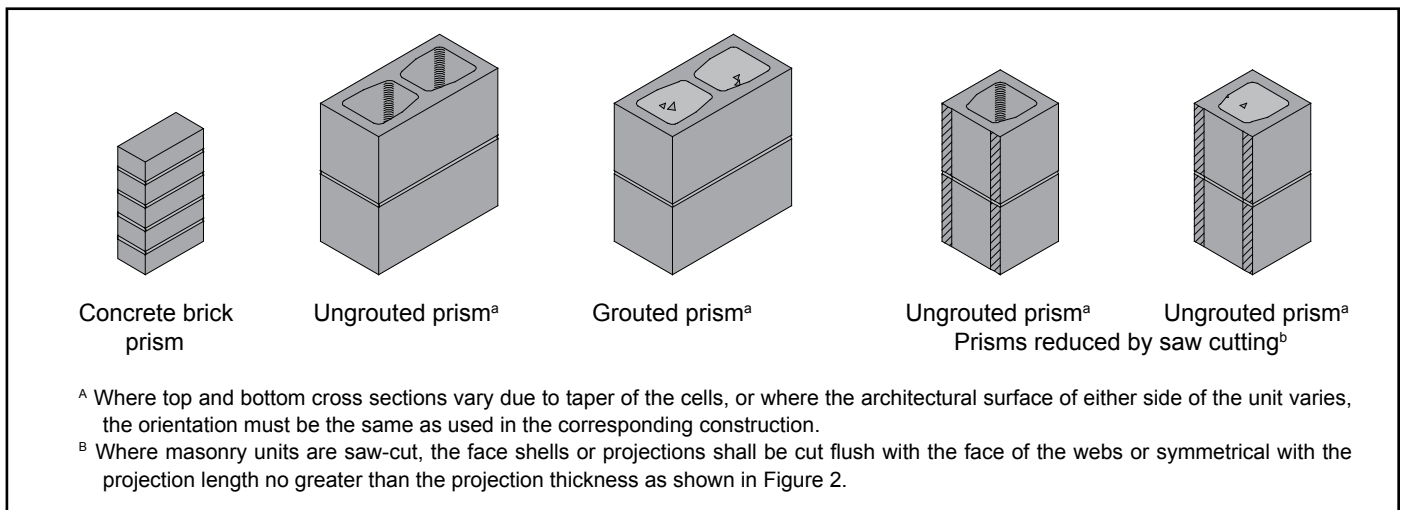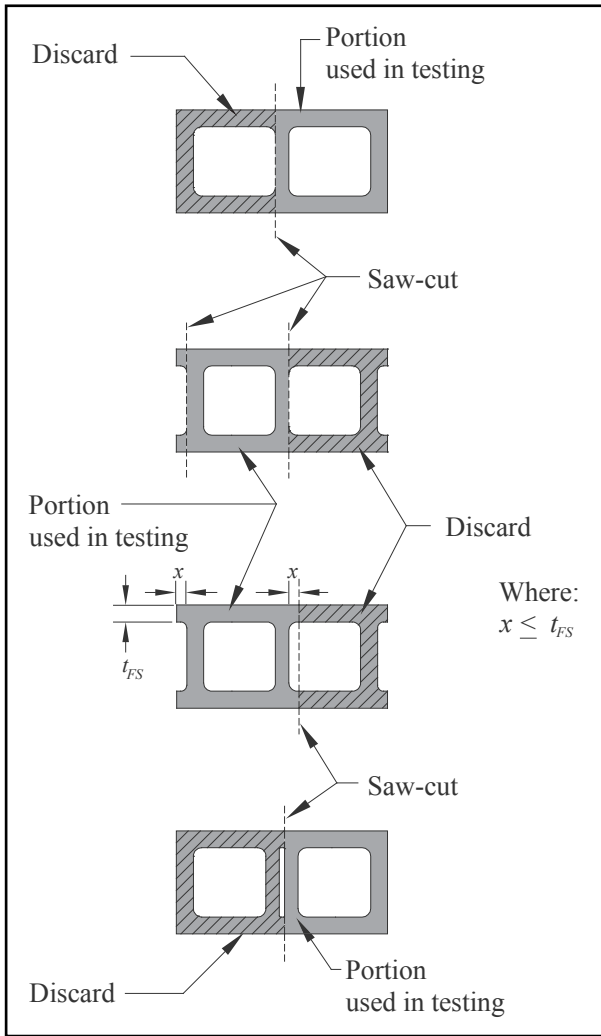

| Concrete brick prism | Ungrouted prism[a] | Grouted prism[a] | Ungrouted prism[a] | Ungrouted prism[a] |
| | | | Prisms reduced by saw cutting[b] | |

