FREEZING AND THAWING
OF
EXTERIOR TILE MORTAR JOINTS

by

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Submitted in Partial Fulfillment of
the Requirement for the Degree of
BACHELOR OF SCIENCE
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Signature of Authors Signature redacted

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Department of Building Engineering
and Construction, May 20, 1949

Signature of Professor
in Charge of Research Signature redacted

Signature of Head of
Department Signature redacted

Cambridge, Massachusetts
May 20, 1949

Professor Joseph S. Newell
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In partial fulfillment of the requirements for the degree of Bachelor of Science in Building Engineering and Construction, we herewith submit a thesis entitled, "Freezing and Thawing of Exterior Tile Mortar Joints".

Respectfully submitted,

Signature redacted

Paul T. Reynolds

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Richard W. Warren

Acknowledgments

We wish to express our sincere thanks and appreciation to Professors Voss and Murray for their help and guidance throughout this work, without which we would have been severely handicapped; to Mr. A.J.O'Neill, whose experience in laboratory practice helped us in many ways; to the Department of Mechanical Engineering for making available and maintaining the freezing room used throughout this work; and to the members of the Department of Building Engineering and Construction for their helpful suggestions and advice.

We wish also to express our thanks to The Gladding, McBean Company for furnishing the tile used in this thesis, and to Mr. C.W.Planje of that company, for his interest and encouragement. We hope that our work in some way will prove to be of value to them in the future.

P.T.R.
R.W.W.

May 20, 1949
Cambridge, Massachusetts

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Object and Conclusions

The ultimate objective of this work was to determine the practicability of using, on an exterior wall face, a glazed ceramic tile veneer in a climate of extremes in temperature and humidity.

Due to the scope of the work, this thesis has been limited to a study of the effects of wetting, freezing, thawing and heating on the mortar joints of six specimens, half of which were made using the straight cement grout, as recommended by the manufacturer, while the other half were made using a grout of dolomitic lime hydrate and cement.

As a result of the tests, the conclusion was reached that a more watertight wall would result if the grout between the structural wall and the tile face were made of lime and cement.

Previous Work

Most of the work done in the past on masonry assemblages has been limited to subjecting the specimens to a single type of exposure. However, the Bureau of Standards completed, in 1940, a three year test on masonry walls exposed to actual climatic conditions. The specimens in this test were of two types; one type was brick throughout, while the other was a brick face backed up with hollow tile. In these tests, no attempt was made to maintain an unfrozen state on one face.

Theoretical Considerations

A grout of straight cement and aggregate has a strong tendency to bleed when worked. Since the facing tile was soaked before being grouted in, and could not absorb any more water, the water that had been worked out of the grout would form planes along the interior face of the tile. After the excess water had evaporated, these planes would form cracks which would be further enlarged by the grout shrinking as it hardened.

If an assemblage, so fabricated, were repeatedly soaked and frozen, these cracks would enlarge and would permit water to penetrate behind the tile face. This could cause an unwatertight wall, and in an extreme case, could result in the tile face being spalled off, if the water were to freeze while behind the tile.

The addition of lime to a grout mix will materially reduce the tendency to bleed. This would tend to eliminate cracks along the tile surface, which in turn, would reduce the possibility of water penetration. If the water could not get behind the tile, there would be no possibility of the tile being spalled off, due to water freezing behind the tile face.

If the bond in masonry walls laid up with lime bearing mortar is broken, but subjected to the normal wetting action of rain, it will be reformed. This is explained by the fact that some of the compounds formed during the hydration of the lime are water soluble, but will be redeposited upon drying, if not permitted to leach away while in solution.

Procedure

To meet natural conditions and to stay within the limits of the object of the thesis, a test cycle was devised including the following elements: (1) soaking the exterior tile face to approximate wet weather conditions; (2) freezing the tile face, keeping the back or interior face unfrozen to approximate conditions encountered in normal construction; (3) thawing at room temperature; (4) raising the tile face to a temperature as would result from direct sunlight; (5) cooling again to room temperature; and (6) testing the mortar joint for water absorption as a measure of the weather tightness of the wall.

This cycle was chosen as one which would represent natural conditions without introducing too many experimentat variables.

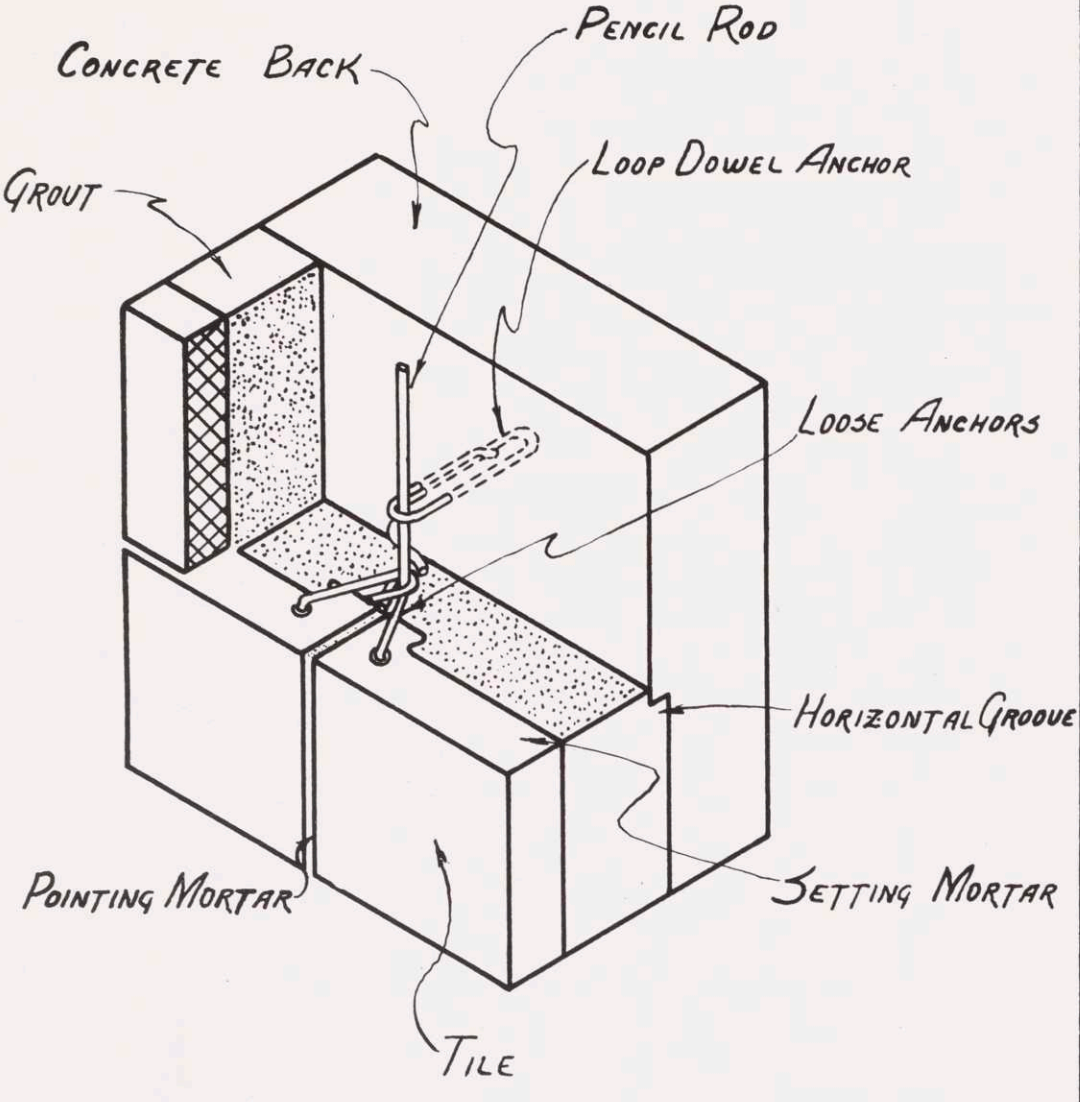
Detailed Description of Specimens and Apparatus

