NATIONAL BUREAU OF STANDARDS REPORT

5428

VOLUME-CHANGE TESTS OF MASONRY MATERIALS
USED AT CHINCOTEAGUE NAVAL AIR STATION

by

L. E. Cattaneo and D. Watstein

Report to
Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Abstract

In order to determine the cause of severe cracking in brick walls at Chincoteague Naval Air Station, laboratory specimens of brick masonry were constructed of materials from the same source as those used in original walls which exhibited cracking. Specimens of masonry and of component materials were observed for volume changes caused by moisture content variation induced by normal curing and by cyclic soaking and drying. Mortar specimens exhibited ordinary contraction and expansion with drying and soaking. Slight expansions were observed in masonry and brick specimens during certain drying periods. Results are discussed and presented in graphic and tabular form.

1. INTRODUCTION

During construction of an infirmary building at Naval Air Station, Chincoteague, Virginia, under Contract NOy 91316, it was observed that severe cracking had occurred in certain areas of the brick-faced cast concrete foundation walls. In order to obtain data which might help determine the cause of such cracking, samples of the masonry materials were submitted to the National Bureau of Standards for testing.

Photographs on file at the Bureau of Yards and Docks under Code D-231 show that cracks developed both in the concrete foundation and in the mortar joints of its brick facing. The cracks had an appearance which indicated a relative movement between concrete and masonry that could be attributed to excessive shrinkage of the concrete or excessive expansion of the masonry. Since this observation pointed to volume change as

the property of major interest it was planned to investigate the effect of moisture on various combinations of the materials submitted.

2. SPECIMENS AND TESTS

The samples received from the Naval Air Station Public Works Office at Chincoteague, Virginia, consisted of one bag of masonry cement, three cu ft of masonry sand, and 130 cored clay facing brick. These materials were used to prepare the volume-change specimens listed in Table 1 which shows their designation and treatment.

Brick wall specimens and accompanying mortar specimens were made for long term observation of volume change during air-curing after construction. Small 3-course masonry assemblages and additional mortar specimens were made for observation of volume change caused by oven-drying. Individual brick specimens were prepared for observation of volume change caused by soaking followed by (1) normal drying, (2) oven-drying, and (3) autoclaving. These tests consumed a period of 102 days designated as Phase I. During an additional period of 63 days, designated as Phase II, all specimens were observed for volume change caused by cyclic soaking and drying. Tests were begun on November 8, 1956, and were terminated on April 22, 1957.

Table 1. Schedule of Test Specimens

Type of specimen	Designation of specimen	Treatment (by days) (*End of Phase I)
Wall	W-1	Fabricated; air-dried 102. * Oven-dried 7, immersed 7; air dried 42.
Wall	W-2	Fabricated; air-dried 102. * Immersed 7; air-dried 21; immersed 7; air-dried 28.
Wall	W-3	Fabricated; air-dried 102. * Immersed 7; oven-dried 7, air-dried 42.
3-course assemblage	A-1	Fabricated;moist-cured 28, air-dried 7; oven-dried 5; air-dried 62. * Oven-dried 7; immersed 7; air-dried 42.

Table 1. Schedule of Test Specimens (continued)

Type of specimen	Designation of specimen	Treatment (by days) (*End of Phase I)
3-course assemblage	A-2	Fabricated; moist-cured 28; air-dried 7; oven-dried 5; air-dried 62. * Immersed 7; air-dried 21; immersed 7; air-dried 28.
3-course assemblage	A-3	Fabricated; moist-cured 28; air-dried 7; oven-dried 5; air-dried 62. * Immersed 7; oven-dried 7; air-dried 42.
Mortar	M-1	Molded; treatment same as for W-1.
Mortar	M-2	Molded; treatment same as for W-2.
Mortar	M-3	Molded; treatment same as for W-3.
Mortar	M-4	Molded; treatment same as for A-1
Mortar	M-5	Molded; moist-cured 28; air-dried 7; oven-dried 5; air-dried 9; therm.coeff. determ. and autoclav. test 21; oven-dried 7; air-dried 25. *
Mortar	M-6	Molded; treatment same as for A-3
Brick	B-10	Immersed 5; air-dried 10; oven-dried 5; air-dried 62. * Oven-dried 7; immersed 7; air-dried 42.
Brick	B-20	Immersed 5; air-dried 10; oven-dried 5; air-dried 23; autoclav. test 7; oven-dried 7;air-dried 25. * Oven-dried 7; immersed 7; air-dried 42.
Brick	B-30	Immersed 1; air-dried 9; oven-dried 5; air-dried 9; thermal coeff. determ. and autoclav. test 21; oven-dried 7; air-dried 25. * Immersed 7; oven-dried 7; air-dried 42.
Brick	B-40	Immersed 1; air-dried 9; oven-dried 5; air-dried 62. * Immersed 7; oven-dried 7; air-dried 42.

3. MATERIALS

3.1 Cement

One bag of North American Corporation Blue Bond Masonry Cement which had been in storage at the construction site since August 10, 1956, was received on October 29, 1956, and stored in a dry laboratory. The cement was found to contain lumps as large as 1 inch. Sieving through a #8 mesh sieve eliminated approximately 10 percent of the cement sample. Testing of the cement for flow after suction, autoclave expansion and time of setting showed that it complied with the requirements stated in ASTM Specification C91-55T . (See Table 2).

Table 2. Physical Properties of Cement

Flow after suction, %	82
Autoclave expansion, %	0.08
Time of setting	Satisfactory

3.2 Sand

The masonry sand submitted was received and maintained in a damp, approximately saturated surface-dry condition. Sieve analysis of the sand performed in accordance with ASTM Specifications C136-46 and C117-49 provided the data given in Table 3.

Table 3. Sieve Analysis of Sand

Sieve No.	% Passing (by weight)
4	100
8	100
16	100
30	92
50	54
100	7
200	0.7

3.3 Brick

Clay bricks used in the tests were manufactured by the Roanoke Webster Company at Suffolk, Virginia. Each brick contained 3 cores 1 in. in diam and had average dimensions of 7.90- by 3.65- by 2.25 in. When laid the bricks were damp, having been hosed and allowed to drain in the laboratory for about 20 hours. Physical properties of the bricks determined in accordance with ASTM Specification C67-50 are given in Table 4.

Table 4. Physical Properties of Cored Clay Brick

Dry weight lb/brick	Initial rate of absorption gr/brick/min		Absorption percent		Saturation coefficient	Modulus of rupture psi	Compressive strength psi
	As laid	dry	24-hr cold	5-hr boil			
4.36	9.1	10.6	5.7	8.7	0.64	947	15,980

4. FABRICATION OF SPECIMENS

4.1 Masonry cement mortar

Mortar was hand-mixed and consisted of 1 part cement and 3.7 parts damp sand, by weight; this is equivalent to approximately 1 part cement and 3 parts sand, by volume. The amount of water added was adjusted to the satisfaction of the mason and was about 13 percent by weight of the dry materials. The water-cement ratio was 0.6 by weight, or 0.7 by volume. All specimens of mortar and of masonry construction were fabricated using one batch of mortar without retempering.

Three 2-in. mortar cubes were molded and moist-cured for 24 hr before being removed from the molds and immersed in water for 27 days. The average compressive strength of the mortar cubes in a saturated surface-dry condition at 28 days was 1020 psi.

Six prismatic volume-change specimens of mortar measuring 1- by 1- by 11-in. were cast in steel molds which provided for the embedment of spherical contact reference points in the ends. (See Fig. 1). Molds were designed so that the distance between the innermost ends of the reference inserts (used as the gage length in computations of unit length change) was 10 ± 0.1 in. (cf. ASTM Specification C157-54T). After mortar specimens M-1, M-2, M-3, were air-cured in the molds for 24 hr, they were removed from the molds and exposed to free circulation of laboratory air. Mortar specimens M-4, M-5, M-6, were moist-cured in the molds for 24 hr, then removed, and subjected to immersion curing for an additional 27 days.

4.2 Brick specimens

Four volume-change specimens were prepared by cementing brass gage plugs into pairs of holes in each of two opposite faces of whole bricks (cf. ASTM Specification C341-54T). After moist curing of the portland cement paste in the gage plug holes, a 0.04-in. diam reference hole was drilled in each plug to provide a 5-in. gage length on each brick face. (See Fig.1).