[A] Where top and bottom cross sections vary due to taper of the cells, or where the architectural surface of either side of the unit varies, the orientation must be the same as used in the corresponding construction.

[B] Where masonry units are saw-cut, the face shells or projections shall be cut flush with the face of the webs or symmetrical with the projection length no greater than the projection thickness as shown in Figure 2.

Figure 1—Types of Prisms

Figure 2—Saw-Cut Locations for Reduced-Size Prisms

Figure 3—Constructing a Half-Length Prism in a Plastic Bag

evaluation or for research, prism grouting must occur between 4 hours and 48 hours following the construction of the prisms.

After grouting, the grout in each prism is consolidated and econsolidated using procedures representative of those used in the corresponding construction. After each consolidation, the grout in the prism will likely settle due to water absorption from the grout into the masonry units. Therefore, after each consolidation, additional grout should be added as necessary and be screeded level with the top of the prism to facilitate capping. Reinforcement is not included in prisms. Immediately following prism grouting, the moisture-tight bag is resealed around each prism.

If the corresponding construction will be partially grouted, two sets of prisms are constructed—one set grouted and one set ungrouted.
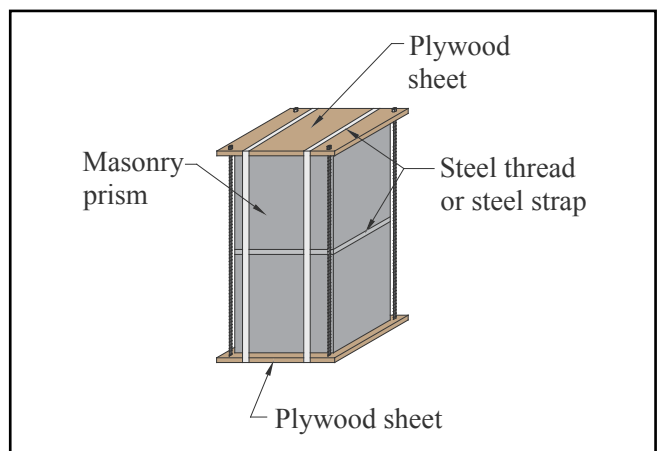

Figure 4—Transporting Prisms

Transporting Prisms

Since mishandling prisms during transportation from the job site to the testing facility can have significant detrimental effects on the tested compressive strength of prisms, extreme care should be taken to protect against damage during transport.

Prior to transporting, the prisms should be strapped or clamped as shown in Figure 4 to prevent damage. Tightly clamping or strapping plywood to the top and bottom of a prism prevents the mortar joint from being subjected to tensile stresses during handling. The prisms should also be secured during transport to prevent jarring, bouncing or tipping.

Curing Prisms

As previously stated, each prism is constructed in a moisture-tight bag (Figure 3) large enough to enclose and seal the completed prism. The bags should have adequate thickness to prevent tearing; a thickness of 2 mils (0.0051 mm) or greater has been found to work well. After the initial 48 hours of job site curing in the moisture-tight bag, each prism is carefully moved to a location where the temperature is maintained at 75 ± 15° F (24 ± 8° C) for full curing prior to testing.

Prism Net Cross-Sectional Area

To provide accurate an accurate strength calculation, the laboratory needs to determine the net area of the prisms. ngrouted masonry prisms should be delivered to the testing agency with three additional units, identical to those used to construct the prism. If reduced-length prisms are used, dditional reduced-length units should accompany the prisms to the laboratory for this purpose.