Specimens (see figures #1 and #2)

The specimens used in the tests were made in two stages. Each "back-up" representing the structural portion of the wall, was cast of a 1-2½-5 (cement, sand, gravel) concrete mix of approximately 4½" slump. The forms were stripped in eighteen hours and the "back-up" cured in the moist room for twenty-eight days at 60°F.

After curing, the "back-up" was again placed in forms and the tile face grouted in following the manufacturer's recommended practice with three exceptions: (1) plain reinforcing rods were used instead of zinc coated rods; (2) sodium stearate integral waterproofing was not used; (3) a completely hydrated dolomitic lime (Type S--ASTM Spec. 207-46T) was used to replace, wherever specified, a high calcium lime putty.

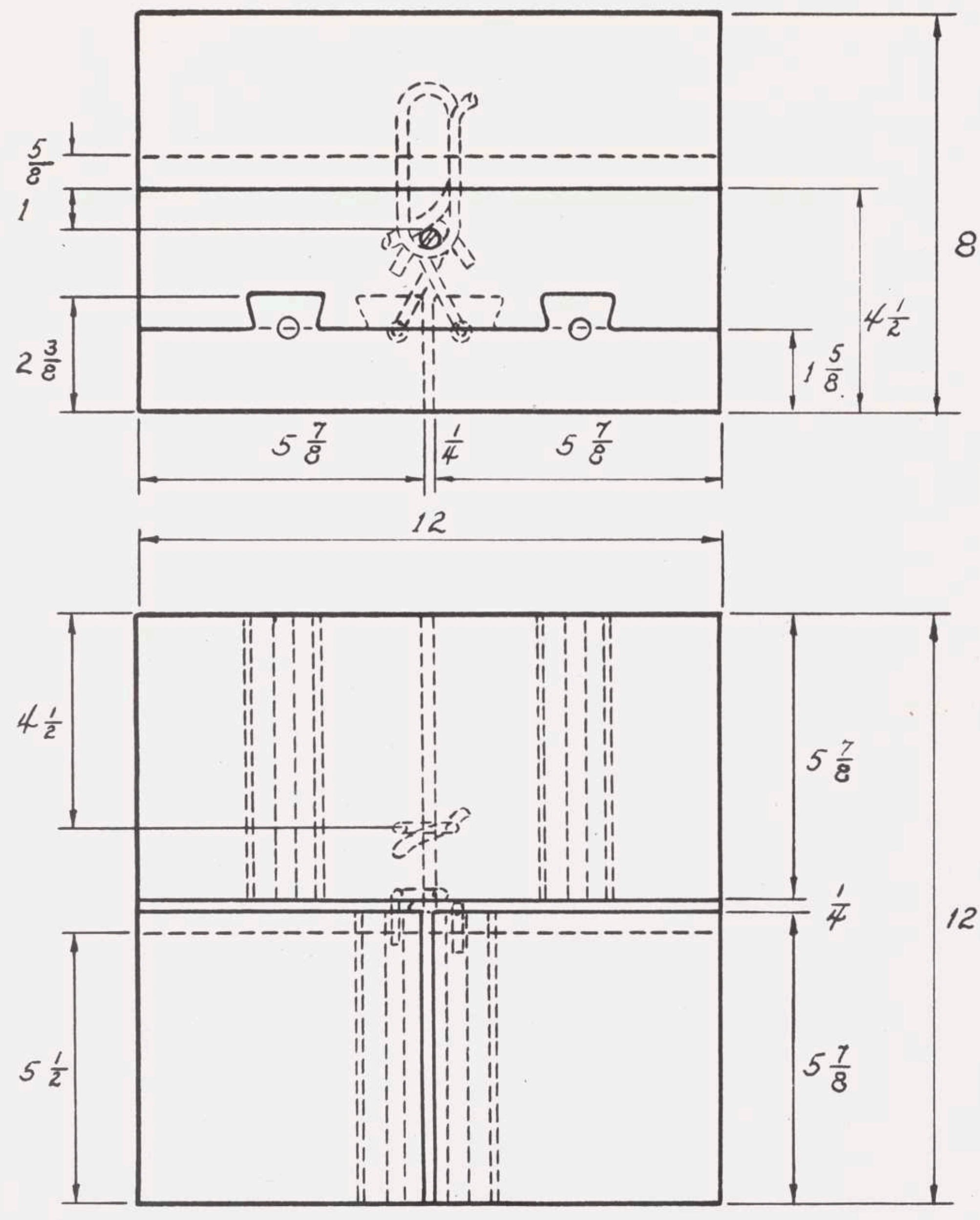
Of the ten specimens prepared, five (numbered 1 to 5) were made using a grout of 1-5½ (cement, sand) by volume. The other five (numbered 6 to 10) were made using a 1-1-6 (cement, lime, sand) grout. The tile were set in a 2-1-8 (cement, lime, sand) mortar. The joints were raked one half inch and pointed with a 1-2-9 (cement, lime, sand) pointing mortar. The sand in the pointing mortar all passed a #14 Tyler series sieve. All of the tile were cut to size from stock pieces. (see figure #2)



Cut-away Sample

Scale $\frac{3''}{16} = 1''$

Fig. 1



TILE DETAILS

SCALE 1/4" = 1"

Fig. 2

In one of the straight cement specimens, #5, we embedded in the grout, at various depths and locations, eight chromel-alumel thermocouples (see figure #3).

Apparatus

To approximate natural wetting conditions, the apparatus used (see figure #4) was a large cement mixing trough. The specimens were placed face down resting on sponge rubber strips and water brought up to a height of ½ inch on the tile face.

The freezing apparatus (see figure #5) consisted of a large insulated copper box placed in a low temperature room which was maintained at 0°F. The specimens, tile face up, were laid in a copper pan set inside the box (see figure #6). The box was insulated on the sides and bottom with four inches of cork and the top, except for the space taken up by the pan, was insulated with one inch "Rubbatex" sheet fastened to ¼" plywood. The heat necessary to prevent freezing of the back surface was supplied by four 60W electric light bulbs fastened to the pan supports (see figure #5).