4.3 3-Course assemblages

Three small volume-change specimens of brick masonry construction, approximately 8 in. high and 16 in. long, were fabricated for ease of handling in performing accelerated oven-drying tests. These contained 3-courses of two bricks each and three beds of mortar approximately 1/2 in. thick. (See Fig. 1). Spherical contact reference points were cemented in the ends of the six sawed half-bricks in the middle courses before laying. The distance between the inner-most ends of the reference inserts (used as the gage length) was 14.5 ± 0.1 in. These specimens were air-cured for 24 hr and cured by immersion for 27 days.

4.4 Wall specimens

Three brick walls approximately 2 feet square and one wythe thick were constructed for volume change observation under laboratory conditions. Each of these contained nine courses of three bricks each with horizontal and vertical mortar joints approximately 1/2 in. thick. Before construction, brass plugs were cemented in holes drilled in one face of the necessary whole or sawed half-bricks which, when laid, positioned the plugs as shown in figure 2. Twenty-four hours after fabrication of the walls a 0.04 in. diam reference hole was drilled in

each brass plug so that any vertical or horizontal pair of reference holes determined a 20-in. gage length. Walls were constructed on 1/4- by 2- by 4-in. steel bearing plates resting on 1/2- by 4-in. steel rollers to minimize resistance to movement caused by shrinkage or expansion.

4.5 Joints

All bed and vertical joints in specimens of masonry construction were approximately 1/2 in. thick and were made full. Mortar for bed joints was troweled on and furrowed; mortar for end joints was buttered on edges. Desired joint thickness was obtained by tamping brick and extruding excess mortar. Joints were cut flush with the face of the wall and left untooled. At conclusion of tests, examination of joint interiors in wall specimen W-3 confirmed existance of solid joints.

5. MEASURING APPARATUS

5.1 Balances

One of three balances was used to weigh each of the various specimens to determine moisture content. Choice of balance was governed by proximity of its maximum capacity to weight of specimen. All balances were sensitive to within 0.2 percent or less of the weight of the lightest specimen weighed on them. Mortar specimens and brick specimens were weighed to the nearest 0.5 gram, 3-course assemblages to the nearest 5 grams, and walls to the nearest 0.1 lb.

5.2 Extensometers

Determinations of change in linear dimensions were made with one of four extensometers, all equipped with 0.0001-in. micrometer dials. Mortar specimens having a gage length of 10 ± 0.1 in. were measured with a dial micrometer of the type suggested in ASTM Specification C157-54T. Brick specimens having a gage length of 5 in. were measured with a 5-in. Whittemore strain gage. Small 3-course assemblages having a gage length of 14.5 ± 0.1 in. were measured with the dial micrometer shown in figure 2. Wall specimens having 20-in. gage lengths were measured with a 20-in. Whittemore strain gage. Readings made with all extensometers were estimated to the nearest 0.1 dial graduation and were referred to appropriate Invar standard bar datum readings. Extensometer readings were repeated to obtain a value reproducible within 0.5 dial graduation.

6. PROCEDURE

Fabrication, air-drying, immersion, and observation of specimens took place in a laboratory in which the temperature was normally 72° ± 2° F. However, length change determinations were corrected to 72° F for thermal movement caused by exceptional temperature variations. The coefficient of linear thermal expansion used for this purpose was determined experimentally and found to be $5 \times 10^{-6}/°F$ for both mortar and brick, separately. Variations in laboratory relative humidity were recorded for comparison with corresponding length change data. All oven-drying was done at temperatures between 230°F and 239° F.

Tests were conducted in two phases. During the first period of approximately three months (Phase I) wall specimens were permitted to air-dry undisturbed, being observed for length changes only. All other specimens were observed at intervals for length and weight changes during this period. Analysis of data accumulated during the first three months suggested the need for extended observations of the walls subjected to further tests. During this second period of about two months (Phase II) both length and weight changes were determined for all specimens.

6.1 Phase I

6.1.1 Wall specimens W-1, W-2. W-3 and mortar specimens M-1, M-2, M-3

The treatments of wall and mortar specimens bearing the same identification number were identical. Initial gage lengths were determined after the first 24 hr of curing in laboratory air and were used as bases for all subsequent length changes. Specimens were measured at progressively longer intervals over a total air-drying period of 102 days.

6.1.2 Assemblages A-1, A-2, A-3 and mortar specimens M-4, M-5, M-6

Gage lengths of all six specimens measured at the age of 28 days in a saturated surface dry condition (after 27 days

immersion curing) were used as bases for subsequent length changes. 1/

Specimens A-1, A-2, A-3, M-4, and M-6 were then air-dried for 7 days, oven-dried for 7 days, and air-dried for an additional 62 days.

Similar treatment of mortar specimen M-5 was interrupted during the 62 day period for determination of its coefficient of linear thermal expansion, and autoclave expansion. 2/ The 62 days period for M-5 comprised 9 days of air-drying, 21 days of handling for thermal and autoclave expansion determinations, and 7 days of oven-drying followed by 25 days of air-drying. Specimen M-5 was discarded at the end of Phase I.

6.1.3 Brick specimens B-10, B-20, B-30, B-40

Measurements of all brick specimens were begun 25 days after fabrication of masonry and mortar specimens.

The gage lengths of B-10 and B-20 which were used as bases for subsequent length changes were measured after 5 days immersion. Both specimens were then air-dried for 10 days, and oven-dried for 5 days. B-10 continued to air-dry for 62 additional days while B-20 underwent 23 days air-drying, 7 days handling for autoclaving, 2/ 7 days oven-drying and 25 days air-drying (totalling 62 days).

Base gage lengths of prepared specimens B-30 and B-40 were measured in an "as received" condition prior to 24 hr immersion. Both were then air-dried 9 days and oven-dried 5 days. While B-40 continued to air-dry for 62 days, B-30 received 9 days air-drying, 21 days handling for thermal and autoclave expansion determinations, 7 days oven-drying and 25 days air-drying (totalling 62 days).

1/ Measurements of mortar specimens M-4, M-5, M-6 at the age of 24 hr made possible a calculation of their average expansion (.012%) after 27 days of immersion curing (see Fig. 6). The heavier weight of the assemblages A-1, A-2, A-3, and the method used to measure them (see Fig. 1) made handling at such an early age for comparable measurements seem inadvisable.

2/ Autoclaving procedure used is described in ASTM Specification C151-54.

6.2 Phase II

At the end of Phase I, specimens were subjected to additional cyclic treatment in three groups containing specimens of various types and were measured intermittently for length and weight changes.

6.2.1 Group 1

Wall W-1, assemblage A-1, mortar specimens M-1, M-4, and bricks B-10, B-20, were oven-dried 7 days, immersed 7 days, and air-dried 42 days.

6.2.2 Group 2

Wall W-2, assemblage A-2, and mortar specimen M-2 were immersed 7 days, air-dried 21 days, immersed 7 days, and air-dried 28 days.

6.2.3 Group 3

Wall W-3, assemblage A-3, mortar specimens M-3, M-6, and bricks B-30, B-40 were immersed 7 days, oven-dried 7 days and air-dried 42 days.

7. RESULTS

7.1 Graphs and Tables

Test results of Phase I are recorded in figures 3, 4, 5, 6, 7, and Table 5; test results of Phase II are recorded in figures 8, 9, 10, and Table 6. Graphs show the results of observations made during the entire test period while Tables 5 and 6 present values of special interest.

Tabular values of length changes calculated to the nearest 0.001 percent, and of moisture contents to the nearest 0.1 percent are consistent with the sensitivities of the instruments used to determine them. Length change tabulated as 0, corresponds to a length measurement used as reference for subsequent readings. Degree of saturation tabulated as 0, indicates the first determination of the oven-dry weight (in case of repeated soaking and drying); the percentage of saturation tabulated as 100.0, indicates the first determination of saturated, surface-dry weight.

