5-15-1953

An Experimental Method of Predicting Strength Variations in Portland Cement

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Sprouse — Strength Variations in Portland Cement

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AN EXPERIMENTAL METHOD OF PREDICTING STRENGTH VARIATIONS IN PORTLAND CEMENT

By

James H. Sprouse, Jr.

A Thesis

In partial fulfillment of the

Requirements for the Degree of

Master of Science in Engineering

The University of New Mexico
1953

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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Thesis committee

W. C. Wagner
CHAIRMAN

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Ray Foss

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CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

Most present-day architects and engineers write their specifications for Portland cement concrete on a strength basis, rather than on a maximum water content or on a minimum cement content basis. Frequently, concrete specifications are written which include minimum strength requirements, maximum water content requirements, and minimum cement content requirements. When this occurs, the strength requirement usually governs the physical make-up of the concrete mix. The concrete producer, whether he be a contractor or a ready-mix concrete company, is held responsible for any failure of his product to meet the strength requirement as set forth in the specifications as written by the architect or engineer. Since the strength of Portland cement concrete depends upon the quality of the ingredients from which it is made, any variation in the quality of the ingredients will affect the strength of the concrete.

I. THE PROBLEM

Statement of the problem. It was the purpose of this study (1) to show the variations that may be expected in the strength characteristics of different shipments of Portland cement of the same brand from the same cement mill; (2) to

show the variations in the strength characteristics of different brands of cement; and (3) to develope an accelerated strength test for Portland cement upon which the strength of the concrete made from the cement could be predicted.

Importance of the study. The cornerstone of the modern theory of concrete design is the fact that using the same type and amount of cement and aggregates, the mix which has the highest concentration of cement in the cement paste will have the greatest strength. This theory was first stated and proved by the American, Duff A. Abrams in 1918 when he gave us his water-cement-ratio law:

> With given concrete materials and conditions of test, the quantity of mixing water used per bag of cement determines the strength of the concrete, so long as the mix is of a workable plasticity.[1]

Mr. Abrams was only interested in the effect of the amount of mixing water on the concrete strength, and did no work in determining the effect of variations in the quality of the ingredients from which the concrete was made. Abrams' law was based on the assumption that such items as quality of cement and aggregates, method of curing, curing temperatures, and age of curing would be kept constant.

A modern and well-equipped concrete plant is capable of controlling the quality of the water and the aggregates

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[1] D. A. Abrams, "Design of Concrete Mixtures," Structural Materials Research Lab. Bull. 1, Lewis Institute, 1918.

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ferent brands [illegible]

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the concrete [illegible].

Importance of the [illegible]

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used in the production of concrete. Such a plant, however, has no control over the quality nor the uniformity of the cement being used in the concrete. Portland cement is purchased from large cement mills, and is usually shipped to the concrete producer in hopper-bottom railway cars or packaged in 94-pound sacks and shipped in freight cars. The producer uses the amount of cement in his concrete that is commonly assumed to produce a minimum strength, when the concrete is cured and tested according to standard procedures. If the age of the concrete at the time of testing is to be 28 days, the concrete producer has no way of knowing the quality of the concrete he has sold until this period of 28 days has elapsed from the time of sale. If the concrete producer is to be held responsible for the quality of his product, based on strength alone, he is liable for much damage caused by having to replace the concrete. Replacing the defective concrete, and any other construction which might have been built on it during the elapsed time of the curing period, is a very expensive operation in most instances.

In order to reduce the risk of having to replace concrete which does not meet a strength requirement, many concrete producers add extra amounts of cement to their mixes to provide a large safety factor. This practice accounts for a waste of several million sacks of cement per year in the United States. This great waste of material

can be shown by the use of a simple illustration. An average-size ready-mix plant will batch about four hundred cubic yards of concrete in a working day. If the average cement content per cubic yard is five sacks, the total amount of cement used in the day's output would be two thousand sacks of cement. If the concrete producer is using one fourth of a sack per yard as a safety factor, he is wasting one hundred sacks of cement per day, or five per cent of the total amount used. Most concrete producers probably use nearer a half sack than a quarter sack for a safety factor. This practice wastes money as well as material, since a sack of cement costs the concrete customer approximately $1.25. The practice of adding cement to a concrete mix will, of course, lower the water content per sack of cement, thereby increasing the durability and the watertightness of the concrete.[2] However, when a strength requirement is specified, it is to be assumed that the durability and the watertightness of the concrete will be satisfactory. Strength is generally taken as the measure of concrete quality.[3]

It would be difficult for the layman to comprehend

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[2] Design and Control of Concrete Mixtures, Portland Cement Association, Tenth Edition, 1952, p. 4.

[3] J. W. Kelly "A. C. I. Manual of Concrete Inspection", American Concrete Institute, 1941, p. 17.

the magnitude of this excessive use of cement in the United States. Due to the unprecedented demand for cement which is far beyond the capacity of the cement plants, an undue problem is posed for the cement manufacturer in an impossible attempt to supply all their customers and keep them satisfied. On the consumers' side of the picture in most sections of the country, there does not appear to be any relief in the forseeable future. This condition is further exaggerated by the increasing demand for cement to be used in construction of Governmental projects and also the stepped-up tempo of highway construction by most State highway departments. If the concrete producer could eliminate the use of extra cement in his product for the purpose of obtaining a large factor of safety in strength, he could assist in the alleviation of the present nation-wide cement shortage. A method for accelerated testing of Portland cement upon which ultimate concrete strength could be predicted would be of great value to the concrete producer in the reduction of the use of Portland cement.

II. DEFINITIONS OF TERMS USED

Accelerated testing. This type of testing includes any method in which an unusually short period of time elapses between the beginning and the end of the test.

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II. [illegible]

Accelerated [illegible] any method in which [illegible] elapses between [illegible]

Aggregates. Sand, gravel, stone, slag, cinders, or other inert material used in the composition of concrete.

Cement factor. The number of bags or cubic feet of cement per cubic yard of concrete.

Compressive strength of concrete. The ultimate strength of concrete in compression.

Concrete. A mixture of Portland cement, fine aggregate, coarse aggregate, and water.

Consistency. The degree of fluidity as determined by a slump test.

Cube strength. The ultimate compressive strength of mortar when tested in the form of a cube.

Curing. Any means provided for the retention of moisture in concrete during the process of setting.

Fineness modulus. An empirical factor found by dividing the total of the percentages retained on specified sieves by 100. Sieve sizes are as follows (U. S. Series): $1\frac{1}{2}$ in., 3/4 in., 3/8 in., Nos. 4, 8, 16, 30, 50, and 100.

Moist room. A storage room used for the purpose of curing concrete and mortar specimens in which temperature and humidity can be controlled.

Ottawa sand. A sand produced in Ottawa, Illinois, used throughout the United States as a standard by all testing agencies.

Screen or sieve. A device with regularly spaced apertures for separating materials according to size. When not otherwise specified, a "sieve" has rectangular openings and a "screen" has circular openings.

7-day strength. The ultimate compressive strength of a concrete specimen when tested at the age of 7 days.

Slump. The subsidence measured in inches after removal of the mold from a sample of freshly mixed concrete molded in a standard slump cone.

28-day strength. The ultimate compressive strength of a concrete specimen when tested at the age of 28 days.

Unit weight. The weight in pounds per cubic foot of a material when the container is filled according to certain specified procedures.

Water-cement ratio. The ratio of water to cement, usually expressed in gallons per sack, ratio by weight, or ratio by volume.

III. ORGANIZATION OF REMAINDER OF THE THESIS

Chapter II of this thesis will consist of a presentation of the history and present status of the problem of predicting 28-day and 7-day-strengths based on accelerated strength tests on the cement used in the making of the concrete. An attempt will be made to show the inadequacies of the methods developed in the past by which this problem has been attacked.

Chapter III will show the method of experimental laboratory procedure used in gathering the data upon which the findings and conclusions are based.

Chapter IV of the thesis will be devoted to the data compiled from the procedure used in the laboratory. This chapter will contain the analysis of the data, and the correlation between the 24-hour cube strength and the 7 and 28-day concrete strengths.

Chapter V will be the final chapter, and will contain a summary of the findings of the study. The conclusions of the study and problems of research beyond the limits of this study will be presented in this chapter.

CHAPTER II

REVIEW OF RELATED EXPERIMENTAL STUDIES

Some work has been done in engineering circles toward the development of methods of predicting 28-day concrete compressive strengths based on the strengths of concrete when tested at earlier ages. It has not been a study in which definite relationships have been established. It seems that nearly every person, or group of persons, that has undertaken a study of the problem has arrived at the same general conclusion. Most everyone who has made such a study agrees in principle. Disagreement has arisen in the method of application of the finer points of techniques developed. A brief review of the studies made on the subject follows.

I. 7-DAY STRENGTH VS 28-DAY STRENGTH

Gowen, Leavitt, and Evans, in their investigation of the relationship between the 7-day and 28-day strengths of concrete, found that for any set value of the water-cement ratio used a correlation could be established between 7 and 28-day concrete compressive strengths. This correlation depended upon such factors as type of cement, aggregates, specimen dimensions, and method of curing of specimens. Factors such as the slump and the gradation

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correlation [illegible]

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of the aggregates did not adversely affect the correlation established in their study.[1]

Slater, in a study of the same type, corroborated the general findings of Gowen, Leavitt, and Evans.[2]

II. 3-DAY STRENGTH VS 28-DAY STRENGTH

Creskoff, in a study of the possible correlation between the 28-day strength of concrete with the strength of concrete at earlier ages, developed a method by which 3-day strength of concrete could be used as an index of ultimate strength of concrete.[3] In brief, the method consists of four steps: (1) making a pilot test series with varying water-cement ratios; (2) plotting the strengths of 28-day cylinders against those of companion cylinders broken at an earlier age; (3) fitting the data with a straight line passed through the point defined by the averages of the two series; and (4) using for subsequent

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1 J. W. Gowen, H. W. Leavitt, and W. S. Evans, "The Prediction of the 28-Day Breaking Strengths of Mortars from Their 7-Day Results," Univ. of Maine, Bull. 10, 1925.

