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THE EFFECTS OF CONCRETE MASONRY UNIT MOISTURE CONTENT ON GROUT BOND AND GROUT COMPRESSIVE STRENGTH

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ABSTRACT

This research study was performed to address questions from masonry inspectors about whether grouting operations should be permitted when concrete masonry walls are wet. The magnitude of bond developed between grout and concrete masonry units as well as the compressive strength of the grout was determined for concrete masonry units grouted at moisture contents of 30, 50, 70, and 90% moisture contents (expressed as percent of total absorption). Bond strengths were determined using a guillotine shear test as required by the California Building Code[2]. The research showed that the moisture content of CMU's at the time of grouting has little effect on grout bond strength and grout compressive strength. It is believed that the hydrostatic head pressure is sufficient to drive free water from the grout into the concrete masonry units, regardless of the moisture content at the time of grouting.

Keywords: bond, bond strength, concrete masonry, compressive strength, guillotine, grout, inspection, shear

INTRODUCTION

Background

During construction, the moisture content of concrete masonry units varies depending on the conditions to which the units are exposed. In some cases, moisture within the units will be visible following exposure to rain or other sources of water. Masonry inspectors have occasionally not permitted grouting operations to be performed when the walls are in this condition.

Masonry grout is mixed and placed with a high water to cement ratio so the grout will have adequate fluidity to flow into small confined spaces in masonry walls. Fresh grout transfers free water into the concrete masonry units so that the final water to cement ratio is in the range necessary to permit proper strength development of the grout. The presence of moisture in the concrete masonry units has previously been conjectured by some to adversely affect the absorptive characteristics of the units thus limiting the rate of water migration from the grout into the units and thereby reducing the strength of the grout.

Concerns have also been raised that the reduced flow of water from the grout into the units will prevent the grout from properly bonding with the concrete masonry units. Conventional reinforced concrete masonry design assumes that adequate bond is developed between these two materials to permit shear transfer between the units and the grout.

It is difficult to document the adequacy of the bond strengths developed in the field between grout and units since no standard consensus test method is published by organizations such as the American Society of Testing and Materials (ASTM). Moreover none of the major model building codes include minimum bond strength requirements. The California Building Code[2] however requires that at least one core be taken for every 5,000 square feet (465 m^2) of construction and that half of these cores be tested in shear. Tested grout bond shear strengths of these cores must exceed $2.5\sqrt{f'_m}$.

Purpose

The purpose of this study was to document the effect of concrete masonry unit moisture content on the magnitude of bond developed between masonry grout and the unit itself as well as its effect on the compressive strength of the grout.

Based on the results of this research, recommendations were made for concrete masonry construction practices. Masonry inspectors will be able to use the results of this research to make informed decisions about grouting operations.

Scope

While there are a variety of parameters that can influence the magnitude of bond that is developed between masonry grout and concrete masonry units, the purpose of this research was to evaluate the effects of unit moisture content. Therefore, the scope was limited to permit that evaluation and included the use of:

- one set of concrete masonry units manufactured within the same run by a single manufacturer
- one grout mix design using a single initial water to cement ratio
- four concrete masonry unit moisture contents: 30, 50, 70, and 90% of total absorption

Eighteen cores were drilled from grouted masonry piers constructed with units of each of these four different unit moisture contents. From each core, two tests could be performed to measure the magnitude of bond developed between the grout and the faceshell of the unit. Therefore, a total of 36 tests were performed for each of the four unit moisture contents, resulting in 144 bond tests for this research study. Grout bond strengths were measured using a guillotine shear test method consistent with that required by the California Building Code[2].

A total of six grout compression specimens were also sawn from piers constructed with units at each of the four unit moisture contents (24 grout compression specimens in all). While these specimens were saw cut rather than mold formed, they were tested in compression in accordance with ASTM C 1019, *Sampling and Testing Grout*[1]. The properties of the concrete masonry units used were also determined using ASTM C 140, *Sampling and Testing Concrete Masonry Units*[1].

MATERIALS

The nominal dimensions of the hollow concrete masonry units were 8 × 8 × 16 in. (203 × 203 × 406 mm). These units had square corners on both ends and two symmetrical square cores. In comparison to the average surface texture of those units manufactured by different producers using different mix designs, the laboratory considered the surface texture of these units to be "moderately rough". No test methods were employed to quantify the degree of roughness. The units were determined to have the following unit properties: Oven-dry density = 115.7 pcf (1854 kg/m^3); Absorption = 11.7 pcf (187 kg/m^3); Net compressive strength = 2560 psi (17.7 MPa).

