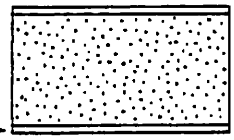
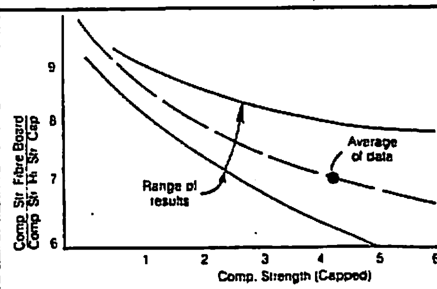
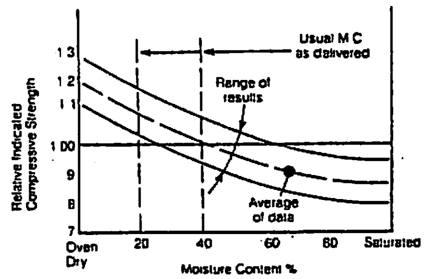
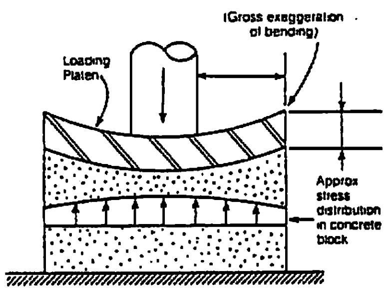
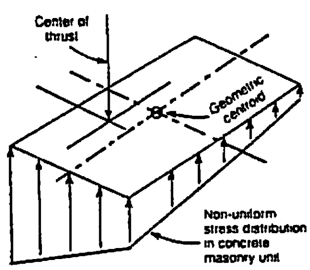
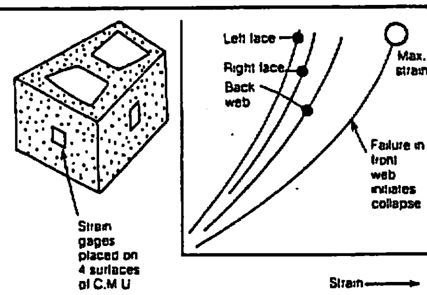
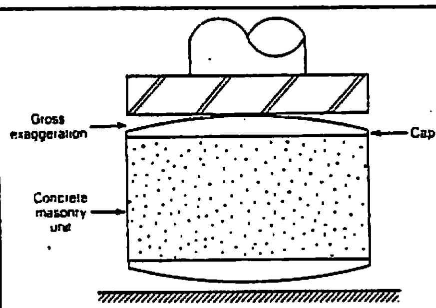
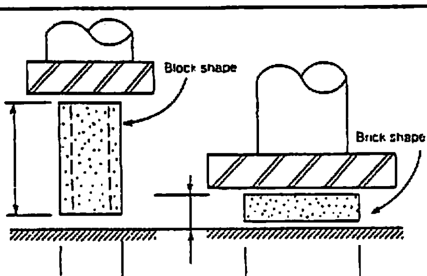
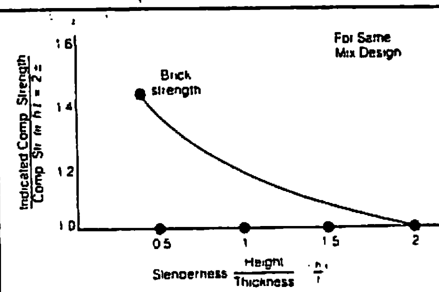
Table I. Influence of Major Testing Variables on the Indicated Compressive Strength of Concrete Masonry Units

