NATIONAL BUREAU OF STANDARDS REPORT

4839

Tests of "Precision Building System" Masonry

by

J. O. Bryson, L. F. Skoda, and D. Watstein

Report to
Federal Housing Administration

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Abstract

Masonry walls of precision molded hollow concrete masonry units constructed by a grouting method were tested for compressive strength, drying shrinkage, heat transfer properties and water permeability. The concrete masonry units known as "Precision Block" contained expanded shale aggregates.

The average compressive strength of three walls was 37.1 kips/ft or 387 psi on the gross area of the walls. The average drying shrinkage of a grouted wall 8 ft long was 0.0103 percent while the shrinkage of a similar wall having conventional mortar joint was 0.0057 percent. The thermal transmittance u was 0.25 and the corrected thermal transmittance U was 0.28. (See text for definitions of u and U).

A specimen of Precision Block masonry subjected to a water permeability test received a rating of "Very Poor." The method of test and the rating system were those described in BMS Report 95.

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1. INTRODUCTION

Whenever new materials or methods of construction are introduced, it is important that the relative properties of their end products as regards to present standards be examined. One such new method of construction has been introduced by the Precision Building System, Inc., of Canton, Ohio. This method makes use of precision molded concrete masonry units of lightweight aggregate so designed that when set up as a wall the units interlock and provide a continuous system of vertical and horizontal apertures to receive a grout mix which serves to bond the units in the wall.

At the request of the Federal Housing Administration, testing of "Precision Building System" masonry walls was performed by the Structural Engineering Section of the Division of Building Technology. The test program included the following:

3 compressive strength tests,
2 shrinkage tests,
1 water permeability test.

A test of the heat transfer properties of one wall was also made in the laboratories of the Heating and Air Conditioning Section.

2. MATERIALS

The Precision Building System, Inc., furnished all materials and constructed the wall specimens with the exception of one shrinkage specimen which was constructed with 3/8 in. mortar joints by a qualified mason.

Precision Block with expanded shale aggregate were used in construction of all wall specimens. The general features of the 8- by 8- by 16-in. block are shown in figure 1, and the physical properties are given in table 1. The properties of the blocks were determined in accordance with Federal Specification SS-C-621, and the blocks met the requirements for load-bearing units.

A grout of creamy consistency containing air-entraining portland cement, hydrated lime and a mortar sand "A" was used in bonding the test walls. The grout was proportioned by volume in the ratio of 1:0.5:3 and had a water-cement ratio of approximately 0.75. The sieve analysis of the sand "A" used in the grout mix is given in the following table:

Sieve Analysis of Sand "A"

Sieve No.	Percent Passing
4	100
8	100
16	91
30	77
50	58
100	34
200	19

It is noted that the fineness modulus of sand "A" was 1.14.

A sample of the grout mix was taken during the grouting of each wall specimen and the properties of the grout in the respective walls are given in table 2. The dry densities and compressive strengths of the grout were determined with 2 in. cubes. The grout cubes were aged under the same conditions as the corresponding wall specimens and were tested at the age of 28 days.

The mortar which was used in the construction of a shrinkage wall specimen having conventional 3/8-in. joints was proportioned in the ratio of 1:0.15:3, by weight, but the sand was a coarser sand designated as sand "B". The sieve analysis of sand "B" was as follows:

Sieve No.	Percent Passing
8	100
16	86
30	69
50	37
100	10

The consistency of the mortar used in the conventional wall was adjusted in accordance with the mason's wishes. The water-cement ratio in this mix was 0.46 and the average compressive strength was 2080 psi.

3. CONSTRUCTION OF WALL SPECIMENS

The dimensions and the numbers of the various test walls constructed are given in the following table:

Description of Test Wall	Dimensions, in.		
	Thickness	Height	Length
2 - thermal transmittance test	8	108	64
3 - compression test	8	96	48
1 - drying shrinkage test, grouted construction	8	40	96
1 - drying shrinkage test, conventional joints	8	41	98
1 - permeability test	8	48	40

The general procedure for constructing the wall specimens by the Precision Building System method called for the first course of the wall to be laid in a full bed of mortar. After the mortar in the base course hardened, the remaining courses were set up to the specified height, and sheet metal channels were placed over the ends of the wall and held in place with metal strapping. The grout was then pumped into the walls through holes provided in the top course. A view of the grouting operation and the view of sheet metal bulkheads are shown in figures 2 and 3.

The shrinkage specimens illustrated in figure 4 were constructed so as to permit unrestrained shrinkage in each of their five courses (see HHFA Research Paper 34 for a detailed description of the unrestrained shrinkage walls). The thermal, compression and permeability specimens were constructed on 12-in. channels to facilitate handling and were transported to the appropriate laboratories by means of an electric fork lift truck.

The thermal specimens were faced on the cold surface with two coats of cement base paint. The base coat consisted of high-early strength portland cement and sand passing a No. 40 sieve. The mix was proportioned in the ratio of 1:2 1/2, by weight. The second coat consisted of a cement-water paint proportioned in the ratio of 1 part cement to 0.6 parts of water, by weight. Both coats were applied with a fender brush.

In the preparation of the permeability specimen, a mortar parging approximately 3/8 in. thick was applied on top and on each end of the wall to prevent the escape of an appreciable amount of air or water through these surfaces.

The Precision Block which were used in the construction of both shrinkage test walls were conditioned in a constant temperature room in which the shrinkage tests were conducted, for a period of 20 days. During this period the relative humidity varied from 22 to 35 percent. The moisture content in the units was checked at intervals and at the time the walls were constructed the moisture content was 14.1 percent of total absorption in the grouted wall units and 13.2 percent in the conventional wall units. These two walls were constructed on March 29 and April 4, 1956, respectively. Prior to the construction of the shrinkage wall specimens, the end blocks for each course of the walls were selected for the establishment of reference points to measure the linear changes of the walls along each course. The units were selected from a group stored in the constant temperature laboratory. A hole, approximately 1 in. in diameter and

2 to 3 inches deep, was drilled at the center point of the appropriate end of each unit using a masonry drill. Cold rolled steel and brass bars, 3/4 in. in diameter and 5 inches long were cemented in the holes with a neat cement paste. After the installation of the gage plugs the units were returned to the constant temperature laboratory for conditioning with the rest of the Precision Block.

4. TESTING PROCEDURE AND RESULTS

4.1 Compressive test

The specimens were tested at the age of 28 days in a 600,000 lb capacity hydraulic testing machine. A plaster cap was placed between the platen of the machine and the steel channel at the base of the wall to insure a full bearing area. The loads were applied to a steel plate covering the top of the specimen. The top course consisted of specially cut blocks having a flush surface. A plaster cap was used between the top of the wall and the steel plate. The load was applied uniformly through a 1- by 1- by 50-in. steel bar placed between the steel plate and the loading beam along a line parallel to the inside face, and one-third the thickness of the specimen from the inside face.

The specimens were alternately loaded and unloaded, the load increments being 5 kips up to a load of 10 kips, 10 kip increment up to a load of 20 kips, and 20 kip increments thereafter until failure occurred. Readings of all gages were taken at each load and succeeding zero load. Figure 5 shows a specimen in the testing machine prior to test.

The apparatus used to measure the vertical shortening consisted of four compressometers attached to the face of the specimen near each corner. The lateral deflection was measured at each end of the specimen with a dial gage attached to a free hanging straight edge that was restrained from lateral motion at the bottom. The measuring devices used in the compressometers and deflectometers were 0.001-in. micrometer dial gages. The measuring devices can be seen in place in figure 5.

4.1.1 Results

The results of the compressive tests are presented graphically in figures 6 and 7. It is noted that the data in these figures are given only up to loads of 120 kips; the measuring devices were removed after this load to avoid damage to the apparatus. The compressive strengths of the three walls tested were 140, 134.5, and 171 kips. The average for the three walls was 37.1 kips per foot, or 387 psi on the gross area of the walls. Wall No. 1 was .0547 in. at 120 kips with a shortening set of .0056 in. The average lateral deflection was .0736 in. at 120 kips with a lateral set of .0242 inches.