Coarse grout was proportioned by volume using 1: 4.8 : 3.2 (portland cement, fine aggregate, coarse aggregate) material ratios. These proportions were selected to yield a grout compressive strength that was as close as possible to the minimum strength permitted by ASTM C 476, *Grout for Masonry*[1], which is 2000 psi (13.8 MPa). Although the grout batch sizes did not permit the fabrication of grout compressive strength specimens in accordance with ASTM C 1019, strength tests were performed on 3.5 x 3.5 x 7 in. (89 x 89 x 178 mm) specimens saw-cut from the bottom course of the grouted piers. The average strength of these specimens was 1990 psi (13.7 MPa). The grout was mixed within the laboratory using a rolling drum type concrete mixer. Water was added to the grout as necessary to achieve a slump of 9.5 to 10 inches (241 to 245 mm) when determined in accordance with ASTM C 143, *Slump of Hydraulic Cement Concrete*[1].

PIER CONSTRUCTION AND SPECIMEN SAMPLING

Sixty concrete masonry units were immersed in water for a period of not less than 24 hours. Four sets of fifteen units were removed from the water at four different intervals and the saturated weight of each unit was recorded. Each set of fifteen units was allowed to air dry in the laboratory. The removal times were determined based on the estimated amount of time required for each set of units to air dry to their specified target moisture content (30, 50, 70, and 90%). The intent was for each set to reach their own target moisture content at the same time.

Preliminary tests were performed on additional units from the same batch to determine the relationship between the initial received weight of the units, the saturated weight of the units and the oven-dry weight of the units. These relationships permitted calculated estimates for the oven-dry weight of every unit so that the unit's used moisture content could be estimated within ± 3% at any time.

Once the units reached their target moisture, three piers were constructed for each of the four unit moisture contents (12 piers total). Each pier consisted of 5 units laid in stack bond. The piers were constructed without mortar, but rope caulk was placed between each unit to prevent water loss or grout seepage between the unit interfaces during grouting. All piers were grouted within 1 hour of pier fabrication. The grout was placed using buckets and hand scoops. Each pier was filled in one lift. The grout in the piers was then consolidated using a 1-in. (25 mm) diameter mechanical vibrator and was reconsolidated after approximately 10 minutes.

Once the piers were grouted, they were stored in laboratory air for a period of approximately 28 days. Following the curing period, each grout pier was lifted and rotated to a horizontal position. A water-cooled, diamond-tipped core drill with a 6-in. (152 mm) outside diameter and 5.75 in (146 mm). inside diameter was used to remove cores from the piers. As shown in Figure 1, two cores were taken from each unit in the pier with the exception of the top unit and the bottom unit, resulting in 6 cores per pier and 18 cores per each unit moisture content. Once the cores were removed, they were allowed to air dry in the laboratory for a period of approximately one week prior to testing.

The resulting height of the sampled core was equal to the width of the concrete masonry units in the pier (7.60 in., 193 mm). The top and bottom of the cores were made up of the faceshell of the concrete masonry units (approximately 1.25 in., 32 mm, each) while the remaining middle portion of the cores were comprised of the grout fill.

Two compressive strength specimens were also saw-cut from the bottom unit of each of 12 piers (24 specimens total) using a water-cooled, diamond-tipped masonry table saw. Each specimen had a cross-section of 3.5 x 3.5 in. (89 x 89 mm) and a height of 7 in. (178 mm).

TEST PROCEDURES

Each core was placed in a guillotine-type test apparatus (Figures 2 and 3). The base of the device firmly supported the grout portion of the core while the faceshell of the concrete masonry unit cantilevered out from the support. Each specimen was clamped tightly in two locations to the lower platform assembly to prevent rotation and tipping of the core during testing. A thin piece of neoprene was placed across the top circumference area of the faceshell portion of the core to assist in distributing loads during testing. The upper platform was then placed on top of the specimen and into the guides in the lower platform such that the radial surface of the upper platform bore only on the cantilevered concrete masonry faceshell.