Variable	Cause of Variation	Effect on Indicated Strength	Reference (Remarks)
Capping Material	 In-plant use of fibre board in place of lab prepared thin cap of high-strength gypsum, sulfur, mortar etc. Soft fibre board spreads, causing lateral tension.		(A) Holm (C.O.B.) (B) Roberts. (C) Self 1. Solid block tend to have smaller loss of indicated strength when tested with fibre board. 2. Irregularly surfaced blocks produce wide scatter and greater loss.
Moisture Content of Concrete Masonry Unit at Time of Test	Axial loading causes secondary hydrostatic pressures due to moisture content resulting in additive lateral tensile forces.		(B) Roberts (C) Self (D) NCMA (Concrete Masonry Units should be delivered to lab at moisture contents comparable to intended use)
Thickness of Loading Platen		Considerable loss of indicated compressive strength on high strength CMU's if ASTM C140 is followed ($t = l/_3$ to furthest corner). California Concrete Masonry Tech. Comm. recommends $t = l$ to minimize bending of platen—thus developing uniform deformations and stresses.	(E) C.C.M.T.C.
Center of Thrust Not Co-Linear With Geometric Centroid			(A) Holm (H) Failure is precipitated by excessively loaded corner or face resulting in false, low indicated strength.
Non-Uniform Thickness of Capping		15% loss of indicated strength from tests on units sampled from same cube sent to second lab for re-testing. (Actual high rise project).	(A) Holm (F) ASTM C140 stipulates planeness within 0.003 inches in 16 inches. Max. thickness of cap ¼" with sulfur, ⅛" with gypsum plaster.
Shape Effect			(A) Holm (S) Indicated relationship applies to one type and strength of unit. Strength ratio varies with aggregate type, block strength, etc.

(A) Holm, T. A., unreported data from experimental block runs in various plants. (C. O. B. H. F. S.)
(B) Roberts, J. J., see ref (8) at end of paper
(C) Self, M., see ref (7) at end of paper
(D) NCMA, see ref (6) at end of paper

2. Testing of Masonry Units, Mortar, Grout, and Assemblages

Sampling. ASTM C140 (1975) (Sampling and Testing of Concrete Masonry Units) is cited in almost every block specification, but it appears that it is rarely enforced. Five samples should be tested in compression for every 10,000 units (or fraction thereof) used in a project. Furthermore, units should be tested periodically for the related properties of moisture content and concrete density. This data will yield other information, including net area and net volume. On a load bearing wall job, testing frequency may be modified to five units (or prisms) in compression for every 465 m² (5000 sq ft) of wall area, or once per floor.

It is important to recognize that consistent control of production variables has allowed careful manufacturers to reduce the overdesign factor in concrete block mixes to a statistically acceptable minimum. Block producers are cognizant of this fact and make significant in-plant efforts to produce economical, quality units conforming to the project specifications. Characteristically, however, concrete masonry units are tested without an equivalent degree of care and attention. There is widespread lack of recognition that concrete masonry units have either a specific or indirect structural role and should receive at least comparable attention to that given compression test specimen cylinders for structural concrete. Table 6.10 depicts and describes the more important testing variables that may cause indicated test strengths to vary from (normally fall below) the actual strengths provided through the producer's diligent efforts.

These variables are:

1. Capping techniques. For economy and convenience, fiber board is often used for in-plant quality control of commercial units. While producers generally recognize that fiberboard capping procedures reduce indicated test strength 10% to 15% below actual strength for normal commercial units, few recognize that the percentage of loss increases for high-strength units.
2. Moisture content. Concrete block producers should provide units with appropriately low moisture contents for acceptance testing. High moisture decreases the compressive test strength (NCMA, 1966; Self, 1975; Roberts, 1973). Load bearing walls are generally protected from the weather, and laboratory testing procedures should recognize the lower equilibrium moisture contents of protected masonry construction.
3. Rigidity of load platens. Various investigators (California Concrete Masonry Technical Committee, 1975) have determined that the ASTM thickness requirement for compression test plates is not sufficient. Thicker plates are required to develop uniform distribution of test load from the spherical test head of the testing machine to the outer corners of the concrete block units and prisms.
4. Precision of vertical and horizontal alignment. Colinearity of the geometric axis of the specimen relative to the centroid of the loading thrust is vital in the testing of high-strength masonry. Misalignments and lack of perpendicularity can cause premature failure due to biaxial bending and horizontal shearing forces. In some instances, investigators have noticed horizontal tensile cracks opposite to the heavily loaded side of a specimen after initial failure, thus indicating misleading test strengths.
5. Nonuniform cap thickness (out-of-plane). Another area of poor practice is the occasional failure to provide planar capped surfaces within a flatness tolerance of 1 mm/m (0.003 in. in 16 in.). In one instance, capped surfaces were so poorly aligned that the lack of alignment could be seen from over 3 m (10 ft) away. Measurement revealed almost 6 mm (¼ in.) misalignment. This problem generally occurs with high-strength capping plasters where the high-strength gypsum paste is made too stiff and the average thickness of the cap exceeds 3 mm (⅛ in.). It is vitally important that capping be thin and uniform to assure that the unit, not the cap, is tested. Parallelism of capped surfaces is also important.
6. Shape factor. When comparing strength levels of various types of specimens with different height-to-width ratios, it is important to recognize that the indicated test strength may require adjustment by a correction factor relating the slenderness ratio of the test specimen and the restraining influence of the test machine platens. A brick sized unit may show an indicated compressive strength as much as 40% higher than a much larger concrete block shape made from the same concrete mix with equivalent machine time. The increased test strength is due to the influence on the failure mechanism of frictional restraint by the loading platens as well as the reduction of bending moment magnification caused by the slenderness ratio (Kesler, 1959).
7. Testing age. Concrete masonry units increase in strength with time somewhat less than structural cast-in-place concrete. The rate of strength increase is significantly modified by curing parameters (curing time, pressure, and temperature) and type of unit. Solid units show a greater increase in strength than hollow units. This is because moisture used in molding is released slowly due to the high compaction of high-strength mixes.