In the test of Wall No. 1, cracks on the tension side of the specimen were first seen at a load of 120 kips. Failure was evidenced at 140 kips when the load began to fall and cracks were noticed at the second course from the top on the compression side of the west end. Upon destruction, an examination of the wall was made, and it was found that a single air space was filled with grout to a height of six courses from the bottom at the east end of the wall. Similar filling of an air space was noted at the west end of the wall to a height of four courses from the bottom.

The average shortening of Wall No. 2 was .0715 in. at 120 kips with a shortening set of .0119 inches. The average lateral deflection was .0913 in. at 120 kips with a lateral set of .0408 inches. Spalling cracks were visible in the top two courses at the 120 kip load. Upon destruction and examination of this wall no grout was noticed in any of the air spaces.

The average shortening of Wall No. 3 was .0922 in. at 120 kips with a set showing an elongation of .0011 inches. The average lateral deflection was .0621 in. at 120 kips with a lateral set of .0179 inches. Cracking was first noticed on the tensile side of the specimen at 40 kips with compression spalling first seen at 115 kips. The top four courses were completely sheared off on the compression side at failure as shown in figure 8. Upon destroying this wall a visual examination revealed that three of the four air spaces on the west end were filled with grout to a height of five courses. It is believed that the filling of these air spaces with grout accounts for the significantly greater strength attained by Wall No. 3 compared with the other two walls.

4.2 Shrinkage tests

The shrinkage test consisted of comparing the drying shrinkage of two walls five courses high and about 8 ft long. One

wall was constructed by the grouting method and the other was constructed with conventional 3/8 in. mortar joints. Both walls, constructed 6 days apart, were exposed to the same drying condition in a constant temperature room. During the first 54 days of exposure, the relative humidity varied from 24 to 36 percent, while the temperature was maintained at 75 ± 3° F. During the remainder of the drying period of 120 days, the controls of the temperature and humidity in the laboratory were somewhat erratic and the relative humidity fluctuated from 33 to 49 percent.

In addition to the drying shrinkage measurements on the two 8 ft walls, shrinkage was also determined on three individual units from a saturated condition to equilibrium with air in the same laboratory. These auxiliary tests were made in order to estimate the effective increase in the moisture content of the masonry units resulting from the excess water in the grout being absorbed by the masonry.

The masonry units used in the wall specimens were conditioned for about 20 days in the laboratory. At the time of construction, moisture contents of 14.1 percent of total absorption for the grouted wall and 13.2 percent for the conventional wall were determined.

4.2.1 Instrumentation in measurement of shrinkage

The instrument used in the measurement of length changes in the walls is shown in figure 9. The instrument consists essentially of a frame equipped with a pointed support of hardened steel at one end and a 0.0001-in. micrometer dial gage at the other end. The frame consisted of two 2 1/2 in. thin wall steel tubes joined rigidly with a welded brace at one end and held together with an adjustable brace at the other end. The pointed leg at one end of the comparator was seated in a 1/16 in. hole drilled in a suitable steel or brass reference point embedded in the end block of each course. The other end of the comparator carried a micrometer dial which made contact with a machined face of a steel or brass reference point embedded in the other end block of each course. The dial gage had a spherical contact point. In order to secure coincidence of the gage contact point with the center point of the reference plug and to assure reproducible readings with the instrument, provision was made to support the comparator in the same position relative to each reference plug by means of a yoke which bore on the reference plug and cradled the two tubes of the comparator. A partial view of this arrangement is shown in figure 4. The comparator was checked against a standard bar

made of a steel tube. The length changes in the individual masonry units were measured with a 10-in. Whittemore gage. Two gage lines were installed on each unit.

4.2.2 Results of shrinkage tests

The shrinkage-time relationship of the two wall specimens is shown in figure 10, and each value of shrinkage plotted is the average of the shrinkage on each course of the respective walls. It will be noted that the grouted wall expanded about 0.001 percent and remained close to that value for several days before exhibiting any shrinkage, whereas the conventional wall indicated shrinkage by the first length change measurement. The first set of readings with comparator was obtained when each wall was one day old. The maximum recorded values of shrinkage were 0.0103 percent and 0.0057 percent for the grouted and conventionally constructed walls, respectively. Comparison of the drying shrinkages of the two walls shows that the excess water in the grout causes the grouted wall to shrink 0.0046 percent more than the conventionally constructed wall.

The results obtained with individual units are shown in figures 11 and 12. The drying shrinkage of the block from a saturated condition (3 days in water at $73^\circ \pm 2^\circ$ F) to equilibrium in the laboratory air, was 0.033 percent. Figure 12 gives the relationship between moisture content and shrinkage. It is noted that the shrinkage of the individual units dried in an oven at 220° F for 48 hr was 0.0694 percent.

4.3 Thermal transmittance test

The heat transfer measurements were made in the NBS Rotatable Guarded Hot-Box apparatus. The hot box apparatus conforms substantially to the requirements of ASTM C-236-54T, "Method of Test for Thermal Conductance and Transmittance of Built-Up Sections by Means of the Guarded Hot Box" (Tentative).

One specimen designated as thermal Wall No. 2 was tested in a vertical position. Thermocouples were attached to each face at ten points for measurement of the surface temperatures over the central area of the wall, 32 in. wide and 60 in. high. A layer of caulking compound about 1/4 in. deep and approximately 1 1/2 in. wide was placed along the periphery of this area to assure an air tight seal with the gaskets of the metering box of the test apparatus.

During a test, heat flowed from the metering and guard boxes, (see fig. 13) which were heated electrically to the same temperature, to the cold box which was cooled by a refrigerating machine. The electric energy supplied to the metering box was closely equivalent to the heat energy transferred through the area of the specimen covered by the metering box. The energy so supplied was measured with an integrating watthour meter; and this measurement, converted to Btu and divided by the time, the area, and the temperature difference, yielded the heat-transfer coefficient for the specimen.

By means of the guard box, the space surrounding the metering box was maintained at substantially the same temperature as its interior. This minimized heat exchange to or from the metering box except through the specimen and subjected the face of the specimen not covered by the metering box to air at the same temperature as that in the metering box. The measured heat input to the metering box was corrected for any actual small heat interchange that occurred, during the test, between the metering box and the surrounding guard box by utilizing an apparatus calibration factor and the measured difference of temperature, as determined from 10 series-connected differential thermocouples with the junctions of each pair cemented opposite each other in grooves in the surfaces of the metering box.

The top, two vertical, and bottom edges of the specimen projection beyond the guard, and cold boxes, were heavily insulated to minimize heat gain or moisture condensation from the laboratory air.

To promote uniformity of temperature, the air within the boxes was circulated through the baffle spaces adjacent to the test specimen, by means of electric fans. The air velocities were about 40 to 90 ft/min on the warm and cold sides, respectively. The energy used by the fan in the metering box was included in the measurement of the total energy supplied to the metering box.

Air and specimen-surface temperatures were measured by copper-constantan thermocouples in conjunction with a potentiometer. A recording potentiometer was used for approximate measurements of the interior temperatures of the boxes and the surfaces of the test specimen during the period preceding each test when the apparatus was being brought to the steady temperature conditions required for the test.

In the test, the temperatures in the cold box was approximately 0° F and that in the metering and guard boxes was about 70° F. After a steady state of heat flow was attained, the heat transmission of the specimen, indicated by the rate at which electric energy was supplied to the metering box, was observed. The heat transfer measurement was made for an area 32 in. wide and 60 in. high, centrally located on the face of the specimen covering a representative section of the wall. Thermocouples on the warm and cold faces of the wall were located so as to measure the temperatures of the surfaces at points opposite the air cells, near the joints, and opposite the grout fill.