The apparatus was placed into a compression machine (Figure 4) having a spherically seated head. A downward vertical force was applied to the unit faceshell creating a shearing force along the interface of the grout and the concrete masonry unit. A free-body diagram of the forces acting on the core specimen is shown in Figure 5.

The maximum force required to exceed the grout bond capacity was recorded and the failure mode observed. Once one faceshell of the core specimen was tested, the clamping devices were removed, the core was rotated and testing was performed on the other unit faceshell.

TEST RESULTS AND OBSERVATIONS

The guillotine shear test results are included in Table 1 and the average bond strength for each unit moisture content is shown in Figure 6 along with plus and minus 1 standard deviation error bars. Figure 5 also shows the 1995 California Building Code[2] required minimum grout bond strength (for an assumed specified masonry strength, f'_m , of 1900 psi, 13.1 MPa based on a unit strength of 2560 psi 17.7 MPa) which is determined by 2.5 times the square root of f'_m.

Five different failure modes were observed in the tested specimens:

1) Grout Shear/Interface Shear: The failure surface included both a bond failure at the interface of the unit and the grout as well as a grout shear failure.
2) Interface Shear: The specimen failed at the interface between the grout and the unit. Little damage was observed to the unit at the grout surface.
3) Grout Shear: The applied shear force resulted in a failure plane through the body of the grout. The failure plane was typically parallel to and within 0.5 in. (13 mm) of the unit/grout interface.
4) Unit Shear: The applied shear force resulted in a failure plane through the faceshell of the unit. The failure plane was typically parallel to and within 0.5 in. (13 mm) from the unit/grout interface.
5) Tensile Splitting: This mode of failure was observed only in the first 8 cores tested (all from the No. 2 unit of the "A" pier of each set of specimens). It was determined that this mode of failure was a result of an irregularity in the bearing surface of the upper platform of the guillotine test apparatus that resulted in point loading in the unit faceshell on the top of the core as tested. This point load is believed to have caused splitting forces in the faceshell of the unit that then propagated through the core specimen. Following testing of these cores, the testing apparatus was modified and this mode of failure was not observed again in the testing of the remaining 64 cores. The test results were reviewed to determine whether the tests of these first eight cores should be removed from consideration in any subsequent evaluation of the data. However the maximum shear stress recorded for these specimens were consistent with other values recorded for specimens from the same set and removal of these values from consideration did not change any conclusions drawn. Therefore, these values are included in all data analyses included in this report.

The compressive strengths of the specimens saw cut from the grout in the base unit of each pier are summarized in Table 2

Observations of the test results include:

1) The range of possible moisture contents in concrete masonry units was shown to have some effect on the bond developed between grout and the unit. However, despite a wide range in unit moistures evaluated, from 36% to 91%, the tested bond strengths were within 15% of each other.
2) The highest grout bond strengths were from specimens constructed with units at intermediate moisture contents (50 and 70%).
3) Bond interface failures were characteristic of the lower tested strengths. As bond improved, there was increased likelihood of the occurrence of other failure modes. The specimens constructed with units at 90% moisture content had the highest frequency of bond interface failures (44.4%) and also had the lowest average maximum stress (255 psi, 1.8 MPa). The specimens constructed with units at 30% moisture content had the second highest frequency of bond failures (27.8%) and also had the second height average maximum stress (277 psi, 1.9 MPa).

4) A significant difference was observed in the tested strengths of cores taken from different courses in the pier (Figure 7). For all four moisture contents, the highest tested strengths were observed in the cores taken from the lowest units in the pier. The effect of pier position (distance from top of grout pour) was greatest on the specimens constructed with units at 90% moisture content.
5) The higher tested shear strengths in cores taken from specimens constructed with 50% and 70% moisture contents were achieved despite the fact that these units were filled with grout having compressive strengths less than the grout in the 30% and 90% moisture content specimens and less than the 2000 psi (13.8 MPa) minimum requirement of ASTM C 476.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, the following conclusions and recommendations can be drawn:

1) Concrete masonry unit moisture content does not have a significant influence on the magnitude of bond developed between grout and concrete masonry units or on the compressive strength of the grout.
2) The height of the grout pour does influence grout bond strength. The hydraulic head pressure of the grout thus appears to be a significant contributor to grout bond strength development. This effect is more evident for very wet units (90% moisture content).
3) The results of the research suggest that no limitations should be imposed on grouting operations of concrete masonry walls based on the moisture content of the units.

