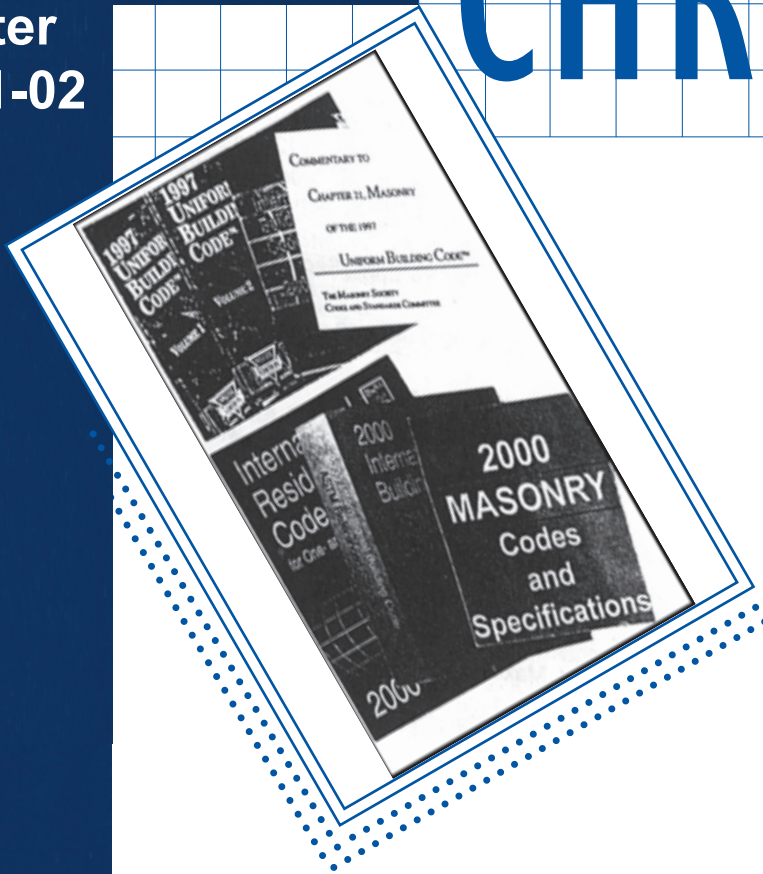


Winter
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CODES AND SPECIFICATIONS UNDERSTANDING AND WORKING THROUGH THE MAZE

TESTING, INSPECTION AND CONSTRUCTION PART III

This is Part III in a series of three articles to understand and locate codes and specification provisions related to concrete masonry design and construction. The purpose of these articles is not so much to provide specific design guidance, but to direct a design engineer to various provisions, primarily in the 1998 California Building Code. Many other codes and standards such as ASTM, UBC-Standards and Masonry Standards Joint Committee (MSJC) provisions are also referenced where appropriate.

Provisions in 1998 California Building Code are discussed, rather than 1997 UBC Provisions, because it is a document based on 1997 UBC adopted in California and also covers State of California Amendments, which are applicable to public schools, community colleges, essential services buildings, and hospitals.

Part I dealt with *Material* and Product Standards.

Part II dealt with *Structural Design Provisions*.

As discussed in Part I, a concrete masonry assemblage is a complex system comprising of four primary materials, *concrete masonry units, mortar, grout and reinforcement*.

Unreinforced masonry is not permitted in seismic zones 3 and 4 as defined in the Uniform Building Code (1997 edition).

Interaction of each of the materials combined with variability in material properties and construction tolerances makes it extremely important to test materials and assemblages and inspect construction to assure a high degree of reliability in quality of the final product.

This article, final in a series of three articles on "Codes and Specifications" attempts to summarize the requirements for a reliable final product.

TESTING

The primary purpose in testing concrete masonry is to verify the specified compressive strength, f'_m . Other important areas cover the compressive strength of grout and mortar and shear strength of masonry cores.

It should be noted that project specifications may require only some of the tests; e.g., testing cores in double shear is required only for projects under State of California Amendments. In California Building Code (CBC) 1998 edition, testing is covered in Section 2105, Quality Assurance.