4.3.1 Results

The heat transfer characteristics of the specimens, based on the observations, were as follows:

Observed thermal transmittance, u	0.25
Corrected thermal transmittance, U	0.28
Thermal conductance, C	0.36
Warm surface conductance, f_i	1.32
Cold surface conductance, f_o	2.08

Temperature averages, °F	Warm side	Cold side
air	72.1	-0.6
surface*	58.4	8.1

*Arithmetic average of all ten temperatures on each surface of tests area.

The definitions of u, U, and C, representing the various coefficients of heat transmission are:

u = number of Btu per hour transmitted through each square foot of specimen for each degree F difference in temperature between the air on the two sides, as observed under the test conditions.

U = u corrected for a 15-mph wind outside and still on inside by means of the surface conductances f_i = 1.65 and f_o = 6.00, taken from the ASHAE Guide.

C = number of Btu per hour transmitted through each square foot of specimen for each degree F difference in temperature between the surfaces of the two sides as observed under test conditions.

4.4 Water permeability test

The wall specimen subjected to the permeability test is shown in figure 14. The specimen was constructed entirely of Precision Block grouted in the regular manner, except that the base course consisted of one course of clay building brick to permit installation of flashings and provide a wall of proper height. The manner of installation of the flashings, the testing procedure and the performance ratings are described in Building Materials and Structures Report BMS95.

4.4.1 Results

The wall specimen was rated "Very Poor" on the basis of the following ratings of performance:

Excellent (E) - No water visible on back of the wall (above the flashings) at the end of 1 day. Not more than 25 percent of the wall area damp at the end of 5 days. No leaks through the wall in 5 days.

Good (G) - No water visible on the back of the wall at the end of 1 day. Less than 50 percent of the wall area damp at the end of 1 day. No leaks through the wall at the end of 1 day.

Fair (F) - No water visible on back of the wall during first 3 hours, but visible at end of 1 day. The rate of leakage through the wall less than 1 liter/hr at the end of 1 day.

Poor (P) - Water visible on back of the wall in 3 hr or less and at the end of 1 day. Rate of leakage less than 5 liters/hr at the end of 1 day.

Very Poor (VP) - Rate of leakage through the wall equal to or greater than 5 liters/hr at the end of 1 day.

The detailed results obtained in the permeability test are given below:

Duration of test	Time to fail as indicated by			Area damp at end of test	Maximum leakage per hour		Rating
	Damp through wall	Leak through wall	Leak through facing		Through wall	Through facing	
days	hr	hr	hr	percent	liters	liters	
1	0.067	0.1	0.1	83	74	18	Very poor

5. SUMMARY

Specimens of "Precision Building System" masonry were tested to determine the following properties:

Compressive strength
Drying shrinkage
Water permeability
Thermal transmittance

The average maximum load supported by the three 4- by 8-ft wall tested in compression was 37.1 kips/ft or 387 psi on the gross area of the walls. The ratio of the compressive strength of the walls to that of masonry units was 0.276.

The drying shrinkage of the grouted wall five courses high and 8 ft long exposed to laboratory air for a period of about 120 days was 0.0103 percent, while the shrinkage of a companion wall constructed with conventional 3/8 in. joints was 0.0057 percent. Visible cracks developed in the vertical joints of the top three courses of the conventional wall several days after construction and it is quite probable that the shrinkage of this wall would have been somewhat greater had the cracks not occurred.

The water permeability specimen received a rating of "Very Poor" in accordance with the performance ratings described in the Building Materials and Structures Report BMS95.

The heat transfer characteristics of the 5- by 9-ft wall having two coatings of cement-water paint on the cold side and tested in the NBS Rotatable Guarded Hot-Box apparatus, were as follows:

Observed thermal transmittance, u	0.25
Corrected thermal transmittance, U	0.28
Thermal conductance, C	0.36
Warm surface conductance, f_i	1.32
Cold surface conductance, f_o	2.08

Temperature Averages, °F	Warm side	Cold side
air	72.1	-0.6
surface*	58.4	8.1

*Arithmetic average of all ten temperatures on each surface of test area.

The definitions of u, U, and C, representing the various coefficients of heat transmission, are:

u = number of Btu per hour transmitted through each square foot of specimen for each degree F difference in temperature between the air on the two sides, as observed under the test conditions.

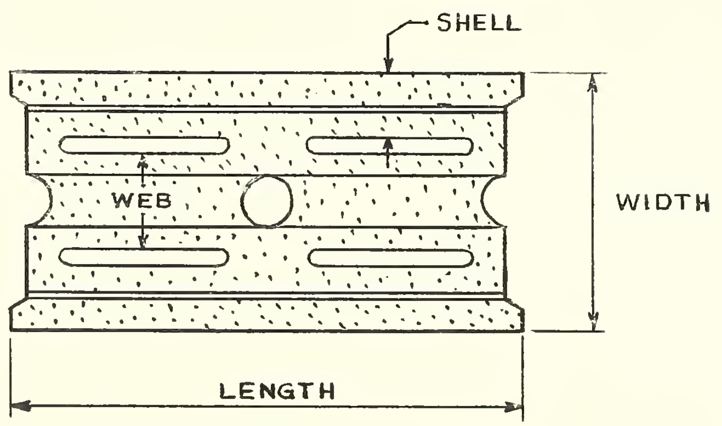
U = u corrected for a 15-mph wind outside and still on inside by means of the surface conductances $f_i = 1.65$ and $f_o = 6.00$, taken from the ASHAE Guide.

C = number of Btu per hour transmitted through each square foot of specimen for each degree F difference in temperature between the surfaces of the two sides as observed under test conditions.

Table 1. Physical Properties of "Precision Building System" Masonry Units.

Dimensions, in.						Weight of unit	Weight of concrete	Absorption by 24 hr immersion	Compressive strength	Drying Shrinkage	
Length	Width	Height	Dia. of center hole	Shell thickness	Web thickness					Dried at 220°F	Dried in air
						lb	lb/cu ft	percent	psi		
15.95	7.95	7.95	1.60	1.90	2.65	33.8	82.1	14.1	1400	0.069	0.033

Note: The results reported in this table are based on 3 units.



TOP VIEW

Table 2. Properties of Grout Mix

Walls	Density of mortar lb/cu ft		Air content in fresh mortar, percent	Compressive strength psi 1/
	Fresh	Air dry		
Thermal 1	124.1	113.8	7.2	1050
Thermal 2 2/	123.8	116.6	7.5	1020
Compression #1	125.3	115.8	6.2	1030
Compression #2	123.9	113.2	7.3	1000
Compression #3	124.5	114.3	6.8	960
Shrinkage	124.4	113.8	7.0	1000
Permeability	125.5	117.3	6.2	1530
Average	124.5	115.0	6.9	1080

1/ Compressive strength was determined with 2-in. cubes and the result reported for each wall is the average of 3 cubes.

2/ Thermal wall #2 was the specimen used for the determination of thermal transmittance.

