Portland Cement Association

MASONRY INFORMATION

Compressive Strength of Masonry

Compressive strength of masonry is an important performance characteristic used by engineers in the design of masonry structures. Defined as the maximum compressive force resisted per unit of net cross-sectional area of masonry, the compressive strength of masonry must equal or exceed the specified compressive strength of masonry, f'_m, used in the structural design. Building codes limit allowable stresses in masonry to a percentage of f'_m.

Determining Compressive Strength of Masonry

According to ACI530.1/ASCE 6/TMS 602, two methods may be used to verify that the compressive strength of masonry equals or exceeds f'_m : the unit strength method and the prism test method. The *Uniform Building Code* also provides for verification of the compressive strength of masonry using on these two methods. In addition, the *Uniform Building Code* allows acceptance based on a record of masonry prism tests representative of corresponding construction.

Unit Strength Method. The compressive strength of masonry may be determined from the net area compressive strength of the units and the type of mortar by using tables included in building codes or in standards referenced in building codes. Tables 1 and 2 have been adapted from ACI 530.1/ASCE 6/TMS 602, which is a referenced standard of *The BOCA National Building Code* and the *Standard Building Code*.

Mortar types indicated in these tables are to be in accordance with the requirements of ASTM C270, the Standard Specification for Mortar for Unit Masonry. For example, to obtain a 1500 psi compressive strength of masonry for concrete masonry construction using a Type N mortar, Table 1 indicates that the net area compressive strength of concrete masonry units must be no less than

Table 1. Compressive Strength of Masonry Based on Compressive Strength of Concrete Masonry Units and Type of Mortar Used in Construction*

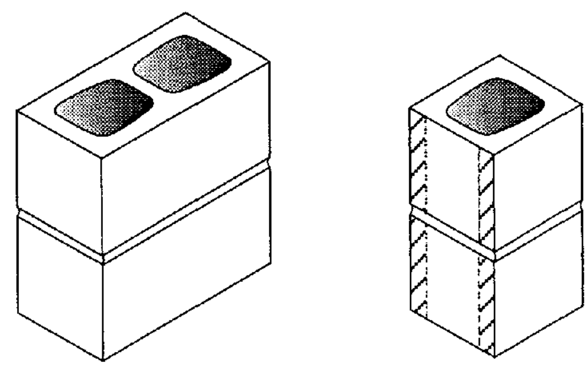
Net area compressive strength of concrete masonry units, psi		Net area compressive strength of masonry, psi**
Type M or S mortar	Type N mortar	
1,250	1,300	1,000
1,900	2,150	1,500
2,800	3,050	2,000
3,750	4,050	2,500
4,800	5,250	3,000

*Adapted from Ref. 1
**For units less than 4 in. high, use 85% of the values listed.

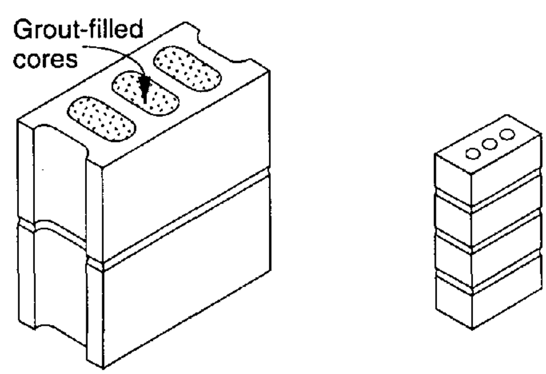
Table 2. Compressive Strength of Masonry Based on Compressive Strength of Clay Masonry Units and Type of Mortar Used in Construction*

Net area compressive strength of clay masonry units, psi		Net area compressive strength of masonry, psi
Type M or S mortar	Type N mortar	
2,400	3,000	1,000
4,400	5,500	1,500
6,400	8,000	2,000
8,400	10,500	2,500
10,400	13,000	3,000
12,400	---	3,500
14,400	---	4,000

*Adapted from Ref. 1



Ungrouted hollow block prisms



Grouted block prism

Solid brick prism

Fig. 1

2150 psi. Table No. 24-C of the *Uniform Building Code* has similar information, although table format is slightly different.

