STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

DRYING SHRINKAGE OF MODEL CONCRETE BEAMS EXPOSED OUTSIDE

(Including the effect of a chemical admixture)

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MATERIALS & RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways

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Department of Public Works
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Dear Sir:

Submitted for your consideration is a report on:

DRYING SHRINKAGE OF MODEL CONCRETE

BEAMS EXPOSED OUTSIDE

(including the effect of a chemical admixture)

Study made by . . . . Technical Section
Under general direction of . . . . Bailey Tremper
Under direct supervision of . . . D. L. Spellman
Report prepared by . . . . Bailey Tremper

Yours very truly

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cc: JEMcMahon
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DRYING SHRINKAGE OF MODEL CONCRETE BEAMS EXPOSED OUTSIDE

(including the effect of a chemical admixture)

SYNOPSIS

Model beams, 14x20x48-inch in size, of concrete with and without a chemical admixture, were exposed outdoors at Sacramento for 16 months starting in August, 1960. Measurements of length changes and internal relative humidity were made at monthly intervals. Smaller specimens, 4x5-inch, 3x3-inch and 1x1-inch in cross-section, were made from the concretes and were exposed outside and in the laboratory at 73°F and 50 percent relative humidity.

In the laboratory, the specimens shortened in an amount that was proportional to the logarithm of time except that in the later stages, interaction with carbon dioxide from the atmosphere modified the rate and increased the final amount of shrinkage. The effect of carbonation was pronounced in 1x1-inch specimens, slight in 3x3-inch specimens, and negligible in 4x5-inch specimens. The data suggest that in the absence of carbonation, the specimens would have stopped shrinking after moisture equilibrium

with the surrounding atmosphere was reached and that the time to reach equilibrium would decrease with decreasing size of specimen.

Specimens exposed outside shortened during the first few months, then gained moisture and lengthened during the winter. During the succeeding drying season, they again shortened progressively up to the time that winter weather caused lengthening. The amount of shrinkage was proportional to the ratio of surface area to volume of the specimen. The behavior of the larger model beams after exposure for the full period was similar to that of the smaller specimens that were dried for short periods of time. This indicates that laboratory tests when intended to represent drying shrinkage of job size concrete members under exterior exposure, should be discontinued at relatively short ages.

The internal humidity in existing highway structures in various parts of the State is compared to that in the model beams. It is indicated that the performance of the full scale structures is comparable to that of the model beams which again points to the desirability of short-time laboratory tests.

The particular chemical admixture that was used in these tests was found to increase drying shrinkage under all conditions and at all ages. The performance of the admixture in this study with respect to drying shrinkage is compared to the results obtained in drying shrinkage by Test Method No. Calif. 530-A, which employs 14 days of drying. The data indicate that this test provides a reliable measure of the effect of chemical admixtures with respect to drying shrinkage of concrete subjected to exterior exposure.

(End of Synopsis)

DRYING SHRINKAGE OF MODEL CONCRETE BEAMS EXPOSED OUTSIDE
(Including the effect of a chemical admixture)

It has been customary to evaluate the drying shrinkage of concrete by means of tests of specimens of 3x3-in. or 4x4-in. cross-section that are exposed to drying in a controlled atmosphere of 73.4 and 50 percent relative humidity, the tests being made more or less in accordance with ASTM Designation: C 157.

Pronounced differences of opinion have developed as to the length of the drying period of such specimens that is required to develop a reliable index of the performance in typical full size structures.

A subcommittee of ASTM Committee C-9 has been considering specifications for the effect of chemical admixtures on drying shrinkage as determined by ASTM Designation: C 157.

This report gives the results of length change measurements of two model concrete beams that have been exposed outdoors at Sacramento for a period of 16 months, from August 1960 to December 1961. Concurrently with the molding of the model beams, a series of smaller specimens was molded, a part of which were subjected to exposure outdoors at the same location as the model beams. The remainder were exposed in a room maintained at 73.4 ± 2°F and 50 ± 4 percent relative humidity. One model beam contains concrete without an admixture; the other contains concrete containing a chemical admixture.

Materials

Portland cement used in concrete was a Type II, low-alkali cement from a California mill. Physical and chemical properties of the cement are shown in Table 1.

Concrete aggregates consisted of uncrushed sand and gravel from the American River near Sacramento. The aggregates were separated into sieve sizes from 1-1/2-inch to No. 50 and were recombined for each batch to yield the gradings shown in Table 3.

The chemical admixture was a lignin base water-reducing agent containing about 18 percent calcium chloride. It was used in accordance with the manufacturer's recommendations at the rate of 0.25-pound per sack of cement. It increased the air content of the concrete an average of 2.7 percent. The effect of the admixture on drying shrinkage of 3x3x10-inch (gage length) specimens tested in accordance with Test Method No. Calif. 530 is given in Table 2.

Test Specimens

Test specimens consisted of:

Model beams, 14 inches wide by 20 inches deep by 48 inches long. Two were made; one containing concrete without admixture, the other containing concrete with the admixture at the rate of 1/4-pound per sack of cement. The beams were cast in plywood forms with 3/4-in. chamfers at all edges except on the top face. They were instrumented as follows:

A Carlson strain gage was installed at the geometric center with its axis coinciding with the long axis of the beam.

Brass gage studs, 3/4-inch in diameter and 2 inches in length were installed at 10-inch centers along four rows on each side face. After curing, the studs were drilled to receive the points of a Whittemore strain gage. There were 16 gage positions on each face of the specimen providing 32 measurements of length change.

Six 1-inch diameter holes were cast in each beam to depths of 3 inches, 5 inches and 7 inches to provide for measurement of relative humidity within the concrete by means of a humidity sensing device. The holes, except for the inner 1-inch and the bottom, were lined with brass tubing which was threaded to receive a cap to form a tight enclosure.

Four thermocouples were installed at distances from the side face of 1 inch, 3 inches, 5 inches and 7 inches.

Two hook eyes were installed in the top face to provide means of suspending the beams for weighing. Two steel plates were installed in the bottom face to provide bearing for the supports during exposure.

The above appurtenances were installed in the forms prior to filling with concrete.

Figure 1 shows the location of the devices and also the method of supporting the beams during outside exposure.

During the placing of the concrete in each model beam, the following auxiliary test specimens were molded from the concrete.

6 - 4x15x18-inch bars with gage studs using the original concrete.

10 - 3x3x11-1/4-inch bars with gage studs using the concrete after wet sieving through a 3/4-inch sieve.

10 - 1x1x11-1/4-inch bars with gage studs using the concrete after wet sieving through a No. 4 sieve.

5 - 6x12-inch cylinders using the original concrete. These were used to determine compressive strength after 7 and 28 days

with results as follows:

Age Days	Number Tested	Compressive Strength, psi Without Admixture	With Admixture
7	2	2610	3690
28	3	4420	4760

Fabrication of Test Specimens

Concrete was mixed in batches of 1-1/2 cubic feet in an open tub mixer. The concrete was proportioned to produce a slump of 3 to 4 inches and to contain 6 sacks of cement per cubic yard. In order to maintain the cement factor in the admixture concrete at the same level as in the plain concrete, the weighed quantities of aggregate were reduced slightly, the reduction being in the fine aggregate. Properties of the fresh concrete are given in Table 4.

From each batch of 1-1/2 cubic feet, 1/2-cubic foot was set aside for casting auxiliary specimens. The remainder was placed in the form for the model beam. Each batch produced a layer about 3 inches deep in the model beam. It was consolidated with a laboratory model spud vibrator. Eight batches were required to cast each model beam.

The portions of the concrete that were reserved for auxiliary specimens were remixed briefly in groups of four from which the specimens were cast.

The elapsed time in mixing and placing the concrete of each type was four hours.

The specimens containing concrete without the admixture were cast on July 26, 1960; those with the admixture, on July 28, 1960.

The model beams were covered with wet cotton blankets and remained in place in the laboratory room which was maintained at 73.4 ± 3°F. At the age of 7 days, the forms were removed and initial measurements were made.

The auxiliary specimens were cured under wet cotton blankets for 24 hours. The molds were then removed and specimens were cured in a fog room at 73.4 ± 3°F to the age of 7 days at which time initial measurements were made.

Exposure of Test Specimens

At the conclusion of the 7-day moist curing period, the model beams and one-half of each size of auxiliary volume change specimens were installed above a concrete slab on a prepared site on the grounds of the Materials and Research Laboratory. The site selected was chosen to avoid shading by buildings or trees. It is surrounded by a fence to prevent unauthorized tampering.