Values were calculated as follows:

% length change =

$$100 \times \frac{\text{(observed gage length)} - \text{(initial gage length)}}{\text{(initial gage length)}}$$

% saturation =

$$100 \times \frac{\text{(observed weight)} - \text{(first oven-dry weight)}}{\text{(first saturated surface-dry weight)} - \text{(first oven-dry weight)}}$$

% absorption =

$$100 \times \frac{\text{(first saturated surface-dry weight)} - \text{(first oven-dry weight)}}{\text{(first oven-dry weight)}}$$

Positive length changes represent expansion and negative ones, contraction.

7.2 Results of Phase I

Comparison of relative humidities with corresponding length changes is shown graphically in figures 3 through 7.

(a) Walls W-1, W-2, W-3, showed a tendency to expand slightly during initial air-curing. Although movement was more apparent in a vertical direction after 15 days, neither horizontal nor vertical expansion exceeded 0.007 percent in 84 days. (See Fig. 3, Table 5). The difference between the amounts of vertical and horizontal expansions might suggest some relationship to the number of joints included by respective gage lengths.

(b) Mortar specimens M-1, M-2, M-3, which accompanied the walls showed a rapid contraction in the first 6 days which almost equalled their maximum shrinkage of 0.065 percent developed in 70 days. (See Fig. 4, Table 5). However, it should be noted that other investigators 3/ have reported that the shrinkage of mortar

3/ R.E.Davis and G.E.Troxell, "Volumetric Changes in Portland Cement Mortars and Concretes," Proceedings, Am.Concrete Inst. Vol. 25, 1929, and F.O.Anderegg, "Some Properties of Mortar in Masonry," Proceedings, Am. Soc. Testing Materials, Vol.40,1940.

specimens cast in non-absorbent molds exceeds considerably that of mortars left in absorbent molds or between bricks. Furthermore, the contrast between the greater rigidity of brick and that of mortar joints (when comparing both their moduli and cross-sectional areas) readily suggests a reason for the apparent ineffectiveness of shrinking mortar in counteracting expansion of adjoining brick.

(c) Assemblages A-1, A-2, A-3, when oven-dried, exhibited an expansion of 0.014 percent over their saturated condition. This increased to 0.019 percent after 48 days of air-drying. (See Fig. 5, Table 5). In view of the behavior of the separate mortar and brick specimens, (see figures 6, 7, and Table 5), such expansion of assemblages might be attributed to thermal cracks developed during oven-drying which fail to close entirely upon cooling. Cracks within the specimen whose widths totalled 0.002 in. in a specimen gage length of 14.5 in. could account for an apparent expansion of 0.014 percent. The additional 0.005 percent expansion which developed in the assemblages during subsequent air exposure is in good agreement with the expansion exhibited by separate mortar and brick specimens exposed to the atmosphere after oven-drying during the same period.

(d) Mortar specimens M-4, M-5, M-6, which accompanied the 3-course assemblages contracted 0.159 percent with the aid of oven-drying. M-4 and M-6 developed an average contraction of 0.141 percent at equilibrium during subsequent exposure to laboratory air. (See Fig. 6, Table 5). M-5, when autoclaved, showed an expansion of 0.087 percent, (cf. autoclave expansion of masonry cement, 0.08 percent, Table 2).

(e) All brick specimens showed slight expansion during air-drying after soaking, and during air exposure after oven-drying. Bricks B-10 and B-20 when soaked for 5 days contracted less with oven-drying than did B-30 and B-40 which had soaked for only 1 day. (See Fig. 7, Table 5). However, it should be noted that B-30 and B-40 exhibited greater absorption in a shorter soaking period. Average autoclave expansion of B-10 and B-20 was about 0.08 percent. (See Table 5).

7.3 Results of Phase II

Since the primary purpose of Phase II was to observe how length change was affected by extreme moisture content conditions produced in different sequences, relative humidity variation was considered irrelevant and was not plotted in the graphical presentation of data. Values of moisture content which corresponded to significant length changes are given in Table 6. The following limited comments are added to the results presented in figures 8, 9, and 10, for different sequences of soaking, oven-drying, and air-drying.

7.3.1 Groups 1 and 3 (Figures 8, 10, Table 6)

(a) Oven-drying of walls W-1 and W-3 produced apparent expansion. This behavior resembled that of assemblages A-1, A-2, and A-3, when oven-dried during Phase I. Cracks which were visible in these two walls during oven-drying were no longer discernible after cooling. The amount by which vertical movement exceeded horizontal movement was especially noticeable for oven-drying periods indicating a possible joint separation phenomenon. Expansion continued during air-exposure which followed either soaking or oven-drying.

(b) Assemblages A-1 and A-3 contracted with oven-drying and expanded with soaking regardless of sequence. Expansion was exhibited by both specimens during air-exposure after oven-drying or after soaking.

(c) All mortar specimens subjected to soaking and drying in either order developed more contraction than was observed during Phase I.

(d) Autoclaved bricks B-20 and B-30 showed greater contraction by oven-drying than non-autoclaved bricks B-10 and B-40. Expansion occurred during soaking and final air-drying for all bricks.

7.3.2 Group 2 (Fig. 9, Table 6)

(a) Repeated soaking and air-drying of wall W-2 and assemblage A-2 resulted in additional expansion each time.

(b) Mortar specimen M-2 showed expansion by soaking and additional contraction for each drying.

(c) Moisture contents of W-2 and M-2 (Table 6) are necessarily approximate, having been referred to estimated oven-dry weights based on measured properties of similar specimens.

8. SUMMARY AND COMMENTS

During the air-drying period following their construction, brick wall specimens expanded less than 0.01 percent and maintained this condition for the three months during which they were observed. Mortar specimens gave no indication of contributing to such expansion whereas brick specimens exhibited slight expansion during air-drying after soaking and a very substantial moisture expansion (0.078%) during autoclaving. Additional soaking and drying of the masonry and material specimens in various ways indicated that oven-drying of jointed masonry specimens might be too severe a method for determining their volume change characteristics because of the possibility of developing thermal cracks.

In attempting to correlate specimen behavior with that of the original walls in which cracking was first observed it is to be noted that the horizontal expansion exhibited by wall specimens (0.004%), when applied to 100 ft of wall, would account for an increase in length or a crack width of only about 0.05 in. However, alternate soaking and exposure to air as were used in testing specimens of Group 2, Phase II, produced length changes of 0.023 to 0.037 percent (see figure 9); these length changes would produce a horizontal movement of 0.28 to 0.44 in. in a wall 100 ft long and might easily account for the severe cracking observed in the brick walls at Chincoteague Naval Air Station. At the same time, it should be remembered that any such relative movements or separations might be augmented by the shrinkage of a supporting concrete foundation.

The expansion of both the wall specimen and assemblage (W-2 and A-2) resulting from alternate wetting and exposure to air suggests that individual brick specimens should exhibit similar behavior. This behavior was indeed observed in two brick specimens (B-10 and B-20) which showed an expansion following both a period of soaking and during a lengthy period of drying in laboratory air. While the expansion of individual brick was less than that of the wall and assemblage, it is believed that the length changes in both cases could be attributed to moisture expansion of the clay body of the brick. It will be recalled that the average moisture expansion of two samples of brick (B-20 and B-30) when autoclaved for 3 hr at 295 psi was 0.078 percent.

The somewhat greater vertical movement observed in brick wall specimens (see figure 9) may be attributed to the greater number of joints in that direction and the possibly greater number of invisible interface separations along horizontal joints.

Table 5. Results of Phase I

Walls W-1, W-2, W-3

Time, days a/	1	15	84	102
Avg. horiz. length change, %	0 (base)	+0.004	+0.005	+0.002
Avg. Vert. length change, %	0 (base)	+0.004	+0.007	+0.005

Mortar M-1, M-2, M-3

Time, days a/	1	6	70	102
Avg. length change, %	0 (base)	-0.058	-0.065	-0.065
Avg. % saturation	31.0	4.7	2.3	1.7

Assemblages A-1, A-2, A-3

Time, days	(water) 28	+7 (air) 35	+5 (oven) 40	+48 (air) 84	+18 (air) 102
Avg. length change, %	0 (base)	+0.004	+0.014	+0.019	+0.018
Avg. % saturation	100.0 (7.9% absorp.)	34.0	0	1.9	1.9

a/ In air only.