Prism Test Method. The compressive strength of masonry may also be determined by testing masonry prisms (Fig. 1) representative of the masonry wall of interest. If the structure is to have grouted cores, the masonry unit cores in the prism are filled with grout. No reinforcement is used in the prisms. Test procedure, apparatus and data should comply with ASTM E447 Method B, modified as indicated by the applicable code.

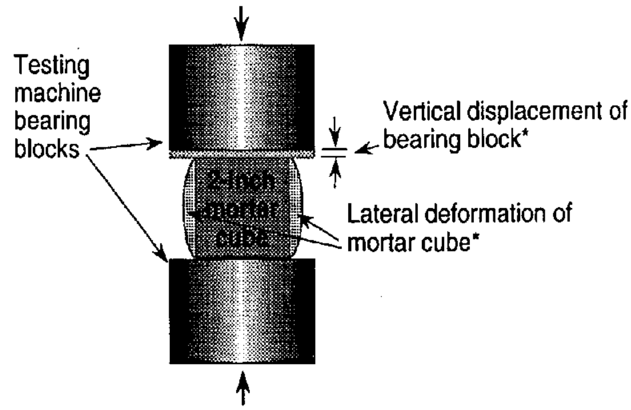
Prisms are constructed in stacked bond with full mortar bedding, and are to be a minimum of two units high. Practical considerations involved in testing prism specimens may dictate that prism height vary depending on unit dimensions and available test equipment. The codes allow the height to thickness ratio of the test prisms to range from 2.0 to 5.0 for clay masonry prisms and from 1.33 to 5.0 for concrete masonry prisms. A correction factor based on the actual height to thickness ratio is then applied to the test results.

Factors Affecting Compressive Strength of Masonry

The compressive strength of masonry is affected by the compressive strength of the units, the type of mortar used, workmanship and curing. These variables are largely reflected in the results of prism tests. Therefore, prism test results are more representative of actual in-place performance of masonry than are tests of component masonry materials. The compressive strength of masonry determined by the prism test method is typically higher than that determined using the unit strength method. Thus, the unit strength method is more conservative from a materials standpoint, but does not provide a quality control check on workmanship and curing as does the prism test method. However, the unit strength method does provide more timely verification of the compressive strength of masonry since the time delay associated with curing prism specimens is eliminated.

Materials. The net area compressive strength of masonry units is the single most critical variable contributing to the compressive strength of masonry. To a lesser extent, the compressive strength of masonry is also affected by the compressive strength of the mortar. However, the effect of mortar strength is less significant than one might intuitively assume. For example, tests have shown that compressive strengths of ungrouted concrete masonry walls increase only about 10% when mortar cube compressive strengths increase 130% (Reference 10). This is largely due to the dimensional difference between mortar joint thickness in a wall or prism and test specimens used for determining compressive strength of mortar.