The model beams were placed end to end in a north-south direction with a space of 12 inches between them. The ends of the beams were painted to restrict evaporation from these faces with the purpose of representing sections from longer beams. They are supported 18 inches above the slab on pedestals with ball and roller bearings to allow unrestrained longitudinal movement. A plywood wall 36 inches wide and 48 inches high is installed 1-1/2 inches from the end of each beam. The walls support removable gable roofs of plywood which have a width in plan of 36 inches. The objective of the partial enclosures is to restrict direct access of rain while permitting free circulation of air past all except the end faces.

At the conclusion of the 7-day curing period, one-half of each size of the auxiliary volume change specimens was placed on racks in a drying room controlled at 73 $\pm$ 2°F and 50 $\pm$ 4 percent relative humidity, with control of air movement adjusted to provide a rate of evaporation of water from an atmometer of 3 $\pm$ 0.5 ml per hour. The remaining half of these specimens was placed on metal racks at one corner of the outside exposure site. These specimens are also covered with a gable roof having a width in plan of 44 inches. Figures 2 and 3 are views of the test specimens at the exposure site.

Measurements

Measurements consist of length changes, temperature, relative humidity within the model beams, and weight.

Measurements were made at the cessation of moist curing at the age of 7 days, which values are used as initial measurements. They were also measured after 7, 14 and 28 days of exposure and thereafter at intervals of 28 days.

Length changes of the model beams at the center were made by means of the Carlson strain gage. A Whittemore strain gage was used to measure length changes between points in the gage plugs at the surface. Length changes of 4x5x18-inch were measured between gage plugs in the longitudinal axis using a freely suspended horizontal comparator of the design shown in Figure 4. Length changes of 3x3x11-1/4-inch and 1x1x11-1/4-inch specimens were measured between gage plugs in the longitudinal axis using vertical comparators of the type specified in ASTM Designation: C 151. All measurements were made to the nearest 0.0001-inch and were repeatable within 0.0001-inch. Ambient fluctuations produced temperature gradients within the model beams and length changes could not be corrected successfully for thermal changes.

After 28 days of exposure, all outside specimens were brought into the laboratory the day before scheduled dates of measurement. This storage resulted in uniform temperatures throughout the specimens and brought them within 2 or 3 degrees of 70°F which was the temperature at the time of initial measurement as shown by thermocouples imbedded in the model beams. A correction factor was applied to reduce all measurements to 70°F.

Relative humidity within the model beams was measured by removing the cap which covered the opening, inserting a humidity sensing element which was connected to an electric hygrometer, the leads of which passed through a metal cap which replaced the one removed and were sealed against leakage. Readings were made until equilibrium was established which required about one hour. The sensing elements were calibrated from time to time at 70°F against saturated salt solutions which produce known relative humidities in the enclosed space above them.

The sensing elements are equipped with temperature indicating devices and the relative humidity at the time of measurement is corrected for temperature by means of a chart that is supplied with the instrument.

Although the relative humidity within the model beams as reported was measured after overnight storage in the laboratory resulted in a temperature of approximately

70°F, measurements were also made during outside exposure to determine if the manufacturer's charts accurately corrected for temperature variations. Relative humidities within the model beams were measured in the morning and the late afternoon during a 10-day period when the temperature of the concrete varied by 10 to 20 degrees. The data are summarized in Table V. It will be noted that the observed relative humidity after correction for temperature, was essentially constant as would be expected over short periods of time. The results therefore, confirm the accuracy of the manufacturer's charts.

Weights of the model beams were determined by suspending them while attached to a load cell having a capacity of 6000 pounds. The claimed accuracy of this instrument is 0.12 percent corresponding to about 1.2 pounds in weight of the beams. The data however, suggest that this order of accuracy was not obtained. The smaller specimens were weighed on balances sentitive to about 0.2 percent or less of their weight. Changes in weight are caused by loss of moisture which produces a decrease and carbonation which produces an increase in weight. The relative amount of carbonation is expected to be much greater in the smaller specimens. Weight changes of the model beams are not reported, but the data of the smaller specimens are given in Table 6.

Data of the Tests

Data of the tests will be found in tables and figures which are listed in the table of contents.

Drying in the Laboratory

Figure 5 shows drying shrinkage in the laboratory plotted against the logarithm of time. Drying shrinkage is approximately proportional to the logarithm of time. The rate however, decreases or becomes substantially zero after some period which depends on the size of the specimen.

The 4x5x18-inch specimens yield a virtually linear plot up to 32 weeks after which there was no change in length except that slight additional shrinkage was indicated after 61 weeks.

The 3x3x11-1/4-inch specimens produced a linear plot up to about 20 weeks. The rate then diminished up to about 32 weeks, after which there was little change in length except that slight additional shrinkage is indicated after 56 weeks.

The 1x1x11-1/4-inch specimens produced a curvilinear plot in the early stages, but there is a linear relationship between 2 to 4 weeks and 16 weeks. An increase in length is shown between 16 and 20 weeks, after which shortening resumed, the slope of the curve being parallel to that of the earlier periods up to the present conclusion of the tests at 69 weeks with no indication of a diminution in rate.

A tentative explanation of some of the breaks in the plotted curves is made on the basis of relative humidity within a 3x3x11-1/4-inch prism which was constructed with a hole along the longitudinal axis leading to the center of the specimen. Brass tubing was cemented in place in the hole in which a humidity sensing element was placed with the leads passing through a sealed enclosure at the outer end of the tube.

The data of humidity measurements are shown in Figure 6. Two curves are shown which conform to the equations shown in the figure. From 1 to 17 weeks the observed values agree within about 1 percent with the equation

$$h = 97 - 32 \log t$$

After 17 weeks, the rate of change diminished. At 36 weeks, the observed relative humidity was about 4 percent higher than that indicated by the equation. Irregularities in observed performance may be due to:

(1) Non-uniform conditions in the drying room. This is believed to be unlikely because of a uniform evaporation rate from the atmometer and because other specimens in the drying room at the same time gave no evidence of abnormal behavior.

(2) Inaccuracies in measurement of relative humidity. While it is true that the electric sensing elements may become erratic with time, the element used was checked against a standard solution from time to time and was found to be accurate within 2 percent.

(3) The effects of carbonation. Since the interaction between carbon dioxide and calcium hydroxide releases water, it is possible that such water at times raised the humidity within the enclosure in which the sensing element was inserted. If this is true, it is logical to assume that the released water evaporated later and resulted in the lowering of humidity as was observed. The change in rate of loss of humidity which is indicated at 17 weeks in Figure 6, may also be explained by the effect of carbonation. On this basis, it may be estimated that the specimen was in equilibrium with the environment at 17 weeks. At this point, the relative humidity in the concrete was 58 percent. Although the surrounding air was at 50 percent, the difference can be explained by the presence of salts in solution within the concrete. The diminishing

rate in loss of humidity within the concrete after 17 weeks and the irregular trend can be explained as the effect of carbonation.

The data of weight changes in Table 6 tends to confirm the occurrence of carbonation. Carbon dioxide reacts with calcium hydroxide which is present in hydrated cement according to the following equation:

$$\underset{74}{Ca(OH)_2} + \underset{44}{CO_2} \longrightarrow \underset{100}{CaCO_3} + \underset{18}{H_2O}$$

This reaction indicates a gain in weight of 44 grams per mol. If the water is lost by evaporation, the gain in weight is 26 grams per mol. This carbonation would be expected to cause an increase in the weight of the specimen. The smaller the specimen, the more the increase should be apparent. If the released water is lost by evaporation, there should be an increase in shrinkage.

The data of Table 6 shows that the 1x1-inch specimens dried in the laboratory lost weight during the first 16 weeks and that subsequently there was a gain in weight. Despite the increase in weight, the specimens continued to shrink as shown in Figure 5. Shrinkage during the latter period must have been due to carbonation.

The 3x3-inch specimens continued to lose weight during the first 36 weeks after which there was a small increase in weight. Figure 5 shows that these specimens shortened slightly after 56 weeks, thus indicating a slight effect of carbonation.

The shrinkage of 4x5-inch specimens appears to correlate well with loss in weight, thus indicating that carbonation had little, if any, effect on these specimens.

It will be noted that the admixture produced an increased amount of shrinkage at all ages with these test specimens when dried in the laboratory. The difference is approximately constant in amount except that there is a tendency to a decrease with time in the 4x5-inch specimens. If the shrinkage of the admixture concrete is expressed as a percentage of the control concrete, the value becomes increasingly smaller with time. The validity of assuming that the effect of the admixture in service becomes increasingly less pronounced percentagewise with time, is discussed in the connection with results of specimens exposed outside.