Table 5. Results of Phase I (continued)

Mortar M-4, M-5, M-6

Time, days	(water) 28	+7 (air) 35	+5 (oven) 40	+62 (air) b/ 102
Avg. length change, %	0 (base)	-0.114	-0.159	-0.141
Avg. % saturation	100.0 (11.5% absorp.)	18.1	0	7.0
Autoclave expansion (M-5) = +0.087%				

Bricks B-10, B-20

Time, days	(air) a/ 20	+5 (water) 25	+10 (air) 35	+5 (oven) 40	+62 (air) c/ 102
Avg. length change, %		0 (base)	+0.002	0.000	+0.002
Avg. % saturation		100.0 (5.5% absorp.)	1.5	0	0.0
Autoclave expansion (B-20) = +0.069%					

Bricks B-30, B-40

Time, days	(air) a/ 25	+1 (water) 26	+9 (air) 35	+5 (oven) 40	+62 (air) d/ 102
Avg. length change, %	0 (base)	-0.001	+0.003	-0.004	-0.001
Avg. % saturation		100.0 (6.1% absorp.)	3.8	0	0.0
Autoclave expansion (B-30) = +0.087%					

a/ stored in laboratory
b/ M-4, M-6 only
c/ B-10 only
d/ B-40 only

Table 6. Results of Phase II

Group 1

Time, days		102[a]	+7 (oven) 109	+7(water) 116	+28 (air) 144	+14 (air) 158
Wall W-1	Avg. horiz. length change,%	+0.004	+0.012	+0.021	+0.030	+0.029
	Avg. vert. length change,%	+0.004	+0.039	+0.047	+0.058	+0.056
	% saturation	4.4	0	100.0 (7.4% absorp.)	24.6	15.8
Assemb. A-1	Length change,%	+0.019	+0.011	+0.025	+0.037	+0.037
	% saturation	2.0	0.0	93.6	10.3	7.2
Mortar M-1	Length change,%	-0.066	-0.115	-0.070	-0.142	-0.143
	% saturation	5.2	0	100.0 (12.2% absorp.)	14.3	14.3
Mortar M-4	Length change,%	-0.142	-0.192	-0.108	-0.166	-0.169
	% saturation	7.3	0.0	102.9	17.6	17.6
Brick B-10	Length change,%	+0.002	0.000	+0.004	+0.014	+0.015
	% saturation	0.0	0.0	103.0	0.0	0.0
Brick B-20 previously autoclaved	Length change,%	+0.069	+0.057	+0.060	+0.068	+0.068
	% saturation	2.5	1.7	102.5	2.5	2.5

a/ cf. Phase I

Table 6. Results of Phase II (Continued)

Group 2

		102[a]	+7(water) 109	+21(air) 130	+7(water) 137	+21(air) 158	+7(air) 165
Wall W-2	Avg. horiz. length change, %	+0.002	+0.011	+0.015	+0.018	+0.023	+0.020
	Avg. vert. length change, %	+0.004	+0.017	+0.026	+0.026	+0.032	+0.030
	% saturation	5.2	100.0 (7.5% absorp.)	31.0	107.8	30.2	25.9
Assembl. A-2	Length change, %	+0.019	+0.024	+0.029	+0.032	+0.037	+0.035
	% saturation	1.9	91.9	16.7	95.7	20.1	15.8
Mortar M-2	Length change, %	-0.066	-0.047	-0.124	-0.096	-0.137	-0.136
	% saturation	0	100.0 (10.6% absorp.)	14.9	113.5	20.9	20.9

a/ cf. Phase I

Table 6. Results of Phase II (Continued)

Group 3

	Time, days	102[a]	+7(water) 109	+7(oven) 116	+28(air) 144	+14(air) 158
Wall W-3	Avg. horiz. length change,%	+0.002	+0.011	+0.013	+0.023	+0.023
	Avg. vert. length change,%	+0.006	+0.022	+0.059	+0.064	+0.063
	% saturation	1.7	100.0 (7.5% absorp.)	0 (base)	1.7	1.7
Assembl. A-3	Length change,%	+0.016	+0.022	+0.017	+0.029	+0.029
	% saturation	1.8	95.1	0.0	0.4	0.4
Mortar M-3	Length change,%	-0.062	-0.034	-0.122	-0.101	-0.104
	% saturation	0.0	100.0 (10.3% absorp.)	0 (base)	9.1	9.1
Mortar M-6	Length change,%	-0.141	-0.102	-0.189	-0.152	-0.153
	% saturation	6.6	85.5	0.0	10.5	14.5
Brick B-30 previously autoclaved	Length change,%	+0.083	+0.088	+0.070	+0.080	+0.080
	% saturation	0.0	130.0	0.0	0.0	0.0
Brick B-40	Length change,%	-0.001	+0.002	-0.005	+0.004	+0.004
	% saturation	0.0	124.0	0.0	0.0	0.0

a/ cf. Phase I

Fig. 1. Brick-, mortar-, and assemblage-type volume change specimens shown with extensometer used to measure the assemblages.

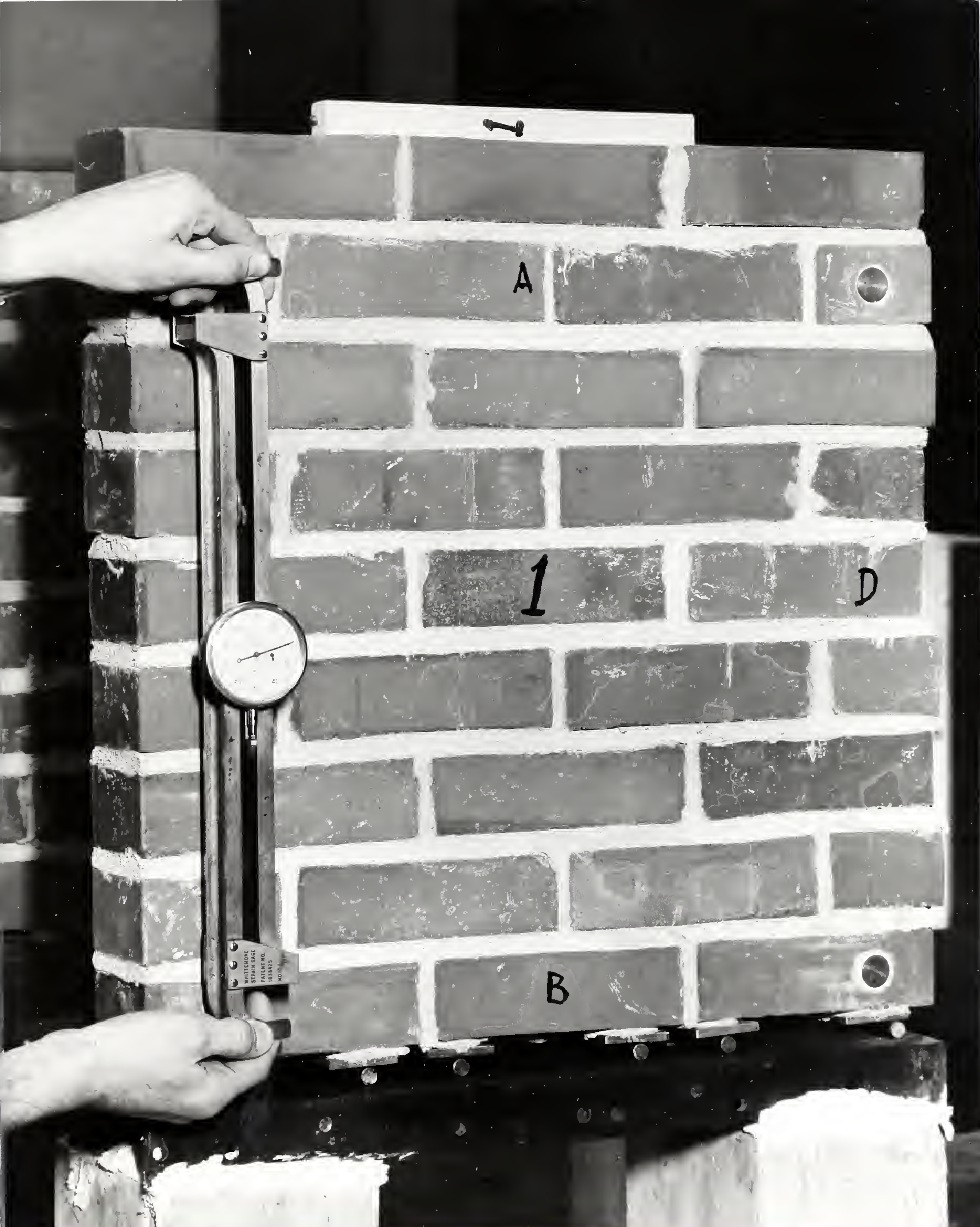

Fig. 2. Typical wall volume-change specimen being measured for vertical length change with 20-inch Whittemore strain gage.

