NATIONAL
CONCRETE MASONRY
ASSOCIATION

COMPRESSIVE STRENGTH OF KORFIL CMU IN 20 FT. HIGH WALLS

For
KORFIL, INC.

Performed By
NCMA RESEARCH LABORATORY

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INTRODUCTION

This report describes the results of a test program conducted by the Research Laboratory of the National Concrete Masonry Association for KORFIL, INC. The objective of this test program was to determine the structural properties of KORFIL standard units in nominal 20 ft. high reinforced masonry walls. KORFIL standard 8x8x16 concrete masonry units (CMU) contain two expanded polystyrene inserts, one in each core, installed at the block manufacturing plant.

The test program included the compression tests of two 19'-4" high reinforced concrete masonry walls, ten grouted prisms, and test of component materials (ie CMU, mortar, and grout). All masonry materials and assemblages were tested as per applicable ASTM and/or UBC standards. Each wall was subjected to a concentric or eccentric compressive load as per ASTM E72 "Conducting Strength Tests of Panels for Building Construction." Ten 8"x8"x16" Korfil masonry prisms were fabricated for each wall, five of which were grouted with the same grout mix used in the wall. Prisms were stack bonded two units high and tested in compression as per ASTM E447 "Test Methods for Compressive Strength of Masonry Prisms."

MATERIALS

KORFIL arranged with York Building Products Co. of York, Pennsylvania to deliver about 430 - 8"x8"x16" autoclaved units with KORFIL inserts on four pallets to NCMA Research Laboratory. The

physical properties of the masonry units were determined in accordance with ASTM C140-75 "Standard Methods of Sampling and Testing Concrete Masonry Units." These properties are shown in Table 1 and a complete test report is included in the appendix. The webs of some units were saw cut in order to form the bond beams in the two walls.

The portland cement and hydrated lime were purchased from the local area in bags and are typical of materials used in the Northern Virginia area for mortar. The mason sand is standard for the NCMA Research Laboratory and is purchased in truck load quantities to assure a reasonable uniformity in mortar testing. A mason with 25 years experience was employed to construct the prisms and walls. The mason controlled the water content of the mortar to his desired workable consistency.

TABLE 1 - CMU PROPERTIES (average 3 units)

	ASTM C90 Requirements	Test Results
Compressive Strength,psi (gross area)...	1000 min.	1310
Compressive Strength, psi (net area)....	N/A	2600
Absorption, lb/cu.ft.	15 max.	11.8
Unit Weight, lb/cu.ft.	N/A	113.9
Minimum Faceshell Thickness, in.	1.25 min.	1.30
Minimum Web Thickness, in.	1.00 min.	1.01
Equivalent Web Thickness, in.	2.25 min.	2.39
Net Area, %	N/A	50.4

The mortar used in building the two walls was Type S, portland cement-lime mortar, mixed in accordance with the proportion specifications of ASTM C270 "Mortar for Unit Masonry." The mortar consisted of: 1 part portland cement, 0.5 parts hydrated lime, and 4.5 parts masonry sand. The unit weight, air content, initial cone penetration, water retention, and 2 in. cube compressive strength were determined for each mortar mix. A summary of the mortar physical properties is presented in Table 2. The compressive strength of each mortar was determined in accordance with ASTM C109 "Standard Method of Test for Compressive Strength of Hydraulic Cement Mortars."

Fine grout was used in constructing the walls and prisms and was mixed in accordance with ASTM C476 "Grout for Masonry." The grout mix consisted of 1 part portland cement, 5 parts of concrete sand, and sufficient water to produce a 9 to 10 inch slump. The compressive strength of grout was determined in accordance with ASTM C1019, "Method of Sampling and Testing Grout" and the Uniform Building Code Standard No. 24-22 "Field Test for grout and Mortar." Specimens for compressive strength tests were 3-1/2"x3-1/2"x7" high made in molds formed by KORFIL units (Figure 1) similar to those used in the tested assemblages. Tests for slump were performed in accordance with ASTM C143, "Test Method for Slump of Portland Cement Concrete". A summary of the grout physical properties is presented in Table 2.