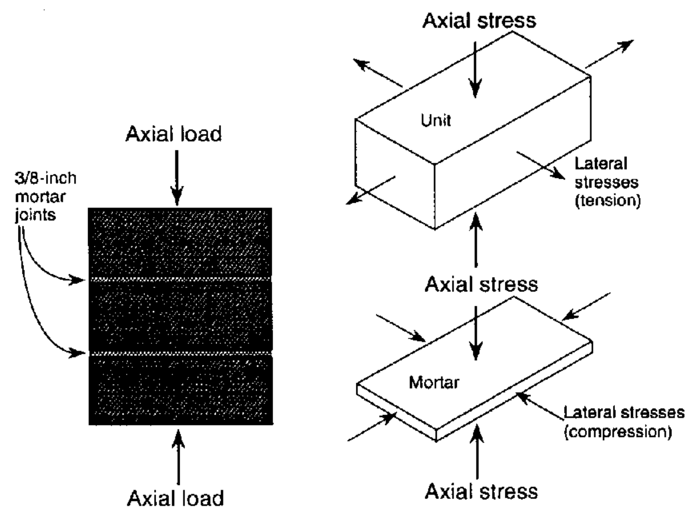
Mortar cube in compression



(a) The effect of bearing block restraint on a 2-inch cube is minimal at center of specimen. Failure of mortar specimen under compressive load first occurs in that area.
*Displacement and deformation are exaggerated for illustrative purposes.

Fig. 2a

Masonry prism in compression**



(b) In a prism mortar joint, the effect of masonry unit restraint on mortar joint is significant over its 3/8-in. thickness . Mortar in joints will sustain a much higher load than in a 2-in. mortar cube and will exhibit more ductile behavior. Masonry prism failure typically occurs in masonry unit at lower compressive strength than the unit would have sustained if tested individually.
**Shown for case when the ratio of lateral deformation (unrestrained) to longitudinal deformation under axial load is greater for mortar than for the masonry unit.

Fig. 2b

Just as height-to-thickness ratios affect compressive strength test results of masonry prisms or concrete cylinders, the height-to-thickness ratio affects test results of mortars. The typical mortar joint can be viewed as a thin plate being placed under compressive load by the adjoining units. The restraining forces generated at the mortar-unit interface result in a much higher failure stress in the 3/8-inch high mortar joint than is realized in a two-inch high cube specimen. Therefore, the compressive strength of masonry may often exceed that of the mortar as determined either by ASTM C270 in the laboratory or by ASTM C780 in the field. For example, it is quite possible to achieve a compressive strength of masonry of 2000 psi or greater with an ASTM C270 mortar having a strength of only 750 psi – provided unit strength is adequate. Fig. 2 illustrates these principles.

Conversely, a masonry prism is expected to fail in compression prior to reaching the load capacity of individual units. Again, this is more easily understood if one views the unit in the prism as being placed under compressive load by adjoining mortar joints or by one bearing plate surface and one mortar joint. The restraint the unit places on the lateral expansion of the mortar joint induces lateral tensile stresses in the unit. Thus the boundary restraints on the unit in the prism will never be as great as they are on individual units placed in compression between steel bearing plates, and the units in a prism fail at a lower compressive strength than when tested individually. The reduction in compressive strength of masonry compared to unit strength is less for units of greater height. For example, masonry constructed with nominal 8-inch high units is not affected as much by changes in mortar strength as is masonry constructed with nominal 3-inch high units.

Unit net area compressive strength affects the compressive strength of both concrete masonry prisms and clay masonry prisms. Differences in mortar strengths generally have a somewhat greater effect on the compressive strength of clay masonry prisms than on the compressive strength of concrete masonry prisms and have less effect on grouted prisms than ungrouted prisms. While some generalizations can be made about relationships between properties of component masonry materials and compressive strength of masonry, accurate assessment of the performance of specific mortar-unit combinations requires actual testing of assemblies.

Construction and Curing. Workmanship and curing also affect the compressive strength of masonry in-place and the compressive strength of masonry determined by the prism test method. Prism specimens used to determine the compressive strength of masonry are to be plumb and true. Properly proportion and mix mortar to a workable consistency, as used in construction. Use full mortar bedding, meaning that both face shells and cross webs of hollow units are mortared. Assure that mortar joint thickness is uniform and consistent with that used in construction – usually ⅜-in. thick. Do not disturb or move prisms for at least two days after they are constructed. Prior to moving, box band prisms to protect joints from tensile stresses. During transportation, securely pack and cushion prisms to avoid damage to specimens.