The heating arrangement (see figure #7) was made by mounting two 250W heat lamps on a stand so that the center of the heat pattern fell on the intersection of the mortar joints when the specimens were placed on edge side by side.

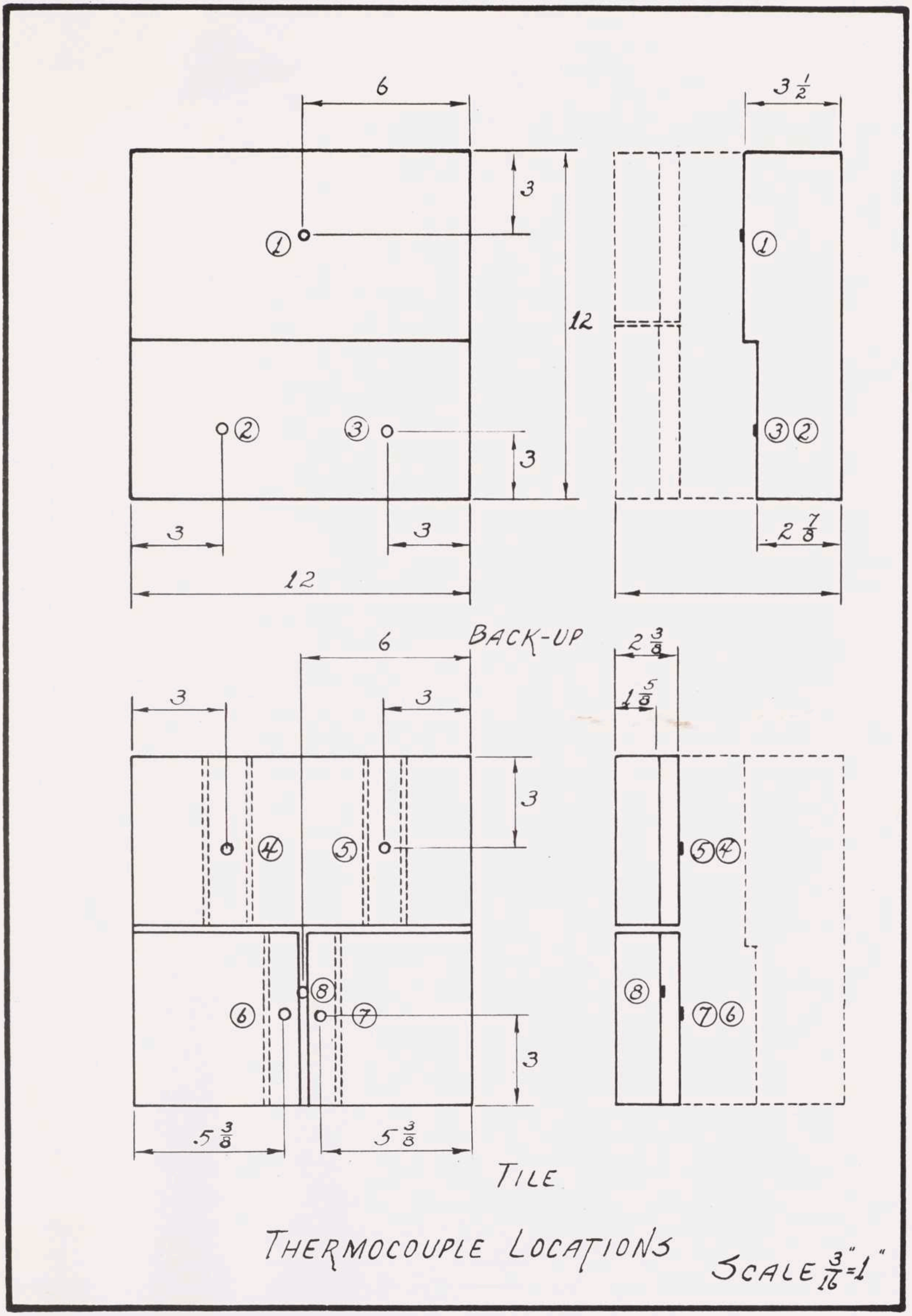

6
3 1/2
3
12
3
3
3
12
2 7/8
BACK-UP
6
2 3/8
1 5/8
3
3
3
3
5 3/8
5 3/8
TILE
THERMOCOUPLE LOCATIONS
SCALE 3/16" = 1"

