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The most common misunderstandings in masonry

By
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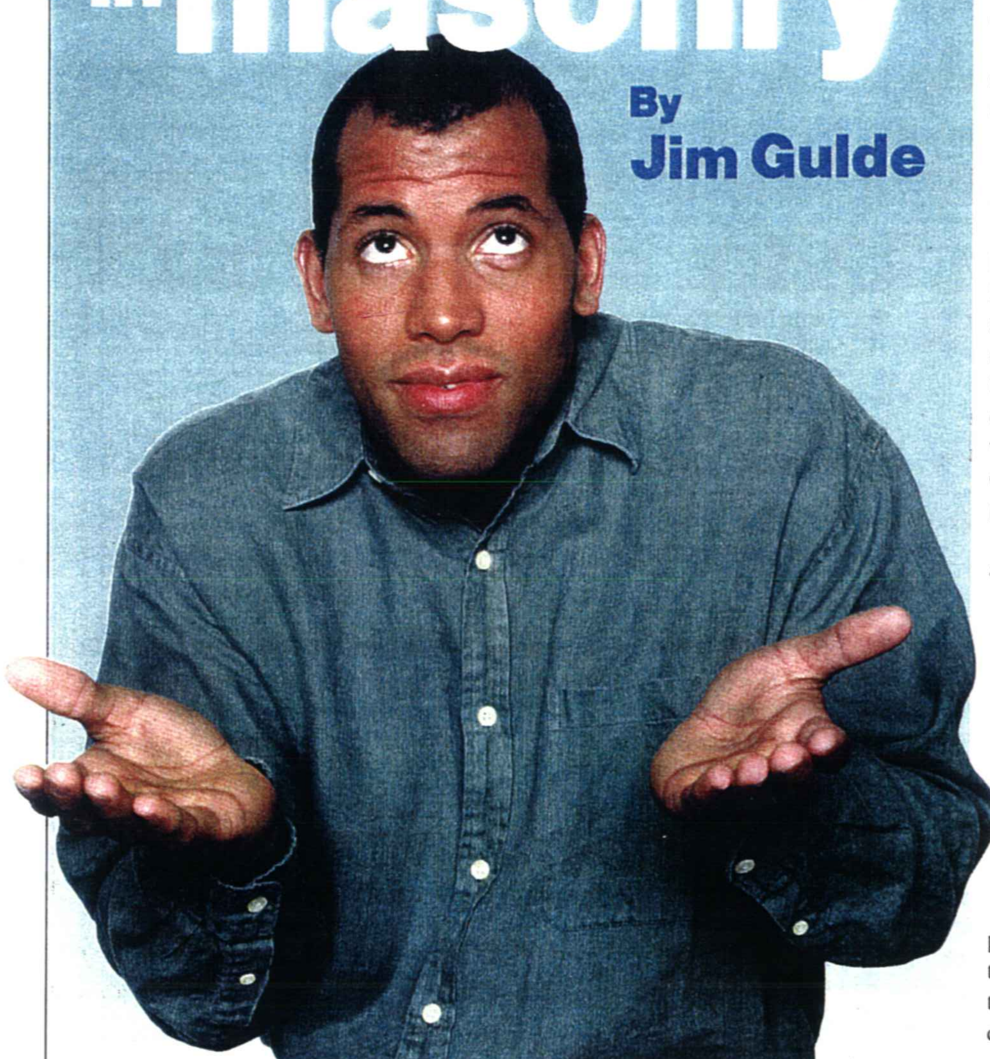


Engineering course work usually includes steel and concrete and sometimes wood, but it almost always neglects masonry. In fact, most practicing engineers did not take any masonry courses in college. Since 70 percent of all existing construction in the world includes masonry, this absence of education is a real detriment to the profession and to society.

It is not surprising, therefore, that many misunderstandings exist. In this article, I will clarify what I believe are the most widespread misunderstandings about codes, mortar strength and testing, grout strength and testing, and the prism test.

Referenced documents are part of code too

The consensus document, "Building Code Requirements for Masonry Structures" (ACI-530, ASCE-5, TMS 402) governs masonry construction for most of this country, with the exception of those who use the Uniform Building Code (UBC). Although the Masonry Standards Joint Committee (MSJC) released a new version of this code is 1999, we are going to discuss the 1995 version since it is used more prevalently.

