THE HISTORY AND SIGNIFICANCE OF CORING MASONRY WALLS

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ABSTRACT

The genesis of coring masonry walls can be traced back to California Schoolhouse Section Circular No. 10, July 1960 and codified in Article 4 of the 1963 California Administrative Code. The 1963 code required a minimum shear bond between the grout and masonry unit of 0.69 MPa (100 psi). Double-wythe reinforced grouted brick masonry was predominant in school construction and the concept of bond between the masonry unit and grout was a concern. The bond requirement of 0.69 MPa (100 psi) seems to be arbitrary. The 1988 edition of the California Building Code (CBC) modified the minimum bond interface between the grout and masonry unit to $2.5\sqrt{f'_m}$, or about 0.67 MPa (97 psi) for f'_m = 10.3 MPa (1,500 psi).

Currently, the coring provision still exists in the CBC; however, the type of construction has changed significantly over the past 50 years. Schools and other buildings that were constructed of double-wythe clay masonry are now built of single-wythe concrete masonry units with face shells connected by one or more cross-webs. Increased structural reinforcement in masonry has made it more difficult to avoid cutting reinforcement during the coring extraction process. Additionally, there are no published standards to follow for the core sample extraction or core shear test procedure.

In 2011, the Masonry Institute of America and Concrete Masonry Association of California and Nevada conducted a test program to evaluate the significance of the coring process and subsequent test results. This paper will elaborate on the history of the coring process, outline test procedures and results and make recommendations for coring procedures.

KEYWORDS: bond, code, core, grout, shear

INTRODUCTION

In order to understand why masonry walls are cored, the history of masonry, particularly unreinforced masonry, must be considered. Masonry has been used as a successful building material for at least 4,500 years throughout the world. There are many positive attributes of masonry. One example would be durability and resistance from natural elements, such as wind. Another would be resistance to lateral forces as imposed by soil against a masonry retaining wall. There are also drawbacks to masonry. For example, the weight of masonry causes lateral loads in seismic events. In order to balance the good and the bad, an appropriate quality assurance program is essential.

HISTORY

Drilling cores in masonry walls may not seem like an appropriate method of verifying Quality Control, and perhaps in the 21st Century there are better non-intrusive ways to verify the quality of masonry. Sadly, there are at least two code enforcement agencies in North America that require coring of masonry walls even after the system compressive strength has been verified and when there is no reason to believe that the masonry walls are not structurally sound.

Looking back at the genesis of building codes, however, provides some insight on the rationale behind coring of masonry walls. The advent of building codes, as we know them today, occurred within the past 100 years with the United States building codes first published in the late 1920's. Shortly thereafter, the Federal Government of Canada published the first National Building Code in 1941.

During this period, along comes the Long Beach, California Earthquake. This March 10, 1933 earthquake, with a Moment Magnitude 6.3, was not huge, but it did register as VIII on the Modified Mercalli scale, with widespread damage and significant building collapse. [1]

Figure 1: Jefferson Junior High School, Long Beach, California

Damage to schools was substantial with 300 schools experiencing minor damage, 120 schools with major damage, and 70 schools were entirely destroyed as depicted in Figure 1. If not for the event occurring at 5:55PM on a Friday evening, the loss of life would have been devastating. It was reported that there were more than 120 fatalities. [1]

Considering that these school buildings were predominately unreinforced brick, the widespread damage is not surprising. Within weeks, California adopted Assembly Bill 2342, which is known as the Field Act after Assemblyman Charles Field. The Field Act established stringent building code and regulatory procedures to assure that school buildings were designed and constructed in a manner to safeguard against the catastrophic damage experienced in the Long Beach Earthquake. Measures included mandatory reinforcement of masonry, review of engineered design by the regulatory agency and continuous inspection by a qualified individual.

Drilling holes, or coring, in masonry walls was accepted as a means to verify the quality of the hidden grout, and to determine if there was a bond between the grout and the clay masonry unit. Intuitively, this seems to make sense as the faces of clay masonry walls were made of two separate wythes. A wythe is defined as a continuous vertical section of a wall, one masonry unit in thickness. Traditionally, unreinforced clay masonry wythes were connected by 'headers', or units that physically connected the two clay masonry wythes together.

CODE BACKGROUND

Starting with the 1960 California Administrative Code, Title 21, Article 4, Section 404 (b), [2] the application of coring masonry walls was unquestionably limited to clay brick masonry. Note that the section header is 'Brick Masonry'.