Specimens are tested at 28 days unless a correlation of earlier age strengths to 28-day compressive strength of masonry has been established. Currently specified prism curing conditions are different in areas where the *Uniform Building Code* is used compared to those where ACI 530/ASCE 5/TMS 402 and ACI 530.1/ASCE 6/TMS 602 are the basis for masonry codes and specifications. Under the Uniform Building Code Standards, specimens are constructed in a plastic bag which is immediately sealed after construction. Specimens remain sealed in the plastic bags until two days prior to testing. ASTM E447 (referenced by ACI 530.1/ASCE 6/TMS 602) stipulates that prisms are to be subjected to two days of initial curing conditions similar to the walls they represent. After two days, they are taken to the laboratory and cured in laboratory air. The ratio of exposed surface area to volume is much higher for prism specimens than for masonry walls – resulting in increased evaporation rates for prism specimens. For this reason, sealed curing (as required by the *Uniform Building Code*) is probably more representative of in-place performance and will yield more consistent results.

Testing Specimens. Capping of specimens is required to provide a smooth, plane bearing surface for application of the compressive test load. The capping material (either sulfur or high strength gypsum plaster) is to be of approximately uniform thickness not exceeding ⅛ in. The surface used for the capping operation must be smooth, plane, and rigid.

Care must be taken while handling specimens during capping and preparation for testing to avoid damage. Specimens (particularly those constructed with full-sized concrete masonry units) may be quite heavy and can be easily damaged if handled improperly.

The bearing surfaces of the compression test machine must meet ASTM E447 requirements. Bearing surfaces have to be adequate in size, hardness, and thickness to accommodate the specimen being tested. If a steel plate is used to accommodate specimens whose cross-section is larger than the spherically seated upper bearing block, the thickness of that plate should be equal to the distance from the edge of the bearing block to the most distant corner of the specimen. Bearing surfaces must be plane, clean, and free of any debris. The prism specimen must be carefully positioned on the bearing blocks. It is important that the specimen be centered with respect to the thrust of the test machine and that the upper bearing block be free to rotate in order to avoid eccentric loading of the specimen.

Calculations and Reports. The compressive strength of each masonry prism is the maximum load divided by the net cross-sectional area of the prism. For solid unit prisms and solid grouted prisms, the net area is simply the product of the average cross sectional width and length of the prism. For ungrouted hollow unit prisms the net area is the net cross sectional area of units determined from a representative sample of masonry units.

According to ACI 530.1/ASCE 6/TMS 602, the compressive strength of masonry is based on the average of three prism strengths, but shall not be taken as more than the strength of the masonry units used in the construction of the prisms. The appropriate height-to-thickness correction factor taken from tables contained in ACI 530.1/ASCE 6/TMS 602 is then applied to the average prism strength (or the masonry unit's strength if less than the average prism strength).

UBC Standard 24-26 requires that the compressive strength of masonry be based on the lesser of either, (1) the average strength of the prism specimens or (2) the least prism specimen strength multiplied by 1.25. The appropriate height-to-thickness correction factor taken from a table contained in UBC Standard 24-26 is then applied to the lower value to obtain the compressive strength of masonry.

Test reports should be prepared according to ASTM E447 as modified by ACI 530.1/ASCE 6/TMS 602 or UBC Standard 24-26, depending on which model code governs the construction.

Saw-Cut Specimens. Occasionally, it may be necessary to verify the compressive strength of a masonry wall in-place. It is possible to cut masonry prisms from an existing wall and test the prisms. Obviously, extreme care must be taken in each step involved in the selection, cutting, removal, transportation, and preparation of prism specimens cut from existing masonry. Some key points to remember when considering such action:

- Safety of personnel performing the task must be considered in the selection of sample areas and procedures.