Drying Outside

The test specimens are exposed to the prevailing weather at Sacramento. The relative humidity within the model beams is an approach to equilibrium between the concrete and its environment. The time required to reach equilibrium depends on the surface-volume relationship of the member, as shown by the data of the specimens exposed under laboratory test conditions. Since the model beams are much larger and have much smaller surface-volume ratios than the specimens used in the laboratory drying tests, it is apparent that they will not reach equilibrium during the drying period of any year. At Sacramento, lower temperatures and higher humidity causes concrete to take on moisture and increase in length during the winter. With the start of the succeeding drying season, the humidity within the concrete is higher than it was at the end of the previous drying season. This is illustrated in the humidity curves of Figure 7. It will be noted that toward the end of each drying season all specimens started to elongate while the indicated relative humidity within the model beams was still falling. In 1960, the internal humidity in the model beams did not rise until some 10 weeks after elongation started. In 1961, although the specimens started to elongate after about 36 weeks of exposure, the internal humidity of the model beams continued to fall up to 45 weeks. Measurements, which are not plotted in Figure 7, were made after 47 weeks with no indication of a rise in internal humidity. Table 6-2 indicates that the smaller specimens began to gain moisture after 28 weeks in 1960 and after 32 weeks in 1961. During

1961, the age at which weight increases were observed corresponds to the age at which elongation started. There is no apparent explanation of the seemingly inconsistent lag in rising internal humidity beyond the time when moisture gain and elongation starts.

Changes in length of test specimens are given in Tables 8 and 9. Center and surface measurements of the model beams vary by a fairly constant amount. In order to smooth the data, the average of these two measurements has been used in plotting the curves shown in Figure 7.

Numerically, the amount of drying shrinkage of the three sizes of auxiliary specimens at the end of the second drying season outside, is about the same as that produced by about 16 weeks of drying in the laboratory. This is evidence that long periods of drying in the laboratory are not warranted and may be misleading because the effects of carbonation apparently become prominent in smaller specimens. Since, up to 16 weeks, shrinkage under constant drying conditions is consistently proportional to the logarithm of time, it is indicated that shrinkage can be evaluated in laboratory specimens after shorter periods of drying.

Exposure at other Locations

Weather conditions at locations other than the test site at Sacramento may be expected to result in different rates and degree of drying. In order to evaluate conditions at other locations, humidity measurements have been made periodically in the concrete of eight existing structures in California. These locations were selected to represent elevations from 200 feet below sea level to 6000 feet above sea level, and from moist coastal to arid desert conditions.

During July 1960, two 1-1/2-inch holes were drilled in the side of an interior girder in each structure except two. In one of these, a box girder, the installation was made on the north side of an exterior face. In the other structure, the holes were drilled into the east face of a flat slab. Holes were drilled to depths of 3 inches and 5 inches. 1-1/2-inch diameter brass tubes 1 inch shorter than the depth of the hole were cemented in place with epoxy adhesive, the tube ends being flush with the surface of the member. The outer end of the tube was threaded and the opening was closed with a screw cap. When tests for relative humidity within the concrete were made, the procedure was the same as described for similar measurements of the model beams. Measurements have been made five times at 3-month intervals with results as detailed in Table 7. This table shows the temperature within the test hole at the time of humidity measurement. There was considerable variation in temperature at the time of measurement, but the effect of these variations on relative humidity at constant temperature are believed to have been eliminated. This conclusion is based on tests made at different temperatures in the model beams as detailed in Table 5.

The average of minimum relative humidities measured at the eight locations is 67 percent at the 3-inch depth and 70 percent at the 5-inch depth. Thus, it appears that the typical expectation in California is that the concrete in structures will reach an average relative humidity of 70 percent. The only area where markedly greater drying may be expected is in the vicinity of Bishop. This is a sparsely inhabited area with few streams to cross and little prospect of freeway construction. For general use, it appears to be warranted to eliminate this area from consideration.

A review of weather records for the continental United States indicates that the test locations in California provide a fair representation of exposure conditions on a nationwide basis. Only in parts of Arizona is it indicated that drying conditions as severe as those at Bishop are encountered.

The relative humidity reached in the model beams in the late fall of 1961, was about 80 percent. From records of an older structure near Sacramento (Location 5, Table 7), it appears that the model beams will eventually become drier. The effect of lower humidity within the model beams on the relationships found to date may be a subject of conjecture, but the data of the smaller specimens indicate that present trends will continue.

Effect of the Admixture

One of the purposes of this study is to determine the significance of the test for effect of chemical admixtures on drying shrinkage of concrete, performed in accordance with Test Method No. Calif. 530-A, with respect to the performance of the admixture in job size members in exterior exposure.

Table 2 gives the data of such tests made with three different aggregates. Notwithstanding the wide differences in drying shrinkage developed by the aggregates, the results show remarkably close agreement for the effect of the admixture as a percentage of the concrete without the admixture when dried for 14 days which is the period provided in Calif. 530-A. The range in relative results is from 137 to 144 percent, and the average value is 140. The admixture therefore, increased the drying shrinkage in this test by 40 percent.

Test Method No. Calif. 530-A is a modification of ASTM Designation: C 157-54 T and is used by the California Division of Highways to determine the maximum dosage of chemical admixtures that will result in relative drying shrinkage within established limits. Differences between Calif. 530-A and ASTM Designation: C 157-54 T are described in the appendix.

A glance at Figures 5 and 7 will show that the admixture always increased the drying shrinkage whether in laboratory or outside exposure. Figure 8 shows the relationship between drying shrinkage and surface-volume ratio of specimens exposed outside for 112 days. During the first 56 days, shrinkage was approximately proportional to the logarithm of time. The curves indicate a linear relationship between drying shrinkage and surface-volume ratio with an indication of modification due to wet sieving of the concrete placed in the two smaller size of specimens.

The lower shrinkage of the model beams (14x20x48 inches) means that during the period of drying each season, the relative effect of the admixture is more nearly similar to that of the smaller specimens dried for a much shorter period of time.

It will be noted in Figure 7 that the numerical difference in shrinkage between the admixture concrete and the control concrete on the model beams increased with time. This is in contrast with the behavior of the smaller specimens in which the numerical difference either remained approximately constant or decreased with time. The same effect is shown in Figure 5 with specimens dried in the laboratory. This means that prolonged drying in the laboratory reduces the effect of the admixture when expressed as a percentage of the control, whereas in the model beams under outside exposure, the relative effect is more nearly constant.

The relative effect of the admixture in the model beams with time is shown in Table 10. It will be noted that toward the end of the exposure period, the relative effect of the admixture has tended to stabilize at about 132 percent, or an increase of about 32 percent in drying shrinkage. The laboratory test, Calif. 530-A, shows the increase in shrinkage to be 40 percent. Table 2 shows that had the period of drying in the test been extended beyond 14 days, the value obtained should also have been reduced to 32 percent increase in shrinkage.

It should not be inferred however, that the present drying period of 14 days does not afford a realistic measure of the effect of the admixture. It is to be expected that the relative effect of an admixture on concrete in service will vary, depending on weather conditions and size of member. No single laboratory test can be expected to predict service performance exactly under all conditions. For specification purposes, the present test is as significant as would be a longer drying period. Furthermore, early shrinkage may be of greater importance than final shrinkage. The test has the very great advantage that elapsed time in conducting the test is less than 28 days. It, therefore, provides for the evaluation of admixtures with respect to drying shrinkage in the same period of time that 21-day determinations of strength can be made. It also makes feasible, the use of the test for control purposes of deliveries to the work.

Effect of Bleeding on Drying Shrinkage

In large members, the settlement of solids in the fresh concrete tends to produce higher effective water-cement ratios near the upper surface. Shrinkage on drying therefore, should be greater near the top of the member. The data of the surface measurements of length changes of the model beams provide a means of determining the effect of depth since there were four lines of gage plugs at distances of 4, 8, 12 and 16 inches below the top surface.

The results of surface measurements at 8 periods from 36 weeks to 65 weeks, have been averaged at each position in depth to obtain representative values. The data are given in Table 11. The beams were supported in such a way that creep due to dead load should not be a factor. The data show the greatest shrinkage along the highest line of measurement which was 4 inches below the top surface. Shrinkage decreased significantly at each lower level to a depth of 12 inches. At the 16-inch level, which is 4 inches above the bottom surface, the shrinkage was slightly greater than at 12 inches, which undoubtedly is due to the influence of evaporation from the lower face.

The effect of the admixture with respect to change in shrinkage at different levels is similar in trend to that found in the concrete without the admixture. At each position, the admixture increased drying shrinkage. The shrinkage of the admixture concrete at the level giving the lowest amount exceeds that of the plain concrete at any level except the 4-inch depth.

Conclusions

The rate at which concrete specimens lose moisture and shorten during drying is proportional to the ratio of exposed surface to volume. Under outside exposure, the length of the drying season in any year is too short to accomplish full drying and shortening of large members. As a consequence, laboratory tests of specimens of the customary size should be discontinued at relatively short ages.