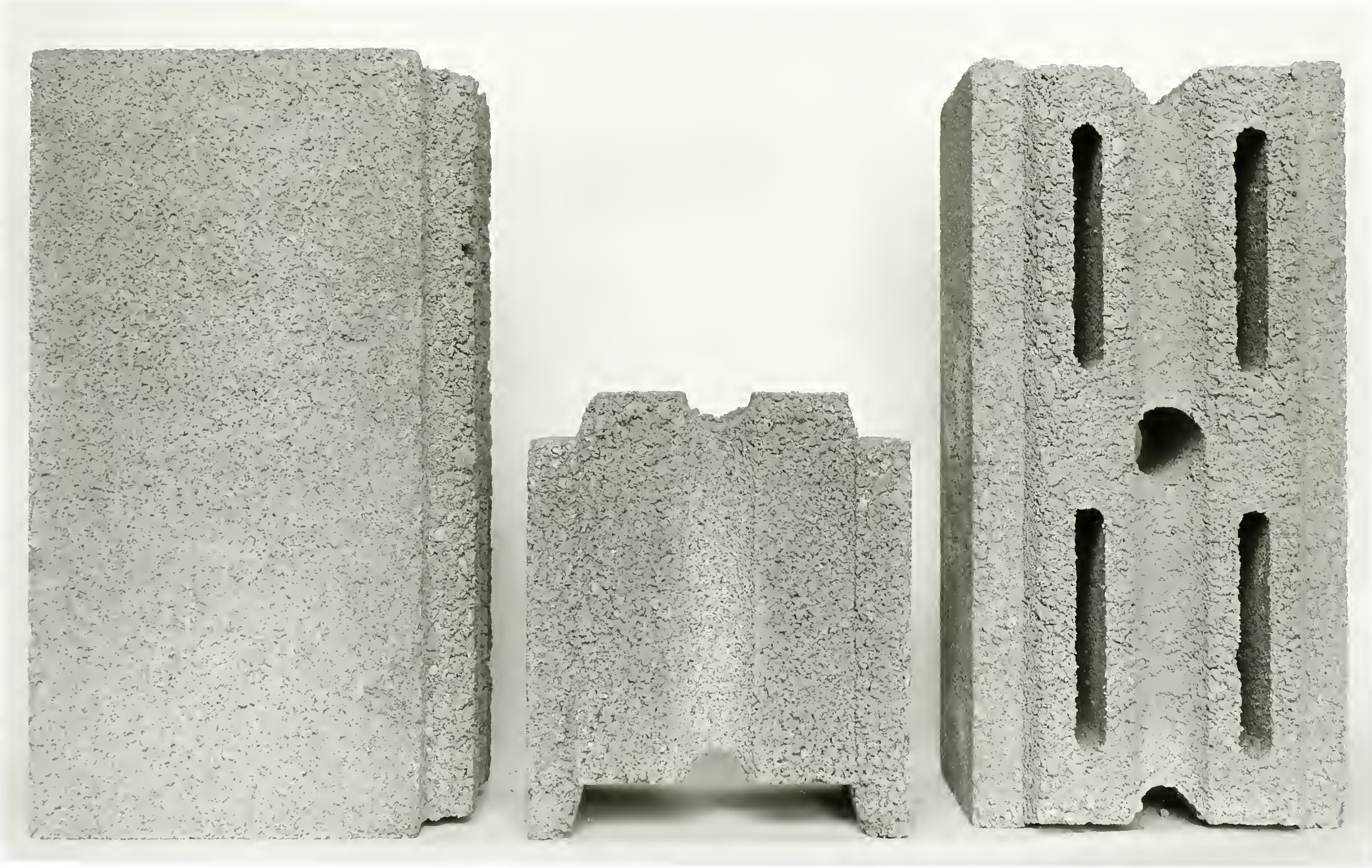


Fig. 1 - View of "Precision Building System" masonry units.

Fig. 2 - View of thermal and compression wall specimens after grouting.

Fig. 3 - View of grouting operation.

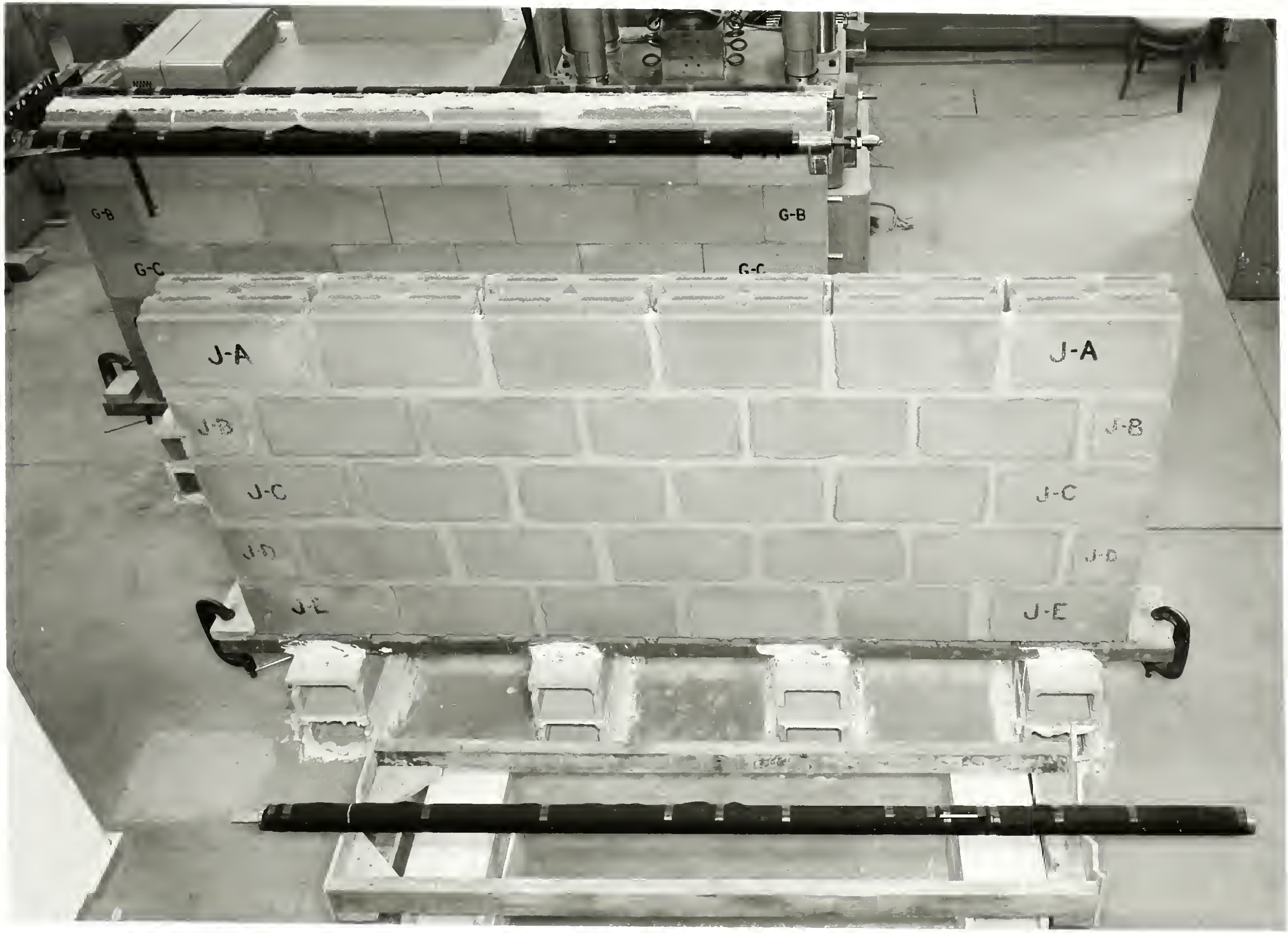


Fig. 4 - View of grouted and conventionally constructed shrinkage test specimens.