The net cross-sectional area used to calculate compressive strength of a prism depends on whether the prisms are grouted or ungrouted. For ungrouted full-size prisms, the cross-sectional area is the net cross-sectional area of the concrete masonry units determined in accordance with ASTM C140 on concrete masonry units identical to those used to construct the prisms. When reduced sized units are used to construct ungrouted prisms, the net cross-sectional area is based on the reduced sized units.

When testing fully grouted prisms, net cross-sectional area is determined by multiplying the actual length and width of the prism per ASTM C1314. These areas are illustrated in Figure 5.

Testing Prisms

Two days prior to the 28 day time interval or the designated testing time, typically 28 days, each prism is removed from the moisture tight bag. Prism age is determined from the time of laying units for ungrouted prisms, and from the time of grouting for grouted prisms.

To provide a smooth bearing surface, prisms are capped with either a sulfur capping material or high-strength gypsum compound in accordance with ASTM C1552, *Standard Practice for Capping Concrete Masonry Units, Related Units and asonry Prisms for Compression Testing* (ref. 12). No other capping materials are permitted, nor are unbonded caps.

Capping provides level and uniform bearing surfaces for testing, thereby eliminating point loads due to surface irregularities. The result is more uniform and reliable compressive strength values. Patching of caps is not permitted because it is difficult to maintain a planar surface within the tolerances of ASTM C1552. Capping materials must have a compressive strength of at least 3,500 psi (24.13 MPa) at an age of 2 hours when cubes of the material are tested in accordance with ASTM C617, *Standard Practice for Capping Cylindrical Concrete Specimens* (ref. 13).

The average thickness of the cap must not exceed 1/8 in. (3.2 m). Caps are to be aged for at least 2 hours before testing the specimens, regardless of the type of capping material. Capping plates of adequate stiffness and smoothness are critical to achieving accurate results. Machined steel plates of 1 in. (25.4 mm) minimum thickness are required as a base. Glass plates not less than 1/2 in. (12.7 mm) in thickness may be used as a earing surface to protect the plates. The capping wear plate must be plane within 0.003 in. in 16 in. (0.075 mm in 400 mm) nd free of gouges, grooves and indentations greater than 0.010 in. (0.25 mm) deep or greater than 0.05 in.^{2} (32 mm^2).

One of the most common oversights in testing masonry prisms is compliance with the established requirements for the testing machine itself. The testing machine is required to have a spherically seated head with a minimum 6 in. (150 mm) diameter and capable of rotating in any direction. The spherically seated head is then attached to a single thickness steel bearing plate having a width and length at least 1/4 in. (6.4 mm) greater than the length and width of the prism being tested. The required thickness of the steel bearing plate depends on the diameter of the spherically seated head and the width and length of the prism being tested. The thickness of the steel bearing plate must equal or exceed the maximum distance from the outside of the spherically seated head to the outmost corner of the prism—designated d in Figure 6. Failure to provide the required
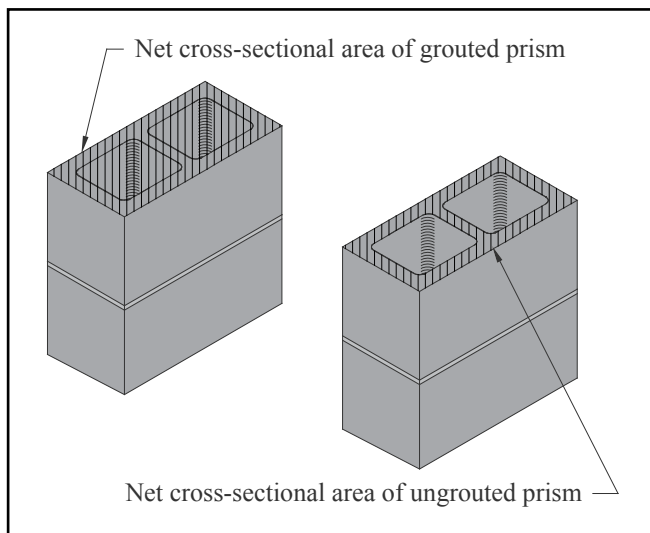