2 W. A.Slater, "Relation of 7-Day to 28-Day Compressive Strength of Mortar and Concrete," American Concrete Institute Journal, Proceedings, Volume 22, 1925, pp. 437.

3 Jacob J. Creskoff, "Estimating 28-Day Strength of Concrete from Earlier Strengths," American Concrete Institute Journal, Proceedings, Volume 41, 1945, pp. 493-512.

tests the numerical value of the slope of the line as the coefficient by which an observed departure of an early age test from its mean is to be multiplied to obtain the predicted departure of the 28-day strength from its mean. These coefficients (slopes) would vary from about five-tenths (0.5) to two (2.0), the exact value being dependent on the particular job.

III. INADEQUACIES OF METHODS DEVELOPED

Excessive time required for trial tests. If a concrete producer were forced to depend on a 7-day test of his concrete mixes upon which to predict 28-day strengths before he could be secure in the use of a particular shipment of cement, he would have to have facilities for the storage of approximately eight days' supply of cement. Such facilities would work an extreme hardship on the average producer, since they would demand an enormous outlay of capital. An alternative solution would be to hold the cement on the rail siding in the hopper-bottom cars for a period of about 8 days. This would result in the payment of excessive demurrage. The most detrimental effect of this practice would be the nation-wide tie-up of cement cars. During times of peak construction periods, there is frequently a severe shortage of cement cars, even if cement customers unload cars on the date of arrival on the siding.

Inaccuracies which might be possible in 3-day tests. The method of predicting 28-day strengths based on 3-day trial tests developed by Mr. Creskoff contained only a single variable. This variable was the water-cement ratio. The method's weakness might possibly lie in the fact that it was based on only one variable, whereas many variables control the relation between late and early strengths. These variables are not adequately represented in a study of the effects of water-cement ratio alone. They include inadvertent changes in fineness of cement, differences in the clinker caused by chemical and physical blending and curing, and mixing temperatures of concrete.

[illegible]

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The method used [illegible]
It was based on [illegible]
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CHAPTER III

METHOD OF EXPERIMENTAL LABORATORY PROCEDURE

In conducting a study of this kind, it is absolutely essential that utmost care be exercised in the preparation, testing, and recording the data, of test samples. Great care was used in the laboratory procedures in this study to prevent variations in results due to laboratory technique. In dealing with a problem of this type, one finds a certain amount of variation in results which are unexplainable. One must use great care in order to minimize such variations.

I. THE SAMPLING OF CEMENT

Obtaining samples from hopper car. Figure 1, page 14, shows a cross-sectional view of a typical railroad car used in the shipment of bulk Portland cement from the cement plant to the concrete producer. Cement is also shipped in 94-pound sacks packed in ordinary railway box cars. All samples of cement used in this study were taken from hopper cars similar to that shown in Figure 1. When the hoppers shown at the bottom of the car are opened, and if no vibration on the car bottom is used, the cement will flow through the hopper gate from points almost directly above the gates. Mounds of cement will remain in the car, as indicated by the shaded areas on the Figure. During the cement sampling

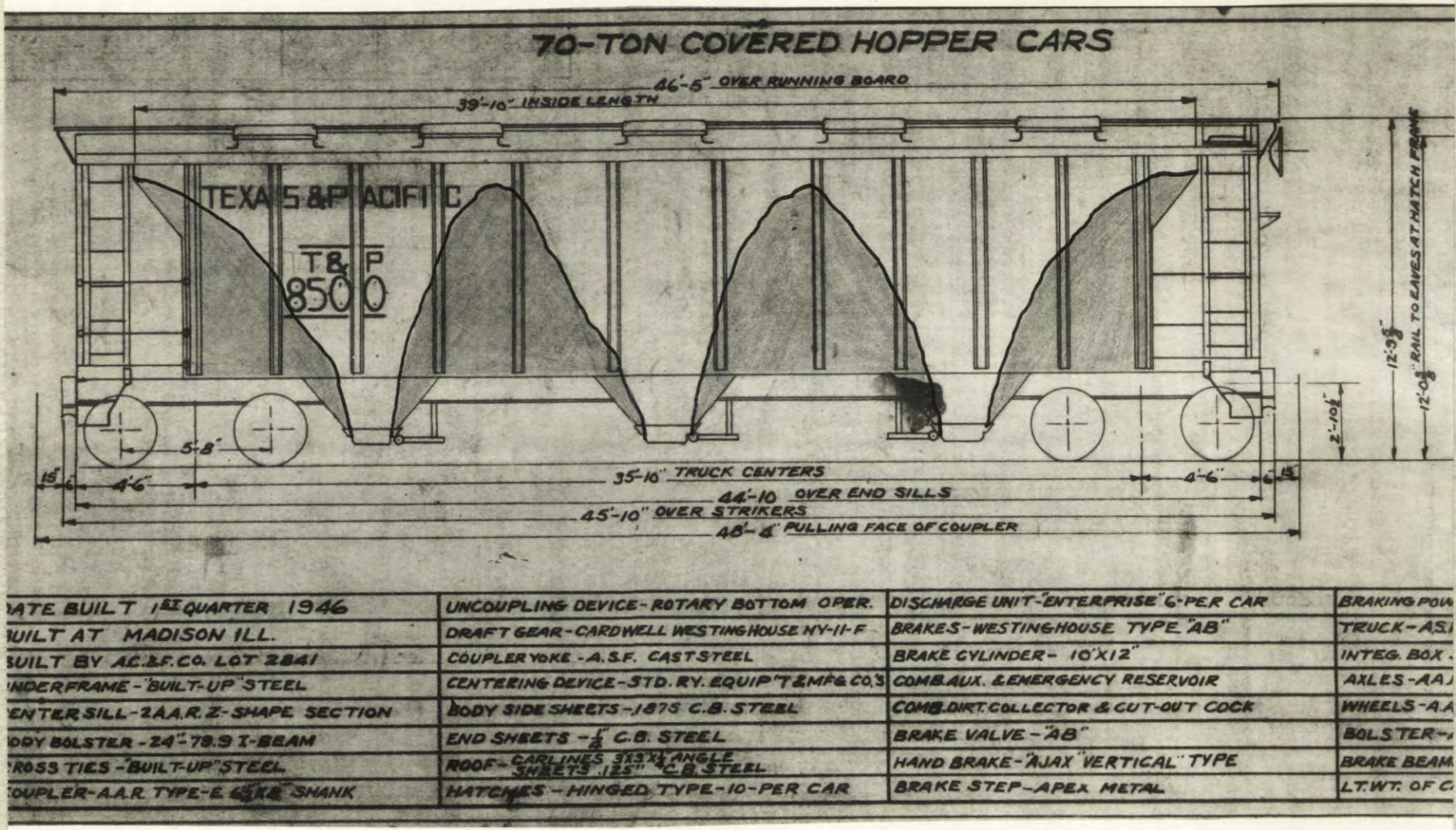

FIGURE 1

SECTIONAL VIEW OF TYPICAL CEMENT CAR
SHOWING MOUNDS OF CEMENT

operation, enough cement was allowed to flow from the car to form the mounds of cement in the car. A trough was formed above the hopper which extended nearly to the bottom of the car. The hopper cars had a row of hinged type hatches on the top on both sides of the car. These hatches were spaced close enough to allow convenient access to the sides of the cement mounds below. A gallon-size bucket suspended on a long rope was lowered into the car through the top hatches. The bucket was drawn up the sides of the cement mounds in order to get a sample of cement from as many points in the car as possible. A total of approximately ten samples was taken from each car of cement. It was believed that this method of sampling would give the most correct representation of the cement from top to bottom, end to end, and from side to side.

Blending samples from car. After removal from the car, the samples of cement were thoroughly mixed into one well-blended sample. After this blending process was completed, the sample was stored in an airtight container until it was used in the making of concrete test cylinders and mortar cubes. The container was identified with the following information: (1) railway car number, (2) date car was unloaded, (3) temperature of air in car, (4) temperature of cement in car, and (5) brand of cement. For obvious

operation, enough cement was lifted by the bucket to form the mounds of cement in the car. A platform was placed above the hopper which extended nearly to the bottom of the car. The hopper cars had a number of hatches along the top on both sides of the car, which were spaced closely enough to allow convenient access to any of the cement mounds below. A bucket on the end of a long rope was lowered into the car through the hatches. The bucket was drawn up the sides of the mound, in order to get a sample of cement from as many points in the car as possible. A total of approximately ten pounds was taken from each car of cement. It was believed that this method of sampling would give the most accurate representation of the cement from top to bottom, end to end, and side to side.

__Blending samples from car.__ After sampling each car, the samples of cement were thoroughly mixed into one well-blended sample. After this blending operation was completed, the sample was stored in an airtight container until it was used in the making of concrete test specimens and mortar cubes. The container was labelled with the following information: (1) number of the car, (2) date car was unloaded, (3) temperature of cement, (4) amount of cement in car, and (5) brand of cement.

reasons, the car numbers and brand of cement will not be shown in this study.

II. PROCEDURE USED IN CONCRETE TESTS

Aggregates used in concrete tests. In this study, emphasis was not placed on the use of any ideally graded aggregates. The aggregates used in the study were not specifically selected because of gradation characteristics. They were locally-produced aggregates of a known high quality. The sand and gravel used in the study were tested for compliance with A.S.T.M. Designation C 33-49.[1] All concrete tests were made with the use of aggregates from the original stockpiles in order to prevent strength variations caused by variations in aggregate quality. Frequent checks were made on the aggregates in order to detect abnormal variation.

Water-cement ratios used. Two water-cement ratios were used in this study. One of these was a water-cement ratio of eighty-eight hundredths (0.88) by weight, which corresponds to nine and ninety-three hundredths (9.93) gallons of water per sack of cement. The other was a water-cement ratio of sixty-five hundredths (0.65) by weight, which corresponds to seven and thirty-four hundredths

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[1] American Society for Testing Materials, Philadelphia, Pa., Book of A.S.T.M. Standards, 1949, Part 3, pp. 715-719.

reasons, the car makers and [illegible] shown in this study.

II. [illegible]

Aggregates used in concrete [illegible] emphasis was not placed on [illegible] aggregates. The aggregates used in this study were [illegible]-ically selected because of [illegible] were locally-produced [illegible]. The sand and gravel used in [illegible] pliance with A.S.T.M. Specification C [illegible] tests were made with [illegible] stockpiles in order to [illegible] by variations in aggregate quality. [illegible] made on the aggregates [illegible].