TABLE 2 - MORTAR AND GROUT PROPERTIES

Mortar Type S (1:0.5:4.5)					
Mix (Date)	1	2	3	4	5
Date	6/25/90	6/27/90	6/28/90	6/29/90	7/2/90
PC, Lbs.	47.0	47.0	47.0	47.0	47.0
Lime, Lbs.	10.0	10.0	10.0	10.0	10.0
Mason Sand, Lbs.	180.0	180.0	180.0	180.0	180.0
Water, Lbs.	41.6	41.6	41.0	43.2	43.5
Cone Penet.,mm	66	64	69	63	62
Unit wt., pcf	130.0	130.8	130.6	130.3	130.0
Air Content, %	3.0	2.4	2.1	2.1	2.2
Water Retention,%	91.6	95.1	93.8	88.9	89.4
Cube Strength, psi	3252	3088	3218	3273	3462
Grout (Fine 1:5)					
Mix	1	2	3	4	5
Date	6/26/90	6/28/90	6/29/90	7/2/90	7/3/90
PC, Lbs.	31.0	41.0	41.0	41.0	41.0
Conc. Sand, Lbs.	150.0	200.0	200.0	200.0	200.0
Water, Lbs.	28.0	41.0	41.2	41.0	41.0
Slump, in.	10.0	10.25	9.75	9.75	9.75
*Strength, psi	--	2704	2764	2626	3540

*Note: Lab technicians used cylinder molds for the first grout specimen, resulting in a higher net water/cement ratio than the other grout samples. As a result, the compression test results from this specimen are not comparable to the other values presented and are not reported.

CONSTRUCTION OF TEST SPECIMENS

The two 20 ft walls (actual wall height was 19'-4") and twenty prisms were constructed by a mason with 25 years of experience. The walls were constructed over a period of five days, with 4 ft. sections (1 lift) built each day. The two walls were reinforced with 1-#4 bars spaced at 24 inches vertically and at 48 inches horizontally. The units were laid in running bond using faceshell mortar bedding except at the grouted cores where the units were

fully bedded. Mortar joints in the walls and prisms were tooled with a concave pointer. The test walls were air cured in a laboratory environment.

Bond beams were constructed throughout the walls to provide typical 4 ft. vertical spacing of horizontal steel. To form the bond beams, the webs of the standard Korfil CMU were cut to seat the steel reinforcement. The first and last course consisted of grouted bond beam units without Korfil inserts. This provided solid load points that would better distribute the applied load and reduce the possibilty of localized failure. The twelfth course was also grouted without Korfil inserts. A threaded #4 bar, which extended past each end of the wall, was placed at this level to facilitate lifting of the specimen into the testing apparatus. The remaining bond beam courses at the sixth and eigtheenth courses were formed using standard CMU with the Korfil inserts.

All mortar batch weights for dry materials were carefully weighed by laboratory technicians and mixed in a 3-1/2 cubic foot Muller paddle-blade mortar mixer to a workable consistency determined by the mason. Each mortar mix was used to fabricate both the 4 ft. section for each wall and four 2-unit high concrete masonry prisms. Mortar was sampled during fabrication and tested for water retention, cone penetration, air content, unit weight and 2 in. compressive cube strength.

Fine grout mix was used to fill the bond beams and those cores containing vertical reinforcement. Grouting was done the day after

fabrication of each section. Grout materials were weighed, mixed, placed, and vibrated in the walls and prisms by the lab technicians. Grout was mixed in a typical 5 cubic foot mixer with sufficient water to produce a slump of 9 to 10 inches. After being poured into in each core or beam, the grout was vibrated with a 1 in. diameter "pencil" vibrator. The vertical reinforcement was supported by a template to prevent displacement during grouting.

Masonry prisms for compression tests were made with two KORFIL units in stack bond with full bedded mortar joints. For each section of each wall, two prisms were fabricated by the same mason using the same mortar. One of the two prisms was then grouted the following day with the same grout used in the corresponding wall section. Prisms were covered with plastic bags to cure and tested at 28 days.

TEST PROCEDURES

To determine the physical properties of the masonry materials, prisms and walls, laboratory tests were performed as per applicable ASTM and/or UBC specifications. The materials tests for the concrete masonry units, mortar and grout were discussed in the "MATERIALS" section of this report. The five grouted and five ungrouted prisms for each wall were tested for compressive strength as per ASTM E477-84 and UBC Code Standard 24-26 "Compressive Strength of Masonry Prisms."