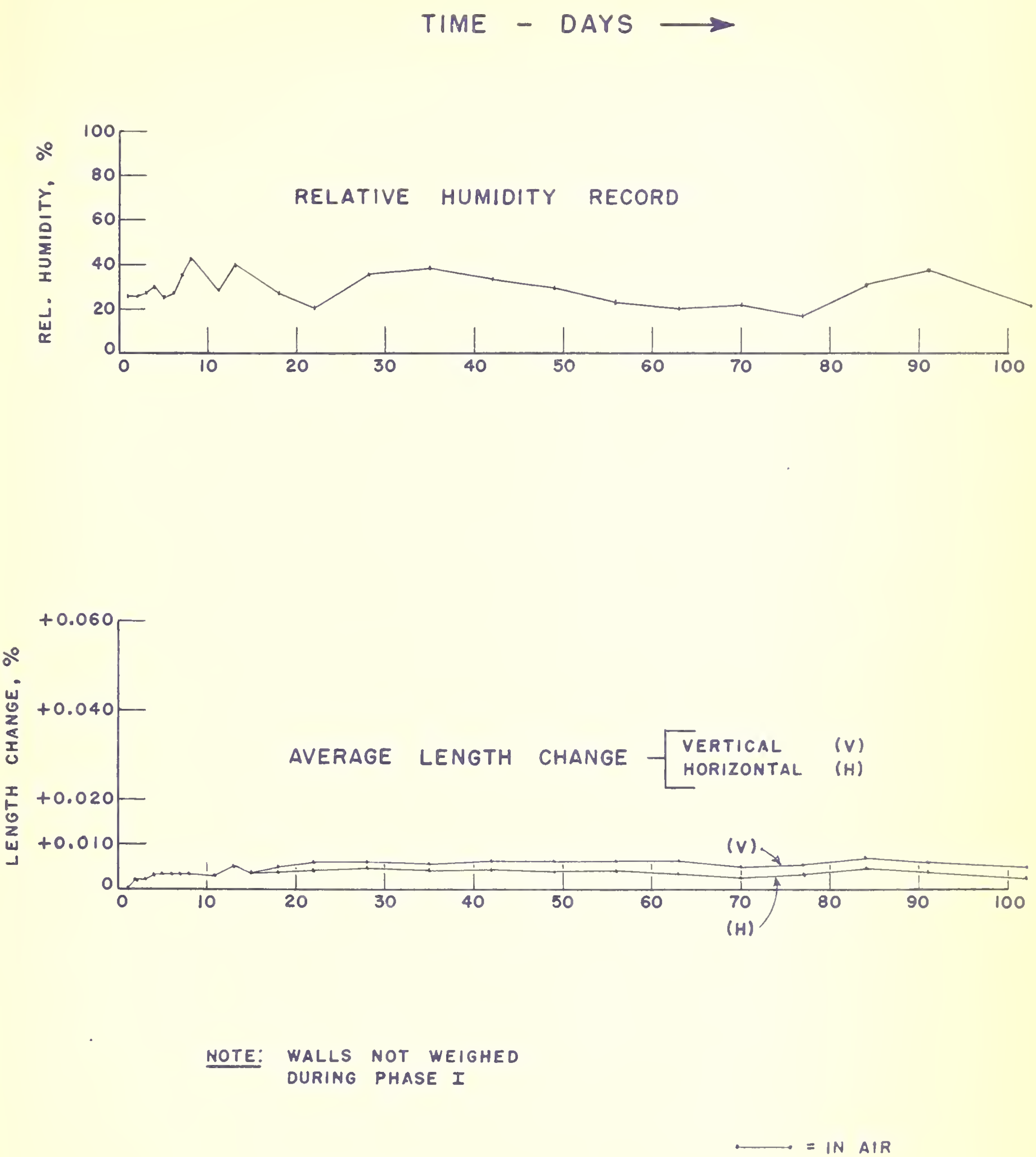

FIG. 3 LENGTH CHANGES OF WALLS W-1, W-2, W-3 (PHASE I)

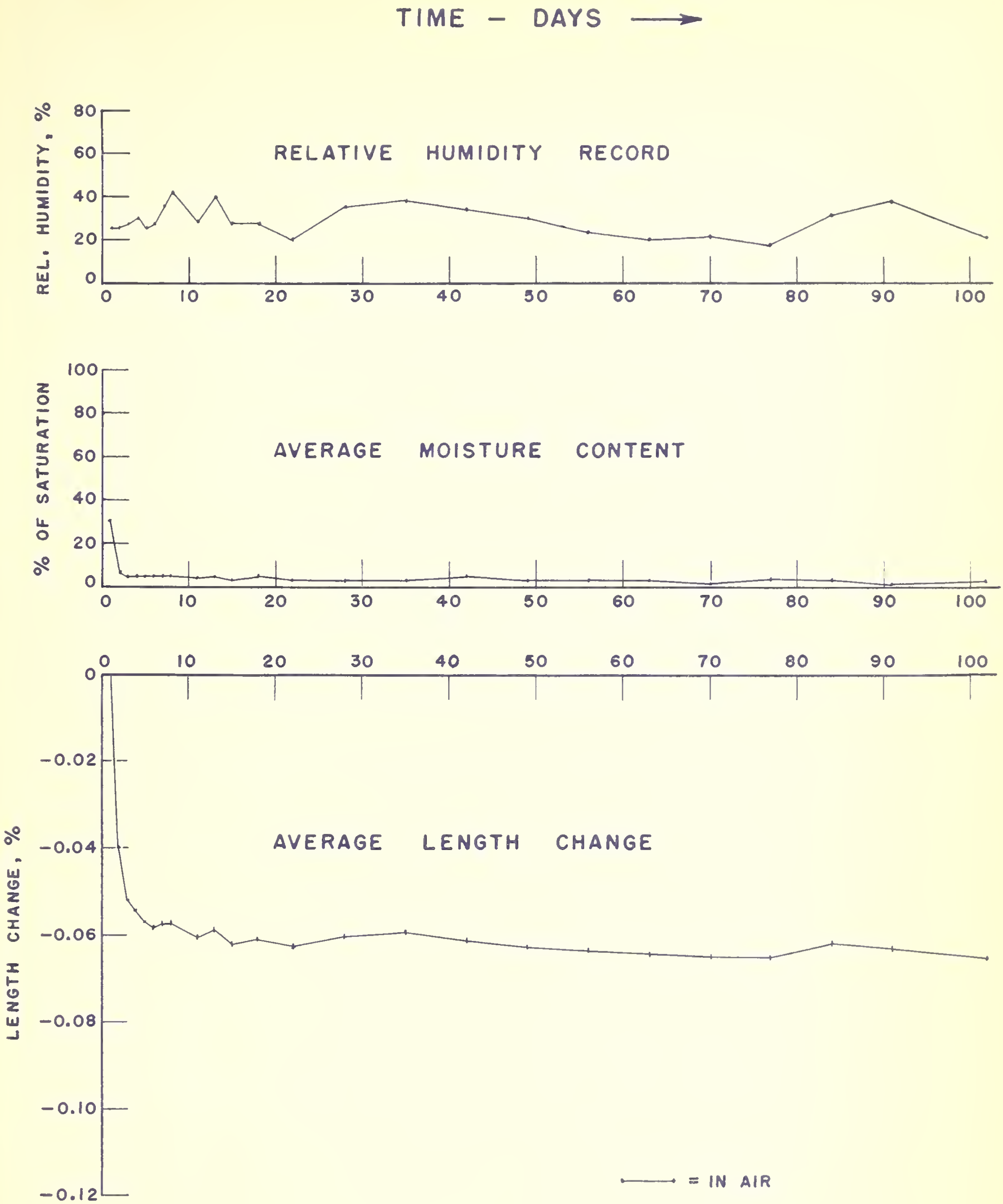

FIG. 4 LENGTH CHANGES & MOISTURE CONTENTS OF MORTAR SPECIMENS M-1, M-2, M-3 (PHASE I)