This code covers it all: design, construction and inspection. It even has its own specifications. This requires all members of the masonry construction team, including the architect, engineer, contractor, mason contractor, mason, and the inspector, to understand this document.

Too often, people ignore the fact that the MSJC code references many other documents (ASTM, ACI, ASCE, TMS, and ANSI/AWS), which "are declared to be a part of the code as if fully set forth in the document" (MSJC 1.3.1). This neglect is a problem since it is arguable that the real content of the code is found in the footnotes of the tables and in the appendix of the referenced documents. Unless one is familiar with the footnotes and the appendix, one does not understand the code.

Mortar

Proper proportioning of the mix is the most important factor in making mortar. Large batch to batch variations need to be avoided; ASTM C-780 is used to monitor these variations to mortar production on the job. There are five questions to ask yourself when evaluating mortar production:

- Is it mixed for three to five minutes after all ingredients are introduced?
- Is some sort of measuring device evident on the jobsite for checking the volumetric control? (A cubic foot box can be used to calibrate the shovel, and a five gallon pail is equal to 2/3 cubic feet.)
- Is the sand kept damp and loose?
- Is the cement covered and stored off the ground?
- Is the water "cool"?

With the basics said, lets discuss two commonly misunderstood topics: strength and interpretation of mortar strength tests.

1. Stronger is not always better: There is a general perception that stronger is better, but in the case of mortar, weaker is better. The most common mortar types are M, S, and N. The corresponding compressive strengths are: M = 2,500 psi; S = 1,800 psi; N = 750 psi. In almost all cases, the best mortar is the *weakest* mortar that will adequately do the job. The authority for this statement comes right out of ASTM C-270. A close look at table X1.1 "Guide for the Selection of Masonry Mortar," shown on page 40, clearly shows that the recommended mortar in all cases, except for footnote (c), is the weakest mortar. The stronger mortar is considered the alternate, not the recommended.

As an example, if a type S mortar is sufficient to accommodate the structural requirements, a type M mortar should not be used. Why is this so? It is primarily a matter of bond.

There are two important elements to bond: bond strength and extent of bond. The bond strength is the force required to separate the units. The extent of bond is the amount of contact the mortar has with the masonry unit.

Interestingly enough, bond strength is adversely affected by compressive strength. The graph below illustrates the relationship between mortar compressive strength and bond strength. As the compressive strength decreases, the bond strength increases. This fact explains why weaker is better and why a lesser strength should be used, if sufficient.

Complete and full contact between the unit and the mortar (good extent of bond) is important for watertightness and tensile bond strength.

2. The truth about mortar strength tests: Many people in the industry agree that the number one misunderstanding in masonry design and construction is the interpretation of mortar tests. Many engineers do not know how to properly interpret the strength reports and, as a result, they may shut down jobs incorrectly.

This situation occurs because the engineer doesn't understand that the field strength, as determined by ASTM C-780, is not expected to equal the laboratory strength, as determined by ASTM C-270. The authors of the ASTM documents have done an excellent job of clarifying this. Both ASTM C-270 3.3 and ASTM C-780 1.4 clearly state that the two tests can not be directly compared.

ASTM C-270 is a laboratory procedure used to specify mortar. Specifying ASTM C-270 assures a "good" specification for mortar.

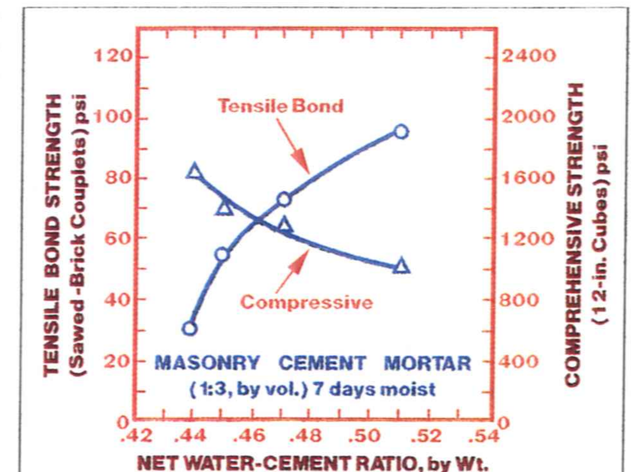
ASTM C-780 cannot achieve the strength specified by ASTM C-270. The introduction of ASTM C-780 states, "No attempt is made to claim or substantiate specific correlations between the measured properties and mortar performance in the masonry. However, data from these test methods can be combined with other information to formulate judgments about the quality of masonry." ASTM C-780, Section 1.4 states, "The test results obtained under this test method are not required to meet the minimum compressive values in accordance with the property specifications in Specification C-270."