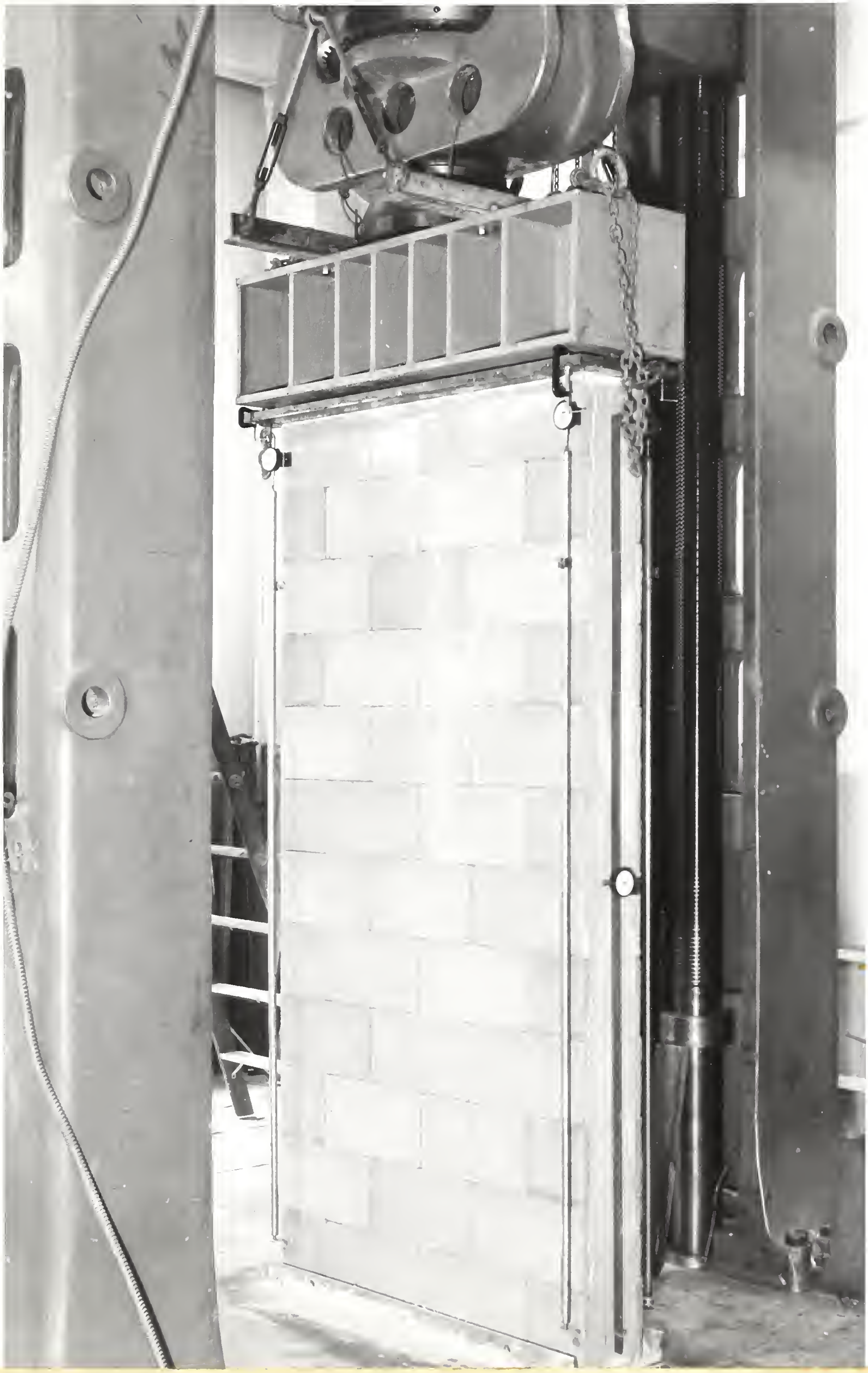


Fig. 5 - View of compressive test specimen in testing machine.