While these tests were conducted using only one set of variables for concrete masonry unit mix design and configuration and only one grout mix and consolidation method, the conclusions noted above are believed to apply to other combinations of variables as well. The hydraulic head pressure from the column of grout would be consistent for other combinations of variables not included in this text program. It is this head pressure that is considered to be the driving force of moisture from the grout into the concrete masonry units.

It should be noted that despite using the minimum permissible grout strengths (which at 2000 psi, 13.8 MPa, is much weaker than most field grout mixes), tested grout bond strengths greatly exceeded required limits from the 1995 California Building Code[2]. For the compressive strengths of the concrete masonry units and grout strengths used, the masonry strength would have likely just exceeded f'_m values of 1900 psi (13.1 MPa). Using this specified masonry strength in the 1995 California Building Code[2] grout bond shear strength equation of 2.5 $\sqrt{f'_m}$ results in a minimum requirement of approximately 100 psi (0.7 MPa). For the worst case scenario tested (specimens having 90% moisture content units, minimum grout strengths, and an average distance to the top of the grout pour of 12 in., 305 mm), the grout bond strengths were more than 60% greater than that required. For all other tested variables, bond strengths averaged more than 125% greater than that required.

In the laboratory setting used for this research, the environment for sampling, transporting, and testing the grout cores was more ideal than typical field methods. These laboratory results demonstrate the bond development capabilities for grouted concrete masonry. Additional work should be performed on field sampling methods to be sure that these methods do not damage the specimens and result in an incorrect assessment of the actual condition of the wall.

REFERENCES

[1] *1997 Annual Book of ASTM Standards*, Volumes 4.02 and 4.05. American Society for Testing and Materials. West Conshohocken, Pennsylvania, 1997.

[2] *1995 California Building Code*, Volume 2. International Conference of Building Officials. Whittier, California, 1995.

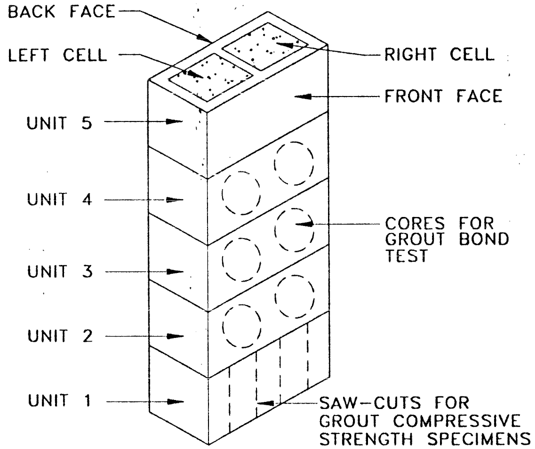

Figure 1: Locations of six grout bond cores and two compressive strength specimens sampled from each grouted pier