The test for effect of chemical admixtures on drying shrinkage of concrete performed in accordance with Test Method No. Calif. 530-A provides a reliable measure of the performance in concrete subjected to exterior exposure.

APPENDIX

Comparison of Test Method No. Calif. 530-A and ASTM Designation: C 157-54 T

ASTM Designation C 157-54 T provides a number of options in test procedure which are exercised in Calif. 530-A. In addition, other modifications have been made in Calif. 530-A. Features of Calif. 530-A that consist of options or are departures from ASTM Designation: C 157-54 T are described below.

1. The test cement is a blend of equal parts of Type II, low-alkali cement from five named California mills.
2. The aggregates, produced without crushing from a bar in the American River near Sacramento, are separated on 8 sieves from 1 inch to No. 50 and are recombined for each batch of concrete to produce a prescribed grading with 100 percent passing 1 inch.
3. The concrete is proportioned to contain 7.0 $\pm$ 0.1 sacks of cement per cubic yard and a slump of 3-1/2 $\pm$ 1/2 inches.
4. The test specimens are 3x3x11-1/4-inch prisms with gage studs giving an effective length of 10 inches.

5. Test specimens are standard cured to the age of 7 days and are then measured for initial length. They are then stored on racks in a room maintained at 73.3 ± 2°F and 50 ± 4 percent relative humidity. The movement of air is regulated to produce an evaporation from an atmometer of 3 ± 0.5 ml. per hour. At the age of 21 days (14 days of drying) they are again measured for length. The difference is reported as a percentage of 10 inches.
6. Three test specimens are molded from each batch of concrete and at least three batches are mixed, each on a different day.
7. Drying shrinkage is reported as the average, calculated to the nearest 0.001 percent, of not less than 7 specimens, the individual values of which do not depart from the average of all specimens by more than 0.004 percentage point.
8. The change in drying shrinkage produced by the admixture used is reported as a percentage of the control concrete containing no admixture.

Table 1

Properties of Test Cement	
SiO_2	23.4
Al_2O_3	4.2
Fe_2O_2	2.6
CaO	64.7
MgO	1.7
SO_3	1.9
Loss on Ignition	0.9
Insol. Res.	0.1
Na_2O	0.36
K_2O	0.24
Alkalies (Na_2O Equiv.)	0.52
C_4AF	8
C_3A	7
C_3S	48
C_2S	31
Fineness (Air Permeability)	3212 sq.cm./gm.
Autoclave Expan.	0.02 percent
Air in Mortar	7.8 percent
Initial Set	2 Hrs. 55 Min.
Final Set	5 Hrs. 0 Min.
Compressive Strength:	
3 days	2020 psi
7 days	2900 psi

Table 2

Effect of Chemical Admixture Used in These Tests on Drying Shrinkage

Tests were conducted in accordance with Test Method No. Calif. 530-A when Aggregate C was used, and also when Aggregates A and B were used except with respect to source of aggregate. Admixture was added at rate of 0.25-lb. per sack of cement. Aggregate C was used in constructing model beams.

Properties of Fresh Concrete
(Average of 3 or 4 Batches)

Agg't.	Admix-ture	Slump, Ins.	Air %	W/C Lbs./Sk.	Unit Wt. Lbs./C.F.	Cement Factor Sks/C.F.
A	No	3.5	1.8	41.8	148.0	7.06
A	Yes	3.4	5.0	36.5	144.4	7.02
B	No	3.8	1.5	44.0	150.5	7.05
B	Yes	3.6	4.4	38.1	148.0	6.99
C	No	3.7	1.6	44.4	152.6	6.99
C	Yes	3.4	4.0	40.8	150.0	6.99

Shrinkage after Number of Days of Drying Shown
(Average of 9 or 12 Specimens)

Agg't.	Admixture	7 days	14 days	28 days
A	No	.0170	.0230	.0293
A	Yes	.0240	.0319	.0397
	Difference	+.0070	+.0089	+.0104
	% of Control*	141	137	135
B	No	.0305	.0443	.0594
B	Yes	.0455	.0611	.0760
	Difference	+.0150	+.0168	+.0166
	% of Control*	149	138	128
C	No		.0270	
C	Yes		.0390	
	Difference		+.0120	
	% of Control*		144	

*No admixture

Table 3

Grading of Aggregates used in Concrete

Sieve Size	Percent Passing	
	Without Admixture	With Admixture
1-1/2-inch	100	100
1-inch	80	80
3/4-inch	65	64
3/8-inch	43	42
No. 4	36	35
No. 8	30	30
No. 16	25	25
No. 30	15	15
No. 50	5	5

Table 4

Properties of the Fresh Concrete
(Average of Selected Batches)

	Slump, Ins.	Air %	Cement, Sks/Cu.Yd.	Unit Wt. Lbs./Cu.Ft.	W/C Lbs./Sk.
Without Admixture	3.5	1.2	6.05	155.3	44.9
With Admixture at 0.25-lb. per sack	3.4	3.9	6.01	153.0	41.8

Table 5

Effect of Temperature on Indicated Corrected Relative Humidity in Concrete
Tests made on Model Beam

Date, 1961	Hour	Temperature and Relative Humidity at depth shown					
		2"-3"		4"-5"		6"-7"	
		T	H	T	H	T	H
5-11	0800	55	84	55	85	58	81
	1600	65	84	65	85	65	81
5-12	0800	52	84	52	85	55	81
	1600	67	84	67	85	68	81
5-15	0800	61	85	63	89	65	81
	1600	75	85	74	89	75	81
5-16	0800	60	84	61	89	63	81
	1600	75	85	74	89	75	81
5-17	0800	55	84	56	88	58	81
	1600	70	83	68	87	70	81
5-18	0800	55	84	56	88	58	81
	1600	75	84	74	88	74	81
5-19	0800	58	84	59	87	60	81
	1600	70	84	70	88	71	81

Table 6-1

Weight Changes of Specimens Exposed Inside

Loss in weight in grams from as-cured condition

Weeks Exposed	4" x 5"		3" x 3"		1" x 1"	
	Plain	Admix.	Plain	Admix.	Plain	Admix.
1	201	175	80	79	20	16
2	241	211	99	95	23	20
4	286	250	114	108	26	21
8	328	278	130	122	26	21
12	345	295	138	128	27	23
16	358	306	144	131	25	22
20	372	317	147	135	24	20
24	380	325	150	137	24	20
28	388	330	152	138	24	20
32	395	335	153	141	24	21
36	399	340	155	142	24	22
40	400	342	155	142	22	22
44	402	343	155	142	22	22
48	402	343	155	142	22	21
52	402	343	153	140	22	22
56	401	341	153	141	22	22
61	409	348	154	143	22	22
65	409	348	153	143	22	22
69	409	347	153	143	22	22
As As Cured Weight	14,954	14,825	4,082	4,048	439	436

Table 6 - 2

Weight Changes of Specimens Exposed Outside
(Model Beams not included)

Loss in weight in grams from as-cured condition

Weeks Exposed Total	Second Season	4" x 5" Plain	4" x 5" Admix.	3" x 3" Plain	3" x 3" Admix.	1" x 1" Plain	1" x 1" Admix.
1		242	218	97	90	24	19
2		292	250	120	115	27	24
4		347	285	141	129	29	24
8		390	345	156	142	30	25
12		385	340	154	139	27	22
16		359	290	139	128	23	20
20		336	272	125	117	19	16
24		310	245	110	101	15	11
28	4	300	238	105	98	14	12
32	8	316	255	115	106	16	14
36	12	337	275	124	115	18	15
40	16	341	282	126	119	18	15
44	20	348	291	129	121	19	16
48	24	388	326	147	137	20	19
52	28	412	348	155	145	21	20
56	32	417	351	156	147	21	20
61	37	427	360	159	151	21	20
65	41	423	356	155	145	--	21
69	45	404	342	144	138	--	19
As Cured Weight		14,971	14,824	4,089	4,051	439	436