- Select specimen locations such that they contain no reinforcement.
- Locate specimen to produce symmetry about the vertical centerline of the prism.
- Mark location of prism specimens on wall.
- Make the first cut at the bottom of the prism. Shim the first cut and proceed with the sides and top shimming each cut to support the prism before proceeding to the next cut.
- Make the bottom cut along the bottom edge of a mortar joint and the top cut along the top edge of a mortar joint.
- Remove the cut specimen from the wall very carefully.
- Strap and protect prism from damage during handling and transportation.
- Carefully trim all mortar from top and bottom units prior to capping.
- Follow test procedures for masonry prisms given in ASTM E447.
- For ungrouted hollow units, use area bedded in mortar (usually face shells only) for net cross-sectional area in calculating compressive strength of masonry.

Recent research indicates that test results for the compressive strength of prisms cut from masonry walls are approximately equivalent to those obtained from quality control prisms constructed of the same materials.

REFERENCES

1. *Building Code Requirements for Masonry Structures (ACI 530-92/ASCE 5-92/TMS 402-92), Specifications for Masonry Structures (ACI 530.1-92/ASCE 6-92/TMS 602-92), Commentary on Building Code Requirements for Masonry Structures (ACI 530-92/ASCE 5-92/TMS 402-92), and Commentary on Specifications for Masonry Structures (ACI 530.1-92/ASCE 6-92/TMS 602-92),* American Concrete Institute, Detroit, American Society of Civil Engineers, New York, and The Masonry Society, Boulder, Colorado, 1992.
2. *Uniform Building Code 1991 Edition*, International Conference of Building Officials, Whittier, California, 1991.
3. *Uniform Building Code Standards 1991 Edition*, International Conference of Building Officials, Whittier, California, 1991.
4. *The BOCA National Building Code/1993*, Building Officials & Code Administrators International, Inc., Country Club Hills, Illinois, 1993.
5. *Standard Building Code 1991 Edition*, Southern Building Code Congress International, Inc., Birmingham, Alabama, 1991.
6. Panarese, W. C., Kosmatka, S. H., and Randall, F. A., Jr., *Concrete Masonry Handbook for Architects, Engineers, Builders*, EB008M, Portland Cement Association, 1991.
7. *NCMA -TEK 22B Concrete Masonry Prism Testing* , National Concrete Masonry Association, Herndon, Virginia, 1992.
8. *BIA Technical Note 39A Testing for Engineered Brick Masonry Determination of Allowable Design Stresses*, Brick Institute of America, Reston, Virginia, 1988.
9. *BIA Technical Note 39B Testing for Engineered Brick Masonry Quality Assurance*, Brick Institute of America, Reston Virginia, 1988.
10. Fishburn, C. C., "Effect of Mortar Properties on Strength of Masonry," *National Bureau of Standards Monograph 36*, National Bureau of Standards, Washington, DC, 1961.
11. Atkinson, R. H., Noland, J. L., Abrams, D. P., and McNary, S., "A Deformation Failure Theory for Stack-Bond Brick Masonry Prisms in Compression," *Proceedings of the Third North American Masonry Conference*, University of Texas at Arlington, Arlington, Texas, 1985, Paper #18.
12. Self, M. W., "Structural Properties of Load-Bearing Concrete Masonry," *Masonry: Past and Present*, ASTM STP 589, ASTM, Philadelphia, 1975, pp. 233-254.
13. Hamid, A. A., and Chukwunenye, A. O., "Compression Behavior of Concrete Masonry Prisms," Journal of Structural Engineering, Vol. 112, No. 3, ASCE, New York, March 1985, pp. 605-613.
14. Abrams, D. P., *A Set of Classnotes for a Course in: Masonry Structures*, The Masonry Society, Boulder, Colorado, 1991.
15. Houston, J. T., and Grimm, C. T., "Effect of Brick Height on Masonry Compressive Strength," *Journal of Materials*, Vol. 7, No. 3, ASTM, Philadelphia, Sept. 1972, pp. 388-392.

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An organization of cement manufacturers to improve and extend the uses of portland cement and concrete through market development, engineering, research, education, and public affairs work.

Printed in U.S.A.

IS276.01M