> **"404. General Requirements—Brick Masonry…**
>
> (b) **Core Tests.** Not less than two cores having a diameter of approximately two-thirds of the wall thickness shall be taken from each project. At least one core shall be taken from each building for each four classrooms or equivalent area. The architect or registered engineer in responsible charge of the project or his representative (inspector) shall select the areas for sampling.
>
> One-half of the number of cores taken shall be tested in compression normal to the wall face and one-half shall be tested in shear. The shear loading shall test the joint between the masonry unit and the grout core. The materials and workmanship shall be such that when tested in

compression these cores shall show a strength at least equivalent to that required for the mortar in Table 403(e). When tested in shear the unit shear on the cross section of the core shall not be less than 100 pounds per square inch. Visual examination of the cores shall be made to ascertain if the joints are filled. See Section 707(e) (2) for method of making and testing cores.

The school board inspector or testing agency shall inspect the coring of the masonry walls and shall prepare a report of coring operations for the testing laboratory files and mail one copy to the Division of Architecture. Such reports shall include the total number of cores cut, the location, and the condition of all cores cut on each project regardless of whether or not the core specimens failed during cutting operation. All cores shall be submitted to the laboratory for examination.

History: 1. Amendment file 4-6-60; designated effective 5-16-60 (Register 60, No. 8)."

The requirements did not change until 1971 when the California Administrative Code was reorganized and reformatted. The core testing provision came under Section 2401, Non-Building Regulations. [3] Since the title was no longer specific to brick masonry, the text was modified by adding 'In the case of brick masonry' to keep the application of the shear test provision between the unit and grout unmistakable.

"(d)…In the case of brick masonry one-half of the number of cores taken shall be tested in compression normal to the wall face and one-half shall be tested in shear."

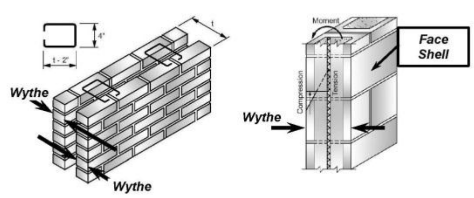


Figure 2: Masonry Wythe as Defined in Code

Language was maintained through several cycles until the 1988 version of the California State Building Code. In 1988, the California enforcement agencies adopted and amended the Uniform Building Code (UBC) resulting in the California Building Code (CBC). There was a subtle, but significant, change of wording in the core testing provision. The term 'width' was replaced with 'wythe'. Wythe is a masonry term, formally defined in the UBC as shown in Figure 2, and, with UBC as a basis for the CBC, 'wythe' was recognized for the first time in the CBC [4], with the stated definition as:

WYTHE is the portion of a wall which is one masonry unit in thickness. A collar joint is not considered a wythe.

With 'wythe' as a defined term, the specific application to 'brick masonry' was removed resulting in the following language: [5]

2405A (c).4.C Masonry Core Tests…One-half of the number of cores taken shall be tested in shear. The shear loading shall test both joints between the grout core and the outside wythes and webs of masonry.

This modified language effectively changed the provision to include both brick and concrete block multi-wythe masonry and specifically did not include structural clay brick and concrete block containing both wall faces manufactured as a single unit. One requirement in the 1988 modification is a shear bond requirement between the web and grout, which was impossible to effectively evaluate. This error was corrected in the subsequent code publication.

The provision remained essentially the same through the 2010 publication of the California Building Code. In 2010, California regulators included a shear bond requirement between face shells and grout departing from 50 years of a clear and justified requirement. Further, there was no rationale provided for the 2010 change.

EXPLOITATION OF CORING

Notwithstanding the code provisions, the practice in California on certain types of projects has been to extract cores from single-wythe concrete masonry walls with the expectation of meeting the shear bond requirements for multi-wythe clay or concrete masonry walls. The history of core provisions shows that shear bond core testing single-wythe walls was never intended. There are other problematic issues.

There is no ASTM or other industry recognized standard for the extraction or testing of masonry cores. This lack of guidance leads to inconsistencies from project to project in both the extraction and testing process. Because there are no industry recognized Standards to follow, some of the observed extraction problems include:

- Misalignment of the coring equipment
- An insufficient amount of water being used during the coring process
- The pressure applied during the coring process, particularly when coring at the grout-to-unit interface
- The manner in which the coring equipment is mounted
- Excessive vibration during the coring process
- Curing time of wall before cores are extracted
- Using excessively worn or out-of-round core bits
- Coring cells that contain reinforcing steel

Additionally, there is no guidance for testing procedures. Laboratories have been known to follow ASTM C42, *Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*, which is totally inappropriate. First, there is no connection between this Standard and masonry core specimens. There are three types of tests cited in ASTM C42, Compression, Splitting Tensile Strength and Flexural Strength. Compressive strength in masonry is verified by other code-required means and Splitting Tensile and Flexural Strength tests do not apply to masonry cores. Most laboratories devise their own means for a guillotine-type device, and given the nature of shearing a round element (wythe) from a round element (the core), the apparatus will vary, thus affecting the test results from laboratory to laboratory.