COMPRESSIVE LOAD
VS.
SHORTENING & SHORTENING SET

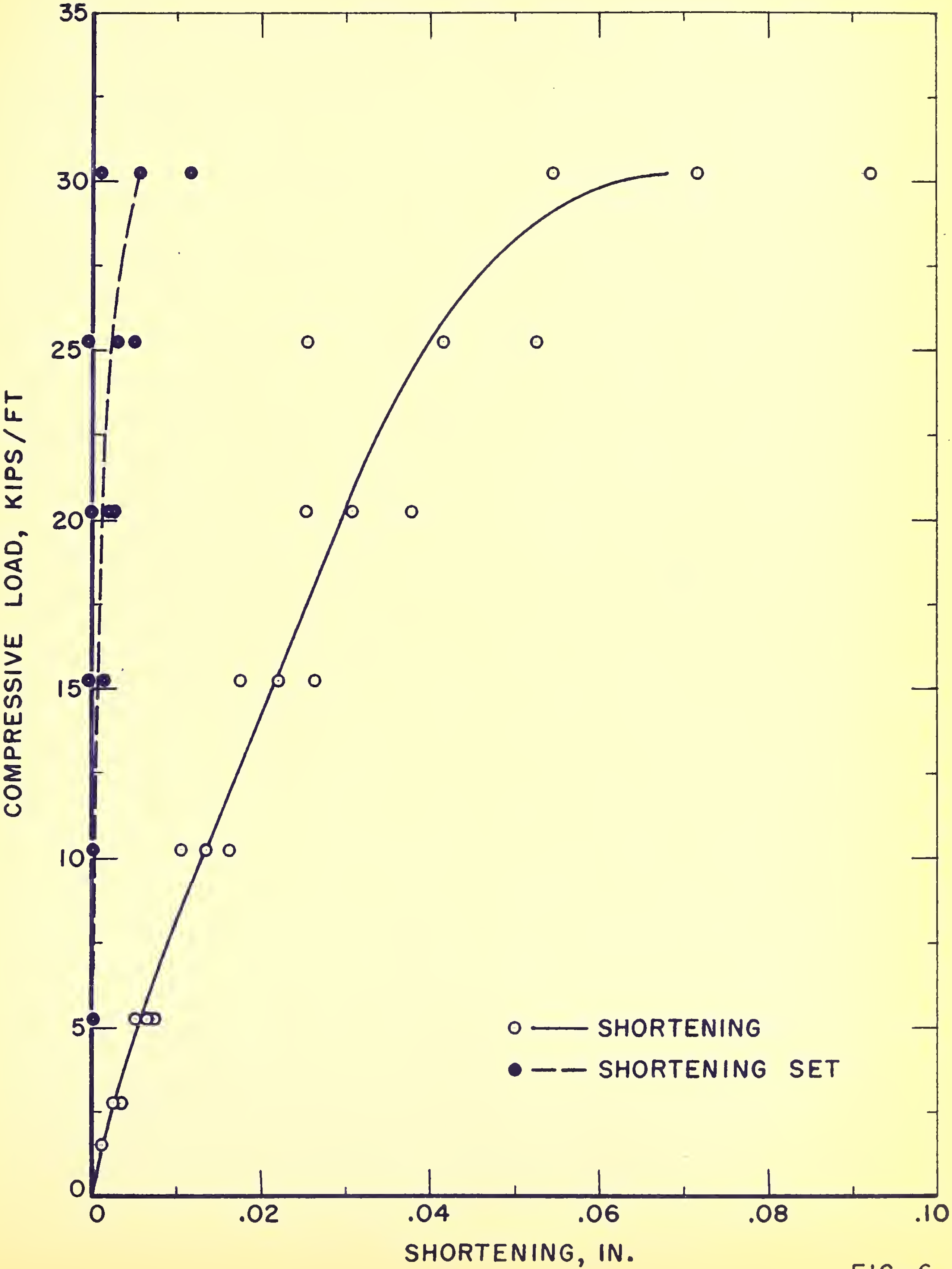


FIG. 6

COMPRESSIVE LOAD
VS.
LATERAL DEFLECTION & LATERAL SET

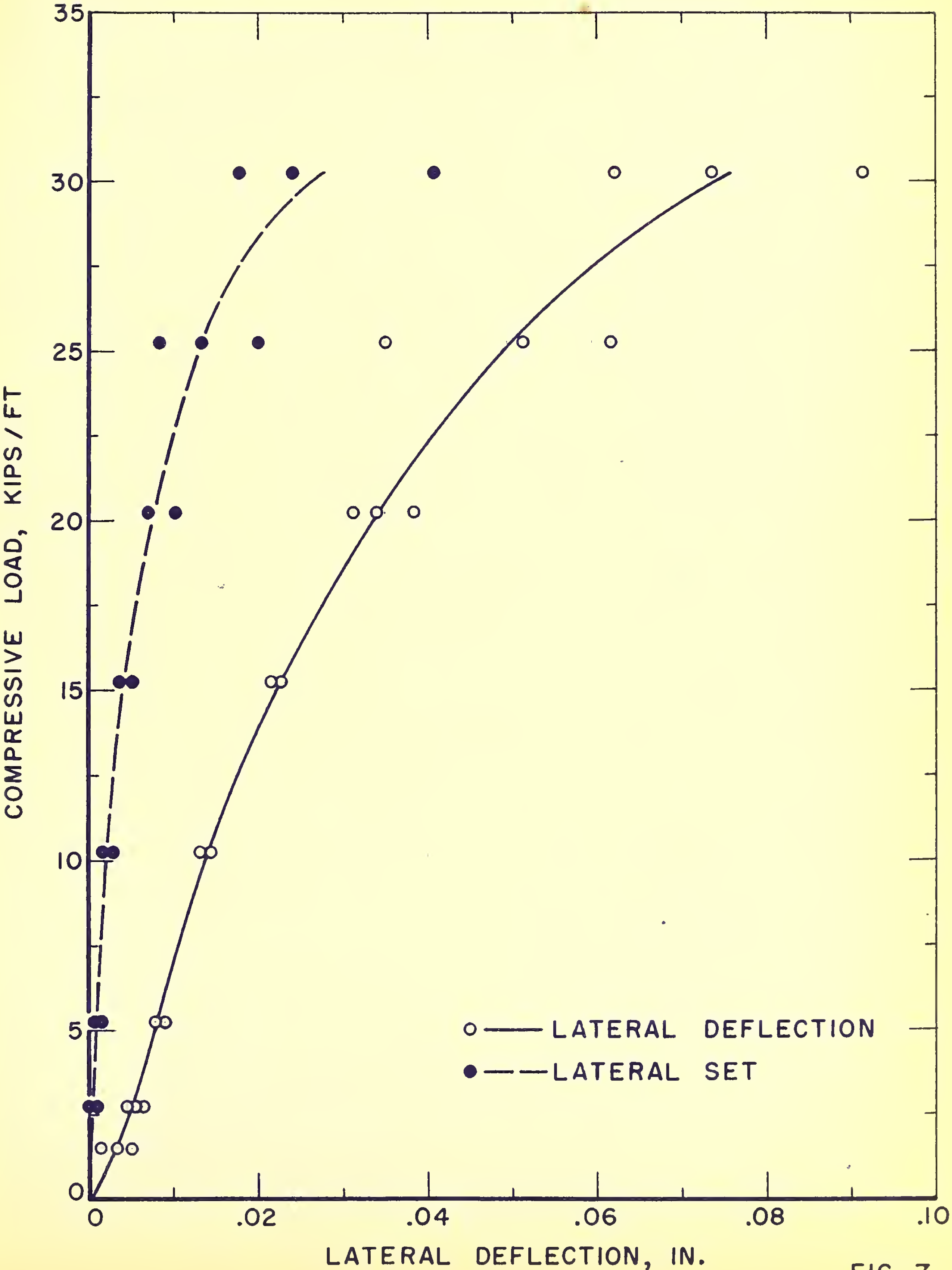


FIG. 7

Fig. 8 - Compression Wall No. 3 after failure.

Fig. 9 - Horizontal comparator used in measuring length changes of shrinkage specimens.

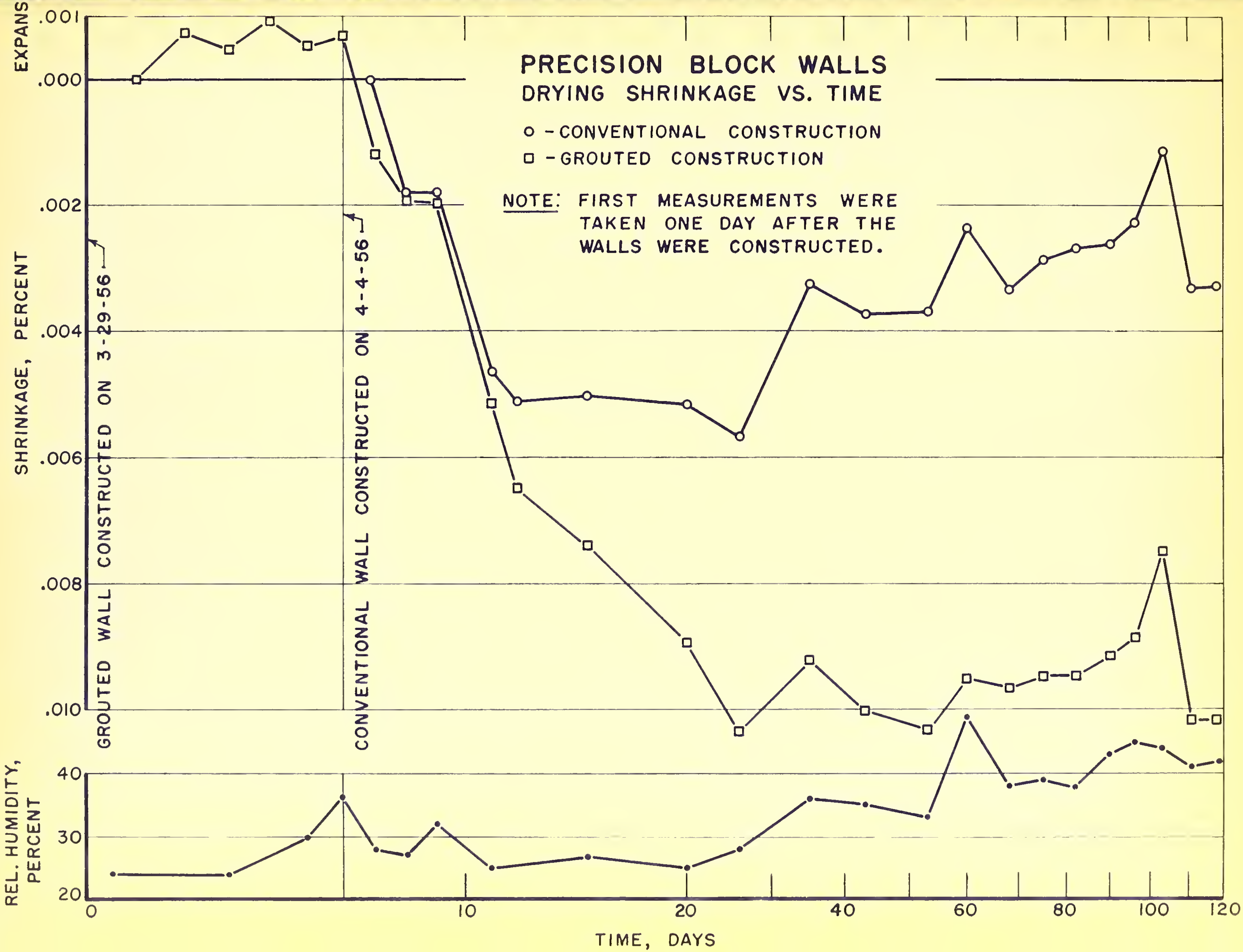

PRECISION BLOCK WALLS
DRYING SHRINKAGE VS. TIME
o - CONVENTIONAL CONSTRUCTION
□ - GROUTED CONSTRUCTION
NOTE: FIRST MEASUREMENTS WERE TAKEN ONE DAY AFTER THE WALLS WERE CONSTRUCTED.
GROUTED WALL CONSTRUCTED ON 3-29-56
CONVENTIONAL WALL CONSTRUCTED ON 4-4-56
EXPANS
SHRINKAGE, PERCENT
.001
.000
.002
.004
.006
.008
.010
REL. HUMIDITY, PERCENT
40
30
20
0
10
20
40
60
80
100
120
TIME, DAYS