CONCRETE MASONRY UNITS (CMU's)

Testing of concrete masonry units can be divided into three areas:

- a. Dimensions
- b. Moisture content/absorption
- c. Compressive strength (discussed under verification of f'_m)

a. Dimensions

When required, details of measurement of a unit including calculating equivalent web thickness and equivalent wall thickness are covered in UBC Standard 21-4. Detail test procedures are covered in ASTM C140. Equivalent wall thickness is useful in calculating fire resistance of concrete masonry.

Linear drying shrinkage is the change in linear dimension due to drying from a saturated condition to an equilibrium weight and length. **ASTM C426** gives detail procedures to conduct this test. Although moisture controlled units (Type I) are no longer recognized in current ASTM Standards, UBC Standard 21-4 is based on 1995 edition of ASTM Standards and still covers moisture controlled units. This fact should be recognized. Linear drying shrinkage calculations are useful for assessing movement of wall due to shrinkage so that appropriate control joints can be designed to accommodate such movement.

b. Moisture Content/Absorption

As discussed above, ASTM does not require moisture content to be determined as Type I and Type II designations have been eliminated.

UBC Standard 21-4 still specifies Type I and Type II units, since it is based on an older edition of ASTM. Procedures to determine moisture content are detailed in **ASTM C140**.

Water absorption depends on density of unit. Maximum allowed percentage of water absorption is given in **UBC Standard 21-4 Table "B" and in ASTM C90 Specification**.

c. Verification of Compressive strength, f'_m

1998 California Building Code (CBC) specifies that verification of f'_m of concrete masonry can be achieved by one of the following three methods:

1. Masonry Prism Testing
2. Masonry Prism Test Record
3. Unit Strength Method

Design professionals routinely specify two or more of the above methods to verify f'_m , this is not correct. It neither adds to extra safety provisions nor to clarity of the intention. *It actually creates added confusion.*

Masonry Prism Testing is the preferred method, as it closely simulates the actual construction, considering grout, mortar and the masonry units.

1. Masonry Prism Testing (Section 2105.3.2)

UBC Standard 21-17 and ASTM C1314 are applicable documents.

CBC Section 2105.3.2 specifies requirements as follows:

- a. Tests are to be conducted at 28 days unless relationship between 3 day, 7 day and 28 day tests has been established for the project.

b. Prior to start of construction

- i. A set of 5 prisms in conformance with UBC 21-17 is required.
- ii. Materials for prisms are to be the same as for the project.
- iii. Prisms are to be constructed under the observation of the engineer, special inspector or an approved agency.
- iv. Prisms are to be tested by an approved agency.

c. During Construction

- i. Minimum one set of three prisms. Each 5,000 square feet of wall area requires one set of three prisms.

- ii. When one half allowable stresses are used in design, no prisms are required, but a letter from the supplier certifying that materials used in project are the same as in the five prisms constructed prior to construction, is required.

2. Masonry Prism Test Record (Section 2105.3.3)

This is an effective method of verifying f'_m , but is not commonly used for reasons unknown. This method allows verification of f'_m by prism test records.

a. Prior to Construction

- i. Prisms are to be representative of project construction.
- ii. Test records of at least 30 prisms is required.
- iii. Prisms shall have been constructed under the observation of an engineer, special inspector or an approved agency.
- iv. Prisms shall have been tested by an approved agency.
- v. Average compressive strength of the test record to be at least $1.33 f'_m$.

b. During Construction

Requirements are same as under Masonry Prism Testing.

- i. When one half allowable stresses are used, field testing during construction is not required. A letter similar to that described under "c ii" is required.

3. Unit Strength Method (Section 2105.3.4)

This is perhaps the most commonly used method to verify f'_m . It needs to be clearly understood that this method essentially requires compliance with three components, concrete masonry units, mortar and grout.

Concrete Masonry Units

a. Prior to Construction

Three units are to be tested. Tests should conform to **UBC Standard 21-4**, which is based upon ASTM C140 Specification. Compressive strength must comply with

CBC, Table 21-D. In general, for type M or type S mortar, the required unit strength varies from 1.25 to 1.6 times f'_m .