The nominally 20 ft. high x 4 ft. wide x 8 in. thick walls

were tested in compression as per ASTM E72 "Standard Methods of Conducting Strength Tests of Panels for Building Construction." 28 days after construction, the walls were placed in a two million pound capacity ATS testing machine. Prior to placement in the testing machine, the top of the walls were capped with "hydrostone" to insure a uniform testing surface. The bottom of each wall was capped once the walls were placed into position within the testing machine.

The first wall was subjected to a concentric compressive load applied through a 5 in. diameter, solid steel half-round placed at the top of the wall. The second wall was subjected to an eccentric compressive load applied through the same steel half-round placed at an eccentricity of 1.27" (t/6), measured from the center of the wall (See Figure 2).

The compression load was applied incrementally. For each recorded load, out-of-plane deflection was measured. Testing continued until failure occurred in the specimen.

TEST RESULTS AND CONCLUSIONS

The concentrically loaded wall failed at a load of 282,200 lbs with a mid-height deflection of .048 in. The eccentrically loaded wall failed at a lower load, as expected, of 220,940 lbs with a deflection of 0.686 in. The results of the test program are summarized in Table 3, and mid-height deflections are shown in Figure 3. Complete results are tabulated in the appendix.

Some problems were encountered in obtaining deflection data during testing of the first wall which was subjected to concentric loading. As the initial load was applied to the wall, the gauges at mid-height and three-quarter height were dislodged on the left side of the wall. Therefore, deflection data was only accumulated for the right side of wall #1. In an attempt to prevent a similar occurrence during testing of the second wall, deflection was measured with a surveyors transit. Deflections for wall #2 were only recorded for one side of the wall as well.

TABLE 3: RESULTS OF COMPRESSION TESTS OF WALLS

Wall	Net Area A_n, sq. in.	Moment of Inertia I, in^4	Max. Comp. Load, P, Lbs.	Eccentricity from centroid	Max. M in.-Lb.
1	194	1415	282,200	1.27	185,970
2	194	1415	220,940	0	151,896