PERFORMANCE CONSIDERATIONS

There are three basic factors to consider in the performance of masonry walls; compression, flexure and shear.

Masonry cores should never be tested for compression evaluation. Model codes require verification of masonry compressive strength by either the Unit Strength or the Prism Test method. Any compression testing of masonry cores is superfluous. Any attempted test will result in a nonstandard compression value that is perpendicular to the load. Once again, lack of an industry recognized Standard leads to inconsistency and confusion.

Flexure appears to be the driving force behind the development of the shear bond requirement for double-wythe masonry systems. Until the 1988 UBC and CBC, double-wythe walls could be low-lift grouted without the use of wall ties. Without bond between the grout and wythes, flexure could cause the three elements (brick wythe / grout / brick wythe) to act independently, with masonry units individually or collectively falling away from the wall system.

When considering in-plane shear, a broad assumption would be that there is some bond between the masonry wythes and grout in a double-wythe system; however current Building Codes assume that hollow unit (single-wythe) solidly grouted masonry acts as a homogeneous system, even if there is marginal bond between the grout and face shells. [6, 7]

CORE TESTING PROGRAM

A compelling conclusion is that a shear bond test between grout and face shells in single-wythe masonry was never intended. Notwithstanding, the practice has been to core and test hollow unit single-wythe masonry walls for shear bond between grout and face shells. Research studies performed on the grout bond to the masonry face shell indicate that shear bond values are inconsistent. [8, 9]

One such test program was to determine the influence of different masonry units and varying grout mixes on the bond of grout to the hollow concrete masonry unit face shell. The test program required the construction of masonry sample panels similar to those found in the field. Grout was placed, consolidated and cured in a manner consistent with field practices; then cored by traditional means. Specimens were tested in the laboratory and test results were reported. There was an effort to minimize variables in the system, such as plasticizers, that replace water in grout.

Twenty four concrete masonry panels were constructed on July 20, 2011. A summary of the CMU materials, including various properties of block used is listed in Table 1. Included in the table is an indication of Concrete Masonry Units manufactured with an Integral Water Repellent (IWR).

Table 1: Concrete Masonry Unit (CMU) Properties

Panel	Supplier	Plant	Size/Type	Color	Finish	Weight	IWR	Strength
1-8	Angelus[10]	Fontana, CA	8x8x16 OE BB VS	Tan	S/1/S	Med	Y	1,900
9-16	Angelus	Fontana, CA	8x8x16 OE BB	Grey	Precision	Med	N	1,900
17-24	Angelus	Ventura, CA	8x8x16 OE BB	Grey	Precision	Med	Y	2,800

Mortar used for this test program was Pre-Mixed Type S mortar supplied by EZ Mix, Rialto, California. No integral water repellent admixture was added to the mortar.

PANEL CONSTRUCTION

Panels were constructed in a stack bond configuration, 2 units in length, 6 or 7 courses (40 or 48 in.) in height. Bond beams were used to aid horizontal grout flow and the bond beam opening of the units at panel ends were mortared to confine grout. Reinforcement, which would have interfered with the core location selection, was not used in the panels. After construction, the panels were cured for 5 days before grouting. Figure 3 shows the panels prior to grouting.

GROUTING

All walls were grouted on the same day. Five different mix designs were batched rendering a variety of grout combinations. All grout was batched and transported to the test site using ready-mix concrete trucks. Table 2 provides the grout mix designs. Batches 1 through 4 were used to grout four panels each, two with grout aid (an admixture that creates expansion of the grout during initial curing) and two without grout aid. Batch 5 was used to grout panels 17 through 24; a total of 8 panels. Grout aid was added to the grout for half of the 8 panels.

Figure 3: Masonry panels prior to grouting (bond beams mortared to restrict grout)

Prior to discharge, grout slump was measured and trim water was added as necessary to bring the slump to a code consistent 255 to 280 mm (10 to 11 in.). Slump was also measured after the addition of grout aid to verify a grout slump of 205 to 280 mm (8 to 11 in.).