Table 1: Summary of Guillotine Shear Test Results

	Target Unit Moisture Content											
	30%			50%			70%			90%		
Test Ref. No.	Actual Unit Moisture Content, %	Bond Shear Stress, psi (MPa)	Failure Mode	Actual Unit Moisture Content %	Bond Shear Stress psi (MPa)	Failure Mode	Actual Unit Moisture Content %	Bond Shear Stress psi (MPa)	Failure Mode	Actual Unit Moisture Content %	Bond Shear Stress psi (MPa)	Failure Mode
A-2LF	36.4	399 (2.8)	1	57.5	415 (2.9)	5	73.4	290 (2.0)	2	92.0	341 (2.4)	5
A-2LB		379 (2.6)	5		326 (2.3)	5		289 (2.0)	1		329 (2.3)	5
A-2RF		205 (1.4)	3		428 (3.0)	5		449 (3.1)	5		345 (2.4)	5
A-2RB		376 (2.6)	5		376 (2.6)	3		340 (2.3)	5		372 (2.6)	1
A-3LF	32.3	303 (2.1)	1	56.9	291 (2.0)	1	74.4	267 (1.8)	1	92.2	316 (2.2)	1
A-3LB		332 (2.3)	3		260 (1.8)	3		207 (1.4)	1		314 (2.2)	3
A-3RF		393 (2.7)	1		278 (1.9)	1		346 (2.4)	3		252 (1.7)	2
A-3RB		378 (2.6)	3		260 (1.8)	3		214 (1.5)	1		304 (2.1)	3
A-4LF	38.7	180 (1.2)	2	57.7	143 (1.0)	2	72.6	253 (1.7)	2	93.5	126 (0.9)	2
A-4LB		181 (1.2)	1		207 (1.4)	1		168 (1.2)	2		232 (1.6)	1
A-4RF		318 (2.2)	1		261 (1.8)	2		274 (1.9)	1		132 (0.9)	2
A-4RB		305 (2.1)	1		233 (1.6)	1		223 (1.5)	1		235 (1.6)	1
B-2LF	34.9	318 (2.2)	1	53.9	370 (2.6)	3	69.4	396 (2.7)	4	91.9	260 (1.8)	1
B-2LB		314 (2.2)	2		376 (2.6)	3		446 (3.1)	3		236 (1.6)	1
B-2RF		223 (1.5)	2		343 (2.4)	3		370 (2.6)	3		330 (2.3)	1
B-2RB		319 (2.2)	1		403 (2.8)	3		402 (2.8)	1		331 (2.3)	1
B-3LF	37.9	274 (1.9)	1	52.8	343 (2.4)	3	70.8	330 (2.3)	3	92.5	249 (1.7)	1
B-3LB		120 (0.8)	2		341 (2.4)	3		377 (2.6)	1		157 (1.1)	2
B-3RF		331 (2.3)	1		307 (2.1)	3		335 (2.3)	1		251 (1.7)	1
B-3RB		313 (2.2)	1		317 (2.2)	1		291 (2.0)	1		163 (1.1)	2
B-4LF	39.1	261 (1.8)	2	54.7	316 (2.2)	1	71.7	229 (1.6)	1	92.6	212 (1.5)	1
B-4LB		56 (0.4)	2		333 (2.3)	1		191 (1.3)	1		117 (0.8)	2
B-4RF		307 (2.1)	2		303 (2.1)	3		274 (1.9)	1		113 (0.8)	2
B-4RB		237 (1.6)	2		239 (1.7)	1		273 (1.9)	1		133 (0.9)	2
C-2LF	35.9	322 (2.2)	1	53.5	314 (2.2)	3	68.8	329 (2.3)	3	87.4	391 (2.7)	3
C-2LB		229 (1.6)	1		269 (1.9)	1		300 (2.1)	1		444 (3.1)	1
C-2RF		319 (2.2)	3		340 (2.3)	3		279 (1.9)	1		412 (2.8)	1
C-2RB		304 (2.1)	1		340 (2.3)	2		334 (2.3)	1		362 (2.5)	1
C-3LF	34.8	232 (1.6)	3	55.9	202 (1.4)	1	67.6	341 (2.4)	1	92.1	226 (1.6)	2
C-3LB		258 (1.8)	3		208 (1.4)	1		216 (1.5)	1		312 (2.2)	2
C-3RF		312 (2.2)	3		345 (2.4)	3		239 (1.7)	1		229 (1.6)	2
C-3RB		252 (1.7)	1		357 (2.5)	1		331 (2.3)	1		234 (1.6)	2
C-4LF	36.5	312 (2.2)	1	52.9	243 (1.7)	1	69.4	194 (1.3)	1	90.7	181 (1.3)	2
C-4LB		224 (1.5)	2		166 (1.1)	2		202 (1.4)	2		170 (1.2)	2
C-4RF		194 (1.3)	1		244 (1.7)	1		298 (2.1)	1		188 (1.3)	2
C-4RB		203 (1.4)	2		248 (1.7)	2		265 (1.8)	1		181 (1.2)	2
Avg.	36.3	277 -1.9	-----	55.1	299 -2.1	-----	70.9	293 -2.0	-----	91.7	255 -1.8	-----
Std. Dev.	2.2	76 0.5	-----	2.0	69 0.5	-----	2.4	71 0.5	-----	1.9	90 0.6	-----
COV	6.2	28 -27.5	-----	3.7	23 -23.0	-----	3.3	24 -24.3	-----	2.0	35 -35.2	-----

Test Reference No.