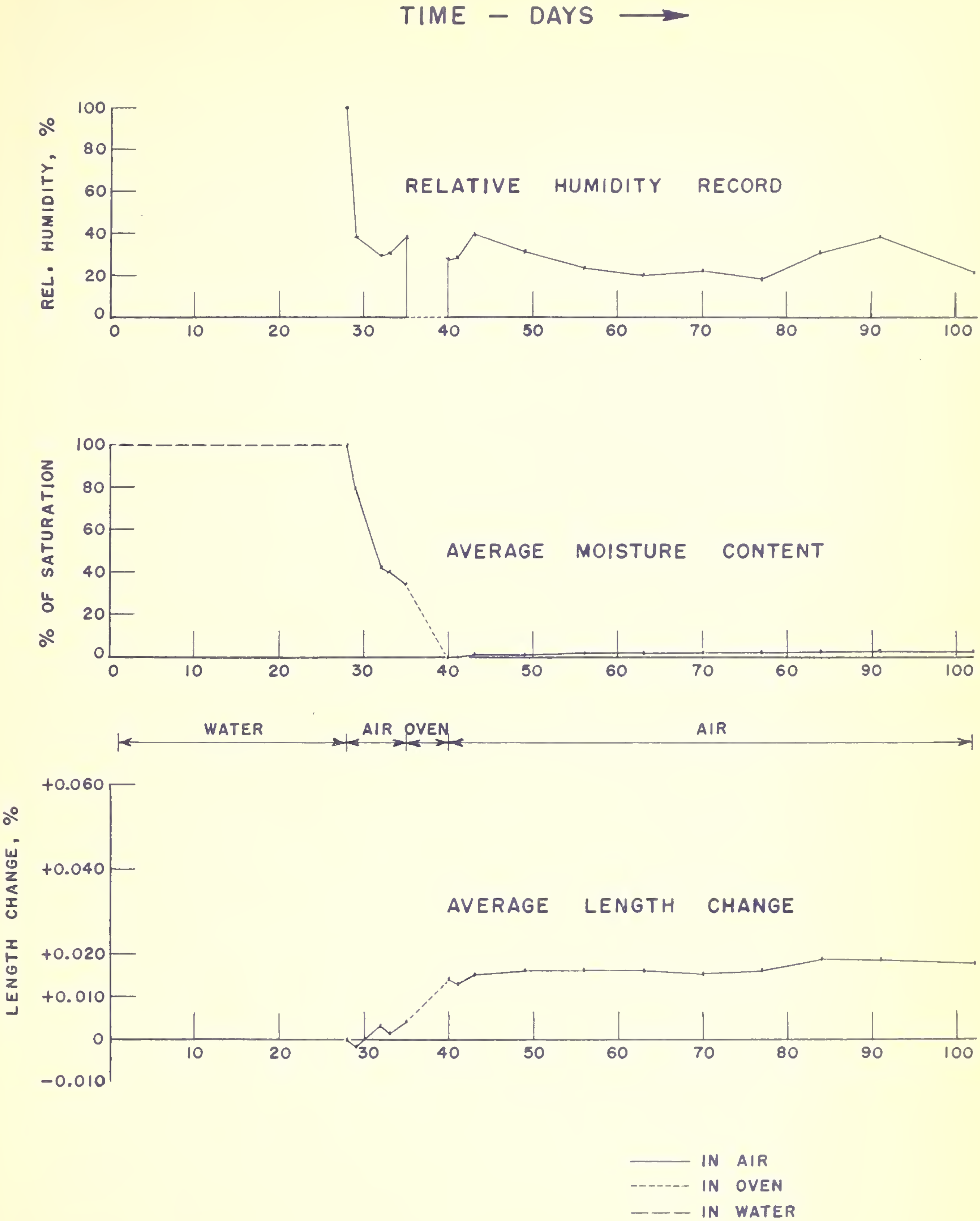

FIG. 5 LENGTH CHANGES & MOISTURE CONTENTS OF 3-COURSE ASSEMBLAGES A-1, A-2, A-3 (PHASE I)

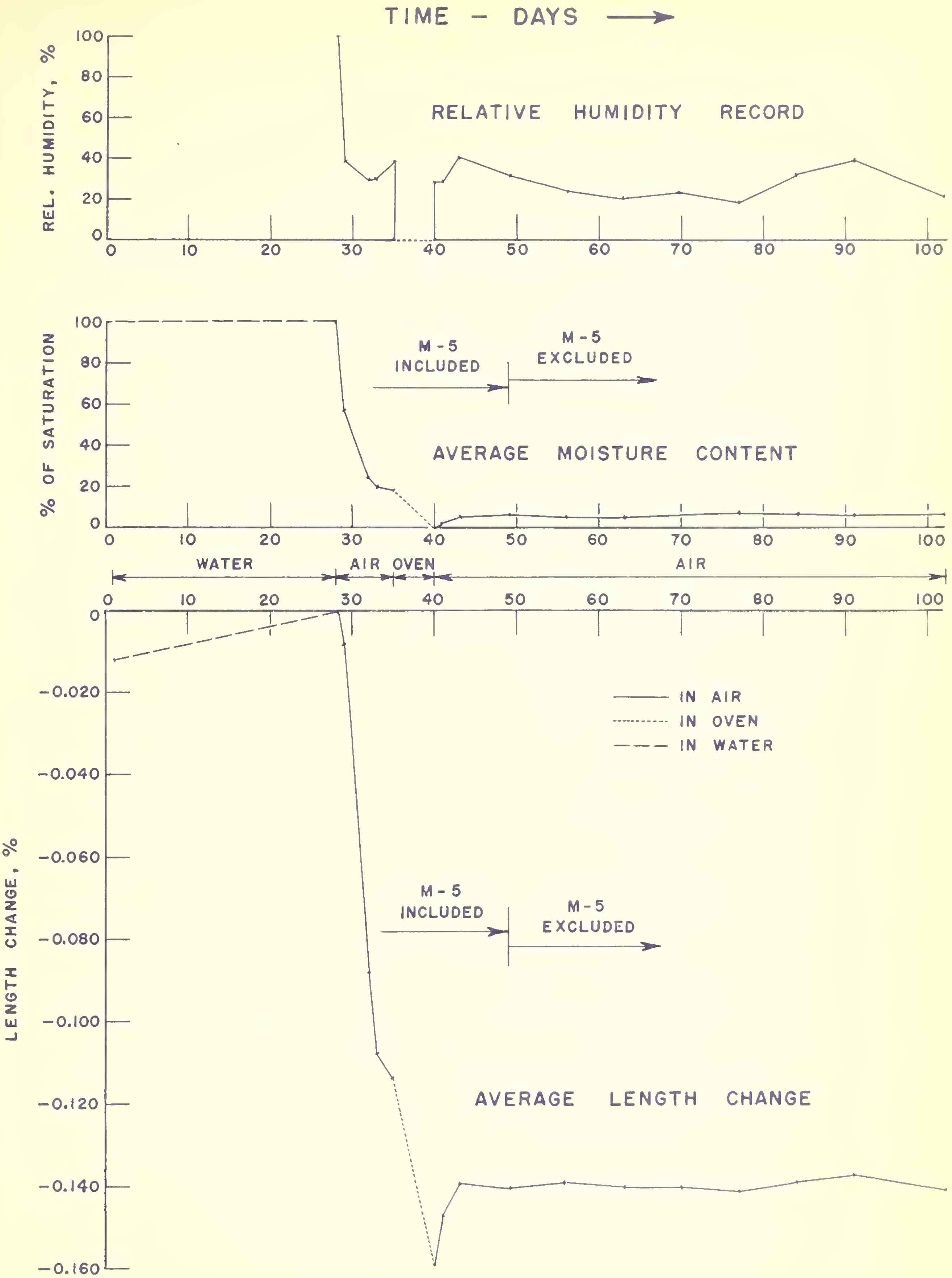

FIG. 6 LENGTH CHANGES & MOISTURE CONTENTS OF MORTAR SPECIMENS M-4, M-5, M-6 (PHASE I)