Water-cement ratios used. [illegible] were used in this study. [illegible] ratio of eighty-eight hundredths (0.88) by weight, which corresponds to nine and ninety-three hundredths (9.93) gallons of water per sack of cement. The [illegible] cement ratio of sixty-five hundredths [illegible] which corresponds to seven [illegible].

American Society for Testing Materials, Philadelphia, Pa., *Book of A.S.T.M. Standards*, [illegible] pp. 715-710.

(7.34) gallons per sack of cement. These ratios were chosen at random and had no relationship with each other. Seven and thirty-four hundredths gallons per sack is a typical water-cement ratio for a great amount of concrete being produced today. Concrete made with this water content per sack of cement is expected to have an ultimate compressive strength of approximately 4,000 p.s.i. Nine and ninety-three hundredths gallons of water per sack of cement is considered by many engineers to be an excessive water content. However, this ratio of water to cement is a typical one for a large amount of small-scale construction. The ratio is expected to provide the concrete an ultimate strength of approximately 2,500 p.s.i. at the age of 28 days.

Mixing of concrete. In all the concrete tests made during this study, the concrete was mixed and test cylinders molded as soon as possible after the cement was sampled from the railway hopper-bottom car. This procedure was followed in order to simulate as closely as possible the conditions under which concrete was produced by the concrete plant. Most concrete producers unload rail cars as soon as possible after receiving them to prevent paying demurrage. In most cases, the cement was unloaded direct into batching bins of the concrete plant, and was used in production of concrete within 4 to 48 hours after being unloaded. Whenever

(7.24) gallons per sack [illegible]
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and thirty-four [illegible]
water-cement ratio for a [illegible]
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bins of the concrete plant, [illegible]
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possible, the cement sampled from the cars was used in making concrete test cylinders on the date of sampling. Before test batches of concrete were made, the moisture content of the aggregates was determined and corrections made in the amount of mixing water to be used. The aggregates, cement, and water were weighed to the nearest hundredth (0.01) pound for the test batches. The order of charging the ingredients into the two cubic foot, motor-driven, mixer was to load the sand, gravel, and cement in that order. After the dry ingredients were well mixed, the water was added to the mix. The mixer was allowed to turn at least 3 minutes before the batch was dumped into the slump pan.

Making concrete slump test. A metal pan, 48 inches square and 4 inches deep was used to receive the concrete from the mixer. After the concrete was dumped into this pan, it was well mixed to reduce segregation. The slump test for consistency was then made in accordance with A.S.T.M. Designation C 143-39.[2] The equipment used was manufactured in compliance with this specification. The concrete used in the slump test was discarded and was not used in molding the test cylinders.

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[2] Ibid., pp. 866-867

possible. [illegible]
mixing concrete [illegible]
fore [illegible]
of the [illegible]
amount of [illegible]
and water [illegible]
for the [illegible]
into the [illegible]
sand, gravel, [illegible]
specific [illegible]
The mixer was [illegible]
batch was dumped into the mixer [illegible]

[illegible]

square and 6 inches [illegible]
from the mixer. [illegible]
pan, it was [illegible]
test for consistency was [illegible]
A.S.T.M. Designation [illegible]
manufactured in [illegible]
concrete used [illegible]
used in [illegible]

[illegible] Ibid., [illegible]

Unit weight test on concrete. A test for the unit weight of the concrete batch was performed on each mix made. A half cubic foot measure was used in this determination. In performing the test, the measure was filled a third full and the concrete rodded 25 times with a five-eighths inch rod. Another third of the volume was added and the concrete rodded another 25 times. The container was then filled, and the rodding procedure was repeated for the top layer. Care was taken in rodding the second and third layers to see that the rod penetrated into the previously placed layer. The measure was carefully struck off and the surface made smooth. The container full of concrete was weighed to the closest hundredth of a pound. The unit weight of the concrete was calculated by subtracting the known weight of the measure from the weight of the container full of concrete, and by multiplying the remainder by two.

Molding of concrete test cylinders. The concrete test cylinders were molded in accordance with A.S.T.M. Designation C 192-49[3], with the following exceptions: (1) 2 cylinders were made from each batch to be tested at 7 days and 2 were made for 28-day tests; (2) the molds used were made from steel tubing and were split down one side and equipped with a circumferential band with a bolt to draw

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[3] Ibid., pp. 836-840.

Unit weight test of concrete. [illegible]
weight of the concrete batch as [illegible]
A half cubic foot measure was used [illegible]
performing the test, [illegible]
the concrete [illegible]
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Molding of concrete test [illegible]
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cylinders were made [illegible]
and 2 were made for [illegible]
made from each [illegible]
equipped with [illegible]

[illegible] Ibid., [illegible]

the mold together, but were not equipped with a machined, watertight base plate--it has been shown that the error resulting from the use of open bottom molds is negligible;[4] (3) the surface of the test cylinders were struck off with a trowel, but were not covered with glass or metal plates.

<u>Curing and testing concrete cylinders</u>. At the age of 24 hours, the cylinders were removed from the molds, marked for identification, and placed in the moist room. The moist room was equipped with controls to regulate the temperature and the humidity of the cylinder storage space. Curing temperature in the moist room during this study for the concrete test cylinders was maintained between 65°F. and 75°F. One hundred per cent humidity was maintained in the storage area. At the end of the curing period, either the 7 day or the 28 day, the cylinders were removed from the moist room and allowed to surface dry. The cylinders were capped with a sulphur-clay mixture, which was allowed to harden for at least 2 hours. The cylinders were tested on a 300,000 pound capacity testing machine manufactured by Tinius Olsen Company. A load rate of approximately 35 pounds per square inch per second was used on this machine

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[4] William C. Wagner and Eldred R. Harrington, "A Study of the Various Types of Molds for Fabricating 6- by 12-inch Concrete Test Cylinders," Univ. of N.M., Eng. Series, <u>Bull</u>. 6, 1952.

the mold together, [illegible]. [illegible] watertight base [illegible] that [illegible] adding [illegible] [illegible] (2) the surface [illegible] a trowel, but [illegible].

Curing and [illegible]. [illegible] 24 hours, the cylinders [illegible] for identification, [illegible] room was equipped with [illegible] and the humidity of [illegible] temperature in the [illegible] concrete test cylinders [illegible] 75°F. The [illegible] storage area. [illegible] 7 day or the 28 day, [illegible] moist room and [illegible] capped with a sulphur-[illegible] harden for at least [illegible] a 300,000 pound [illegible] Tinius Olsen [illegible] pounds per square inch [illegible].

[illegible] Study of the [illegible] 12-inch Concrete [illegible] Series, Bull. [illegible]

in the testing of the 6-inch by 12-inch cylinders. The total load was read on the dial of the machine and recorded. The load in pounds per square inch was calculated by dividing the total load by the area of a 6-inch circle. The average of the 2 cylinders tested for each age, for each water-cement ratio, and for each sample of cement was calculated and recorded.

III. PROCEDURE USED IN CEMENT TESTS

Sand used in tests. The sand used for making test cubes was natural silica sand from Ottawa, Illinois, graded as follows:

Sieve	Percentage Retained
No. 100	98 plus or minus 2
No. 50	72 plus or minus 5
No. 30	2 plus or minus 2
No. 16	none

Ottawa sand is used as a standard for cement strength tests throughout the United States. It was because of this fact that it was used in this study. All cube tests were made using the same sack of Ottawa sand. Great care was exercised to prevent segregation of the sand during use.

Water-cement ratios used. Two water-cement ratios were used in the testing or mortar cubes. One of these was a ratio of eighty-eight hundredths (0.88) by weight. The

in the testing of [illegible]
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The load [illegible]
ing the total load [illegible]
average of the [illegible]
water-cement ratio [illegible]
culated and [illegible]

III. [illegible]

[illegible]
cubes was [illegible]
as follows:

[illegible]

Ottawa sand is used [illegible]
throughout this [illegible]
that it was [illegible]
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to prevent [illegible]

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were used in the [illegible]
a ratio [illegible]

other ratio was one of sixty-five hundredths (0.65) by weight. These 2 water-cement ratios were identical with those used in the making of the concrete test cylinders.

Proportioning and mixing of cube mortar. The proportions of dry materials for the mortars used in this study were as follows: (1) with the water-cement ratio of sixty-five hundredths (0.65), one part of cement to three and five-tenths parts of sand was used; (2) with the water-cement ratio of eighty-eight hundredths (0.88), one part of cement to four and eight-tenths parts of sand was used. One hundred sixty three grams of water, 250 grams of cement, and 875 grams of sand made 3 2-inch cubes for the study of mortar containing a water-cement ratio of sixty-five hundredths (0.65). Two hundred twenty grams of water, 250 grams of cement and 1200 grams of sand made 3 2-inch cubes for the study of mortar containing a water-cement ratio of eighty-eight hundredths (0.88). The mixing bowl used in the mixing of the mortar ingredients was of an 8 quart capacity and was made of stainless steel. The materials for a batch were introduced in the mixing bowl in the following manner: (1) the water was placed in the bowl, which had just been wiped with a damp cloth; (2) the cement was added to the water, and the two ingredients were mixed for 30 seconds with one hand, which was protected by a snug-fitting rubber glove;

(3) approximately one half of the sand was added and the ingredients were mixed for 30 seconds; and (4) the remainder of the sand was added and the total batch was mixed for a period of one and one-half minutes.

Molding test cubes. Mortar test cubes were made in strict accordance with A.S.T.M. C 109-49, paragraph 10.[5] Equipment used in the molding of test cubes was in compliance with A.S.T.M. C 109-49, paragraph 2.[6]

Curing and testing cubes. All test cubes, immediately after molding, were kept in the molds on the base plates in the moist room for a period of 18 hours, plus or minus 15 minutes. The temperature of the moist room was maintained at 55°F. plus or minus 3° for cement brand "A", and at 75°F. plus or minus 5° for cement brand "B". The upper surfaces were exposed to the moist air, but protected from dripping water by the use of glass plates. At the end of 18 hours, the cubes were carefully removed from the molds and placed in a container of boiling water. The cubes were cured in boiling water for a period of 6 hours, plus or minus 5 minutes. At the end of this 6 hour period, the cubes were

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[5] American Society for Testing Materials, Philadelphia, Pa., Book of A.S.T.M. Standards, 1949, Part 3, pp. 92-99.