Some mix designs allowed for entrapped air of up to 3%. The air content was measured for all loads of grout and ranged between 0.1% and 1.0% with one exception that measured at 1.9%.

Table 2-Grout Mix Designs

	Supplier				
	Robertson	**CSM #1**	**CSM #2**	**Holliday**	**National**
Design #	**04SE8673**	**1169-11**	**1172-11**	**HRC06018**	**S70240**
Plant / **Material**	Pomona	Cucamonga	Cucamonga	Upland	Irwindale
Cement	611 lb	583 lb	667 lb	592 lb	658 lb
Cement Eq.	6.5 sk	6.2 sk	7.1 sk	6.3 sk	7.0 sk
Fly Ash	---	---	---	---	---
Sand	1771 lb	1861 lb	1811 lb	1869 lb	1927 lb
3/8 Gravel	965 lb	801 lb	779 lb	921 lb	829 lb
Water (lb)	449.8 lb	450 lb	450 lb	408 lb	416.5 lb
Water (gal)	54 gal	54 gal	54 gal	49 gal	50 gal

Figure 4: Bucketing Grout into Sample Panel

Two ICC Certified Structural Masonry Inspectors were present during the preparation of test panels and performed slump and air content tests, cast grout and prism samples and observed placement and consolidation of grout.

Grout was transported by wheelbarrow from the ready mix truck and buckets were used to grout the test panels as shown in Figure 4.

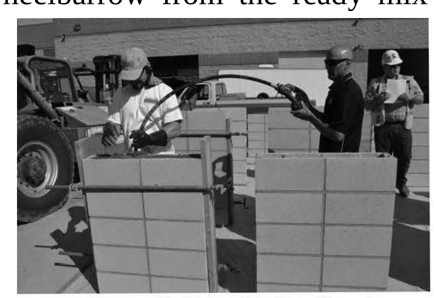


Figure 5: Consolidating Grout

Prior to grout placement, wooden boards were clamped to the ends of the test panels to keep the hydrostatic pressure of the grout from blowing out the mortar infill of bond beams at the ends of the sample panels.

Grout was mechanically consolidated and reconsolidated as shown in Figure 5 using a battery powered vibrator designed for consolidation of masonry grout. Reconsolidation was performed shortly after the initial consolidation and prior to the grout taking a plastic set. Due to ambient temperature, the time between consolidation and reconsolidation was relatively short.

Every effort was made to replicate actual field conditions, including using bricklayers from the staff of an established masonry contractor, using the same equipment that would be used on a similar project, and allowing the wall to cure in ambient field conditions, unprotected from the existing weather conditions.

CORING

Core specimens were extracted at 7, 14 and 28 days. Cores were drilled using two MK Diamond Manta IV coring machines that were bolted to the composite sample panels. Factory new core bits were used. One core bit was a 100 mm (4 in.) diameter and one core bit was a 95 mm (3.75 in.) diameter. The bits produced cores of 99.8 mm (3.93 in.) and 93.7 mm (3.67 in.) diameter specimens. Workers performing the coring operation were instructed to randomly select the location of each core and core various panel locations without concentrating on any specific area of the panel.

The specimens were immediately identified and within 24 hours the specimens were transported to Smith-Emery Laboratories in Los Angeles. The laboratory reported curing specimens in accordance with ASTM C31 between time of receipt and testing.

The following table summarizes core test results for 134 core specimens extracted and tested.

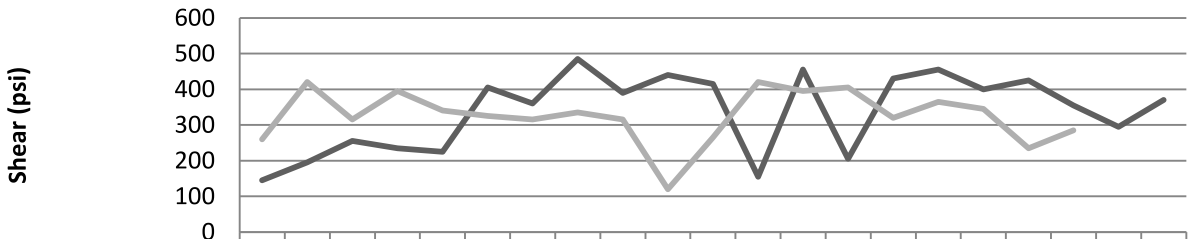
Table 3: Compilation of Core Test Results as Reported by Smith-Emery Laboratories