Compare ASTM C-270, ASTM C-780, and wall in field

To further explain why the test results are not comparable, let's look at the differences between the lab and field tests.

The primary difference between ASTM C-270 and ASTM C-780 is the water content. All of the components of a particular mortar are the same in ASTM C-270 and ASTM C-780 except the water content. ASTM C-270 requires that the mortar have a "flow" of 110 +/- 5% [C-270 -6.4]. Properly constituted field mortar used in ASTM C-780 may have a flow of over 130 percent as specified in PCA's "Trowel Tips — Field Testing Masonry Mortar."

You may think that ASTM C-270 is not con-



This graph illustrates the relationship between tensile bond and compressive strength. It is taken from NCMA TEK.

ASTM C-270, Table X1.1

Guide for the selection of masonry mortars[A]

LOCATION	BUILDING SEGMENT	MORTAR TYPE	
		RECOMMENDED	ALTERNATIVE
Exterior, above grade	Load-bearing wall Non-load bearing wall Parapet wall	N O[B] N	S or M N or S S
Exterior, at or below grade	Foundation wall, retaining wall, manholes, sewers, pavements, walks, and patios	S[C]	M or N[C]
Interior	Load-bearing wall Non-load-bearing partitions	N O	S or M N
Interior or exterior	Tuck pointing	see X3	see X3

[A] This table does not provide for many specialized mortar uses, such as chimney, reinforced masonry, and acid-resistant mortars.
[B] Type O mortar is recommended for use where the masonry is unlikely to be frozen when saturated, or unlikely to be subjected to high winds or other significant lateral loads. Type N or S mortar should be used in other cases.
[C] Masonry exposed to weather in a nominally horizontal surface is extremely vulnerable to weathering. Mortar for such masonry should be selected with due caution.

Comparison of Lab and Field Mortar

ASTM C-270	ASTM C-780
1) Less water than field mortar 2) Samples are taken in non-absorbent molds 3) Laboratory conditions	1) More water than lab mortar 2) Test samples are taken in non-absorbent molds, but in the real world, the masonry units absorb water from the mortar thereby lowering the water/cement ratio 3) Field conditions

servative enough since the sample has a lower water/cement ratio than the field mortar; however, that is not the case for two reasons.

1. Lower water/cement ratio in field: The strength test results from ASTM C-270 and ASTM C-780 are actually lower than the field strengths because the tests use non-absorbent molds, and the masonry units in the wall absorb some moisture in the mortar, thereby lowering the water/cement ratio. This makes the field mortar stronger than the tests.

The field test using ASTM-780 gives a lower compressive strength than the lab test since they both use non-absorbent molds and the lab mortar has a lower water/cement ratio than the test samples for ASTM C-780, which uses field mortar.

It might be noted here, that under the Uniform Building Code there is a method for mortar testing (2105.4) wherein the mortar is spread on the block at the thickness of the mortar joint for one minute and then placed into a mold. The placing of the mortar on the block for one minute allows moisture to escape by being absorbed into the cmu and lowering the water/cement ratio. This is an attempt to more closely approximate the actual strength of the mortar in the field; however, this method has not found its way into ASTM.

2. Aspect ratio: When the aspect ratio, h/t ratio, is taken into account, mortar that tests in a two-inch by two-inch cube testing at 2,000 psi might well be 12,000 psi when tested at 3/8 inch thick by 1 1/4 inch width.

Why choose the compressive strength test?

A review of ASTM C-780 shows that there are eight tests for mortar given in Appendices A1 through A8. The compressive strength test (see A7), which is traditionally used to test mortar, will give results in 28 days. What can be done at that point? Waiting 28 days to take corrective action appears to be counter productive.