[6] Ibid., pp. 92.

removed from the boiling water and tested on a Southwark Emery testing machine. The load rate on the machine during this testing was maintained at approximately 1500 pounds per square inch per minute. An identical rate setting on the testing machine was used in every mortar cube test to prevent variations in strength due to rate of loading. The total load was read from the testing machine dial and recorded. The pounds per square inch strength of the cubes was calculated by dividing the total load by the cross-sectional area of the cubes, which, in all cases, was 4 square inches. The cube strength was recorded on the data sheet.

CHAPTER IV

THE CORRELATIVE ANALYSIS OF DATA

The general pattern to be followed in the presentation of the data will be to show the variation in compressive strengths of concrete made from the 2 brands of cement, both for the 7-day tests and for the 28-day tests. This will be followed by the comparisons of cube strengths and concrete strengths for mortar and concrete, respectively, made from both brands of cement used and from both water-cement ratios.

I. VARIATION IN CONCRETE STRENGTHS

Variation in 7-day strengths. All samples of Portland cement used in this study were given project numbers for identification. Samples numbered 1 through 10 were of brand "A" cement, while numbers 11 through 24 were of brand "B" cement. Table I, page 26, shows the 7-day strengths of concrete made from both brands of cement and from both water-cement ratios. The average of the compressive strength of the samples 1 through 10 was found. The difference between the average of the 10 samples and each sample was calculated and expressed as a percentage of the average. The result was the per cent deviation for each sample, and was expressed as an algebraic per cent deviation. The

THE [illegible] OF DATA

The general [illegible] of the data will be [illegible] strengths of [illegible] both for the 7-day [illegible] will be followed by [illegible] concrete strength [illegible] made from both [illegible] cement ratios.

I. [illegible]

Variation [illegible] cement used in this [illegible] identification. [illegible] brand "A" cement, [illegible] "B" cement. [illegible] concrete made from [illegible] water-cement ratios. The [illegible] of the samples [illegible] tween the average of [illegible] calculated and [illegible] The result [illegible] was expressed [illegible]

TABLE I

VARIATION IN 7-DAY AND 28-DAY
CONCRETE STRENGTHS

	Water-Cement Ratio of 0.65				Water-Cement Ratio of 0.88			
Sample Number	7-Day Strength	Per Cent Deviation	28-Day Strength	Per Cent Deviation	7-Day Strength	Per Cent Deviation	28-Day Strength	Per Cent Deviation
1	3167	8.35	4963	13.67	1880	9.37	3343	17.67
2	3409	16.63	5173	18.48	1871	8.84	3245	14.22
3	2957	1.16	4323	-0.98	1565	-8.96	2833	-0.28
4	2993	2.39	4526	3.66	1863	8.32	2877	1.27
5	3079	5.34	4490	2.84	1818	5.76	2904	2.22
6	3105	6.23	4577	4.83	1792	4.25	2949	3.80
7	3134	7.22	4664	6.83	1960	14.02	3107	9.36
8	2283	-21.90	3693	-15.41	1381	-19.66	2231	-21.47
9	2292	-21.59	3542	-18.87	1330	-22.63	2381	-16.19
10	2809	-3.90	3710	-15.03	1733	0.81	2536	-10.74
11	2669	-1.44	3912	-1.39	1751	3.00	2740	4.34
12	2634	-2.73	4070	2.60	1538	-9.53	2642	0.61
13	2782	2.73	4131	4.13	1862	9.53	2948	12.26
14	2808	3.69	4063	2.42	1698	-0.12	2713	3.31
15	3010	11.15	4216	6.28	1933	13.71	2722	3.66
16	2765	2.10	4043	1.92	1835	7.94	2519	-4.07
17	2589	-4.39	3963	-0.10	1645	-3.24	2597	-1.10
18	2545	-6.02	3772	-4.92	1627	-4.29	2492	-5.10
19	2659	-1.81	3693	-6.91	1680	-1.18	2440	-7.08
20	2730	0.81	3755	-4.84	1662	-2.24	2536	-3.43
21	2747	1.44	3833	-3.38	1758	3.41	2615	-0.42
22	2615	-3.43	3816	-3.81	1654	-2.71	2589	-1.41
23	2660	-1.77	4043	1.92	1556	-8.47	2572	-2.06
24	2704	-0.15	4226	6.53	1600	-5.88	2633	0.27

same procedure was followed for samples numbered 11 through 24, since these 14 samples were of brand "B" cement. Table I, page 26, shows the per cent deviations, expressed algebraically, for each sample of cement tested in concrete cylinders for each water-cement ratio used.

Variations in 28-day strengths. Table I, page 26, shows 28-day strengths of concrete made from both brands of cement and with both water-cement ratios used in the study. The table also shows the per cent deviation, expressed algebraically, for each 28-day test made on each sample of cement.

II. STRENGTH COMPARISONS OF CUBES AND CYLINDERS

Comparison of 24-hour cube strengths with 7-day and 28-day concrete strengths for brand "A" cement with water-cement ratio of sixty-five hundredths. Table II, page 28, shows the cube strength, 7-day strength, and the 28-day strengths for brand "A" cement with a water-cement ratio of sixty-five hundredths (0.65). It also shows the quotient obtained by dividing the 7-day and the 28-day cylinder compressive strengths by the 24-hour cube strengths. The average of the quotients obtained was calculated, and the per cent deviation for each quotient was expressed algebraically. The arithmetical average of the deviations was

same procedure [illegible]
24, since there [illegible]
7, page [illegible]
[illegible]
cylinders [illegible]

Variations in [illegible]
shows 28-day [illegible]
of cement and [illegible]
study. [illegible]
pressed [illegible]
sample [illegible]

II. [illegible]

[illegible]
28-day [illegible]
cement [illegible]
shows the [illegible]
strengths [illegible]
sixty-five [illegible]
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TABLE II

COMPARISON OF 24-HOUR CUBE STRENGTHS
WITH 7-DAY AND 28-DAY CONCRETE STRENGTHS

Brand "A" Cement with W/C Ratio of 0.65

Sample Number	Cube Strength	7-Day Strength	7-Day / Cube	Quotient Per Cent Deviation	28-Day Strength	28-Day / Cube	Quotient Per Cent Deviation
1	1028	3167	3.081	-5.72	4963	4.828	-1.27
2	1062	3409	3.210	-1.78	5173	4.871	-0.39
3	810	2957	3.651	11.72	4323	5.337	9.14
4	993	2993	3.014	-7.77	4526	4.558	-6.79
5	847	3079	3.635	11.23	4490	5.301	8.41
6	1065	3105	2.915	-10.80	4577	4.298	-12.11
7	1031	3134	3.040	-6.98	4664	4.524	-0.53
8	669	2283	3.413	4.44	3693	5.520	12.88
9	661	2292	3.467	6.09	3542	5.359	9.59
10	863	2809	3.255	-0.40	3710	4.299	-12.09
Average	903	2923	3.268	6.69	4366	4.890	8.01

calculated. This average was known as the per cent mean deviation, and was calculated for both the 7-day and 28-day tests made with brand "A" cement.

Comparison of 24-hour cube strengths with 7-day and 28-day concrete strengths for brand "A" cement with water-cement ratio of eighty-eight hundredths. Table III, page 30, shows the cube strength, 7-day strength, and the 28-day strengths for brand "A" cement with a water-cement ratio of eighty-eight hundredths (0.88). It also shows the quotient obtained by dividing the 7-day and the 28-day cylinder compressive strengths by the 24-hour cube strengths. The average of the quotients obtained was calculated, and the per cent deviation for each quotient was expressed algebraically. The arithmetical average of the deviations was calculated. This average was known as the per cent mean deviation, and was calculated for both the 7-day and 28-day tests of samples made with brand "A" cement.

Comparison of 24-hour cube strengths with 7-day and 28-day concrete strengths for brand "B" cement with water-cement ratio of sixty-five hundredths. Table IV, page 32, shows the cube strength, 7-day strength, and the 28-day strengths for brand "B" cement with a water-cement ratio of sixty-five hundredths (0.65). It also shows the quotient

calculated. [illegible]

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Comparison [illegible]

28-day [illegible]

cement [illegible]

shows [illegible]

strengths [illegible]

sixty-five [illegible]

TABLE III

COMPARISON OF 24-HOUR CUBE STRENGTHS
WITH 7-DAY AND 28-DAY CONCRETE STRENGTHS

Brand "A" Cement with W/C Ratio of 0.88

Sample Number	Cube Strength	7-Day Strength	7-Day / Cube	Quotient Per Cent Deviation	28-Day Strength	28-Day / Cube	Quotient Per Cent Deviation
1	480	1880	3.917	-7.00	3343	6.965	0.04
2	488	1871	3.834	-8.97	3245	6.650	-4.48
3	358	1565	4.372	3.80	2833	7.913	13.66
4	499	1862	3.731	-11.42	2877	5.766	-17.18
5	376	1818	4.835	14.79	2904	7.723	10.93
6	445	1792	4.027	-4.39	2949	6.627	-4.81
7	470	1960	4.170	-1.00	3107	6.611	-5.04
8	304	1381	4.543	7.86	2231	7.339	5.41
9	333	1330	3.994	-5.18	2381	7.150	2.70
10	369	1733	4.696	11.49	2536	6.873	-1.28
Average	412	1719	4.212	7.59	2841	6.962	6.55

obtained by dividing the 7-day and the 28-day cylinder compressive strengths by the 24-hour cube strengths. The average of the quotients obtained was calculated, and the per-cent deviation for each quotient was expressed algebraically. The arithmetical average of the deviations was calculated. This average was known as the per cent mean deviation, and was calculated for both the 7-day and 28-day tests of samples made with brand "B" cement.