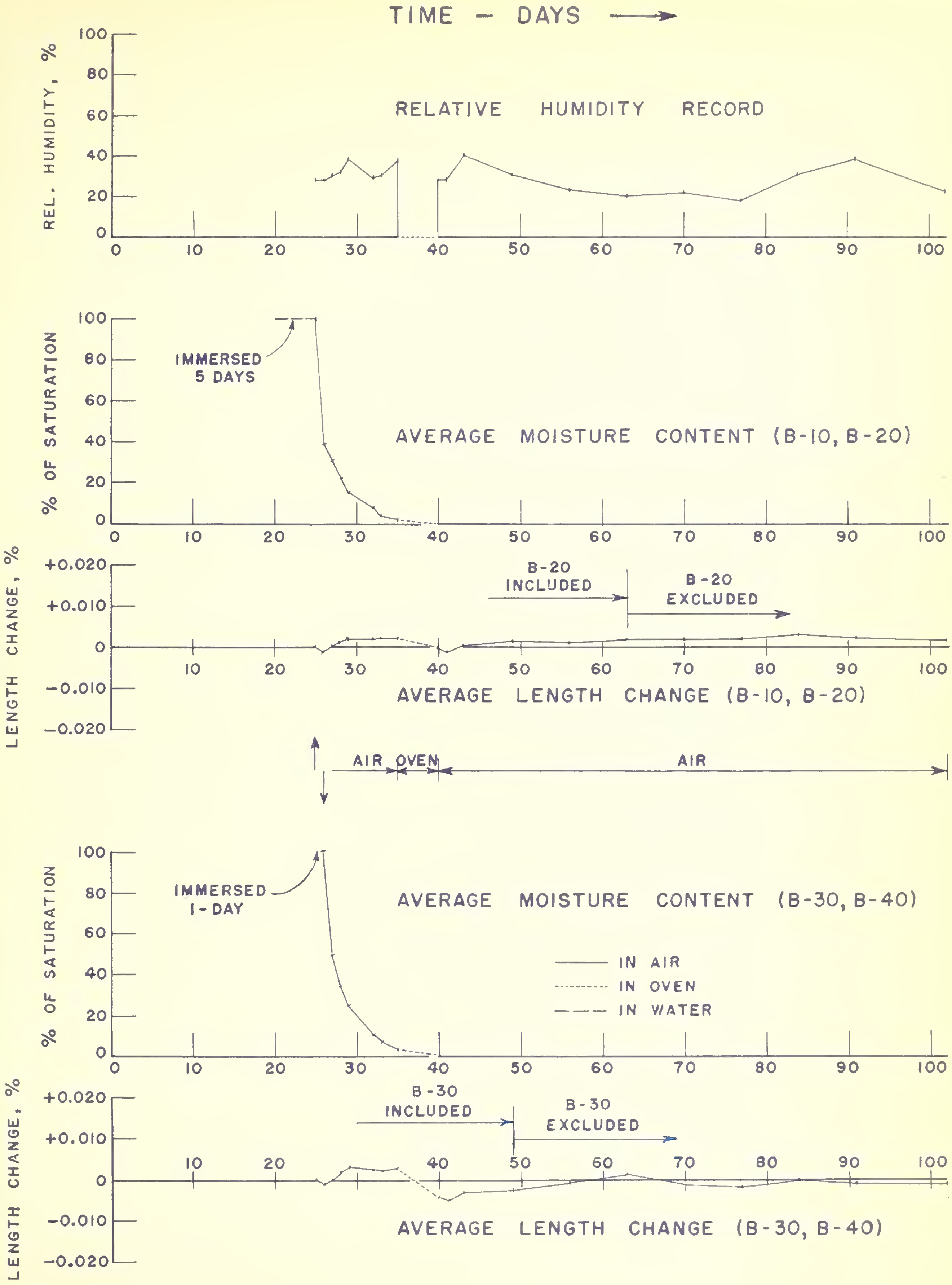

FIG. 7 LENGTH CHANGES & MOISTURE CONTENTS OF BRICK SPECIMENS B-10, B-20, B-30, B-40 (PHASE I)

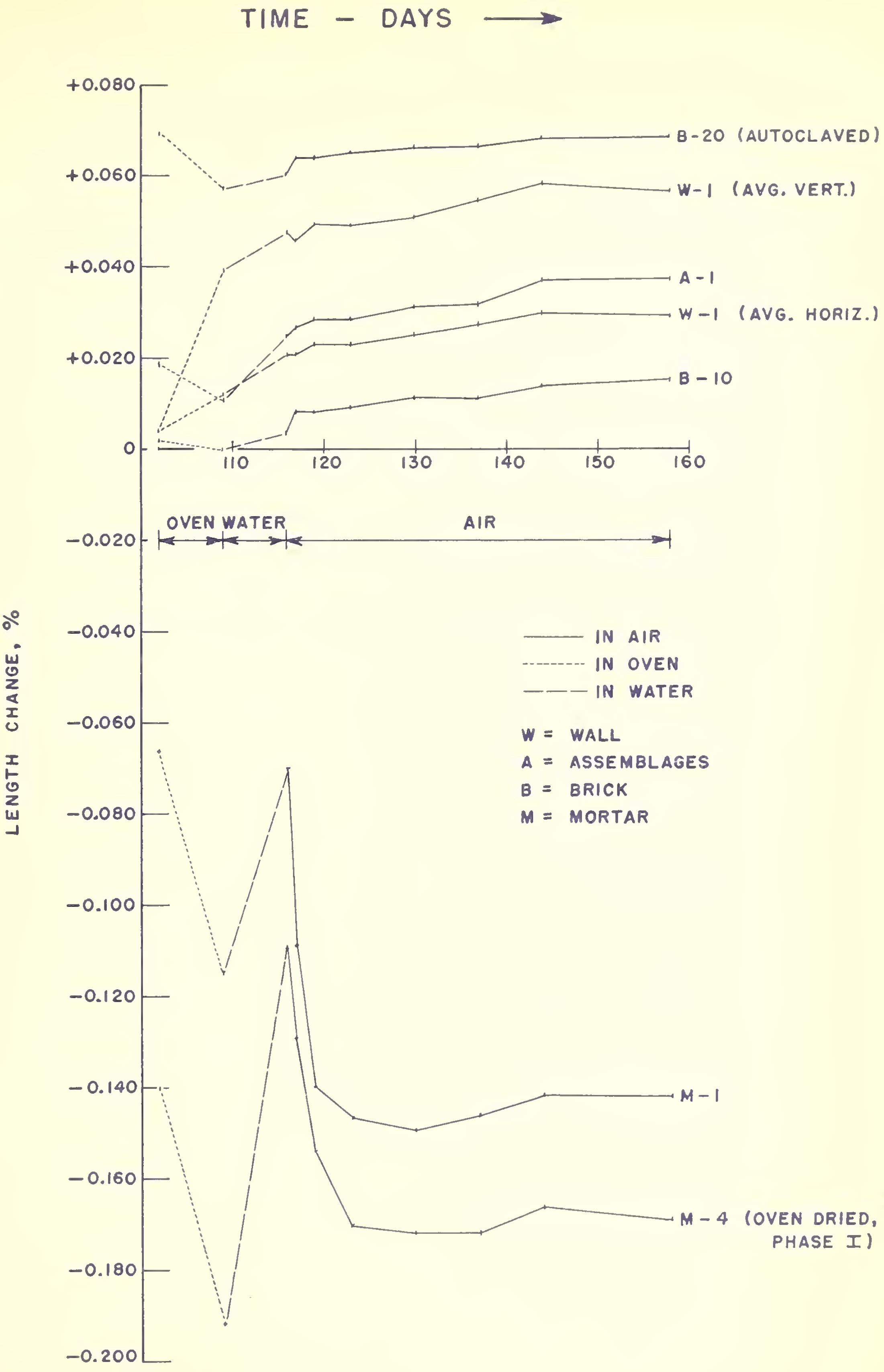

FIG. 8 LENGTH CHANGES OF SPECIMENS TREATED AS GROUP I (PHASE II)