Core #	Date		Shear, psi				Core #	Date		Shear. Psi		
	Cored	Tested	Side 1	Side 2	Average			Cored	Tested	Side 1	Side 2	Average
1A	01-Aug-11	10-Aug-11	290	0	145		2A	01-Aug-11	10-Aug-11	190	200	195
1B	10-Aug-11	15-Aug-11	180	0	90		2B	10-Aug-11	15-Aug-11	130	0	65
1C	10-Aug-11	15-Aug-11	130	130	130		2C	10-Aug-11	15-Aug-11	180	300	240
1D	23-Aug-11	29-Aug-11	90	320	205		2D	23-Aug-11	29-Aug-11	220	70	145
1E	23-Aug-11	29-Aug-11	280	250	265		2E	23-Aug-11	29-Aug-11	30	370	200
		PANEL AVERAGE			**167**				**PANEL AVERAGE**			**169**
3A	28-Jul-11	29-Jul-11	200	310	255		4A	01-Aug-11	10-Aug-11	280	190	235
3D	10-Aug-11	15-Aug-11	340	380	360		4B	10-Aug-11	15-Aug-11	140	0	70
3E	10-Aug-11	15-Aug-11	340	280	310		4C	10-Aug-11	15-Aug-11	260	270	265
3F	23-Aug-11	29-Aug-11	210	0	105		4D	23-Aug-11	29-Aug-11	270	0	135
3G	23-Aug-11	29-Aug-11	300	290	295		4E	23-Aug-11	29-Aug-11	230	160	195
		PANEL AVERAGE			**265**				**PANEL AVERAGE**			**180**
5A	01-Aug-11	10-Aug-11	240	280	260		6A	01-Aug-11	10-Aug-11	430	410	420
5B	10-Aug-11	15-Aug-11	280	270	275		6B	10-Aug-11	15-Aug-11	280	360	320
5C	10-Aug-11	15-Aug-11	330	370	350		6C	10-Aug-11	15-Aug-11	330	400	365
5D	23-Aug-11	29-Aug-11	350	310	330		6D	23-Aug-11	29-Aug-11	160	300	230
5E	23-Aug-11	29-Aug-11	290	380	335		6E	23-Aug-11	29-Aug-11	350	410	380
		PANEL AVERAGE			**310**				**PANEL AVERAGE**			**343**
7B	10-Aug-11	15-Aug-11	200	300	250		8A	01-Aug-11	10-Aug-11	290	340	315
7C	10-Aug-11	15-Aug-11	390	290	340		8B	10-Aug-11	15-Aug-11	180	0	90
7D	23-Aug-11	29-Aug-11	480	410	445		8C	10-Aug-11	15-Aug-11	210	240	225
7E	23-Aug-11	29-Aug-11	350	290	320		8D	23-Aug-11	29-Aug-11	200	260	230
							8E	23-Aug-11	29-Aug-11	260	300	280
		PANEL AVERAGE			**339**				**PANEL AVERAGE**			**228**

Table 3 (Continued): Compilation of Core Test Results as Reported by Smith-Emery Laboratories