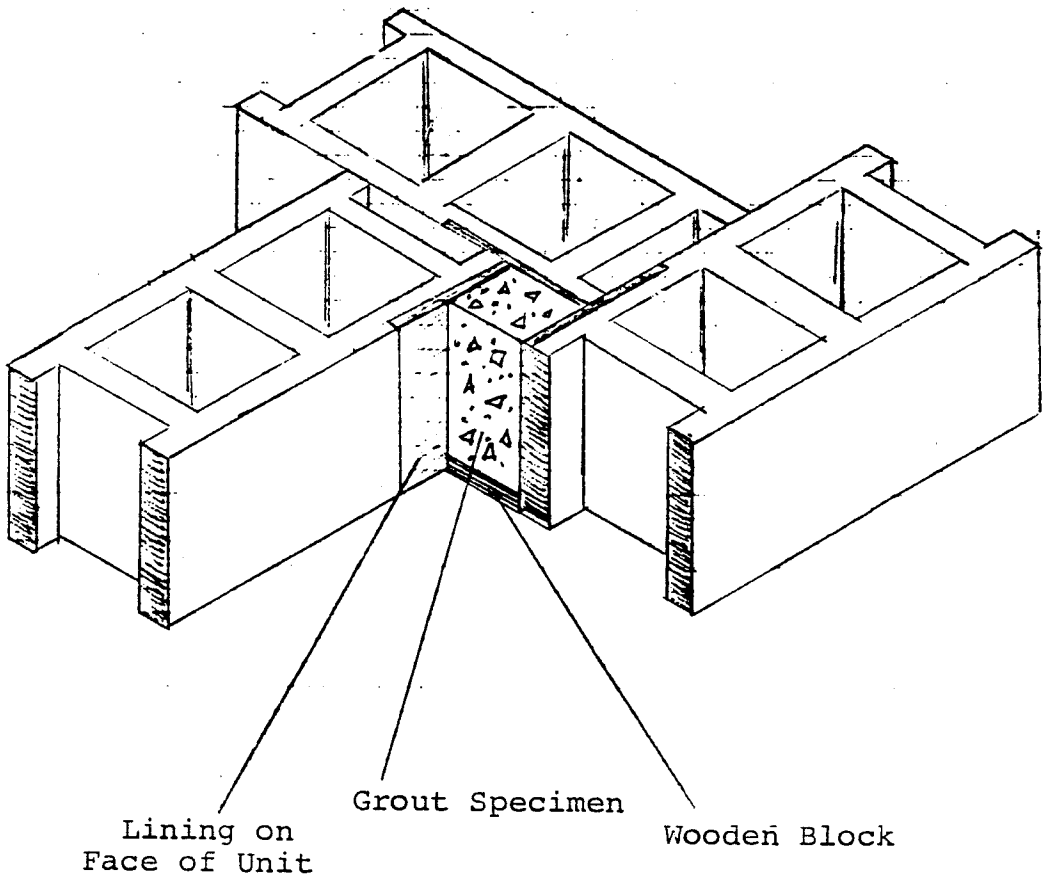


Figure 1: Mold for Grout Test Specimen

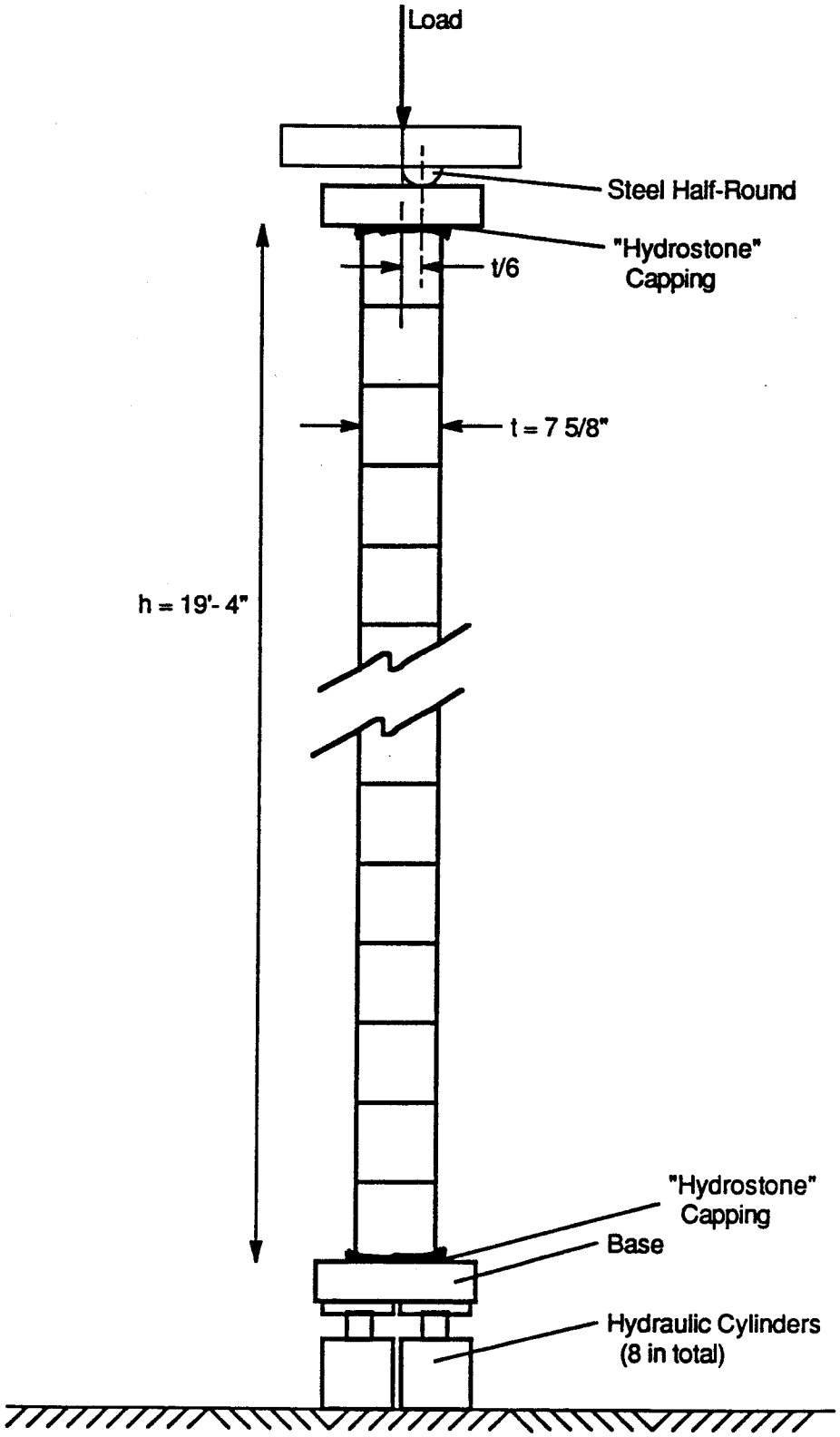


Figure 2: Wall Compression Test Set-Up

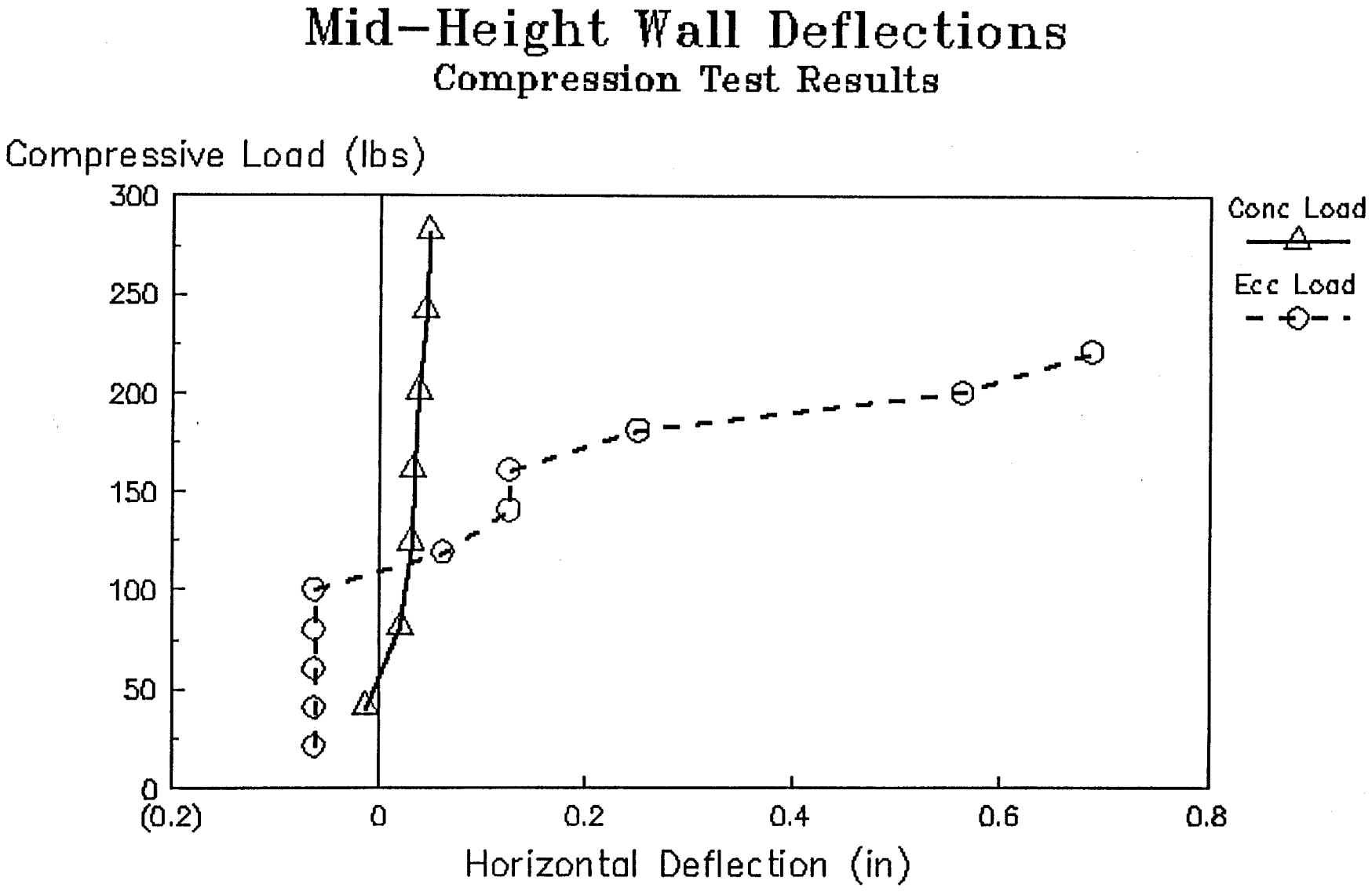


Figure 3: Load-Deflection Curves for Test Walls

APPENDIX

COMPRESSION AND ABSORPTION OF CONCRETE MASONRY UNITS