A-2 L F

- The face shell of the core tested (F = front, B = back)
- The cell of the unit from which the core was taken (L = left, R = right)
- The unit in the pier from which the core was taken (1 = bottom unit through 5 = top unit)
- The pier from which the core was taken. Three piers (A, B, and C) were made for each target moisture content

Failure Mode

1 Grout Shear / Interface Shear
2 Interface Shear
3 Grout Shear
4 Unit Shear
5 Tensile Splitting

Table 2 Grout Compressive Strengths

Target Unit Moisture Content, (% of total absorption	Average, psi (MPa)	Standard Deviation, psi (MPa)	Coefficient of Variation, %
30	2033 (14.0)	215 (1.5)	10.6
50	1835 (12.7)	198 (1.4)	10.8
70	1925 (13.3)	182 (1.3)	9.5
90	2175 (15.0)	187 (1.3)	8.6

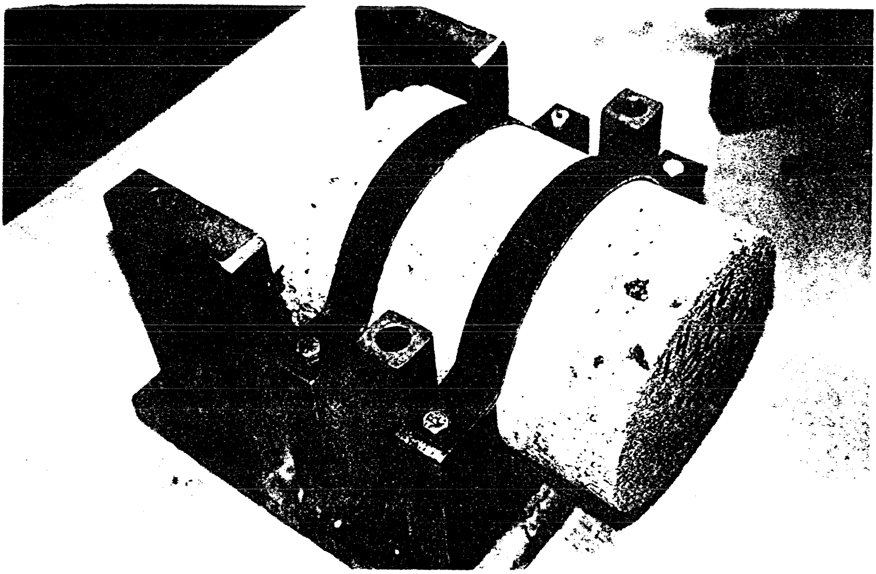

Figure 2: Core specimen clamped firmly to lower platform of guillotine test apparatus