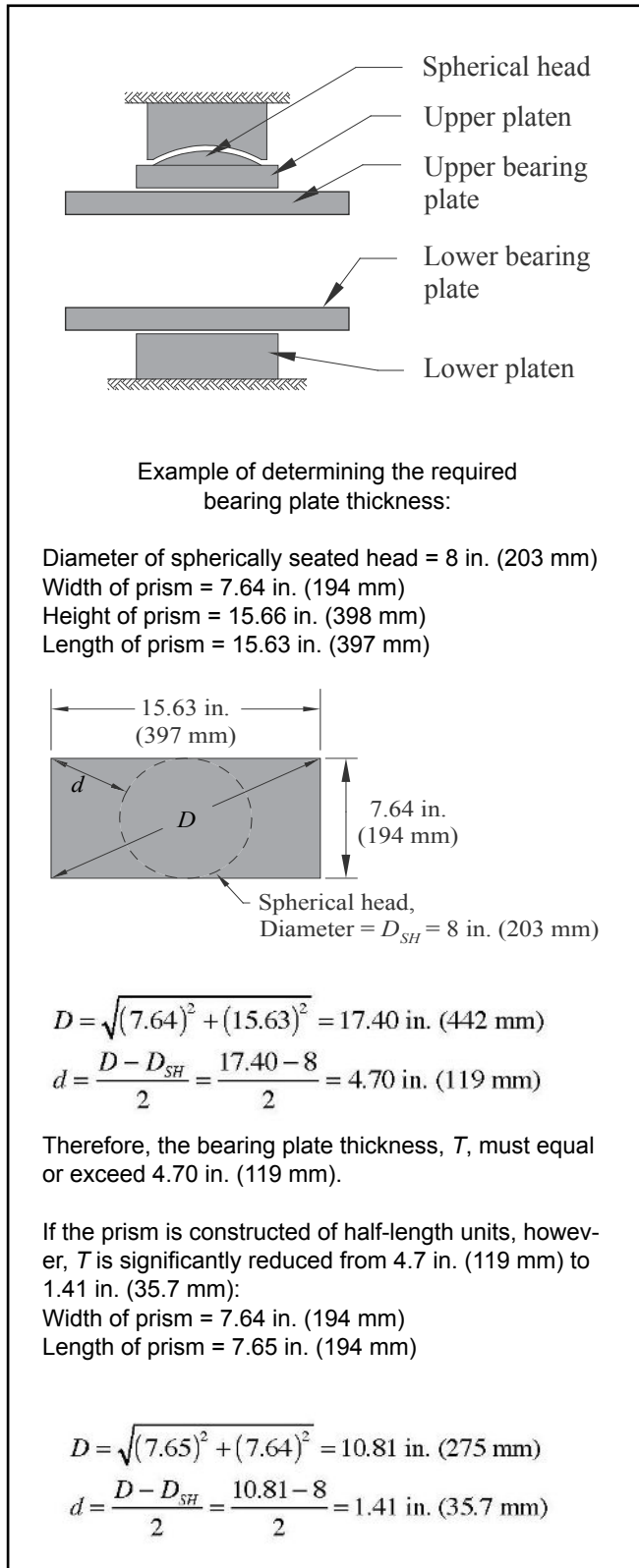**Figure 5—Net Cross-Sectional Areas of Grouted and Ungrouted Prisms**

Example of determining the required bearing plate thickness:

Diameter of spherically seated head = 8 in. (203 mm)
Width of prism = 7.64 in. (194 mm)
Height of prism = 15.66 in. (398 mm)
Length of prism = 15.63 in. (397 mm)

$$D = \sqrt{(7.64)^2 + (15.63)^2} = 17.40 \text{ in. (442 mm)}$$
$$d = \frac{D - D_{SH}}{2} = \frac{17.40 - 8}{2} = 4.70 \text{ in. (119 mm)}$$

Therefore, the bearing plate thickness, *T*, must equal or exceed 4.70 in. (119 mm).