Fig. 3

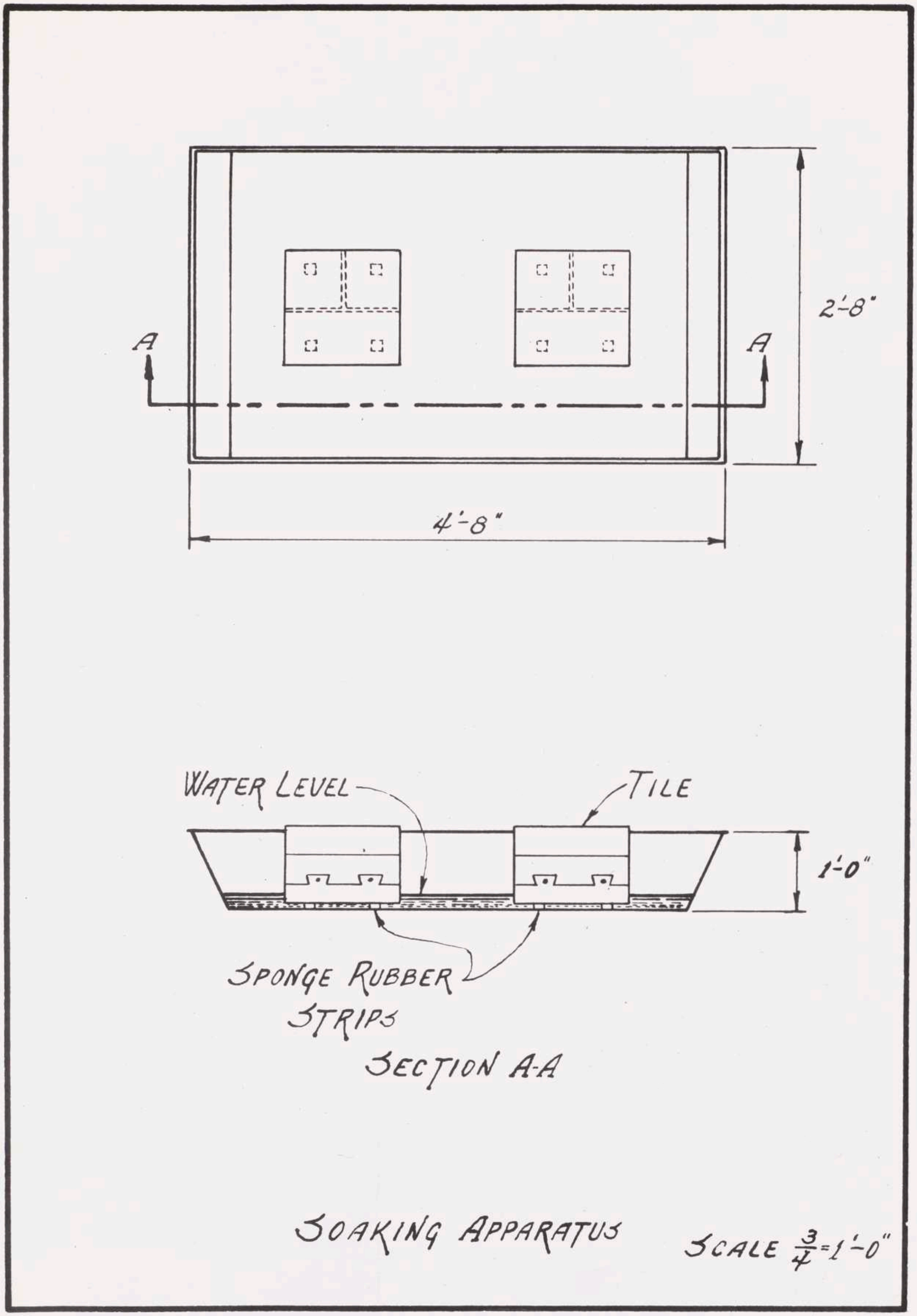

A
A
2'-8"
4'-8"
WATER LEVEL
TILE
1'-0"
SPONGE RUBBER
STRIPS
SECTION A-A
SOAKING APPARATUS
SCALE 3/4=1'-0"

Fig. 4

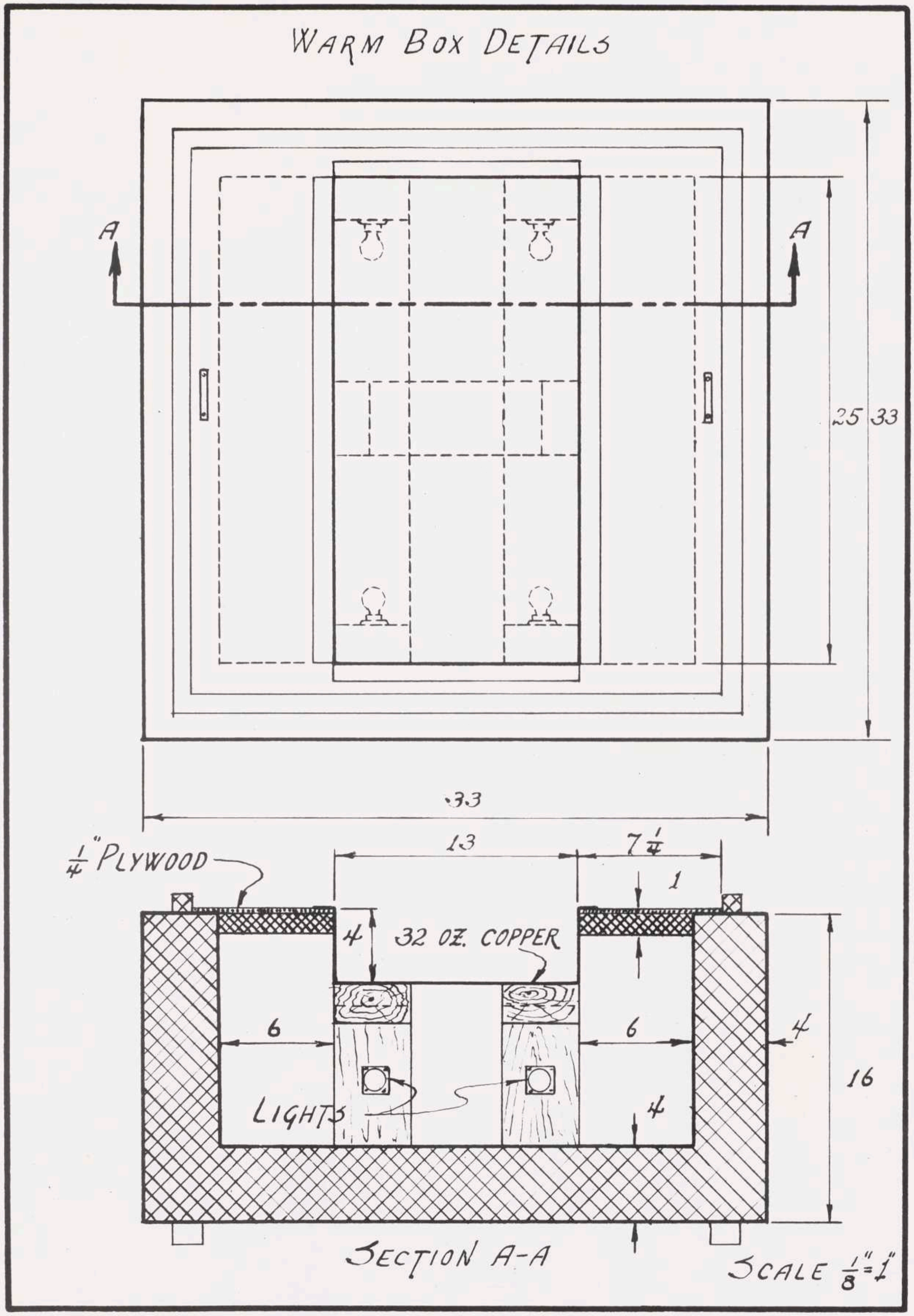

WARM BOX DETAILS
A
A
25
33
33
13
7 1/4
1/4" PLYWOOD
1
4
32 OZ. COPPER
6
6
4
16
LIGHTS
4
SECTION A-A
SCALE 1/8" = 1"