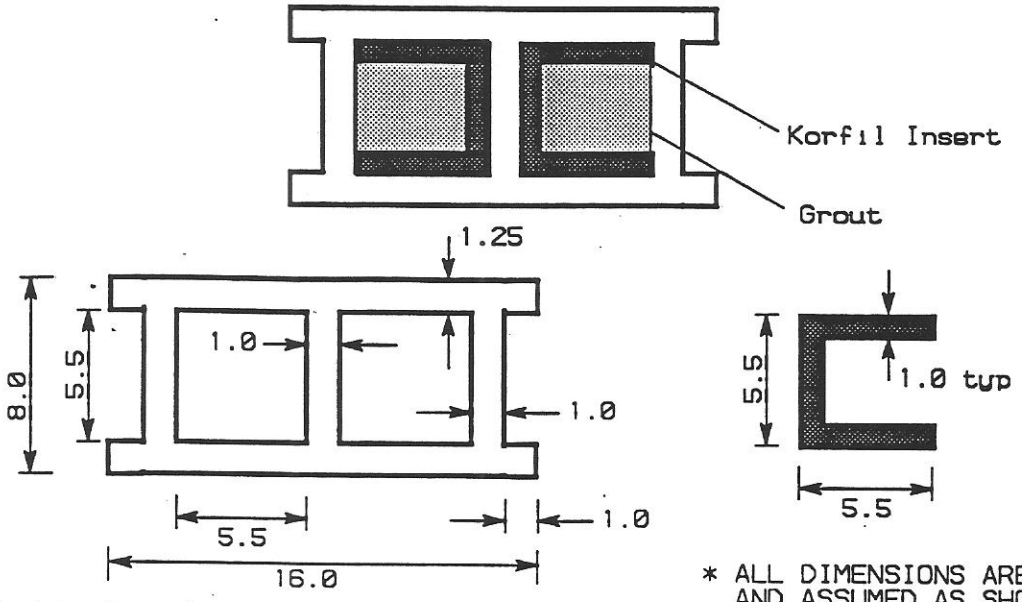
Compression

Unit No.	1	2	3	Avg.
Dimensions				
Height, in.	7.58	7.59	7.61	
Width, in.	7.65	7.65	7.64	
Length, in.	15.61	15.60	15.63	
Specific Weight, lbs.	30.40	30.48	30.22	
Load at Failure, lbs.	146,320	168,900	152,600	
Gross Compressive Strength	1230	1420	1280	1310
Net Compressive Strength	2440	2820	2540	2600

Absorption and Unit Weight

Unit No.	4	5	6	Avg.
Dimensions				
Height, in.	7.60	7.58	7.63	
Width, in.	7.63	7.63	7.65	
Length, in.	15.62	15.62	15.62	
Unit Weight, pcf	113.8	113.7	114.1	113.9
Absorption, pcf	11.7	11.7	11.7	11.8

CALCULATIONS - MOMENT OF INERTIA



* ALL DIMENSIONS ARE NOMINAL AND ASSUMED AS SHOWN.