An excellent and timely way to monitor jobsite mortar is the mortar aggregate ratio test (see A4). This test evaluates the ratio of cement to aggregate within hours so corrective action can be taken.

Summary on mortar

You should not expect the mortar tested in the field using ASTM C-780 to have as high a strength as the laboratory design strength given by ASTM C-270. This fact is often misunderstood and can cause difficulties. Sometimes engineers actually shut down jobsites because they misinterpret the field test results.

Here are the facts:

- Mortar should be designed to meet the requirements of ASTM C-270.
- Mortar is tested in the field by ASTM C-780.
- The field mortar strength tests do not have to equal the laboratory mortar strength tests, as developed under ASTM C-270.
- The key word in ASTM C-780 is EVALUATION.

Grout

Grout is not concrete, and as such, it has different requirements. Grout's mix design, slump, and testing are often confused with concrete's requirements. Let's clarify the true requirements for grout.

Mix Design: The MSJC specification refers to ASTM C-476 for grout provisions. This ASTM standard gives two ways to determine mix design. Proportions can be taken directly from Table 1 in ASTM C-476 or the compressive strength of grout can be specified. If the strength is specified, the ASTM standard requires the grout compressive strength to equal $f'm$ with a lower bound of 2,000 psi.

Most masonry projects are designed around an $f'm$ of 1,500 psi or, when higher strength is required, 2,500 psi. Since the grout must equal $f'm$ or 2,000 psi, whichever is higher, the required strength of grout ranges between 2,000 psi and 2,500 psi. Compare this to concrete strength requirements, which generally range from 3,000 psi to 6,000 psi. The reflection here is that the required strength for grout is relatively low and is equivalent to the $f'm$.

Slump: The MSJC specification requires grout to have a slump between eight and 11 inches. It is important that grout be very fluid so that it flows down the cells easily. Investigations of damage from Hurricane Andrew provide ample evidence of the need for fluidity in the mix. For high lift grouting, a six-inch slump will simply bridge over within two feet of the bond beam and the bond beam will not be grouted solid. A slump of eight to 11 inches is required by code for a good reason.

Testing: The MSJC Specification requires the testing agency to sample and test the grout in accordance with ASTM C-1019.

According to ASTM C-1019 7.2.1, "The mold should simulate the grout location in the wall." In concrete masonry construction, four blocks surround the grout sample are lined with permeable material such as paper towels. This allows moisture to escape from the mold and prevents bonding to the masonry units. A waxed cylinder mold or non-pervious mold should not be used (see illustration at right).

This is the only recognized method for sampling and testing grout. The UBC section 21.1805 outlines a similar procedure.

Summary on grout

- Mix design in accordance with ASTM C-476.
- Slump shall be eight to 11 inches. This cannot be compromised.
- Strength shall be equal to 2,000 psi or $f'm$, whichever is higher.
- Testing shall be done in an absorbent mold in accordance with ASTM C-1019.

Prisms

Engineers and architects specify the field prism test (ASTM C-1314) to confirm the specified compressive strength of masonry ($f'm$). But is the prism test really necessary? Let's look at the MSJC Specification, Table 2 below.

This table gives us much understanding about the assemblies we choose. If we know the strength of a block and mortar type, then we can determine the $f'm$. For example, the standard block meets the requirements of ASTM C-90 and has a compressive strength of 1,900 psi. Examination of the table shows us that we can couple that with a type M or S mortar and have an $f'm$ of 1,500 psi. Additionally, if we had a block with a compressive strength of 2,150 psi coupled with a type N mortar, we would also have an $f'm$ of 1,500 psi.

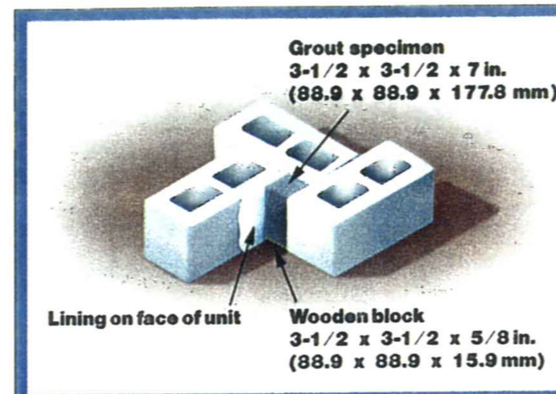
With limited funds for testing, it would be sufficient to test only the block and the mortar. If the block results are okay, and the mortar aggregate ratio tests on the mortar are satisfactory, then we might consider eliminating the prism test.