FIG. 10

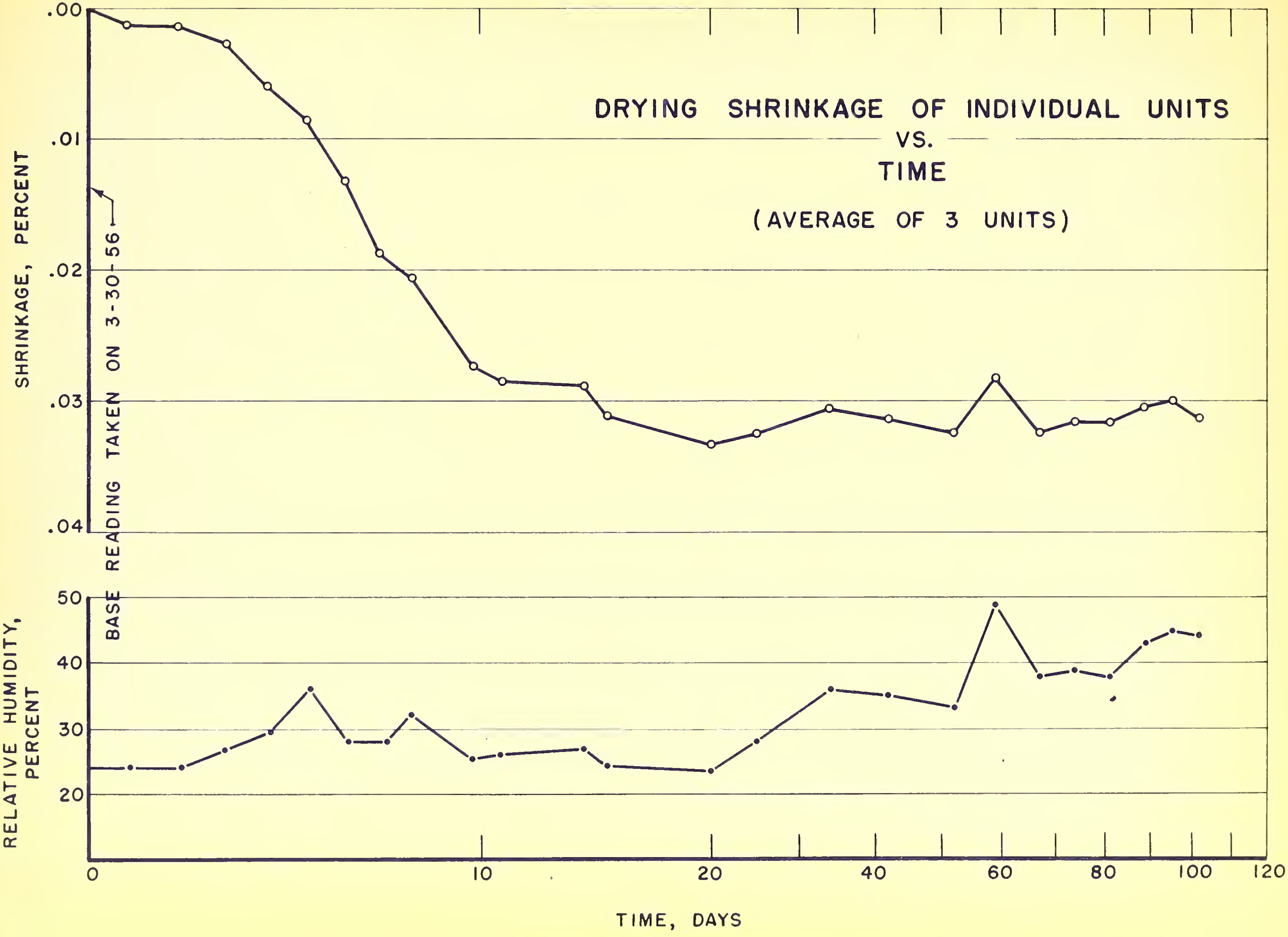

DRYING SHRINKAGE OF INDIVIDUAL UNITS
VS.
TIME
(AVERAGE OF 3 UNITS)
SHRINKAGE, PERCENT
.00
.01
.02
.03
.04
BASE READING TAKEN ON 3-30-56
RELATIVE HUMIDITY, PERCENT
50
40
30
20
0
10
20
40
60
80
100
120
TIME, DAYS

FIG. 11

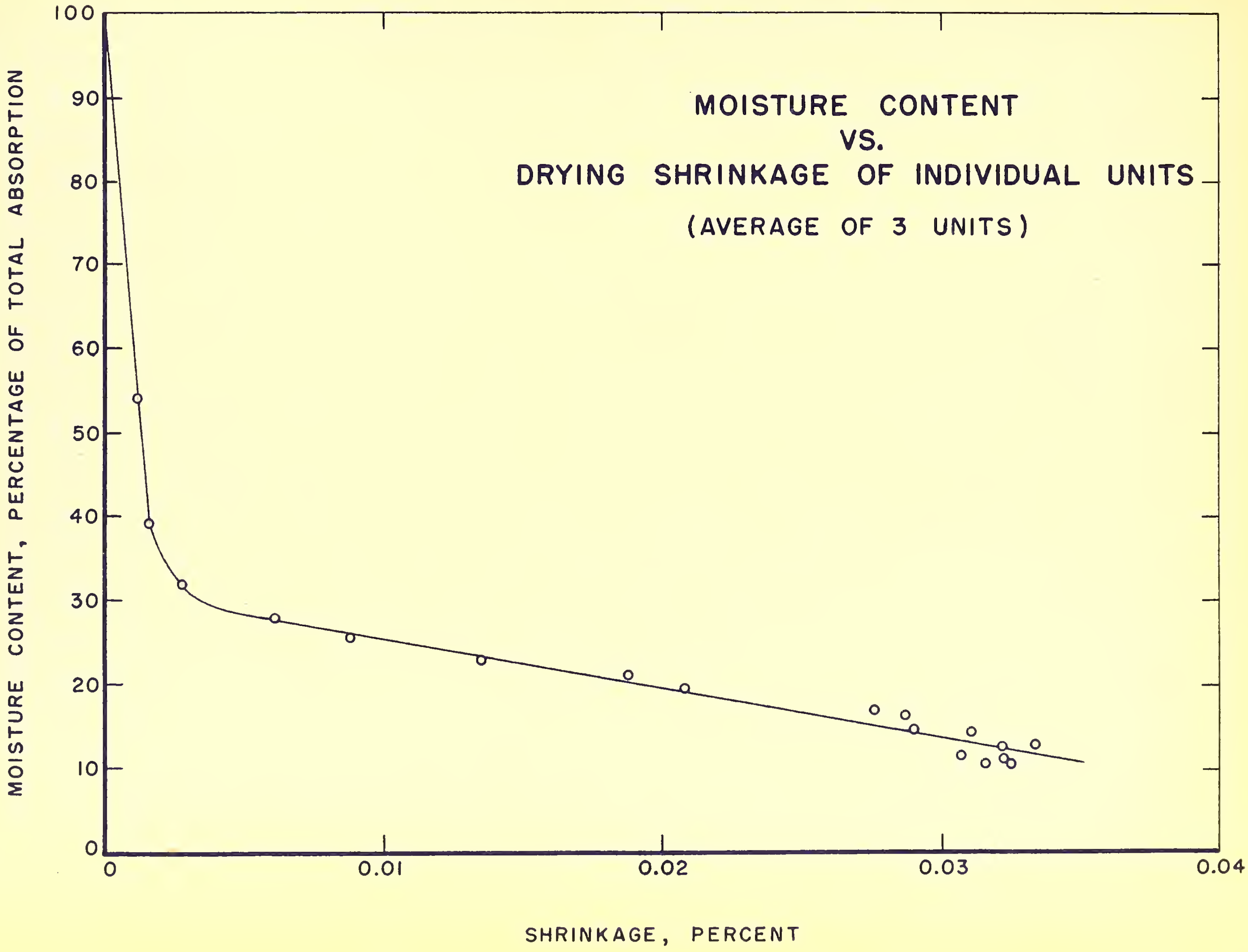
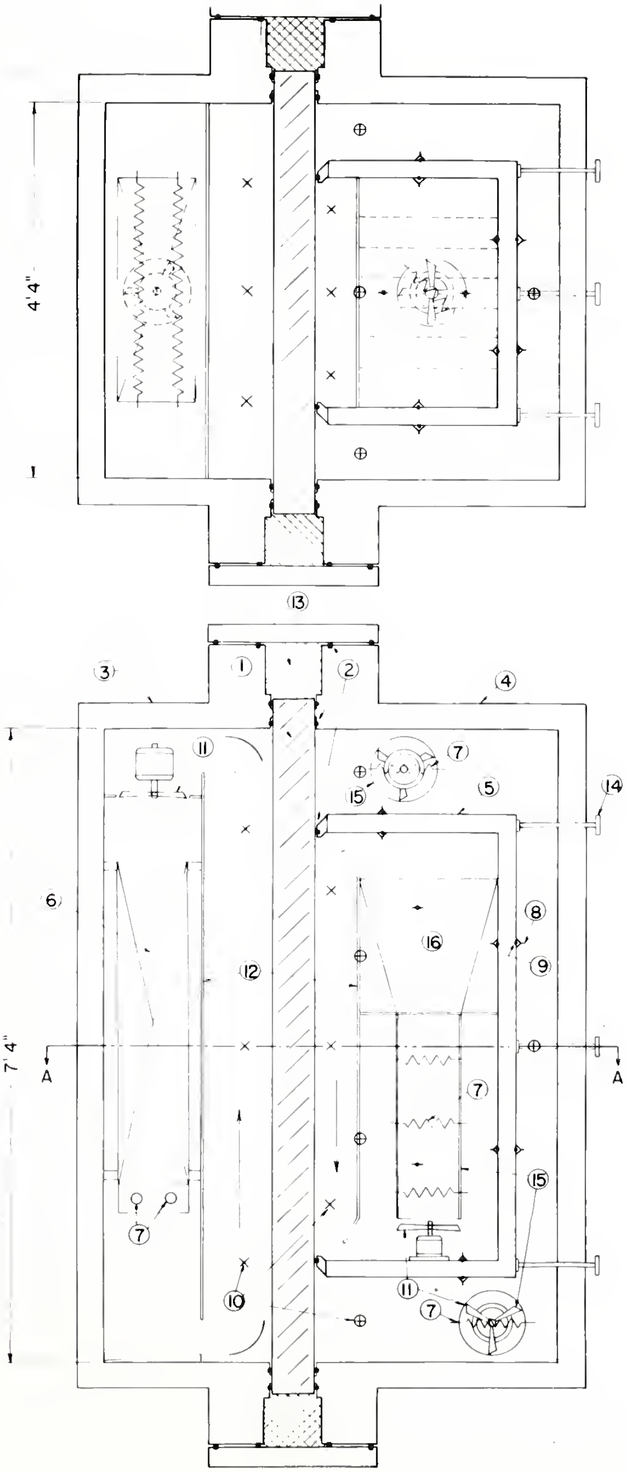