If the prism is constructed of half-length units, however, *T* is significantly reduced from 4.7 in. (119 mm) to 1.41 in. (35.7 mm):
Width of prism = 7.64 in. (194 mm)
Length of prism = 7.65 in. (194 mm)

$$D = \sqrt{(7.65)^2 + (7.64)^2} = 10.81 \text{ in. (275 mm)}$$
$$d = \frac{D - D_{SH}}{2} = \frac{10.81 - 8}{2} = 1.41 \text{ in. (35.7 mm)}$$

Figure 6—Determination of Bearing Plate Thickness

minimum bearing plate thickness decreases the measured compressive strength of the prism due to the bearing plate bending during testing. It is also required that the bearing faces of the plates have a Rockwell hardness of at least HRC 60 (BHN 620).

The last step prior to testing a prism in compression is determining the prisms center of mass. The center of mass of a prism can be thought of as the point on the cross-section of a prism where it could physically balance on a point. The prism is then centered within the test machine such that the center of mass coincides with the center of thrust (which coincides with the center of the spherically seated head).

Failure to align the center of mass with the center of thrust results in a nonuniform application of load and therefore lower measured compressive strengths. For prisms having symmetric cross-sections, the mass centroid coincides with the geometric centroid—or the center of the prism as measured with a ruler. For prisms that are non-symmetrical about an axis, the location of that axis can be determined by balancing the masonry unit on a knife edge or a metal rod placed parallel to that axis. If a metal rod is used, the rod must be straight, cylindrical (able to roll freely on a flat surface), have a diameter between 1/4 in. and 3/4 in. (6.4 and 19.1 mm), and it must be longer than the specimen. Once determined, the centroidal axis can be marked on the end of the prism.

To test the prism, it is placed in the compression machine with both centroidal axes of the specimen aligned with the machine's center of thrust. The maximum load and type of fracture is ecorded. Prism strength is calculated from the maximum load divided by the prism net area. This prism strength is then corrected as described below.

Corrections for Prism Aspect Ratio

Since the ratio of height, h_p, to least lateral dimension, t_p,—designated the aspect ratio or h_p/t_p—of the prism can significantly affect the load carrying capacity of the masonry prism, ASTM C1314 contains correction factors for prisms having different aspect ratios, as outlined in Table 2.

To use the values in Table 2, simply multiply the measured compressive strength of the prism by the correction factor corresponding to the aspect ratio for that prism. Correction factors shown in Table 3 can be linearly interpolated between values, but cannot be extrapolated for aspect ratios less than 1.3 or greater than 5.0.

PRISMS FROM EXISTING CONSTRUCTION

The majority of quality assurance testing of concrete masonry materials is conducted on samples representative of those used in the construction. In some cases, however, it may be ecessary or desirable to evaluate the properties of existing masonry construction using the actual construction materials instead of representative samples. Examples where the inplace (in-situ) masonry properties might need to be considered include old or damaged construction, or during the construction process, when: a testing variable or construction practice fails to meet specifications; a test specimen is damaged prior to

testing; test records are lost; or representative samples are not otherwise available.

The procedures covered in ASTM C1532, *Standard Guide for Selection, Removal, and Shipment of Manufactured Masonry Units and Specimens from Existing Construction*, (ref. 14), are useful when physical examination of an assembly's compressive strength, stiffness, flexural strength or bond strength is needed on a representative sample of the actual construction. These specimens are a portion of the existing masonry, and may include units, mortar, grout, reinforcing steel, collar joint and masonry accessories. The specimens can be taken from single or multiwythe construction. The procedures outlined in C1532 focus on documenting the condition of the masonry and protecting the specimens from damage during removal and transportation to the testing laboratory.

Standard Practice for Preparation of Field Removed Manufactured Masonry Units and Masonry Specimens for Compressive Strength Testing, ASTM C1587 (ref. 15), provides procedures for preparing field-removed specimens for compressive strength testing, and covers procedures such as removing hardened mortar and cleaning.

Compressive strength test results of field-removed masonry units and assemblies are expected to vary from, and will likely be less than, compressive strength test results of new masonry units and newly assembled prisms. Therefore, drawing relationships between the results of tests conducted on field-removed specimens to those of masonry units prior to use or of constructed prisms is difficult.