Table 7

Temperature and Relative Humidity in Concrete of Existing Bridges in California

Location	Elev. Above Sea Level, Feet	Year Built	Date of Test, Mo.-Yr.	Temp. and Rel. Hum. at depth shown 2"-3" T	H	4"-5" T	H
1. Br. No. 54-500R Mojave Desert near Victorville	3000	1958	8-60 1-61 4-61 8-61 11-61	78 53 56 87 59	66 67 67 67 59*	79 55 60 88 58	74 74 75 76 72*
2. Br.No. 57-332L Southern Coast near San Diego	10	1956	8-60 1-61 4-61 8-61 11-61	74 58 64 71 68	80 76* 77 79 77	71 54 61 68 68	81 79 77* 80 79
3. Br. No. 36-65 Central Coast near Santa Cruz	10	1947	9-60 1-61 4-61 8-61 11-61	59 49 54 64 54	77 76 78 79 75*	57 46 50 61 54	80 77* 79 82 78
4. Br.No. 4-84R Northern Coast near Eureka	10	1929	9-60 1-61 4-61 8-61 11-61	54 48 53 57 53	84* 86 84* 86 86	54 48 53 60 53	86 86 84* 87 87
5. Br.No. 24-134 Central Valley near Sacramento	25	1959	9-60 1-61 4-61 9-61 12-61	87 36 57 64 57	74 78 77 72* 80	82 36 55 61 53	77 75 76 75 68*
6. Br.No. 19-106L Sierra Nevada Range near Kingvale	6000	1959	8-60 1-61 4-61 8-61 10-61	57 32 45 68 39	70 72 72 70 66*	57 32 47 67 38	77 72 69* 75 69*
7. Br.No. 48-22 East of Sierras near Bishop	4400	1949	8-60 1-61 4-61 8-61 11-61	83 53 74 85 50	50 47* 49 48 47*	80 52 74 85 52	60 51 57 57 50*
8. Br.No. 58-277 Imperial Valley near Salton Sea	-200	1950	8-60 1-61 4-61 8-61 11-61	88 64 99 101 68	58 71 72 67 56*	88 61 95 103 68	67 63* 73 71 63*

*Minimum observed relative humidity at location

Table 8

Drying Shrinkage of Concrete without Admixture

Weeks Exposed Total	Second Season	Values in Percent								
		Outside						Inside		
		14" x 20" x 48"								
		Surf.	Center	Avg.	4"x5"	3"x3"	1"x1"	4"x5"	3"x3"	1"x1"
1			.0034		.0137	.0220	.0740	.0113	.0160	.0643
2		.0030	.0074	.0052	.0191	.0322	.0944	.0167	.0274	.0868
4		.0036*	.0061*	.0048*	.0245	.0442	.1034	.0253	.0403	.1021
8		.0066	.0125	.0096	.0334	.0532	.1136	.0348	.0536	.1104
12		.0080	.0128	.0104	.0332	.0534	.1056	.0392	.0604	.1145
16		.0082	.0114	.0098	.0323	.0486	.1040	.0406	.0626	.1200
20		.0084	.0098	.0091	.0265	.0420	.0888	.0447	.0673	.1164
24		.0054	.0102	.0078	.0264	.0380	.0848	.0438	.0686	.1211
28	4	.0090	.0100	.0095	.0239	.0388	.0899	.0454	.0708	.1233
32	8	.0073	.0115	.0094	.0286	.0462	.1029	.0484	.0722	.1237
36	12	.0086	.0132	.0108	.0334	.0534	.1152	.0490	.0722	.1267
40	16	.0101	.0146	.0123	.0356	.0558	.1122	.0494	.0718	.1263
44	20	.0119	.0169	.0144	.0370	.0572	.1121	.0494	.0732	.1298
48	24	.0122	.0178	.0150	.0396	.0666	.1239	.0497	.0732	.1300
52	28	.0154	.0206	.0180	.0414	.0680	.1276	.0494	.0724	.1314
56	32	.0162	.0217	.0190	.0414	.0668	.1235	.0485	.0710	.1311
61	37	.0172	.0234	.0203	.0434	.0708	.1320	.0485	.0726	.1351
65	41	.0180	.0218	.0199	.0402	.0650	-----	.0489	.0730	.1384
69	45	.0173	.0202	.0188	.0392	.0620	-----	.0495	.0740	.1386

*Results inaccurate because of temperature gradients at time of measurement

Table 9

Drying Shrinkage of Concrete with Admixture

Weeks Exposed Total	Second Season	Values in Percent								
		Outside						Inside		
		14" x 20" x 48" Surf.	14" x 20" x 48" Center	14" x 20" x 48" Avg.	4"x5"	3"x3"	1"x1"	4"x5"	3"x3"	1"x1"
1			.0081		.0207	.0368	.0966	.0174	.0322	.0956
2		.0038	.0111	.0075	.0252	.0500	.1183	.0239	.0458	.1169
4		.0055	.0100	.0078	.0329	.0623	.1210	.0316	.0610	.1271
8		.0089	.0173	.0131	.0394	.0683	.1310	.0408	.0720	.1378
12		.0110	.0176	.0143	.0380	.0676	.1193	.0443	.0776	.1437
16		.0117	.0167	.0142	.0368	.0604	.1185	.0458	.0802	.1509
20		.0123	.0151	.0137	.0329	.0575	.1023	.0484	.0856	.1451
24		.0093	.0149	.0121	.0299	.0518	.0970	.0477	.0862	.1511
28	4	.0117	.0148	.0133	.0277	.0506	.1026	.0490	.0880	.1530
32	8	.0113	.0163	.0138	.0329	.0578	.1170	.0522	.0906	.1531
36	12	.0116	.0178	.0147	.0361	.0618	.1309	.0522	.0906	.1564
40	16	.0144	.0188	.0166	.0394	.0656	.1280	.0524	.0898	.1555
44	20	.0155	.0244	.0200	.0411	.0688	.1280	.0529	.0906	.1595
48	24	.0164	.0237	.0200	.0439	.0758	.1411	.0529	.0902	.1595
52	28	.0206	.0268	.0237	.0452	.0766	.1442	.0523	.0898	.1606
56	32	.0212	.0287	.0250	.0454	.0766	.1400	.0512	.0884	.1595
61	37	.0224	.0305	.0265	.0471	.0798	.1481	.0512	.0902	.1634
65	41	.0237	.0292	.0265	.0439	.0770	-----	.0521	.0900	.1663
69	45	.0229	.0273	.0251	.0432	.0730	-----	.0535	.0930	.1674

Table 10

Relative Effect of the Admixture on Drying Shrinkage of Model Beams

Weeks Exposed	Relative Increase in Drying Shrinkage due to the Admixture, Percent		Average
	Center of Beams Carlson Gage	Surface of Beams Whittemore Gate	
8	38	35	36
12	37	37	37
16	47	42	44
20	54	47	50
24	46	72	59
28	48	30	39
32	42	55	48
36	35	35	35
40	29	43	36
44	33	30	31
48	33	34	33
52	30	34	32
56	32	30	31
61	31	31	31
65	34	32	32
69	35	32	33

Table 11

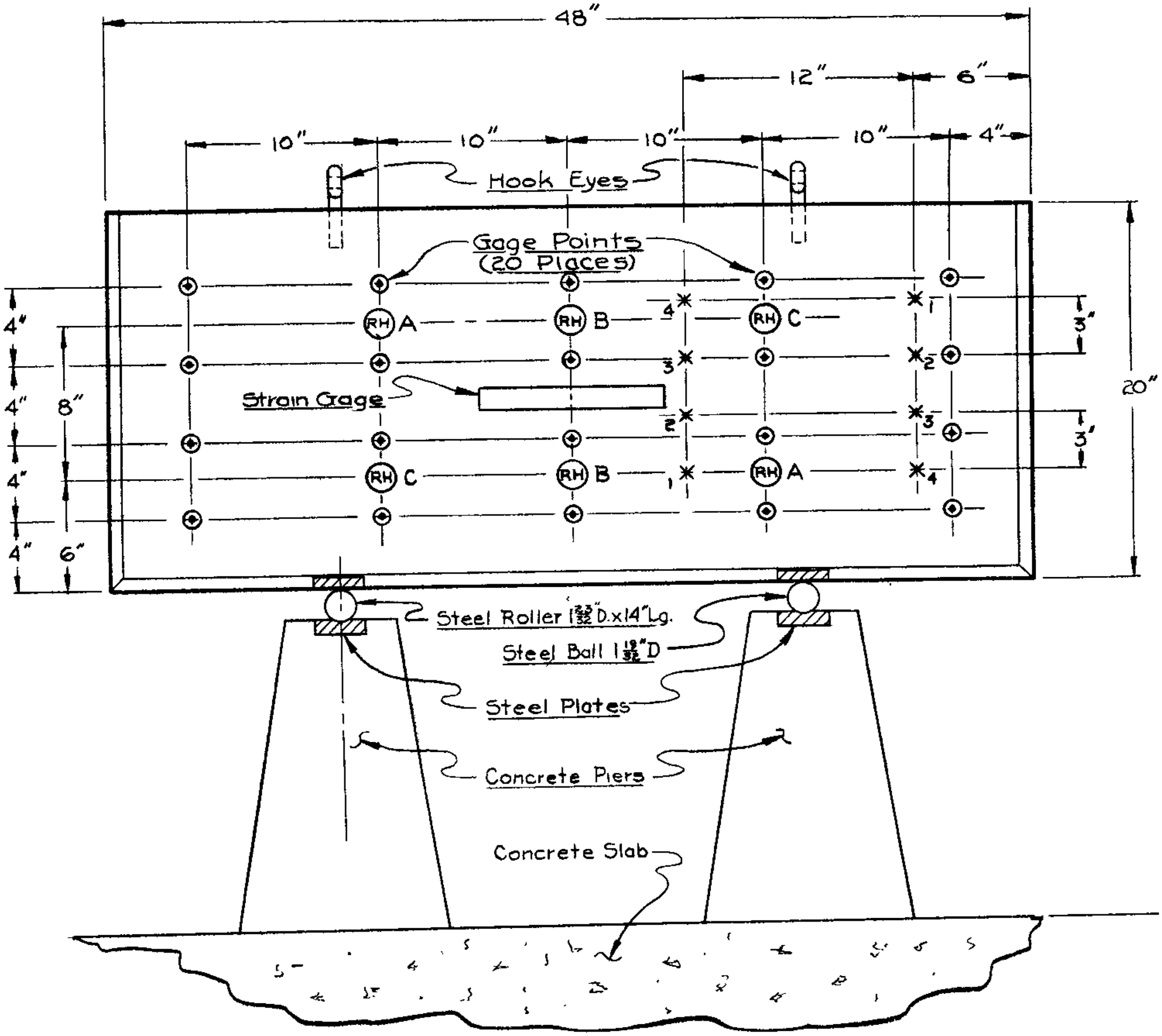
Drying Shrinkage at Various Elevations in Model Beams