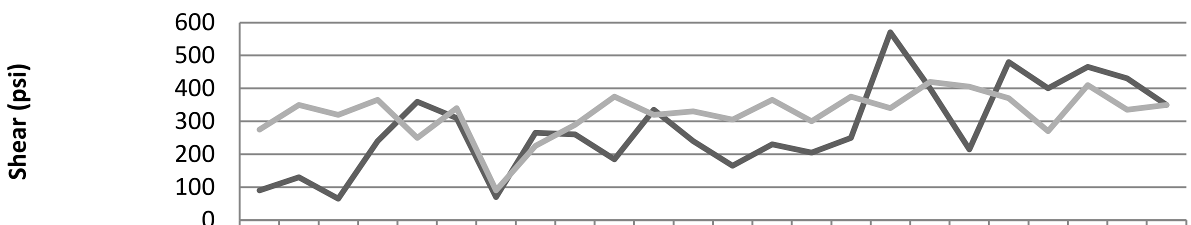
Core #	Date		Shear, psi				Core #	Date		Shear. Psi		
9A	01-Aug-11	10-Aug-11	450	0	225		10A	01-Aug-11	10-Aug-11	400	320	360
9B	01-Aug-11	10-Aug-11	450	360	405		10B	01-Aug-11	10-Aug-11	540	430	485
9C	10-Aug-11	15-Aug-11	320	200	260		10C	10-Aug-11	15-Aug-11	300	370	335
9D	10-Aug-11	15-Aug-11	0	370	185		10D	10-Aug-11	15-Aug-11	250	230	240
9E	23-Aug-11	29-Aug-11	320	330	325		10E	23-Aug-11	29-Aug-11	320	270	295
9F	23-Aug-11	29-Aug-11	260	270	265		10F	23-Aug-11	29-Aug-11	290	300	295
		PANEL AVERAGE			**288**				**PANEL AVERAGE**			**335**
11A	01-Aug-11	10-Aug-11	430	350	390		12A	01-Aug-11	10-Aug-11	420	410	405
11B	01-Aug-11	10-Aug-11	440	440	440		12B	01-Aug-11	10-Aug-11	310	0	155
11C	10-Aug-11	15-Aug-11	330	0	165		12C	10-Aug-11	15-Aug-11	240	170	205
11D	10-Aug-11	15-Aug-11	220	240	230		12D	10-Aug-11	15-Aug-11	220	280	250
11E	23-Aug-11	29-Aug-11	310	0	155		12E	23-Aug-11	29-Aug-11	260	320	290
11F	23-Aug-11	29-Aug-11	250	280	265		12F	23-Aug-11	29-Aug-11	320	280	300
		PANEL AVERAGE			**274**				**PANEL AVERAGE**			**269**
13A	01-Aug-11	10-Aug-11	390	400	395		14A	01-Aug-11	10-Aug-11	270	380	325
13B	01-Aug-11	10-Aug-11	350	330	340		14B	01-Aug-11	10-Aug-11	310	320	315
13C	10-Aug-11	15-Aug-11	240	340	290		14C	10-Aug-11	15-Aug-11	330	310	320
13D	10-Aug-11	15-Aug-11	390	360	375		14D	10-Aug-11	15-Aug-11	300	360	330
13E	23-Aug-11	29-Aug-11	200	340	270		14E	23-Aug-11	29-Aug-11	360	270	315
13F	23-Aug-11	29-Aug-11	320	280	300		14F	23-Aug-11	29-Aug-11	250	270	260
		PANEL AVERAGE			**328**				**PANEL AVERAGE**			**311**
15A	01-Aug-11	10-Aug-11	370	300	335		16A	01-Aug-11	10-Aug-11	240	0	120
15B	01-Aug-11	10-Aug-11	320	310	315		16B	01-Aug-11	10-Aug-11	260	270	265
15C	10-Aug-11	15-Aug-11	320	290	305		16C	10-Aug-11	15-Aug-11	360	240	300
15D	10-Aug-11	15-Aug-11	350	380	365		16D	10-Aug-11	15-Aug-11	340	410	375
15E	23-Aug-11	29-Aug-11	330	370	350		16E	23-Aug-11	29-Aug-11	570	310	440
15F	23-Aug-11	29-Aug-11	290	290	290		16F	23-Aug-11	29-Aug-11	450	400	425
		PANEL AVERAGE			**327**				**PANEL AVERAGE**			**321**
17A	01-Aug-11	10-Aug-11	400	440	420		18A	01-Aug-11	10-Aug-11	430	380	405
17B	01-Aug-11	10-Aug-11	370	420	395		18B	01-Aug-11	10-Aug-11	270	370	320
17C	10-Aug-11	15-Aug-11	310	370	340		18C	10-Aug-11	15-Aug-11	430	380	405
17D	10-Aug-11	15-Aug-11	410	430	420		18D	10-Aug-11	15-Aug-11	370	370	370
17E	23-Aug-11	29-Aug-11	390	520	455		18E	23-Aug-11	29-Aug-11	350	310	330
17F	23-Aug-11	29-Aug-11	390	470	430		18F	23-Aug-11	29-Aug-11	370	360	365
		PANEL AVERAGE			**410**				**PANEL AVERAGE**			**366**
19A	01-Aug-11	10-Aug-11	410	500	455		20A	01-Aug-11	10-Aug-11	390	470	430
19B	01-Aug-11	10-Aug-11	410	0	205		20B	01-Aug-11	10-Aug-11	470	440	455
19C	10-Aug-11	15-Aug-11	650	490	570		20C	10-Aug-11	15-Aug-11	400	30	215
19D	10-Aug-11	15-Aug-11	370	430	400		20D	10-Aug-11	15-Aug-11	420	540	480
19E	23-Aug-11	29-Aug-11	450	400	425		20E	23-Aug-11	29-Aug-11	400	0	200
19F	23-Aug-11	29-Aug-11	380	400	390		20F	23-Aug-11	29-Aug-11	360	470	415
		PANEL AVERAGE			**408**				**PANEL AVERAGE**			**366**
21A	01-Aug-11	10-Aug-11	300	430	365		22A	01-Aug-11	10-Aug-11	260	210	235
21B	01-Aug-11	10-Aug-11	370	320	345		22B	01-Aug-11	10-Aug-11	320	250	285
21C	10-Aug-11	15-Aug-11	250	290	270		22C	10-Aug-11	15-Aug-11	340	330	335
21D	10-Aug-11	15-Aug-11	450	370	410		22D	10-Aug-11	15-Aug-11	320	380	350
21E	23-Aug-11	29-Aug-11	400	380	390		22E	23-Aug-11	29-Aug-11	520	380	450
21F	23-Aug-11	29-Aug-11	520	380	450		22F	23-Aug-11	29-Aug-11	400	360	380
		PANEL AVERAGE			**372**				**PANEL AVERAGE**			**339**
23A	01-Aug-11	10-Aug-11	450	350	400		24A	28-Jul-11	29-Jul-11	320	390	355
23B	01-Aug-11	10-Aug-11	430	420	425		24B	01-Aug-11	10-Aug-11	350	240	295
23C	10-Aug-11	15-Aug-11	390	410	400		24C	01-Aug-11	10-Aug-11	370	370	370
23D	10-Aug-11	15-Aug-11	450	480	465		24D	10-Aug-11	15-Aug-11	420	440	430
23E	23-Aug-11	29-Aug-11	370	410	390		24E	10-Aug-11	15-Aug-11	330	370	350
23F	23-Aug-11	29-Aug-11	370	540	455		24F	23-Aug-11	29-Aug-11	400	370	385
							24G	23-Aug-11	29-Aug-11	370	370	355
		PANEL AVERAGE			**423**				**PANEL AVERAGE**			**363**