Fig. 5

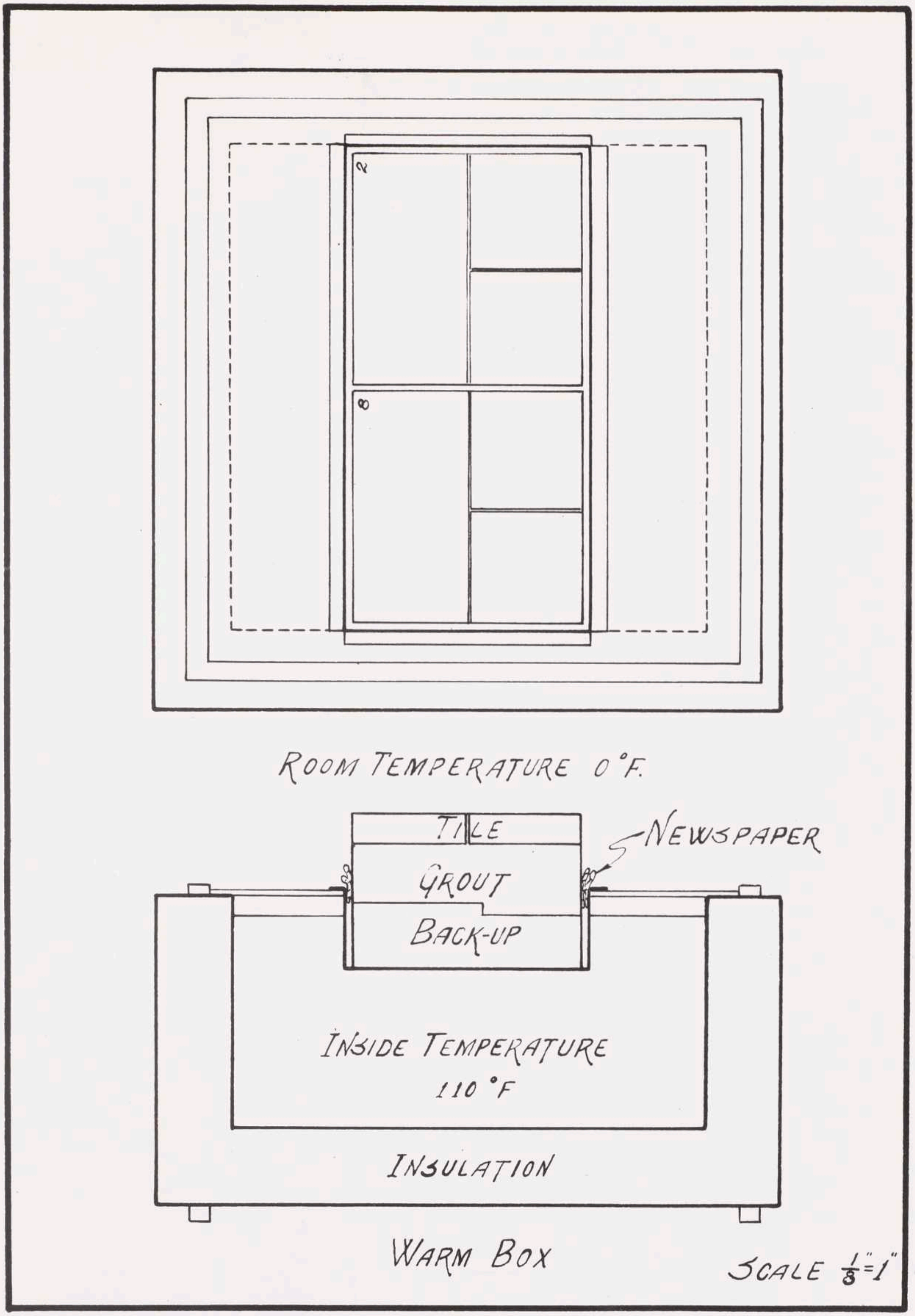

ROOM TEMPERATURE 0°F.
TILE
GROUT
BACK-UP
NEWSPAPER
INSIDE TEMPERATURE
110 °F
INSULATION
WARM BOX
SCALE 1/8"=1"

FIG. 6

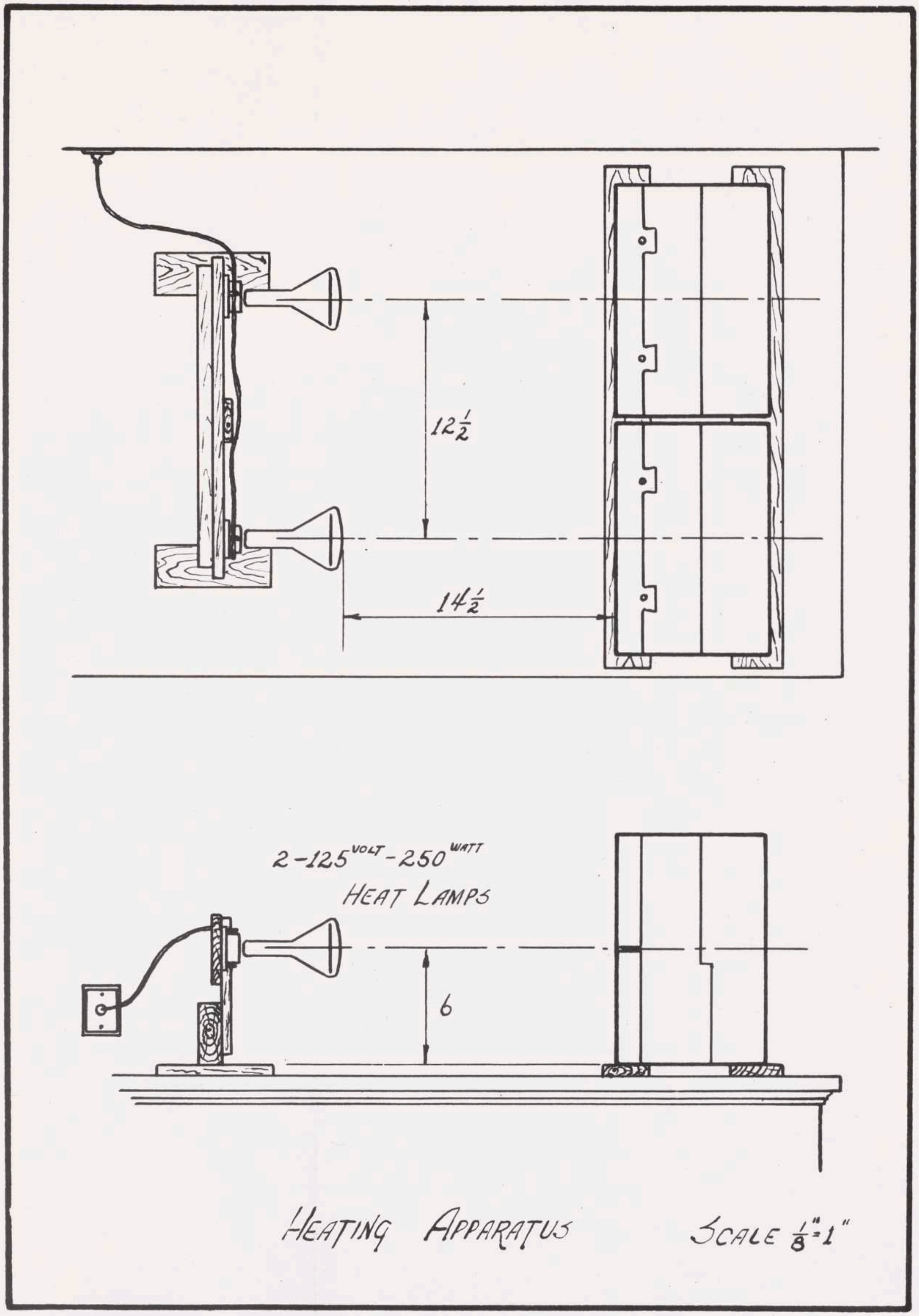

12 1/2
14 1/2
2-125 VOLT - 250 WATT
HEAT LAMPS
6
HEATING APPARATUS
SCALE 1/8" = 1"

Fig. 7

To test the watertightness of the mortar joints, a stand was made that would hold a single specimen and the measuring device (see figure #8). This measuring device consisted of a 50cc burette mounted in a socket in the top of a flange which in turn formed the top of the water chamber. The tile was placed face up on the stand. The water chamber was clamped to the tile face by means of tie rods and the joint between the water chamber and the tile sealed with a soft rubber gasket. This arrangement supplied water to a section of joint four inches along the horizontal joint and two inches along the vertical joint, with a head of approximately two feet.