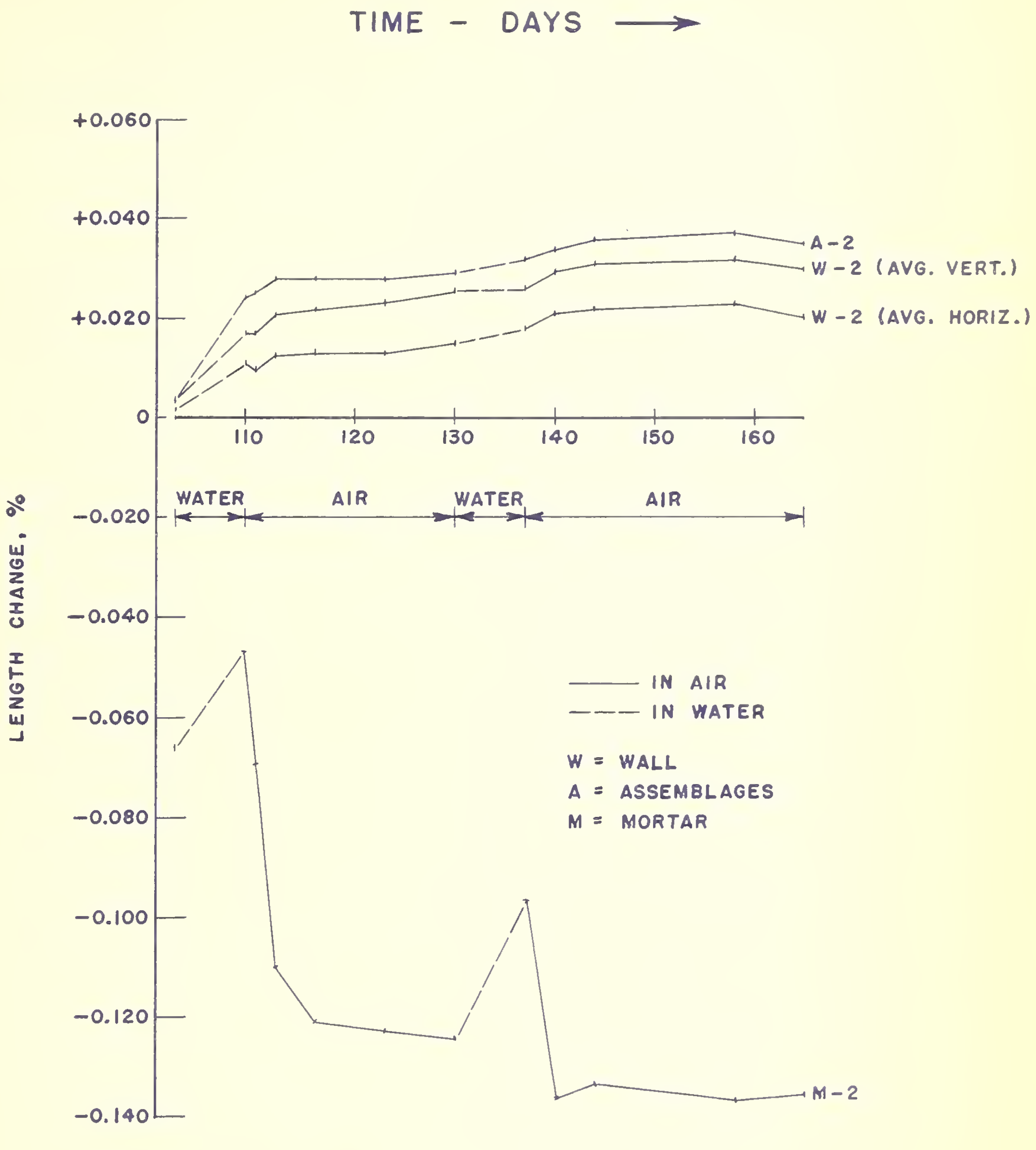

FIG. 9 LENGTH CHANGES OF SPECIMENS TREATED AS GROUP 2 (PHASE II)

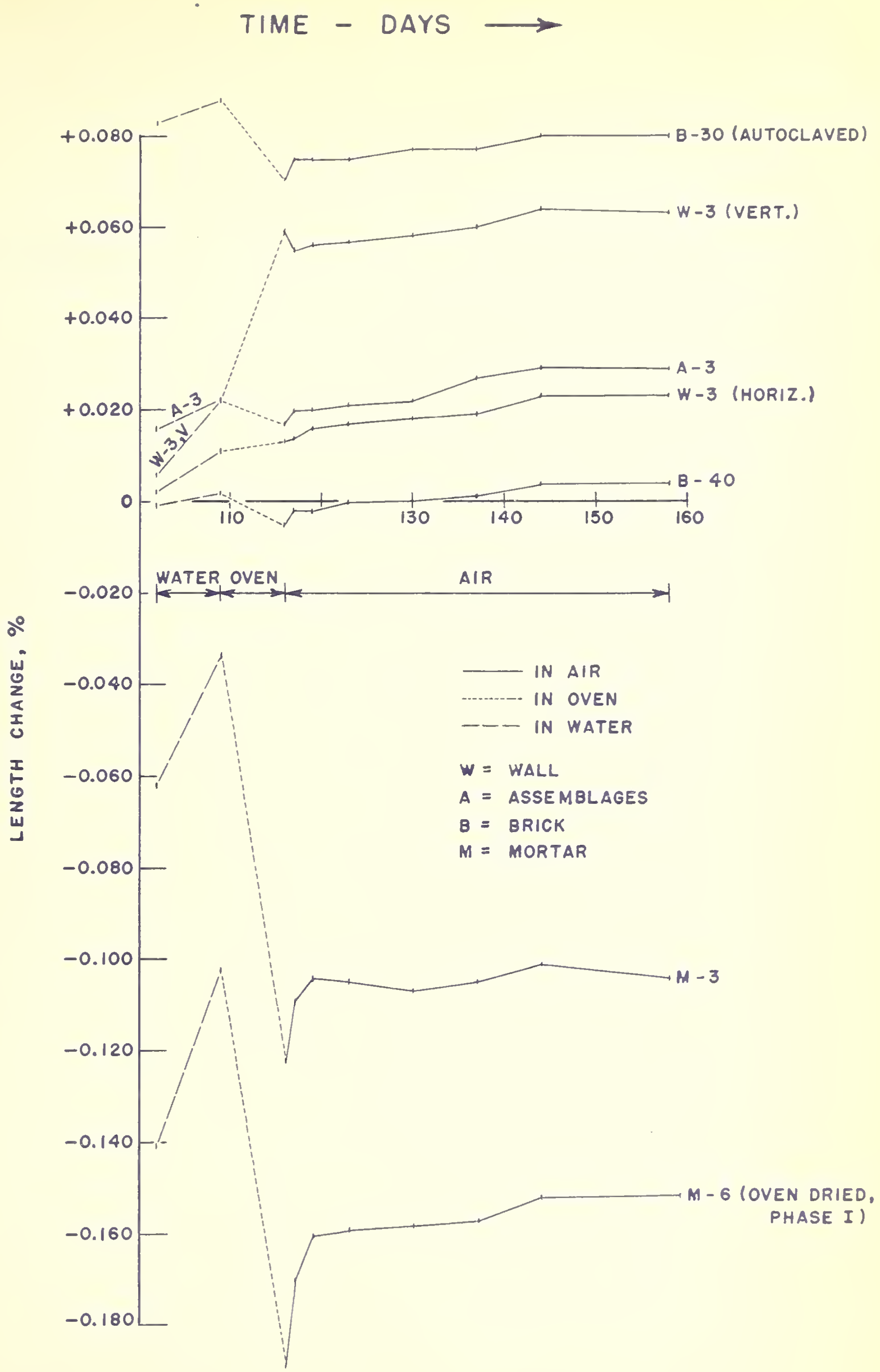

FIG. 10 LENGTH CHANGES OF SPECIMENS TREATED AS GROUP 3 (PHASE II)

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

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Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

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Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering.

Radio Standards. Radio Frequencies. Microwave Frequencies. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

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