Values are averages of surface shrinkage measurements from 36 to 65 weeks, inclusive.

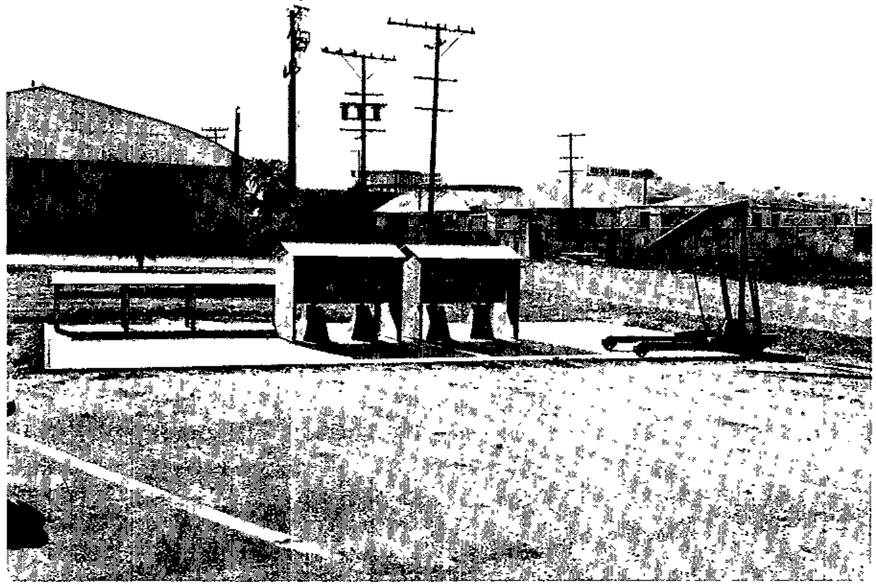
Distance Below Top Surface	Concrete Without Admixture		Concrete with Admixture		Increase due to Admixture Percent
	Shrinkage Percent	% of Avg.	Shrinkage Percent	% of Avg.	
4-inch	.0168	122	.0212	117	26
8-inch	.0131	95	.0185	103	41
12-inch	.0122	89	.0153	86	25
16-inch	.0129	94	.0167	93	30
Average	.0138		.0179		

(RH) = RELATIVE HUMIDITY HOLES	
LETTER	DEPTH (INCHES)
A	7
B	5
C	3

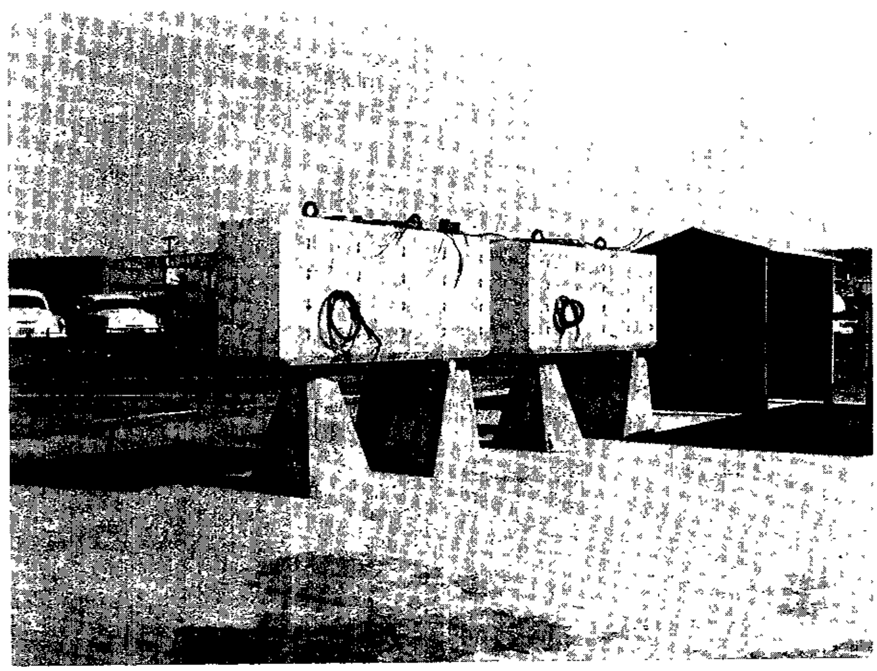
X = THERMOCOUPLES	
NUMBER	DEPTH (INCHES)
1	7
2	5
3	3
4	1



Instrumentation of model beams.

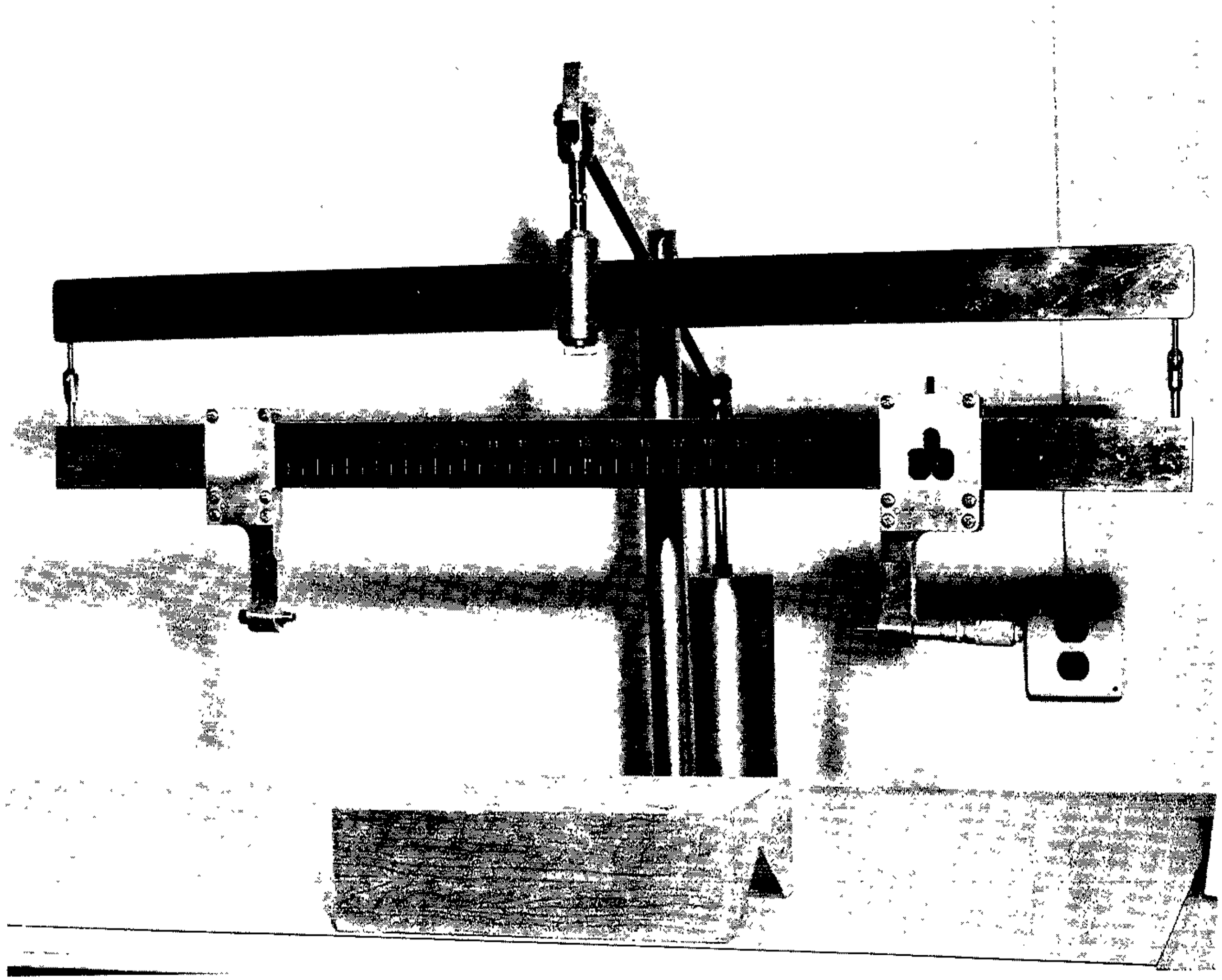


Specimens at exposure site. Roofs in place.