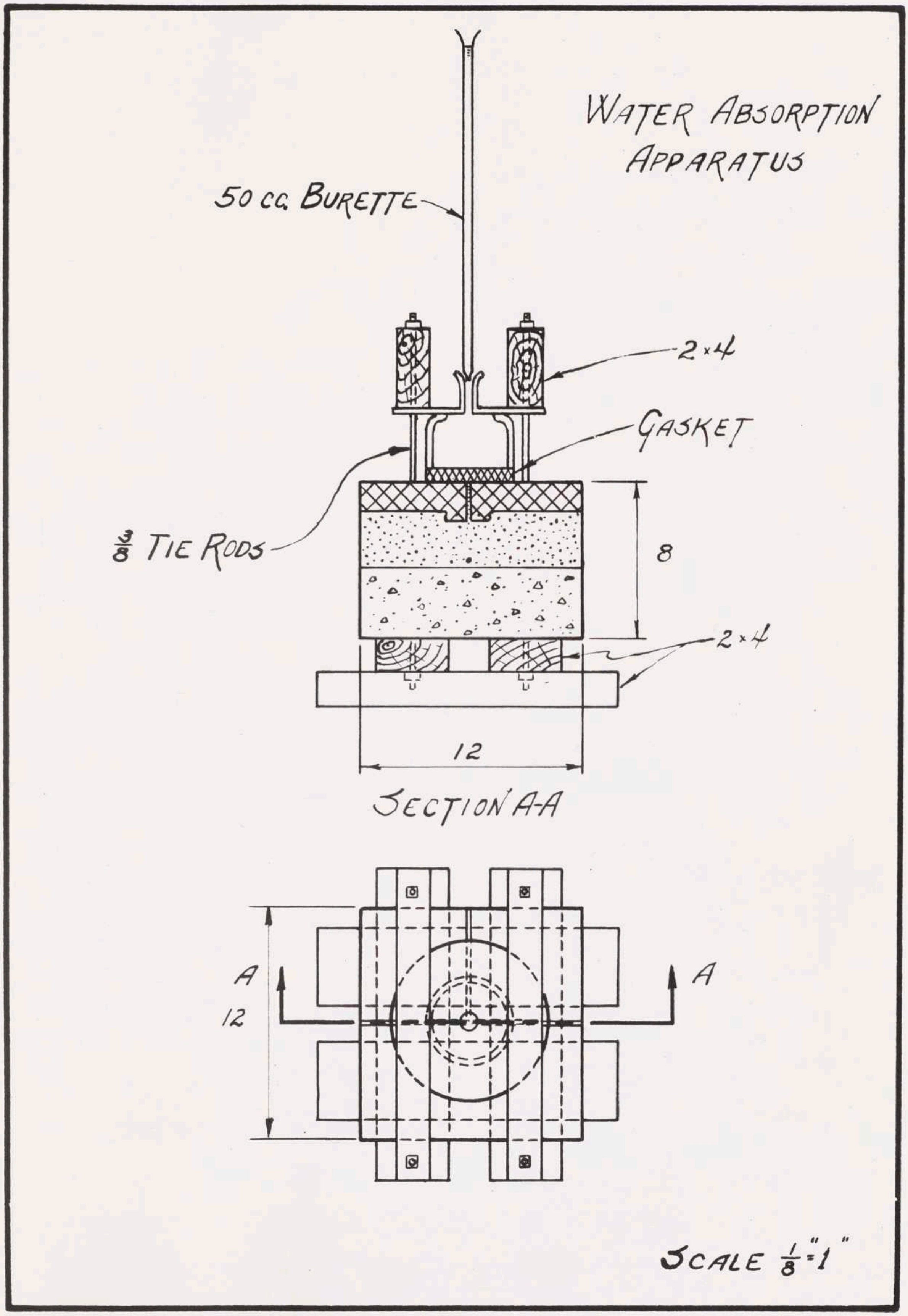

WATER ABSORPTION
APPARATUS
50 CC. BURETTE
2×4
GASKET
3/8 TIE RODS
8
2×4
12
SECTION A-A
A
A
12
SCALE 1/8"=1"

Fig. 8

Testing Procedure

After curing twenty-eight days, three specimens of each type were selected. Those selected were numbers 1, 2, and 4 (straight cement grout) and numbers 6, 8, and 10 (cement-lime grout).

The testing cycle was of the following order and duration:

7 hours	Soaking
24 hours	Freezing
17 hours	Thawing
7 hours	Heating
17 hours	Cooling

Two specimens, one straight cement and one cement and lime, were tested together. The pairs tested simultaneously were numbers 2 and 8, 1 and 6, and 4 and 10, in that order.

The soaking portion of the cycle consisted of placing the specimens, tile face downward, in a large mixing trough and filling the trough with water until it stood ½ inch up on the tile face (see figure #4). The tile face was protected during this portion of the cycle by resting the specimen on strips of sponge rubber laid on the bottom of the trough.

After the soaking period of seven hours, the specimens were transferred to the freezing room. This room was maintained at a constant 0°F. In this room, the specimens were placed tile face upward in the insulated box (see figure #6) and the exposed space between the pan and the specimens filled with crumpled newsprint. The heat supplied by the four 60W light bulbs kept the interior of the box at a fairly constant 110°F. This was enough to insure that the interior face did not freeze.

During an initial trial, the specimen containing the eight thermocouples, located as indicated in (figure #3), was placed in the freezer. The following readings, using a 32°F base, were taken at the end of 18 and 24 hours:

Thermocouple Number	Time in Freezing Room			
	18 Hours		24 Hours	
	P.D.*	Temp.(°F)	P.D.*	Temp.
1	.195	40.9	.042	33.9
2	.183	40.3	.040	33.8
3	.205	41.3	.050	34.3
4	.071	35.2	.072	35.3
5	.104	36.7	.057	34.6
6	.107	36.8	.049	34.2
7	no reading		no reading	
8	no reading		no reading	

*P.D. Potential Difference

The readings indicated that a state of equilibrium had been reached in 24 hours, and that only the face of the specimens were frozen.

At the end of the twenty-four hour freeze, the samples were removed from the freezing room and returned to room temperature for eighteen hours.

To arrive at a distance that would result in 100°F at the tile face, two specimens, (not used in the actual testing), were placed at measured distances from the crown of the lamp and the temperature, at equilibrium, recorded. This procedure was carried out until the equilibrium temperature was 100°F (see figure #7).

Distance from Lamp (Inches)	Temperature (°F)
6	134.6
8	120.2
10	113.0
12	104.0
13	102.2
14	100.4
15	98.6
14½	100.0

The specimens were placed at 14½ inches from the lamp crowns in subsequent seven hour heating operations, after which the specimens stood at room temperature for seventeen hours.