<u>Comparison of 24-hour cube strengths with 7-day and 28-day concrete strengths for brand "B" cement with water-cement ratio of eighty-eight hundredths</u>. Table V, page 33, shows the cube strength, 7-day strength, and the 28-day strength for brand "B" cement with a water-cement ratio of eighty-eight hundredths (0.88). It also shows the quotient obtained by dividing the 7-day and the 28-day cylinder compressive strengths by the 24-hour cube strengths. The average of the quotients obtained was calculated, and the per cent deviation for each quotient was expressed algebraically. The arithmetical average of the deviations was calculated. This average was known as the per cent mean variation, and was calculated for both the 7-day and 28-day tests of samples made with brand "B" cement.

TABLE IV

COMPARISON OF 24-HOUR CUBE STRENGTHS
WITH 7-DAY AND 28-DAY CONCRETE STRENGTHS

Brand "B" Cement with W/C Ratio of 0.65

Sample Number	Cube Strength	7-Day Strength	7-Day / Cube	Quotient Per Cent Deviation	28-Day / Strength	28-Day Cube	Quotient Per Cent Deviation
11	1070	2669	2.494	8.91	3912	3.656	8.84
12	1153	2634	2.284	-0.26	4070	3.530	5.09
13	1168	2782	2.382	4.02	4131	3.537	5.30
14	1443	2808	1.946	-15.02	4063	2.816	-16.17
15	1355	3010	2.221	-3.01	4216	3.111	-7.38
16	1264	2765	2.188	-4.45	3043	3.199	-4.76
17	1083	2589	2.391	4.41	3936	3.659	8.93
18	1045	2545	2.435	6.33	3772	3.610	7.47
19	1119	2659	2.376	3.76	3693	3.300	-1.76
20	1133	2730	2.410	5.24	3755	3.314	-1.34
21	1337	2747	2.055	-10.26	3833	2.867	-14.65
22	1198	2615	2.183	-4.67	3816	3.185	-5.18
23	1168	2660	2.277	-0.57	4043	3.461	3.04
24	1116	2704	2.423	5.81	4226	3.787	3.96
Average	1189	2708	2.290	5.48	3967	3.359	6.71

TABLE V

COMPARISON OF 24-HOUR CUBE STRENGTHS
WITH 7-DAY AND 28-DAY CONCRETE STRENGTHS

Brand "B" Cement with W/C Ratio of 0.88

Sample Number	Cube Strength	7-Day Strength	7-Day / Cube	Quotient Per Cent Deviation	28-Day Strength	28-Day / Cube	Quotient Per Cent Deviation
11	507	1751	3.454	11.74	2740	5.404	13.15
12	548	1538	2.807	-9.19	2642	4.821	0.94
13	553	1862	3.367	8.93	2948	5.331	11.62
14	624	1698	2.721	-11.97	2713	4.348	-8.96
15	657	1933	2.942	-4.82	2722	4.143	-13.25
16	527	1835	3.482	12.65	2519	4.780	0.08
17	510	1645	3.225	4.34	2597	5.092	6.62
18	466	1627	3.491	12.94	2492	5.348	11.98
19	524	1680	3.206	3.72	2440	4.656	-2.51
20	608	1662	2.734	-11.55	2536	4.171	-12.67
21	533	1758	3.298	6.70	2615	4.906	2.72
22	608	1654	2.720	-12.00	2589	4.258	-10.85
23	535	1556	2.909	-5.89	2572	4.807	0.65
24	548	1600	2.920	-5.53	2633	4.805	0.61
Average	553	1700	3.091	8.71	2626	4.776	6.90

III. GRAPHICAL ANALYSIS OF DATA

Brand "A" cement with water-cement ratio of sixty-five hundredths. Figure 2, page 35, is a graphical presentation of the relationship of the mortar cube strength to the strength of the concrete cylinders at the ages of 7 and 28 days. The line designated as "A28" was drawn to show the average of the quotients obtained by dividing the 28-day cylinder strength by the cube strength for each sample of cement. The line shown as "A7" shows the average of the quotients obtained by dividing the 7-day cylinder strength by the cube strength for each sample of cement. Expressed another way, the lines "A28" and "A7" are drawn so that their slope is equal to the average of the quotients of the cylinder strengths divided by the cube strengths. The slope of the two lines under consideration was 3.268 for the 7 day and 4.890 for the 28 day, as given on Table II, page 28.

The points plotted on Figure 2 show the comparative strengths of cylinders and cubes. Upon inspection of the Figure, it became apparent that the lines "A28" and "A7" did not closely represent the graphical average of the points as plotted. Consequently, lines "B28" and "B7" were drawn from inspection, more closely representing the graphical location of the points. Line "B28" was drawn to show the 28-day correlation, and line "B7" to show 7-day correlation.

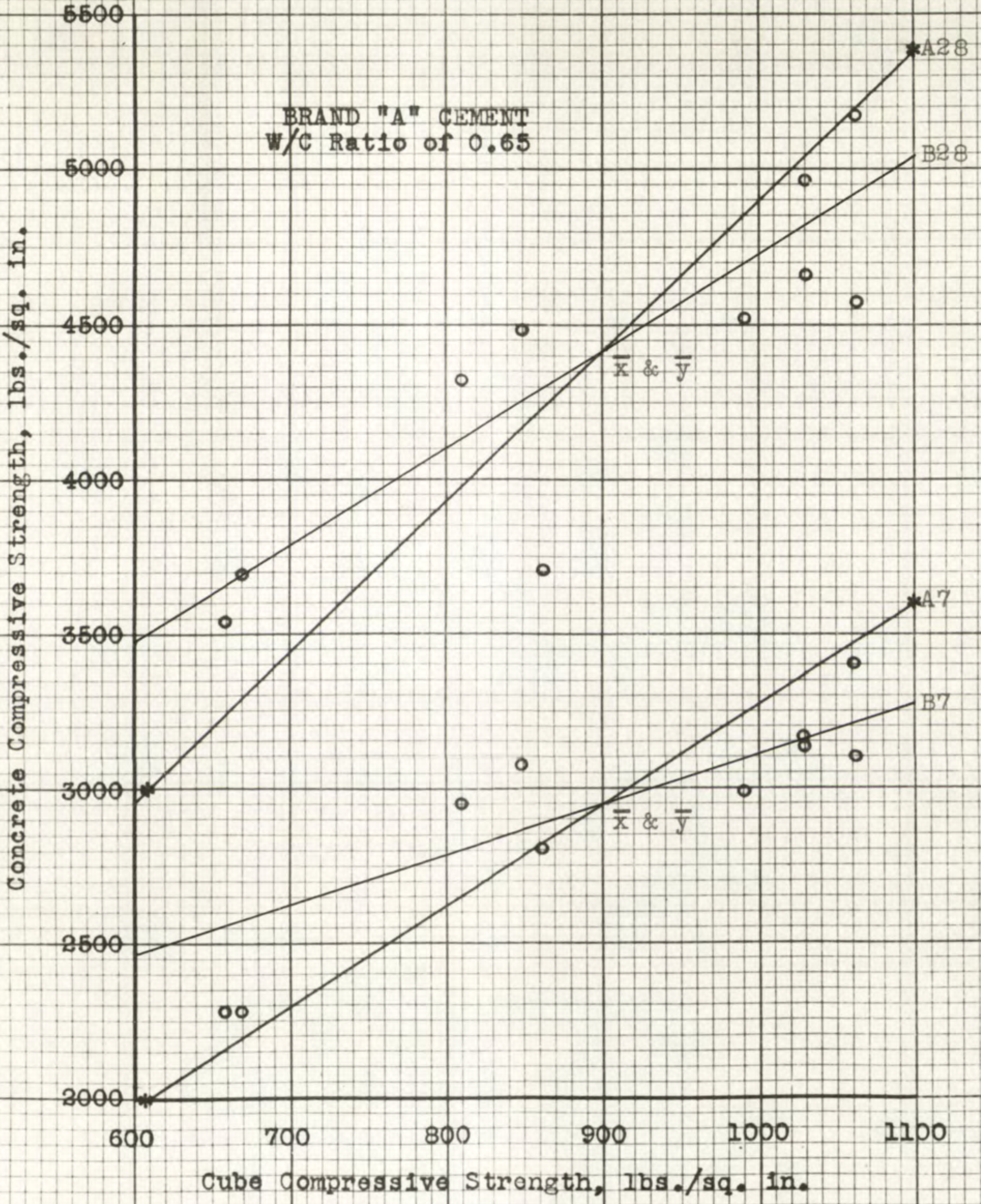

FIGURE 2

COMPARATIVE STRENGTHS OF CONCRETE CYLINDERS
AND 24-HOUR CUBES

The slope of these lines drawn from inspection was 3.13 and 1.58, respectively.

The lines drawn from inspection of Figure 2 were drawn through the point representing the average of the cube strengths and the average of the cylinder strengths. On the Figure, this point is designated as "$\bar{x}$ & $\bar{y}$". Of course, this point also fell on the original lines "A". The values for $\bar{x}$ & $\bar{y}$ for the 28-day line were 903 and 4366 p.s.i. respectively. The values for the 7-day line were 903 and 2923 p.s.i. These values were taken from Table II.