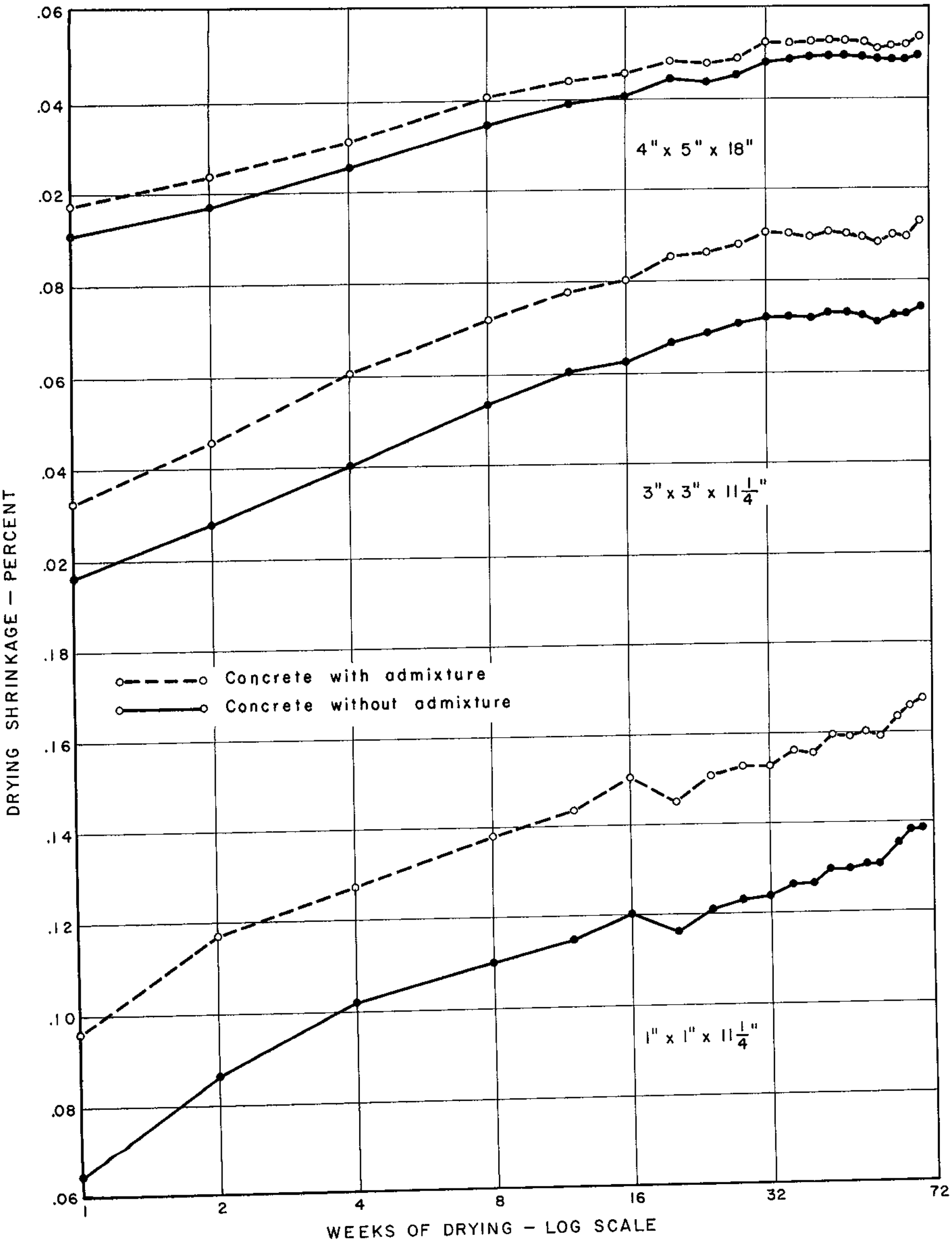


Model beams at exposure site. Roofs and endwalls removed.

Figure 4

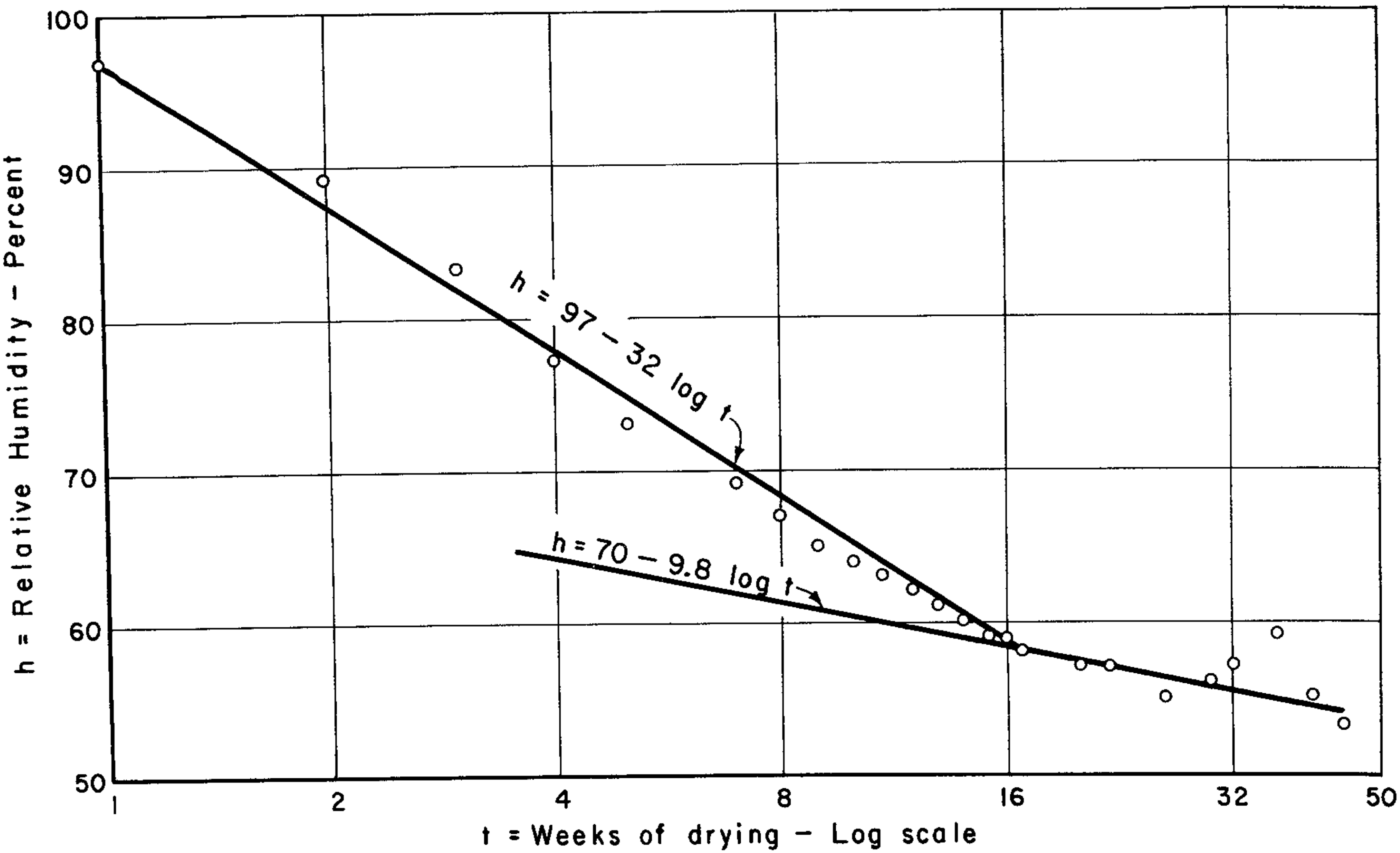


Horizontal Comparator used to measure length changes of 4 x 5 x 18 inch specimens.