Before the specimens had been put through any portion of the cycle, they were tested for watertightness (see figure #8). After three complete cycles, they were again tested in the same manner. After the third cycle watertightness test, the specimens were left at room temperature for a period of eleven days, after which the tests were resumed and carried through a total of nine complete cycles. At the completion of the sixth and ninth cycles, the specimens were tested for watertightness.

Errors and Probable Precision

Since this problem was more qualitative than quantitative, any errors or imprecision in readings would have negligible effect on the end result.

In taking the readings, during the watertightness test, there definitely was an error on all readings, This was due to the fact that in filling the water chamber and the burette, some of the water would be taken in by the joint during the filling of the apparatus and would not show in the readings. It was impossible to use a fixed quantity of water and then measure the remaining water at the end for two reasons; first, the fact that it was impossible under the conditions of the test to recover all the water not absorbed, and second, due to slight surface irregularities, a fixed quantity of water would result in different heads for different specimens. However, since all the specimens had this same condition, the relative magnitudes of the quantities of water absorbed would not be out of line.

Another source of error could have been in the preliminary test to determine the extent of the freezing in the specimens. The potential difference across the terminals of the thermocouples was so slight that it was necessary to use a potentiometer to obtain the reading rather than a millivoltmeter. Since the operation of a potentiometer depends on a standard cell, it was necessary to keep the cell at the temperature at which it was standardized. Although the potentiometer was insulated, it is doubtful whether it was sufficient to prevent the cell from changing. However, the difference would be slight and would not be enough to invalidate the conclusion that only the faces of the specimens were frozen.

Results

The following table shows the amount of water absorbed by the specimens in a fifty minute test period. It was noted after a few tests had been run, that in instances where there was a relatively large water absorption, most of it had been absorbed during the first thirty minutes. As soon as this fact was discovered, the readings were made at 30 and 50 minutes and recorded as follows:

Absorption (cc.)

Cycle		Cement #1	Cement #2	Cement #4	Lime-Cement #6	Lime-Cement #8	Lime-Cement #10
Initial	30 min.	—	—	—	—	—	—
	50 min.	0	0	0	0	0	0
Third	30 min.	—	2.5	—	—	0	—
	50 min.	3.1	3.6	2.4	.3	0	1.4
Sixth	30 min.	20.0*	12.4	—	.7	0	—
	50 min.	21.7*	14.1	2.8	.8	0	1.4
Ninth	30 min.	13.0	9.0	.3	0	0	.4
	50 min.	14.0	10.2	.5	0	0	.6

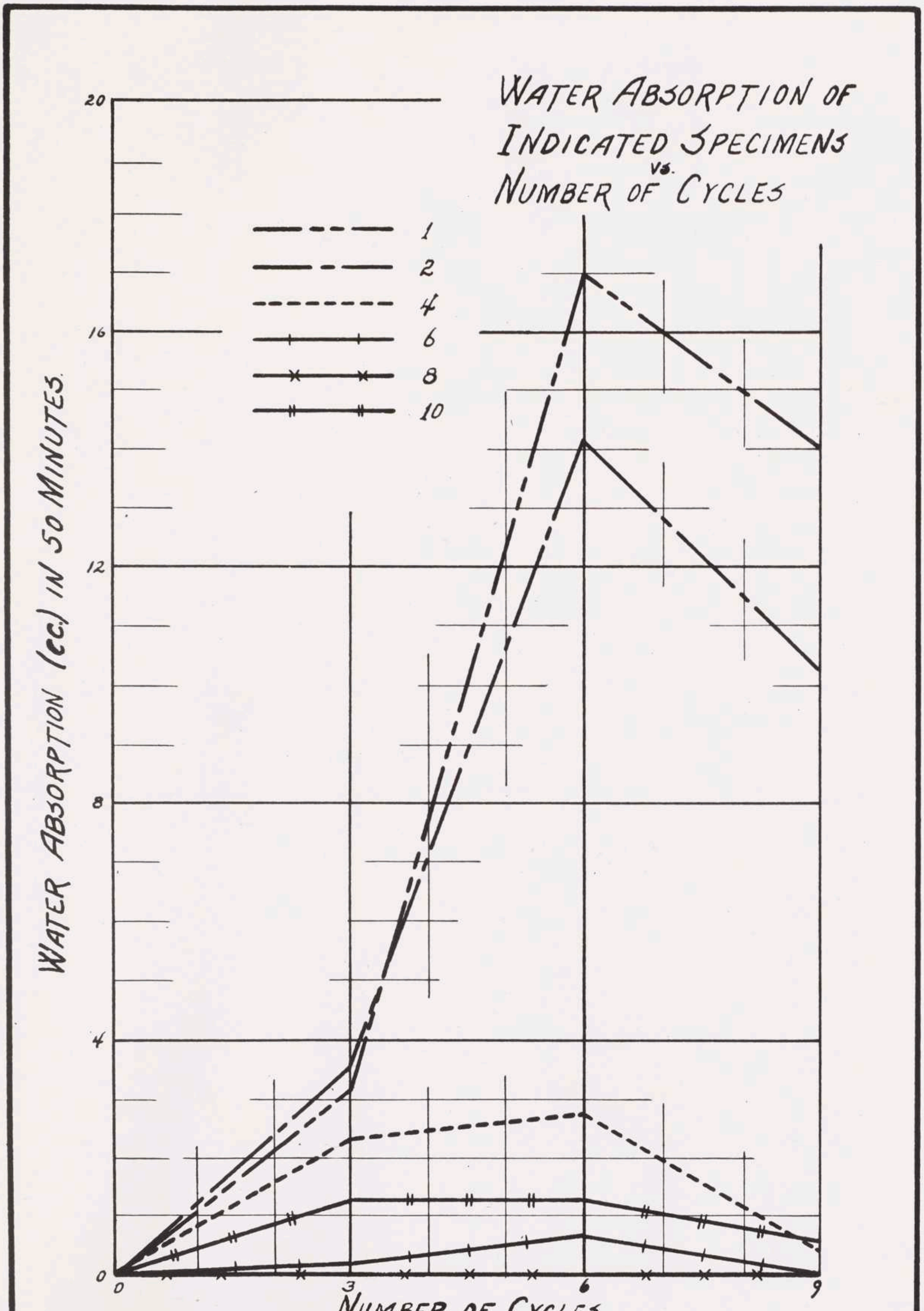
* The water absorption apparatus leaked slightly at the start of this test. It was estimated that approximately 5cc were lost before the leak was stopped.

Graph #1 is a line graph showing the amount of water each specimen absorbed as indicated by the water absorption test. Graph #2 shows the range of water absorptions in the two types of specimens at the end of the third, sixth, and ninth cycles.