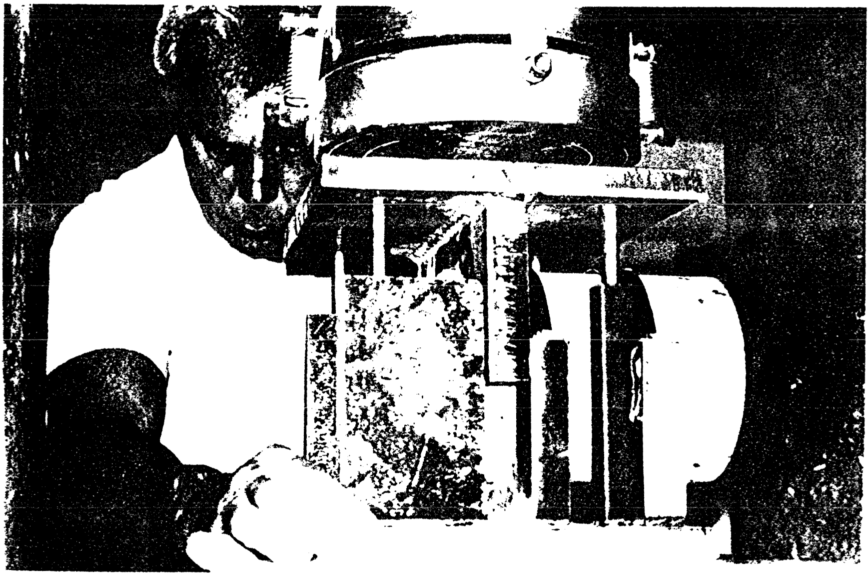

Figure 3: Placing top platform of guillotine test apparatus onto lower platform

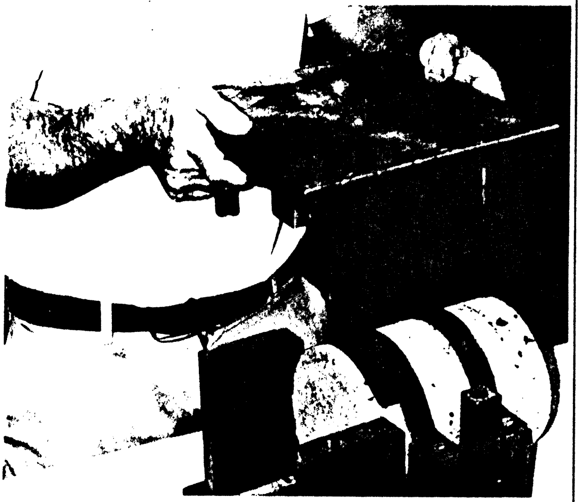

Figure 4: Positioning guillotine test apparatus into compression machine

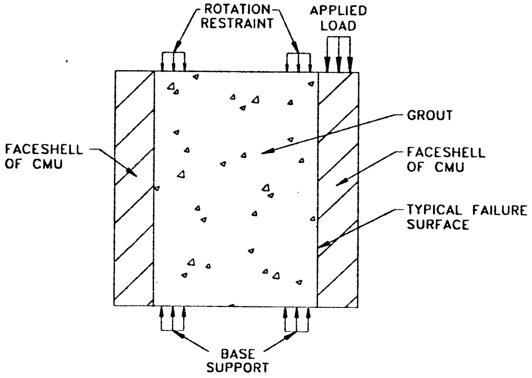

Figure 5: Free-body diagram of forces imposed on the core specimens by the guillotine test apparatus

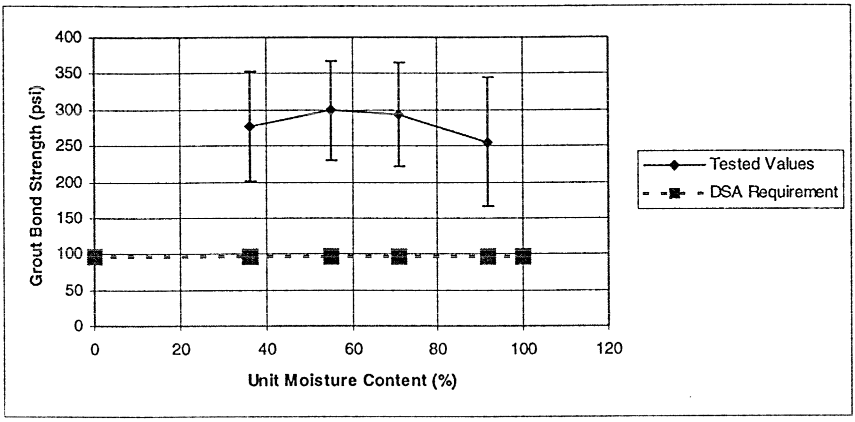

Figure 6: Comparison between grout bond strength and concrete masonry unit moisture content

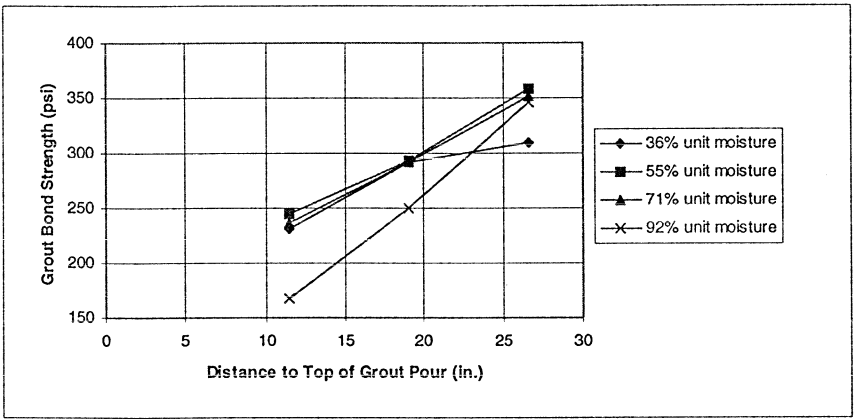

Figure 7: Effect of distance to top of grout pour height on grout bond strength