<u>Brand "A" cement with water-cement ratio of eighty-eight hundredths</u>. Figure 3, page 37, is a graphical presentation of the relationship of the mortar cube strength to the strength of the concrete cylinders at the ages of 7 and 28 days. The slope of the "A" lines was found in the manner described in the preceding paragraphs. The value of the slope of the 28-day line was 6.952; that of the 7-day line was 4.212. The values for $\bar{x}$ & $\bar{y}$ were 412 and 1719 p.s.i. for the 7-day line and 412 and 2841 p.s.i. respectively for the 28-day line. The above values were taken from Table III, page 30. The "B" lines drawn from inspection had slopes of 2.40 and 5.80 for the 7 and 28 day lines respectively

<u>Brand "B" cement with water-cement ratio of sixty-five</u>

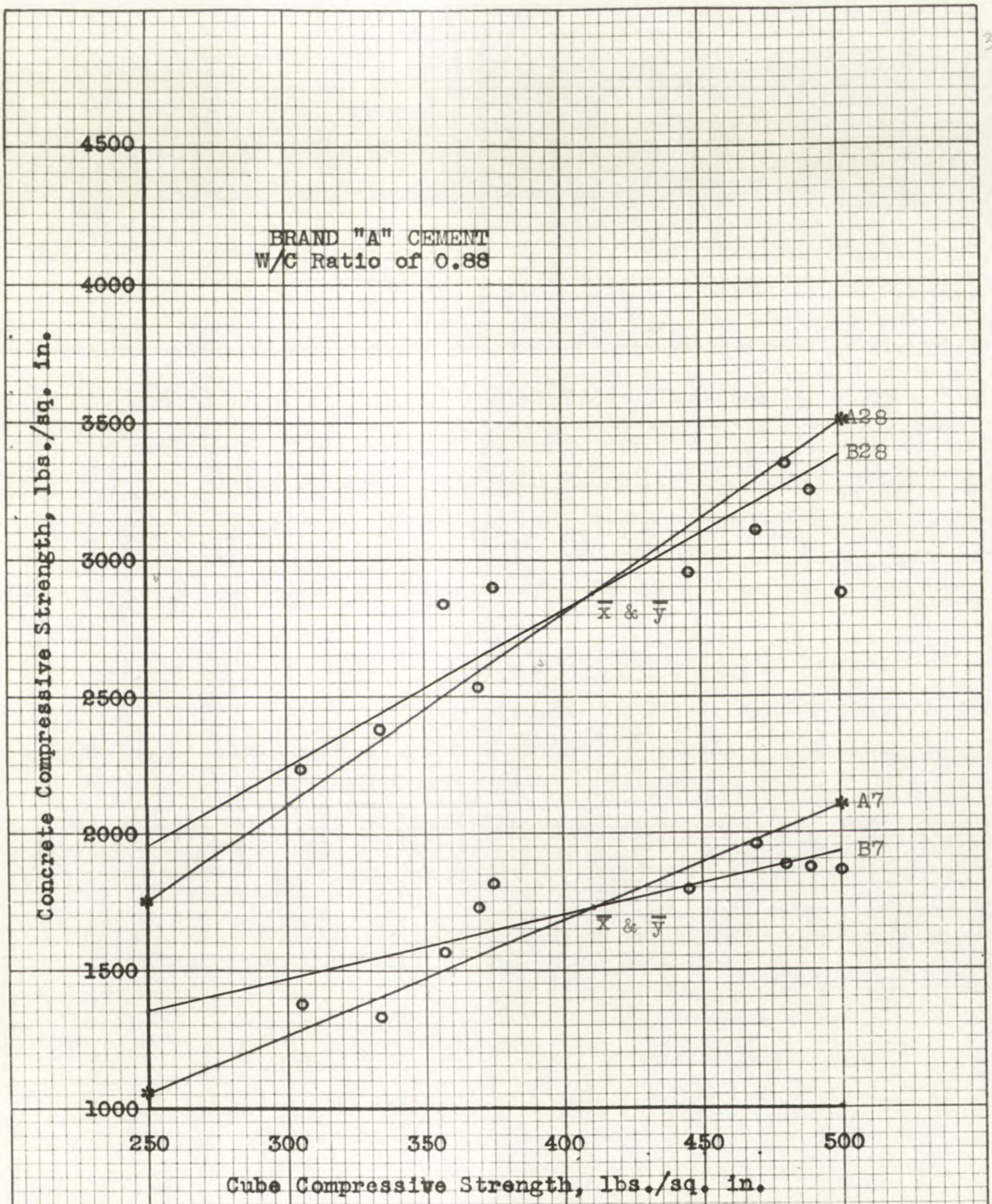

FIGURE 3

COMPARATIVE STRENGTHS OF CONCRETE CYLINDERS
AND 24-HOUR CUBES

hundredths. Figure 4, page 39, shows the "A" and "B" lines for both 7-day and 28-day concrete strengths vs 24-hour cube strengths for brand "B" cement with a water-cement ratio of sixty-five hundredths (0.65). The slope of the line "A28" was found to be 3.359; that of line "A7" was 2.290. The values for $\overline{x}$ & $\overline{y}$ for the 28-day line were 1189 and 3967 p.s.i. respectively. The values for this point were 1189 and 2708 p.s.i. for the 7-day line. These values were taken from Table IV, page 32. The slopes for the "B" lines were found to be 0.850 and 1.200 for the 28 and 7-day lines respectively.

Brand "B" cement with water-cement ratio of eighty-eight hundredths. Figure 5, page 40, is a graphical representation of the comparative strengths of concrete cylinders at the age of 7 and 28 days and strengths of 24-hour cubes made from the same samples of cement. The values for $\overline{x}$ & $\overline{y}$ on line "A28" are 553 and 2626 p.s.i. The slope of this line is 4.776. The values of $\overline{x}$ & $\overline{y}$ for line "A7" are 553 and 1700 p.s.i. respectively. The slope of this line is 3.091. The "B" lines were drawn from inspection. The slope of the 28 day line is 0.286; that for the 7 day line is 0.743. The values for $\overline{x}$ & $\overline{y}$ and the slope of the "A" lines were taken from Table V, page 33.