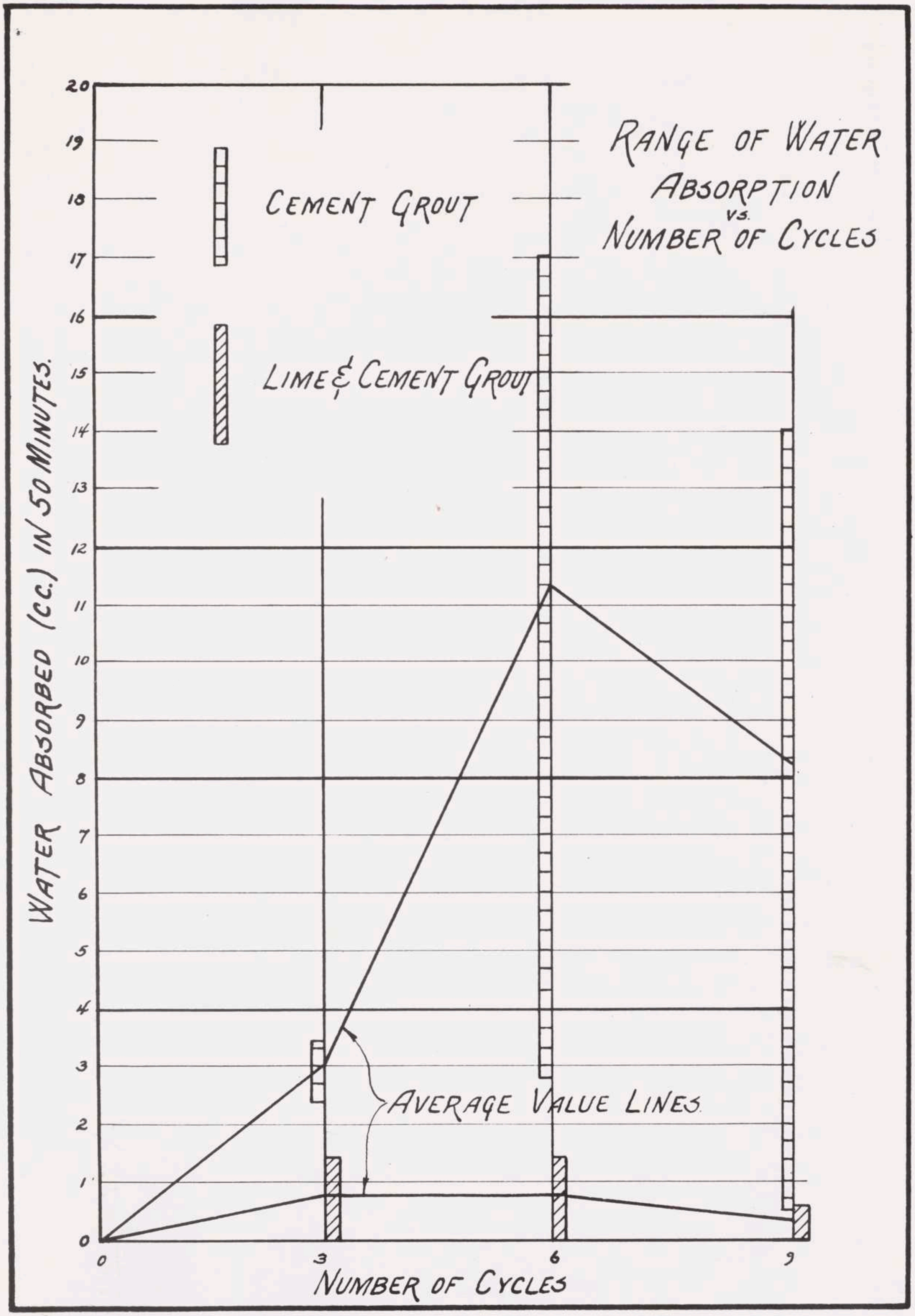
An examination of Graph #1 shows that all the specimens, except #8, took in an increasing amount of water during the absorption test until the end of six cycles. At the end of nine cycles, however, all specimens showed a decrease in water absorption.

This decrease might be explained as follows: during the first portion of the testing period, the water planes enlarged, but not to such an extent that the thawing, heating, and cooling portions of the cycles could not completely evaporate the water taken in. The water absorption test would then indicate the actual extent of the opening of the joints. If, however, the joints opened to such an extent that all the water taken in could not evaporate, the absorption test would not indicate the actual conditions since the water already in the joints would allow less water to enter and give a smaller absorption reading, which would be misleading if taken alone.

From Graph #2, two very noticeable differences between the two types of specimens are apparent. The range of water absorption in the cement specimens is much


WATER ABSORPTION OF
INDICATED SPECIMENS
vs.
NUMBER OF CYCLES
1
2
4
6
8
10
20
16
12
8
4
0
WATER ABSORPTION (cc.) IN 50 MINUTES
0
3
6
9
NUMBER OF CYCLES

GRAPH 1


Range of Water
Absorption
vs.
Number of Cycles
Cement Grout
Lime & Cement Grout
Water Absorbed (cc.) in 50 Minutes.
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Average Value Lines.
0
3
6
9
Number of Cycles

Graph #2

greater than in the lime specimens, and the plot of the average values for the absorption shows a consistently higher absorption for the cement specimens. Since all of the specimens had been made using the same setting and pointing mortars, and the only variable in the specimens was the grout, the difference in absorption must be due to this variable.

The regenerative property of the lime mortar and grout could be the explanation of the difference in the range of values for absorption. The effect of autogeneous healing can be quite largely discounted, since this effect is very slight if the rupture occurs as long after the initial set as was the case in this work.

One effect, unaccounted for, is that, while two of the cement specimens showed relatively great absorption, one of the specimens, #4, showed very little. An examination of this specimen itself did not disclose any reason for the lower water absorption.

As a sidelight, and not intended as a regular portion of the thesis, the glazed surface of specimen #2 was tested before the tests began with the ink used in the recording thermometer attached to the moist room. This test did not show the presence of any crazing. After the ninth cycle was completed, the surface was again tested and there was still no evidence of surface crazing.

Conclusions

After an examination of the results, and from observations made during the conduct of the tests, the conclusion was reached that a grout mixture of lime and cement resulted in a more watertight joint than is obtained using a straight cement grout where the wall face is subjected to alternate extremes of temperatures and humidity.

Recommendations for Further Study

In light of the ultimate goal of the work, these tests should be carried on in a much more extensive series of tests to determine the durability and weathertightness of the units.

Since most cities have in their atmosphere, dust and smoke which, when dissolved in water, form weak acids, it would be well to study the effect of testing these specimens using a mild acid solution in the wetting cycle. Along this line, it would be interesting to study the effects of salt spray on the joints of the masonry units as might be encountered along the coastal portions of the United States.

From an examination of the joints of the specimens tested, it was concluded that the watertightness of the joints would be affected by the grain size of the sand used in the pointing and setting mortars. This effect should be investigated to determine optimum size and fineness modulus.

Another factor that should be investigated is the method of anchoring the tile face to the wall proper. The necessity of using such a complicated system of hooks and anchors is questionable. While this does not affect the joint tightness directly, it is an important part of the erecting procedure, and if it could be simplified, the net result would be a better wall.