The above results were analyzed and graphically sorted by core age, Figures 6 through 8. Although the shear values vary significantly, results show that the vast majority of shear values exceed the minimum requirement of the California Building Code. The value required by CBC Section 2114.9.3 or 2104A.4 is a shear bond equal or exceeding $2.5\sqrt{f'_m}$ psi, which correlates to 0.67 MPa (97 psi) when the f'_m is 10.3 MPa (1,500 psi). For sample panels 17 through 24, the f'_m was 14.5 MPa (2,100 psi) which requires a minimum shear bond value requirement of 0.79 MPa (115 psi).



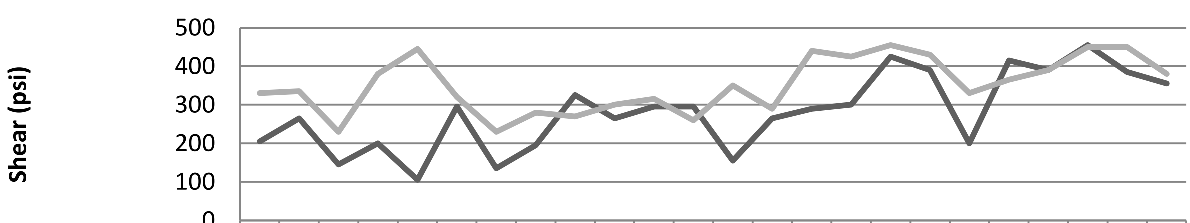
Specimen	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Without Grout Aid	145	195	255	235	225	405	360	485	390	440	415	155	455	205	430	455	400	425	355	295	370
With Grout Aid	260	420	315	395	340	325	315	335	315	120	265	420	395	405	320	365	345	235	285		

Figure 6: 7-Day Core Shear Test Results



Specimen	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Without Grout Aid	90	130	65	240	360	310	70	265	260	185	335	240	165	230	205	250	570	400	215	480	400	465	430	350
With Grout Aid	275	350	320	365	250	340	90	225	290	375	320	330	305	365	300	375	340	420	405	370	270	410	335	350

Figure 7: 14-Day Core Shear Test Results



Specimen	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Without Grout Aid	205	265	145	200	105	295	135	195	325	265	295	295	155	265	290	300	425	390	200	415	390	455	385	355
With Grout Aid	330	335	230	380	445	320	230	280	270	300	315	260	350	290	440	425	455	430	330	365	390	450	450	380

Figure 8: 28-Day Core Shear Test Results

Although grout aid is an expansive agent, the test results indicate that the presence of grout aid had very little effect on the shear bond between grout and masonry face shells.