For example,

for $f'_m = 1500$ psi, unit strength ≥ 1900 psi
 $f'_m = 2500$ psi, unit strength ≥ 3750 psi

Linear interpolation of values given in Table 21-D is allowed.

b. During Construction

For each 5,000 square feet of wall area, three units are to be tested and should meet the same compressive strength requirements as noted above.

Please note that the compressive strength results are based on the average compressive strength of three units. An individual unit shall not test below 1700 psi.

Mortar

Mortar should comply with mortar type of Table 21-D. For specific mortar type, the proportions should comply with Table 21-A

State of California Amendments for schools, hospitals and essential services buildings, requires mortar to attain a minimum compressive strength of 1500 psi at 28 days for f'_m of 1500 psi.

They also require proportions of mortar ingredients to be those required for type "S" mortar.

For requirements of mortar sampling, see **Section 2105 A 3.4 (2)**.

Grout

At least one test for each 5,000 square feet of wall area is required (minimum one test per project).

Grout minimum compressive strength should be the same as f'_m , but not less than 2000 psi.

Selecting proportions and other details are covered under **Section 2103.4.2 and 2103A.4.2** when one half the allowable stresses method is used, *no testing* of the units or grout is required. A letter certifying that they meet the requirements of Table 21-D is needed, however.

When masonry does not meet the requirements of three methods described above, acceptance may be given by the building official if prisms cut from the masonry meet the following requirements.

4. **Prisms Cut from Constructed Masonry (Section 2105.3.5)**
 - a. Masonry construction is to be at least 28 days old.
 - b. A set of three prisms for each 5,000 square feet of wall area shall be cut (at least one set is required for the project).
 - c. Testing shall comply with UBC **Standard 21-17**.
 - d. The average compressive strength of the prisms shall be equal to or more than f'_m based upon net mortar bedded area.

State of California Amendments also require:

5. Core Testing of Masonry

The Requirements are:

- a. Minimum two cores of 6-inch diameter for each 5,000 square feet of greater of wall or floor area.
- b. 50% of the cores to be tested for f'_m .
- c. Core tests should show compressive strength equal to or greater than assumed f'_m .
- d. 50% of the cores are to be tested in shear.
- e. Shear strength shall be minimum $2.5\sqrt{f'_m}$ psi.

For other details on core testing, see **Section 2105A.3.1 and Section 2105.A.6**

GROUT

Number of samples required is covered under "3" Unit Strength Method.

- Grout is commonly specified with required compressive strength. Testing is covered in **UBC Standard 21-19**, which is based on **ASTM C476 Specification**.
- It should be noted, although Table 21-D footnote 4 allows the grout strength to be equal to unit strength (e.g., 1900 psi unit strength for 1500 psi masonry strength), the minimum required grout strength is 2000 psi at 28 days (**Section 2103.4.1**)

MORTAR

Mortar is not generally specified by its property of compressive strength. It is specified by proportion of ingredients. However, when mortar is to be tested for compressive strength, requirements are given in **UBC Standard 21-15 based on ASTM C270 Specification**.

- Specimens should be prepared and tested per **UBC Standard 21-16**. The specimens are 2-inch by 4-inch cylinders.
- Compressive strength must be at least 1500 psi at 28 days
- When mortar is specified to meet a specific compressive strength, laboratory testing shall be conducted on 2-inch cubes and need to meet the requirements of **UBC Standard 21-15**.
- Type of mortar - Average compressive strength
 - M - 2500 psi
 - S - 1800 psi

Maximum air content shall not exceed 12%.

State of California Amendments require at least one set of mortar specimens (three cylinders) at the beginning of masonry work on three successive days and at one week interval thereafter.

INSPECTION

The prime purpose of inspection is to ensure that workmanship and construction are in compliance with plans and specifications and meet the design intent.

In California Building Code, inspection is covered under general section "Quality Assurance" (Section 2105), but we have broken it into two categories, testing and inspection for clarity and simplicity.

Inspection, in specific, is covered in **Section 1701.5 Item 7**.

Generally, the following items should be inspected, noted and reported to the building official, if required.