MOISTURE CONTENT
VS.
DRYING SHRINKAGE OF INDIVIDUAL UNITS
(AVERAGE OF 3 UNITS)
MOISTURE CONTENT, PERCENTAGE OF TOTAL ABSORPTION
SHRINKAGE, PERCENT
0
10
20
30
40
50
60
70
80
90
100
0.01
0.02
0.03
0.04

FIG. 12



① TEST PANEL
② RUBBER GASKETS
③ COLD BOX
④ GUARD BOX
⑤ METER BOX
⑥ REFRIGERATING COIL
⑦ ELECTRIC HEATERS
⑧ AIR COMPOUND THERMOCOUPLES
⑨ SURFACE COMPOUND THERMOCOUPLES
⑩ AIR TEMPERATURE THERMOCOUPLES
⑪ AIR CIRCULATING FANS
⑫ BAFFLES
⑬ EDGE INSULATION
⑭ COMPRESSION SPRING HANDWHEELS
⑮ HEATER DUCTS
⑯ METER HEAT DIFFUSER

Fig. 13 - Diagram of metering and guard boxes used for the thermal transmittance determination.

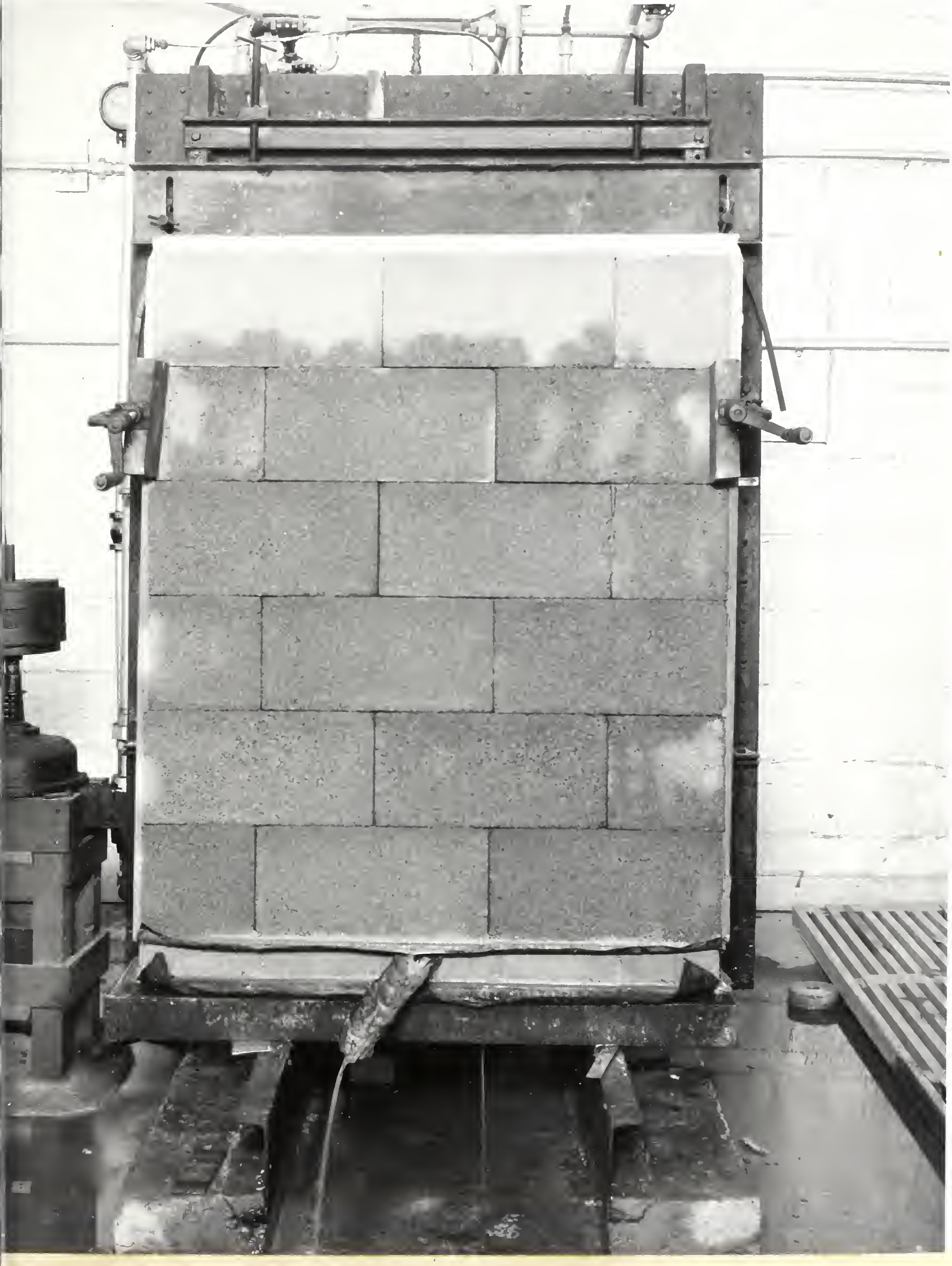


Fig. 14 - Permeability wall after 24 hours of testing.

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