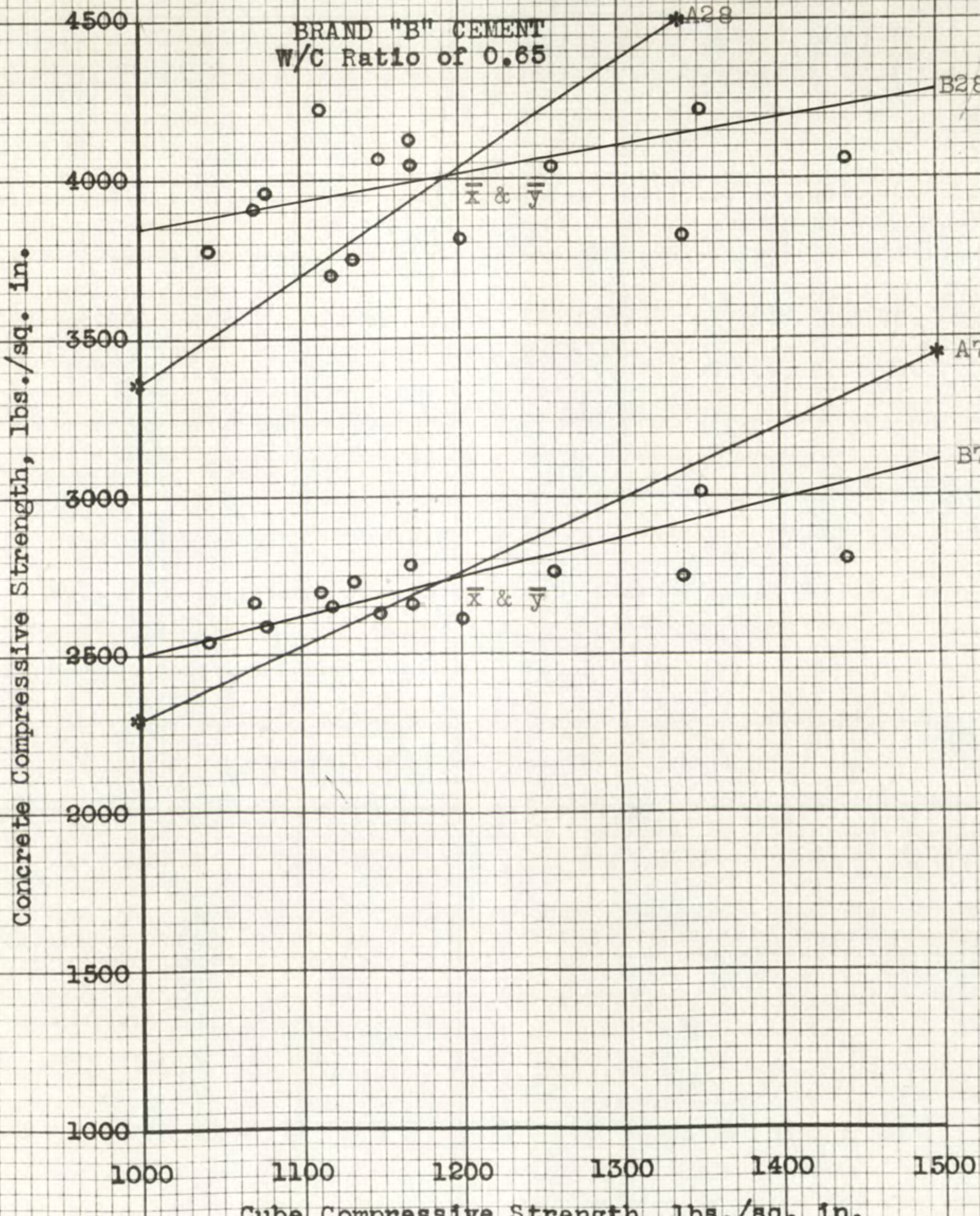

FIGURE 4

COMPARATIVE STRENGTHS OF CONCRETE CYLINDERS
AND 24-HOUR CUBES

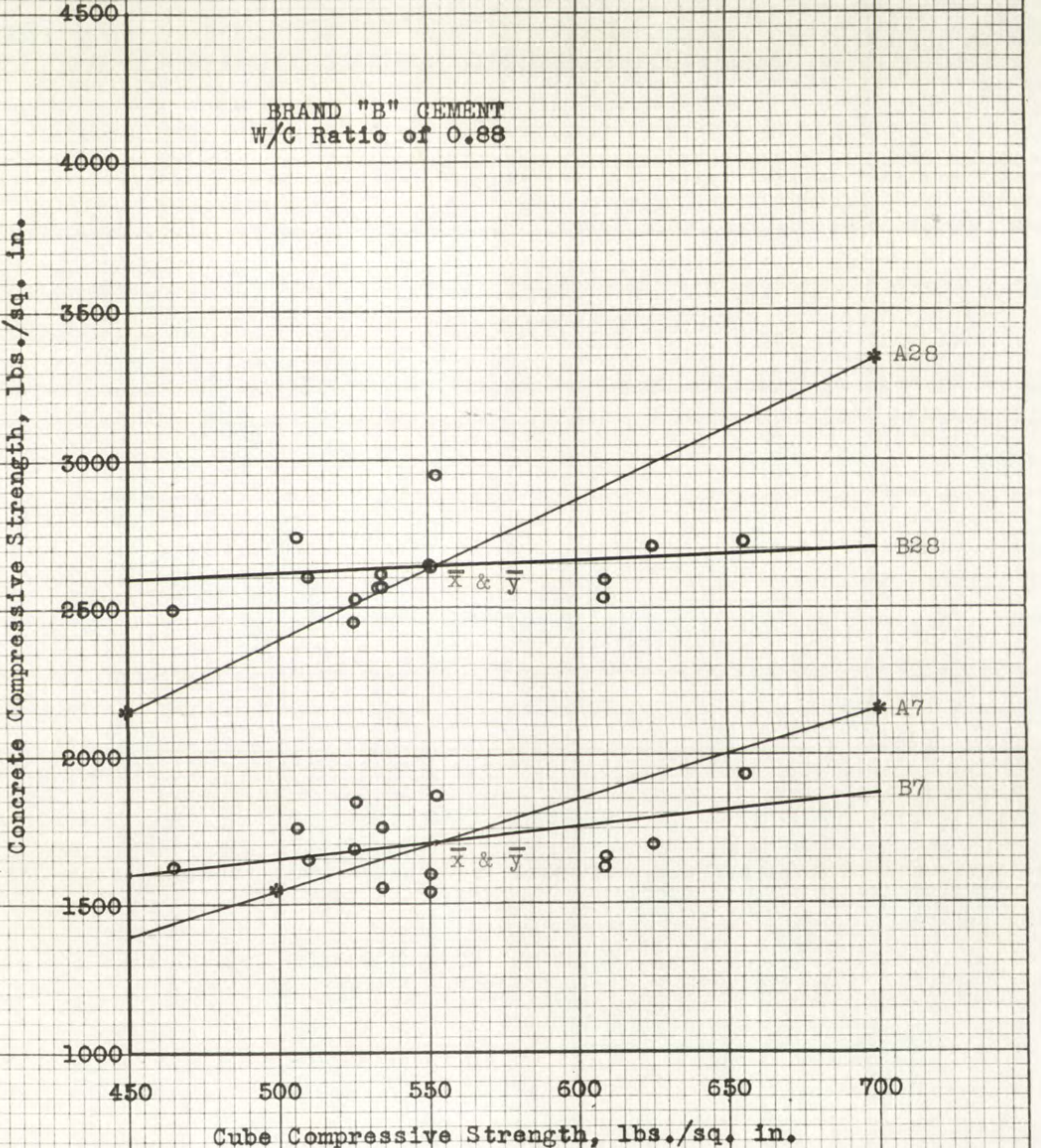

FIGURE 5

COMPARATIVE STRENGTHS OF CONCRETE CYLINDERS
AND 24-HOUR CUBES

Brands "A" and "B" cements with water-cement ratios of sixty-five and eighty-eight hundredths--a comparison of 7-day strengths and 28-day strengths for the complete study. Figure 6, page 42, is a graphical illustration of the comparative strengths of the 7-day cylinders and the 28-day cylinders made during the course of the complete study. The sloping line drawn on the figure represents the average of the individual ratios of 28-day cylinders to 7-day cylinders. Attention is called to the fact that there was a certain amount of variation in the samples from this average. Data from which this figure was produced is found in Table I, page 26.

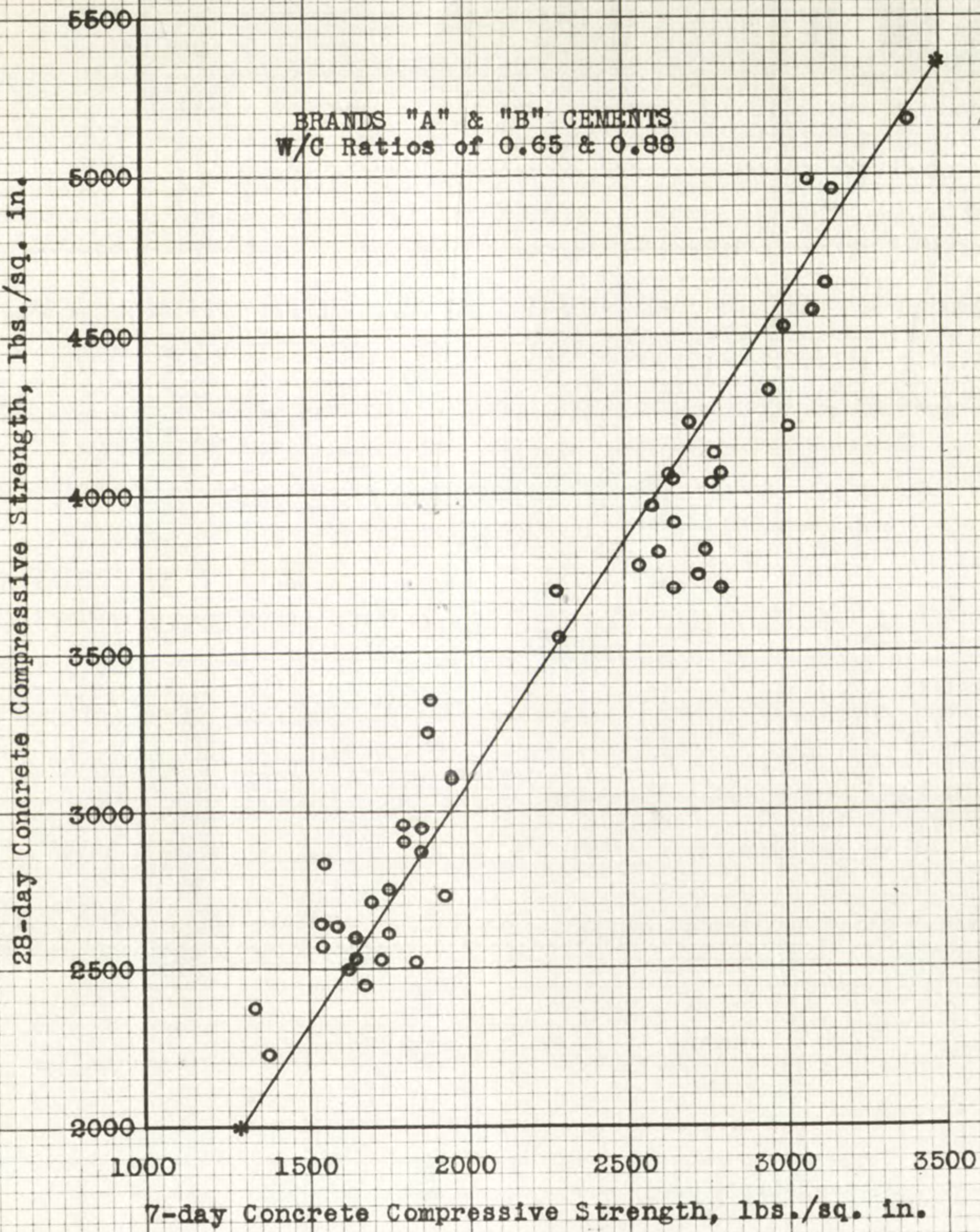

FIGURE 6

COMPARATIVE STRENGTHS OF 28-DAY CYLINDERS
AND 7-DAY CYLINDERS

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

Chapter I of this study dealt with the statement of the problem, the importance of making such a study, and included a list of definitions of terms used. The purpose of this study was to show the variations in different shipments of cement of the same brand from the same cement mill, to show the variations in the strength characteristics of different brands of cement, and to develope an accelerated strength test for Portland cement upon which the strength of concrete made from the cement could be predicted.

The primary justification for making a study of this type stems from the fact that many concrete producers in the United States are being penalized in the use of Portland cement by having to use an excessive amount of cement in their product to provide a safety factor of such magnitude as to take care of variations in cement quality. Such producers ordinarily have control of the aggregates used, but the control of the cement quality is entirely in the hands of the cement companies. In this day of cement shortages and maximum output, cement companies are more concerned with quantity than with quality of their product. Perhaps

this is as it should be. The concrete producer, however, is vitally interested in quality, as well as quantity, of the cement used in his concrete. An accelerated strength test of the shipment of cement which will guide the concrete producer in the quantity of cement to use to produce a concrete of a set standard would be universally accepted by the concrete producers of this country.

Chapter II consisted of a review of the studies which have been made on the subject of predicting 28-day strengths of concrete based on strengths of concrete at earlier ages. All studies of this type known to the author have been made on the concrete itself. None have been made on the cement from which the concrete was made. Several individuals and groups have conducted studies to relate 7-day strengths with 28-day strengths. These studies have been relatively successfull from the standpoint of accuracy. However, it has been shown in Chapter II that having to wait on the results of a 7-day trial test would require facilities for the storage of approximately 8 days' supply of cement.

A review of the 3-day method of predicting 28-day strengths was contained in Chapter II. It was explained that the 3-day tests were based on only one variable. In concrete strength, several variables are present. All of these variables must be considered in the predictions of 28-day strengths based on strengths at earlier ages.

Chapter III was devoted to explaining the method of laboratory procedure used in this study. The sampling of cement was explained in detail. In the use of an accelerated test on cement, it would be very important to obtain a representative sample of the shipment to be tested. The procedure given in this chapter would give the sampler as representative a sample of cememt as could be obtained.

It was explained in this chapter that special aggregates were not used in the making of the concrete test cylinders. However, the same aggregates were used in all concrete tests to prevent variation in strength due to aggregate variation.

The water-cement ratios used in the study were selected on the basis of common usage.

The method of mixing the concrete batches used in all concrete samples was explained in Chapter III. Methods of performing the slump test, unit weight tests, and of molding, curing, and testing concrete test cylinders were explained in this chapter. References were made to the Standards of the American Society for Testing Materials, since procedures given therein are standard throughout the United States.

Laboratory procedures for the making, curing, and testing of mortar cubes were given in Chapter III. The temperature of the moist-room for the curing of the cubes

made from brand "A" cement was different from that used for the curing of cubes made from brand "B" cement. This change was made in order to determine what effect, if any, the initial curing temperature would have on the accuracy of strength predictions.