The data was also sorted by grout supplier, Figure 9, to see if there was any significant difference. Nearly all results were above 0.69 MPa (100 psi) with a significant majority above the 1.38 MPa (200 psi) level. Four of the five grout suppliers had similar results; however National Ready Mix had all results at or above 1.38 MPa (200 psi) shear value. Additionally, there were 48 core specimens representing National Ready Mix and of 96 face shells, 3 separated for a successful test rate of 97%.

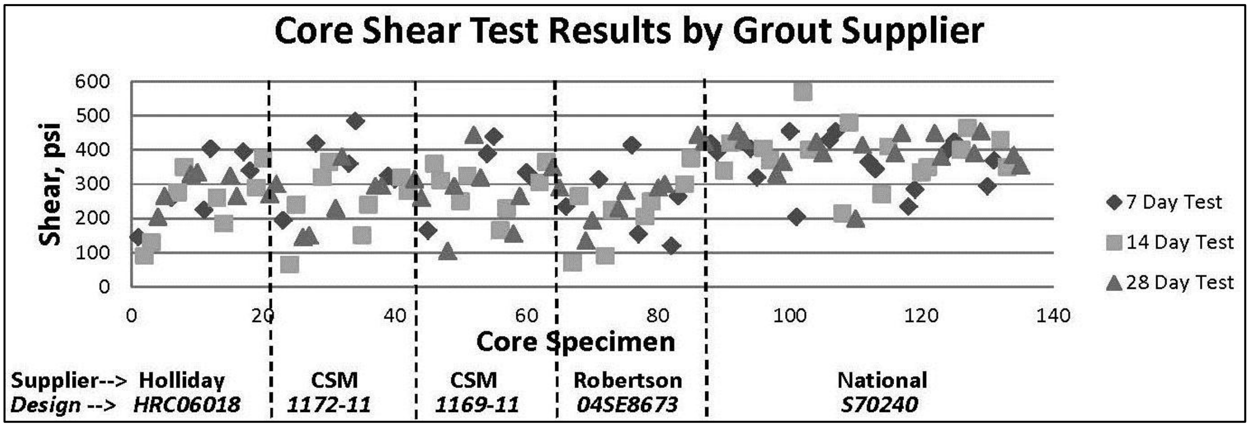


Figure 9: Core Shear Test Results by Grout Supplier

CONCLUSION

Values of shear test results (excluding separations) range from 0.20 MPa (30 psi) to 4.48 MPa (650 psi). Of the 134 cores (268 potential test occurrences) 4 interfaces tested below 0.69 MPa (100 psi) and 6 interfaces tested above 3.45 MPa (500 psi). The manner in which panels were constructed, grouted and tested was consistent and a smaller range of variation within similar materials, especially grout mix designs, was anticipated. The grout was generally homogeneous and cracking observed in the grout was minimal.

Further complicating the test program is no ASTM or other standard to follow in the preparation, handling and testing of masonry grout core specimens. Even though this test program used the same personnel for constructing and grouting the test panels and the same laboratory and lab personnel to test the specimens, results varied widely. Using multiple testing laboratories would likely have provided shear test results with even greater variation.

RECOMMENDATION

The genesis of core testing requirements is clearly a result of the double-wythe brick masonry construction which was popular for school construction in the 1950's and 1960's. Today multi-wythe brick construction is costly, labor intensive and rarely used in modern school and hospital construction. Single-wythe hollow unit masonry is more cost efficient and structurally predictable. Single-wythe hollow unit masonry attaches opposite face shells using webs cast as a single unit and grout bond is not required to keep the face shells from separating from the wall in a seismic event. This test program shows that interface shear values range from about 0.69 MPa (100 psi) to nearly 4.14 MPa (600 psi) indicating little consistency in anticipated results. Such a wide range of values makes the core shear bond requirement for single-wythe masonry wall systems meaningless. Those preparing California Building Codes and Regulations through 2007 understood that there should be no code requirement for a shear bond between grout and hollow unit masonry face shells.

Considering a hypothetical case of an interface failure between grout and units, shear would still be transferred between grout cores and surrounding units by the splay (angle) of the insides of the units in one direction, and by arching of grout against the bed joints of the units in the other direction. Analysis of this condition and calculation of shear demand (if any) between the grout and face shell will further support eliminating this shear bond requirement in single-wythe masonry.

Code Enforcement Agencies continue to be properly concerned about the condition of grout within the masonry wall. Rather than using the coring process as an acceptable threshold for shear interface value between the grout and masonry unit for hollow unit masonry, the coring process should be used by the structural engineer to evaluate that masonry grout has been properly placed. Masonry walls are designed assuming a homogeneous system from face of wall to face of wall without a provision that grout be bonded to the face shell.

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