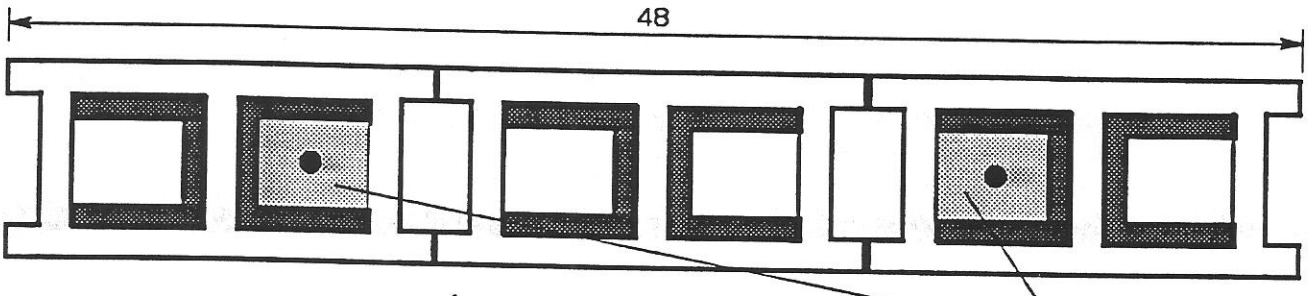
Individual Units

Gross Unit, $I_g = (1/12)(16)(8)^3$
$= 682.67 \text{ in}^4$

Net Unit, $I_n = I_g - I_{cells}$
$= 682.67 - 2[(1/12)(5.5)(5.5)^3]$
$- 2[(1/12)(1)(5.5)^3]$
$= 502.43 \text{ in}^4$

Grouted Prism w/ Insert,

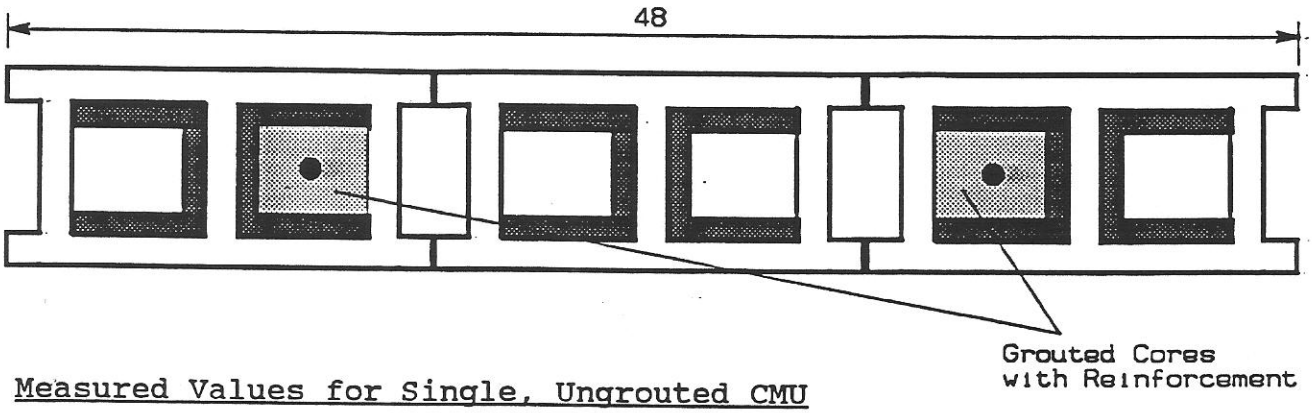
$I_{prism} = I_n + I_{grout}$
$= 502.43 + 2[(1/12)(4.5)(3.5)^3]$
$= 502.43 + 2[16.08]$
$= 534.59 \text{ in}^4$



Wall Cross-Section with 2 Grouted Cores

$I_{wall} = 3I_n + 2I_{grout}$
$= 3(502.43) + 2(16.08)$
$= 1539.45 \text{ in}^4$

CALCULATIONS - COMPRESSIVE STRENGTH OF WALL TEST SPECIMENS



Measured Values for Single, Ungrouted CMU

A_g = 119.4 in^2

% Solid = 50.4

A_n = 119.4 x .504
= 60.2 in^2

Wall Cross-Sectional Net Area

A_g = 119.4 x 3
= 358.2 in^2

A_n = (60.2 x 3) + A_{grout}
= 180.6 + 2(4.5 x 3.5)
= 212.1 in^2

Compressive Stresses at Failure

Wall #1:

$$\text{Gross Strength} = \frac{282{,}000 \text{ lbs}}{358.2 \text{ in}^2} = 787.3 \text{ psi}$$

$$\text{Net Strength} = \frac{282{,}000 \text{ lbs}}{212.0 \text{ in}^2} = 1330.2 \text{ psi}$$