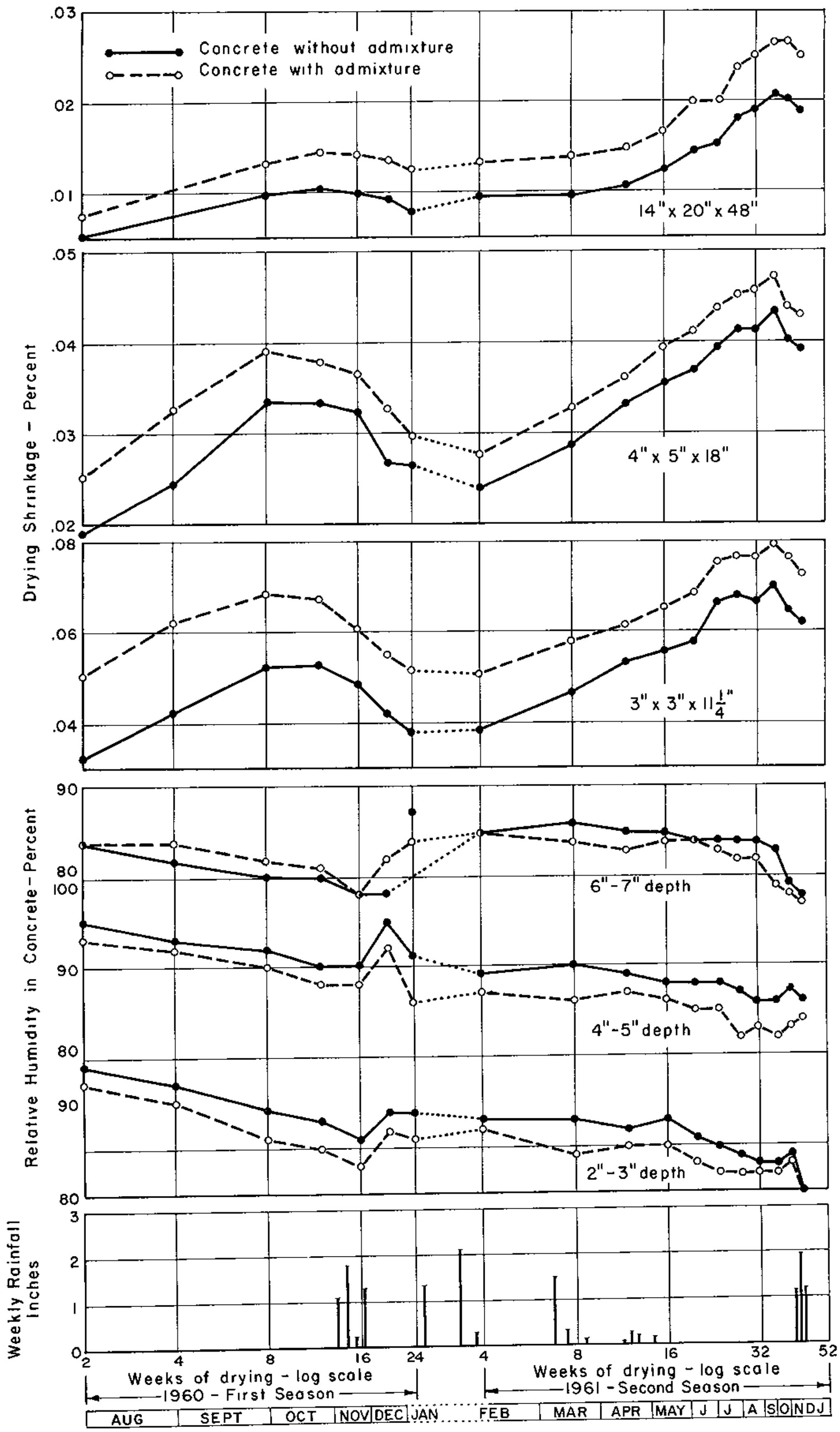


DRYING SHRINKAGE — SPECIMENS IN LABORATORY

Figure 6

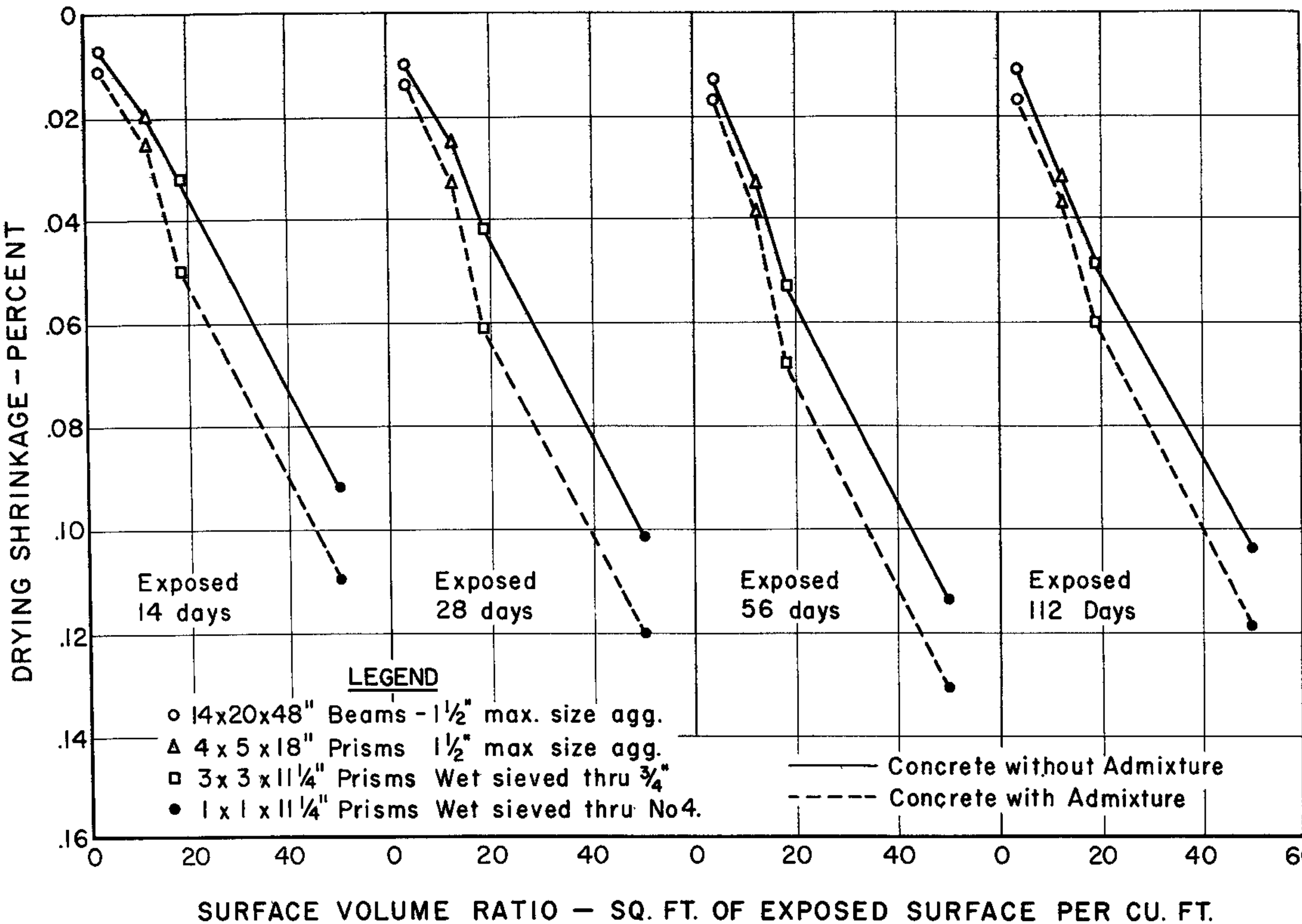


RELATIVE HUMIDITY AT CENTER OF $3'' \times 3'' \times 11\frac{1}{4}''$ CONCRETE PRISM
MOIST CURED 7 DAYS THEN IN AIR 73°F AND 50% RH



RAINFALL RELATIVE HUMIDITY AND DRYING SHRINKAGE OF SPECIMENS EXPOSED OUTSIDE

FIGURE 8



Relationship between drying shrinkage and surface - volume ratio. Specimens exposed outdoors.