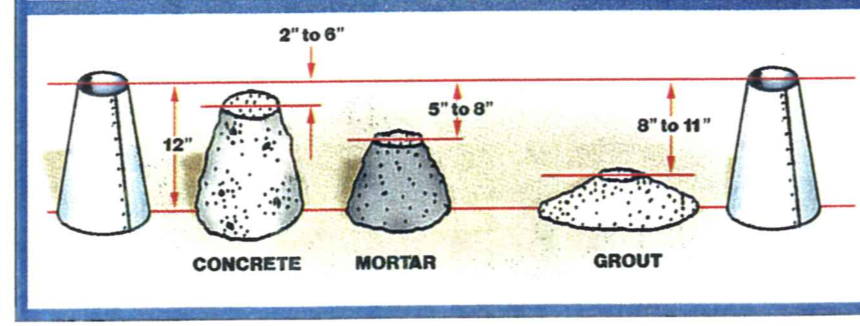
There are two issues about prism testing that are important to understand; cross webs are mortared in the prism test and transportation

MSJC Specification - Table 2

Net area compressive strength of concrete masonry units, psi (MPa)		Net area compressive strength of masonry units, psi[1] (MPa)
Type M or S mortar	Type N mortar	
1,250 (8.6)	1,300 (9.0)	1,000 (6.9)
1,900 (13.1)	2,150 (14.8)	1,500 (10.3)
2,800 (19.3)	3,050 (21.0)	2,000 (13.8)
3,750 (25.8)	4,050 (27.9)	2,500 (17.2)
4,800 (33.1)	5,250 (36.2)	3,000 (20.1)

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





Left: The testing specimen for ASTM C-1019.

Below: Slump test of concrete, mortar and grout. Illustration taken from MIA 1977, James Amrhein.

is a serious concern. The prism test can cause ulcers when it isn't done properly.

1. Cross webs are mortared in the prism test: Except for a few instances, the webs are not mortared in the field; however, the webs are mortared for the prism test. ASTM C-1314 5.6 states clearly, "Build masonry prisms with full mortar bend (mortar all webs and face shells of hollow units)."

There are some exceptions where the MSJC requires the webs to be mortared in the field. The MSJC Specification 3.3B3 states, "Place hollow units so: a) face shells of bed joints are fully mortared; b) webs are fully mortared in all courses of piers, columns and pilasters, in the starting course on foundations, when necessary to confine grout or loose-fill insulation."

So, except for 3.3B3b given above, webs are not required to be mortared in the field, but they are mortared in the prism test. It is not consistent for the engineer to require full web mortar in the field.

2. Transportation: ASTM C-1314 6.1 states that each prism must be strapped or clamped to prevent damage during handling and transportation. The prisms must also be secure to prevent jarring, bouncing, or tipping over during transportation.

This requirement must be covered in the prebid conference; otherwise, exactly who should take responsibility for the prisms may not be clear. Is it the duty of the mason contractor, the general contractor, or the testing laboratory to strap the prism? This task is extremely important since the mortar bed in the prisms can easily rupture and give false results.

Summary of prism testing:

The prism test does have some problems. If the prism isn't handled properly and the assembly breaks in transportation, what value are the results? But if the prism test is required on a project, then:

- Accept the fact that the cross webs are to be fully mortared in the prism test.
- Handle the prism carefully with special attention to strapping and transportation.

Conclusion

For better masonry construction at reduced cost:

- Engage a mason contractor in the design and engineering phase of the project.
- Conduct a prebid conference on masonry to review the highlights of the documents and explain specific responsibilities in detail.
- Eliminate or minimize the mortar compressive test; instead, use the mortar aggregate ratio test.
- Eliminate or minimize the prism test; instead, test the block and mortar. ■

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