Wall #2:

$$\text{Gross Strength} = \frac{220{,}940 \text{ lbs}}{358.2 \text{ in}^2} = 616.8 \text{ psi}$$

$$\text{Net Strength} = \frac{220{,}940 \text{ lbs}}{212.0 \text{ in}^2} = 1042.2 \text{ psi}$$

PRISM COMPRESSION TEST RESULTS

Grouted Prisms

Prism	Gross Area (sq.in.)	Net Area (sq.in.)	1st Crack (lbs.)	Failure Load (lbs.)	Gross Strength (psi)	Net Strength (psi)
1A	119.4	106.4	182000	185000	1550	1740
1B	118.4	105.4	170000	174540	1470	1660
2A	119.2	106.2	172840	175940	1480	1660
2B	119.9	106.9		159780	1330	1490
3A	119.2	106.2	176930	177000	1490	1670
3B	119.4	119.4	185940	186980	1570	1760
4A	119.4	106.4	187740	189970	1590	1790
4B	119.1	106.1	172940	173660	1460	1640
5A	119.4	106.4	192740	194260	1630	1830
5B	119.4	106.4	173460	172780	1460	1630
Avg.	119.3	106.3	179400	179090	1500	1690

Ungrouted Prisms

Prism	Gross Area (sq.in.)	Net Area (sq.in.)	1st Crack (lbs.)	Failure Load (lbs.)	Gross Strength (psi)	Net Strength (psi)
1A	119.3	60.1	134500	138540	1160	2300
1B	119.2	60.1	78940	82660	690	1380
2A	119.3	60.1	128000	128960	1080	2150
2B	119.7	60.3	106000	106680	890	1770
3A	119.1	60.0	107390	107660	900	1790
3B	119.6	60.3	109940	111880	940	1860
4A	119.3	60.1	118120	118320	990	1970
4B	119.4	60.2	142130	143340	1200	2380
5A	119.4	60.2	94680	95700	800	1590
5B	119.3	60.1	86120	87200	730	1450
Avg.	119.4	60.2	110580	112090	940	1860

WALL COMPRESSION TEST RESULTS

WALL 1: Concentric Load Test Date: 7-30-90

LOAD (kips)	LEFT DEFLECTION (in) 1/4 HT (4'10")	1/2 HT (9'8")	3/4 HT (15'6")	RIGHT DEFLECTION (in) 1/4 HT (4'10")	1/2 HT (9'8")	3/4 HT (15'6")	ECC. (in)	MOMENT (in.lbs)
40.8	0.009			0	-0.013	-0.075	1.27	51286
81.4	0.007			0.013	0.021	-0.075	1.27	105087
124.4	0.019			0.009	0.031	-0.075	1.27	161844
161.0	0.026			0.009	0.033	-0.075	1.27	209783
201.0	0.033			0	0.038	-0.075	1.27	262908
241.8	0.045			-0.02	0.045	-0.075	1.27	317967
282.2	0.063			-0.02	0.048	-0.060	1.27	371940

WALL 2: Eccentric Load Test Date: 7-30-90

LOAD (kips)	LEFT DEFLECTION (in) 1/4 HT (4'10")	1/2 HT (9'8")	3/4 HT (15'6")	RIGHT DEFLECTION (in) 1/4 HT (4'10")	1/2 HT (9'8")	3/4 HT (15'6")	ECC. (in)	MOMENT (in.lbs)
21.36	-0.188	-0.063	0.000				0	-1335
40.96	-0.188	-0.063	0.000				0	-2560
60.56	-0.188	-0.063	0.000				0	-3785
80.16	-0.188	-0.063	0.063				0	-5010
100.28	-0.125	-0.063	0.125				0	-6268
119.36	-0.125	0.063	0.188				0	7460
140.76	-0.063	0.125	0.188				0	17595
160.86	0.000	0.125	0.313				0	20108
181.14	0.000	0.250	0.375				0	45285
200.58	0.188	0.563	0.625				0	112826
220.94	0.313	0.688	1.000				0	151896