Engineered masonry codes generally provide two alternative methods for determining the allowable masonry compressive strength f'_m. One method is based on selection from a table of an empirical value for the strength of the walls (f'_m) based on the compressive strength of the individual units (f'_c). The other method allows use of a value for f'_m determined by testing small samples of walls called prisms. ASTM E447 (1974), "Standard Methods of Test for Compressive Strength of Masonry Assemblages," describes the procedure for testing small walls of masonry incorporating typical units, mortar, and workmanship to determine data for a given project. When project specifications call for f'_m to be verified by prism testing, the usual requirement of one series of tests per floor or 465 m² (5000 sq ft) of wall area governs. The obvious purpose is to closely represent the masonry assembly actually constructed. Individual concrete masonry units should be tested concurrently with the prism tests to allow determination of responsibility should prism test results fall below the specified value of f'_m. The need for prism testing is growing due to widespread use of load bearing masonry in high-rise building construction. Prism testing is also used to justify greater f'_m/f'_c ratios through more exacting testing and controls. Economical construction of large buildings requires valid strength information in order to permit structural engineers to utilize the higher design stresses needed to achieve more efficient use of material. Problems confronted in prism testing are similar to the problems experienced in testing individual units (Dickey, 1973), and include the following:

1. Low-strength concrete masonry units.
2. Improper curing and handling, such as dropping or bumping during transportation.
3. Improper caps are more detrimental to accurate prism tests than for individual units due to increased magnification of eccentric and nonuniform loads.
4. Poor workmanship in placement of units on mortar courses will cause decreased f'_m values. High quality workmanship is needed in both prism testing and field construction.
5. Inadequate strength of grout and mortar.

Mortar Testing. Mortar strength requirements and testing procedures are documented in ASTM C270 (1973) for nonreinforced masonry and ASTM C476 (1971) for reinforced masonry. There is great promise for systematic determination of the plastic and hardened properties of mortar using methods described in ASTM C780 (1974), "Standard Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry." An important consideration for designers to recognize is that, in most masonry construction, the relative significance of mortar quality is minimized due to the intermittent location of joints [9.5-mm joint in 203 mm (⅜-in. joint in 8 in.)], the shape factor of joints [9.5 mm high × 32 mm plus in width (⅜ in. × 1¼ in.)], and the similarity in modulus of elasticity of the hardened mortar to the units joined. Self (1975) demonstrated that, beyond a certain critical strength level, a 200% increase in mortar strength will produce only an 11% strength increase in otherwise similar test prisms. Other researchers (Isberner, 1974) have reached similar conclusions. Furthermore, mortar must provide other physical properties equal in importance to compressive strength such as bond, workability, and resistance to weather and rain (Fishburn, 1961). Type S mortar proportioned and mixed in accord with ASTM Specifications seems to provide an effective balance of all important physical property requirements.

Grout Testing. Grout should be proportioned and mixed to meet the requirements of ASTM C476 (1971). For in-place strength testing, field methods differing from ASTM have been devised to correlate grout test strengths with in-the-wall grout characteristics.