Prior to removal of specimens from existing construction, a repair plan should be developed. This plan should include replacement of units removed and repair of any disturbed or cut reinforcement, including those unintentionally damaged during the removal process.

Selecting Specimens

Specimens should be representative of the masonry construction as a whole, considering variations within the construction such as: parapets, corbels, areas where different masonry units are combined for architectural effects, as well as variations in the condition or exposure of the masonry. C1532 includes guidance on random sampling, location-specific sampling, and on condition-specific sampling. When testing to help quantify he effects of various exposures or conditions, the sampling should represent each exposure condition.

Thorough documentation of the specimen's condition prior to removal is necessary to assess whether the specimen was subsequently damaged during removal and transport, and for comparative purposes with the other specimens.

Removing Specimens

Carefully remove each specimen at its perimeter, ensuring the specimen is the appropriate size for the intended testing. Note that hydraulic or electric impact equipment should not be used, due to the potential for damaging the specimens. Saw-cutting or hand chiseling is preferred.

The following procedure is recommended. Make the first cut along the bottom of the specimen (on both sides of the wall if necessary) and insert shims. Make the two vertical cuts at the sides of the specimen, then make the top cut. Provide any necessary shoring, bracing and weather protection for the remaining construction. Similar to the pre-removal ocumentation, assess and document the specimen's condition o determine if the specimen was damaged during removal.

Transporting Specimens

The specimens should be confined as described in *Transporting Prisms*, page 4. In addition, each specimen should be protected on all sides with material such as 1 in. (25 mm) thick packaging foam or bubble wrap, placed in sturdy crates, and the crates completely filled with packing material to ensure the specimens cannot move within the crate during transport.

Testing Specimens

It is not permitted to test grouted or partially grouted specimens that contain vertical reinforcement. Specimens cut from existing construction containing horizontal reinforcement can be tested, but the presence and location of reinforcement should be noted and reported.

Prisms must: include at least one mortar bed joint; have an aspect ratio (h_p/t_p) between 1.3 and 5; have a height of at least two units (each of which is at least one-half the height of a typical unit); have a length one-half the unit length and two unit lengths; not include vertical reinforcement. In addition, when prisms contain units of different sizes and/or shapes, the unit height and length are considered to be that of the largest unit height or largest unit length within the prism.

The specimens should be prepared for capping by smoothing and removing loose or otherwise unsound material from the bearing surfaces, to produce a plumb and level surface.

Note that grouted or partially grouted specimens cannot contain vertical reinforcement. The specimens are photographed to document specimen condition prior to capping. Capping and testing procedures are identical to those for constructed prisms except that a slower loading rate is used for field-removed prisms to account for uncertainty in expected loads for these prisms. For field-removed prisms, the first one-quarter of the expected load can be applied at any convenient rate, and the remaining load should be applied within 2 to 4 minutes.

Field-removed prisms may have non-uniform dimensions that should be considered when determining net cross-sectional area for calculating compressive strength. Professional judgement should be used to determine the minimum bearing area of a non-uniform prism. One effective method for face-shell bedded specimens is to multiply the length of the specimen at the bed joint by the sum of the face shell thicknesses to determine minimum bearing area. A more detailed discussion of making this determination is available in CMU-FAQ-012-14, *How can the Bearing Area of a Concrete Masonry Prism Removed from Existing Construction be Determined?* (ref. 16).

REFERENCES

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ABOUT CMHA

The Concrete Masonry & Hardscapes Association (CMHA) represents a unification of the Interlocking Concrete Pavement Institute (ICPI) and National Concrete Masonry Association (NCMA). CMHA is a trade association representing US and Canadian producers and suppliers in the concrete masonry and hardscape industry, as well as contractors of interlocking concrete pavement and segmental retaining walls. CMHA is the authority for segmental concrete products and systems, which are the best value and preferred choice for resilient pavement, structures, and living spaces. CMHA is dedicated to the advancement of these building systems through research, promotion, education, and the development of manufacturing guides, design codes and resources, testing standards, and construction practices.