1. Preparation and taking of test specimens
2. Foundation surfaces and rebars
3. Grout space prior to grouting
4. Grouting operations
5. Protection of masonry assemblage

- When one half-allowable stresses are used in design, special masonry inspection is not required.
- When strength design is used, special inspection is required (**Section 2107.1.2**)

State of California Amendments have following specific requirements: (**Section 2105A.7**)

1. All structural masonry work is to be continuously inspected during laying and grouting by specially approved inspector.
2. Special inspector is to be approved by the enforcement agency.
3. Inspector is to make test samples, perform tests as required, check materials, details of construction and construction procedures.
4. Inspector is to furnish a verified report that, of his personal knowledge, the work covered by the report complied in all respects with duly approved plans and specifications.

CONSTRUCTION

General construction requirements are covered in **Section 2104.2**. Some of the highlights are given below:

1. Concrete masonry units shall not be wetted unless approved.
2. After initial mixing of water and dry material components,
 - a. Mortar must be used within 2½ hours.
 - b. Grout must be used within 1½ hours

a. Cold Weather Construction

Details are covered in **Section 2104.3**. Numerous specific requirements cannot be covered here, but some of the important points are noted below:

1. Tops of open unfinished walls are to be covered with a strong weather resistive material at the end of each day or shutdown.
2. Units should not be laid below 20°F. Sand and mixing water are to be heated to produce mortar temperature between 40°F and 120°F. (State of California Amendments do not allow units to be laid below 40°F, or grouting when air temperature is below 20°F).

b. Hot Weather Construction

This condition is not specifically covered in CBC provisions. Some of the critical concerns are; early drying up of mortar and grout before curing, and lack of humidity for curing in general.

One of the effective ways to mitigate these concerns is to use cool water for mixing.

Shading of masonry materials is also useful. For more details see **MSJC Specifications**.

c. Placing Masonry Units

Details are covered in **Sections 2104.4 and 2104A.4**.

In general, the following should be observed.

1. Mortar shall be sufficiently plastic.
2. Initial bed joint thickness – ¼ inch to 1 inch.
Subsequent bed joint thickness – ¼ inch to 5/8 inch.

d. Reinforcement Placing (Section 2104.5)

Tolerances in placing reinforcing bars may have impact on design assumptions as unit thicknesses are fairly small compared to allowed tolerances.

For example, for units > 8 inches, but ≤ 24 inches, tolerance is ± 1 inch for placement of reinforcing bars.

e. Grouted Masonry

Nearly all structural masonry in California is grouted. Details are covered in **Section 2104.6.1.2**.

California State Amendments provide a detailed description of low lift grouting (**see 2104A.6.1.2.2**) and high lift grouting (**2104A.6.1.2.3**).

In general,

1. Grout spaces should be clean so that mortar projections do not exceed ½ inch.
2. Grouting of any section of wall is to be completed in one day with no interruptions more than one hour.
3. Between grout pours, a horizontal construction joint shall be formed stopping a minimum of 1½ inch below a mortar joint.

4. Grout pours greater than 12 inches shall be re-consolidated by mechanically vibration.

Grouting limitations related to maximum height of a pour and required dimensions of clear grout spaces are provided in **Table 21C** of the California Building Code.

f. Construction Tolerances

Questions arise many times, related to acceptable deviations of constructed masonry work from those on plans and specifications. California Building Code does not address this area. One of the best resources is MSJC Specifications (ACI-530.1/ASCE 6/TMS 602). This document does not exist separately anymore and is a part of MSJC Building Code Requirements for Masonry Structures.

This document provides acceptable tolerances in units, mortar joints, variations in plumbness, alignment and locations.

As covered in Part I, it is common to have minor cracks, minor chipping or minor imperfections in masonry walls. For specific acceptance criteria see **ASTM C90-01**, and Part I in Spring/Summer 2001 issue of "Masonry Chronicles".

This final article in a series of three articles on "Codes and Specifications" completes this particular series. For Part I, see Spring/Summer 2001 issue and for Part II, see Fall 2001 issue of "Masonry Chronicles".

This issue of Masonry Chronicles was written by Vilas Mujumdar, Executive Director of Concrete Masonry Association of California and Nevada.

"Masonry Chronicles" is a publication of the Concrete Masonry Association of California and Nevada. Please contact the Association Executive Director, Dr. Vilas Mujumdar, with any comments or suggestions for future issues.

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