Chapter IV has dealt with the analysis of data found in the study. Table I, page 26, was produced to show the variation in, and the relationship of, 7-day and 28-day concrete cylinders. These cylinders were made from both brands of cement with both water-cement ratios. The average of 7-day strengths was calculated for both brands of cement with both water-cement ratios. The variation from this average strength was expressed as a percentage. The same procedure was followed for the 28-day strengths. These variations were expressed as a percentage of the average of samples of the same brand.

Tables II, III, IV, and V were produced to show the comparisons of 24-hour cube strength with 7-day and 28-day concrete strengths. Each Table represents one brand of cement and one of the water-cement ratios used in this study. Each Table shows the sample number, the cube strength of each sample tested, the 7-day strength of the concrete made from each cement sample, and the 28-day strength of the concrete made from each cement sample. In order to correlate cube strength with concrete strength of both ages, a

made from [illegible] [illegible] the curing of cubes [illegible] was made in order to [illegible] initial curing [illegible] strength prediction.

Chapter [illegible] in the study. [illegible] variation in, [illegible] crete cylinders. [illegible] of cement with both [illegible] 7-day strengths [illegible] with both [illegible] average strengths [illegible] procedure that followed [illegible] lations were [illegible] samples of [illegible].

Table [illegible] comparisons of 28-day [illegible] concrete strength. [illegible] cement and one of the [illegible]. Each table [illegible] each single [illegible] from each cement [illegible] concrete [illegible] late [illegible]

column in each Table shows the quotients of 7-day concrete strengths divided by cube strengths, and of 28-day concrete strengths divided by cube strengths. The average of each of these columns was calculated. Another column was made to show the variation from this average for each sample of cement. These variations were expressed as a per cent of the average. The average of the individual variations, or deviations, was calculated and was designated as the average per cent mean deviation.

In order to present graphical illustrations of the data, Figures 2, 3, 4, 5, and 6 were drawn. Each Figure is produced from the Tables discussed above. Points on the Figures were so placed to represent both cube strengths and 7-day and 28-day concrete strengths. Lines designated as "A" were drawn on each Figure to represent the average of the quotients obtained by dividing the 7-day and 28-day concrete strengths by the 24-hour cube strength of each sample of cement. On the Figures, the slope of the "A" lines is equal to the average of said quotients. By visual inspection, it was found that the "A" lines did not follow the geometric center line of the points. A new series of lines marked "B" were drawn to closely approximate the geometric center line of the points. The slope of each of the "B" lines was calculated. Figure 6 was made for the sole purpose of showing graphically the relationship of the

7-day and the 28-day strengths for all samples of cement used in this study.

Tables VI and VII in the Appendix were included to show all data collected in the making of this study.

II. CONCLUSIONS

Different brands of cement being produced in the Southwestern section of the United States have different characteristics of strength variation. Of the two brands used in this study, brand "A" indicated a strong tendency toward great variations of strength, even though the over-all average of the concrete strengths of this brand were greater for both 7-day and 28-day ages and for both water-cement ratios than the strengths of concrete made from brand "B". Brand "B" seemed to have little tendency toward great variations in concrete strengths. Brand "A" cement showed an average variation of 9.47 per cent in 7-day cylinder strengths with a water-cement ratio of sixty-five hundredths (0.65) by weight, whereas brand "B" showed an average variation for the same condition of tests of only 3.12 per cent. Brand "A" cement showed an average variation of 10.06 per cent in 28-day tests with a water-cement ratio of sixty-five hundredths (0.65), whereas brand "B" showed an average of only 3.65 per cent for the same conditions. With

a water-cement ratio of eighty-eight hundredths (0.88), brand "A" cement indicated an average of 10.26 per cent and 9.72 per cent for 7-day and 28-day ages, respectively; under the same conditions of tests, brand "B" showed an average variation of only 5.38 per cent and 3.51 per cent for 7-day and 28-day ages, respectively.

A measure of the efficiency of a mortar test is its power to discriminate between samples of cements having different strengths of concrete. Stated in another way, this means whether the mortar tests reveal the same relationship between the strength of different samples of cement as do the concrete strengths. The efficiency of the accelerated mortar test developed in this study varied directly with the strength variations in the particular brand of cement being tested. That is to say, the efficiency of the mortar test was high when the variation in strength of the brand of cement was large. This was shown in Table VI of the Appendix. The average variations in the ratios of 7-day strength to cube strength and in ratios of 28-day strength to cube strength were of less magnitude than the variations of the 7-day and 28-day strengths themselves. Conversely, Table VII of the Appendix indicates that the efficiency of the mortar test is low when the average variations in the concrete strength are small. For brand "B" cement, in which strength

a water-cement ratio [illegible]

mana "A" [illegible]

0.72 per cent for 7-day and 28-day [illegible]

the same conditions [illegible]

variation of [illegible] per [illegible]

and 28-day [illegible], respectively.

A [illegible]

power to distinguish between [illegible]

different strengths [illegible]

means whether [illegible]

between the strengths [illegible]

the concrete [illegible]

mortar [illegible]

strength [illegible]

[illegible]

was [illegible]

ment was large. [illegible]

The average [illegible]

cube strength [illegible]

strength [illegible]

7-day and 28-day [illegible]

of the Appendix [illegible]

test is [illegible]

strength are [illegible]

variations were small, the average of the variations in the ratios of 7-day strength to cube strength and in ratios of 28-day strength to cube strength were of greater magnitude than the variations of the 7-day and 28-day strengths themselves.

The use of a cement having strength characteristics similar to brand "A" would place a concrete producer in a precarious position if he were called upon to guarantee the ultimate compressive strength of his product, unless he used an excessive amount of cement to provide a large factor of safety. In lieu of the use of accelerated strength tests upon which concrete strengths could be predicted, the concrete producer should confine his use of Portland cement to brands which show little tendency toward great variations in strength. Under the present conditions of cement shortages and capacity output, this practice would be impossible. Therefore, the concrete producer must use some sort of test to determine the quality of the cement before he uses it, or use an excessive amount of cement to provide a safety factor.

The fact that the efficiency of the accelerated test developed in this study is low for brands of cement showing insignificant variations in strength does not diminish the importance of such tests. This type of test would not be necessary if the concrete producer could procure consistently

variations were [illegible]

ratios of 7-day [illegible]

28-day strength [illegible]

than the variation [illegible]

selves.

The use [illegible]

similar to [illegible]

precautions [illegible]

ultimate [illegible]

an excessive amount [illegible]

safety. In lieu [illegible]

upon which concrete [illegible]

crete producer [illegible]

brands which show [illegible]

strength. Under [illegible]

and capacity output, [illegible]

Therefore, the [illegible]

to determine the quality [illegible]

use an excessive [illegible]

The [illegible]

developed in [illegible]

insignificant [illegible]

importance [illegible]

necessary [illegible]

uniform shipments of Portland cement.

The author believes that an accelerated test as developed in this study is of great value in determining the quality of cements. It is possible that it would be of greater value if it were made in conjunction with a time-of-set test and a soundness test. The correlation of such tests are beyond the scope of this study.

A general question has arisen among construction people regarding studies of this sort--"Why on a job do we need to make, or to predict the strength of, so many 28-day tests? Would not a part of the effort currently spent on compression testing yield more profitable results if it were applied to a more regular and systemmatic control of the uniformity of the manufacturing processes all the way from the cement mill to the finished structure?" Job specifications usually require 28-day tests, and there is very little liklihood that engineers, architects, or specification writers could be persuaded to eliminate the requirements for 28-day tests. As long as the requirement for 28-day tests exists, the concrete producer will be held responsible for the outcome of such tests. To aid the producer in predicting the outcome of the 28-day tests was the principal reason for making this study.

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BIBLIOGRAPHY

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APPENDIX

TABLE VI

ORIGINAL DATA
BRAND "A" CEMENT

Col. 1 Sample Number	Col. 2 W/C Ratio	Col. 3 Unit Weight	Col. 4 Slump in.	Col. 5 7-day Strength	Col. 6 28-day Strength	Col. 7 Cube Strength	Col. 8 Moist-room Temperature	Col. 9 Col. 5 / Col. 7	Col. 10 Col. 6 / Col. 7	Col. 11 Col. 6 / Col. 5	Col. 12 Col. 5 % Deviation	Col. 13 Col. 6 % Deviation	Col. 14 Col. 7 % Deviation	Col. 15 Col. 9 % Deviation	Col. 16 Col. 10 % Deviation	Col. Col. 1 Deviat
1	0.65	146.00	6	3167	4963	1028	57	3.081	4.828	1.567	8.35	13.67	13.84	-5.72	-1.27	4.7
2	0.65	146.08	4½	3409	5173	1062	57	3.210	4.871	1.517	16.63	18.48	17.60	-1.78	-0.39	1.4
3	0.65	145.00	4½	2957	4323	810	58	3.651	5.337	1.462	1.16	-0.98	-10.29	11.72	9.14	-2.2
4	0.65	146.80	4	2993	4526	993	58	3.014	4.558	1.512	2.39	3.66	9.96	-7.77	-6.79	1.0
5	0.65	146.80	5½	3079	4490	847	57	3.635	5.301	1.458	5.34	2.84	-6.20	11.23	8.41	-2.5
6	0.65	146.68	5	3105	4577	1065	56	2.915	4.298	1.474	6.23	4.83	17.94	-10.80	-12.11	-1.4
7	0.65	146.44	4½	3134	4664	1031	55	3.040	4.524	1.488	7.22	6.83	14.17	-6.98	-7.49	-0.5
8	0.65	146.48	4½	2283	3693	669	53	3.413	5.520	1.618	-21.90	-15.41	-25.91	4.44	12.88	8.1
9	0.65	146.00	3½	2292	3542	661	57	3.467	5.359	1.545	-21.59	-18.87	-26.79	6.09	9.59	3.2
10	0.65	146.72	4½	2809	3710	863	56	3.255	4.299	1.321	-3.90	-15.03	-4.42	-0.40	-12.09	-11.7
Average				2923	4366	903	56½	3.268	4.890	1.496	9.47	10.06	14.71	6.69	8.01	3.72
1	0.88	143.40	6	1880	3343	480	57	3.917	6.965	1.778	9.37	17.67	16.50	-7.00	0.04	7.37
2	0.88	143.20	6	1871	3245	488	57	3.834	6.650	1.734	8.84	14.22	18.44	-8.97	-4.48	4.71
3	0.88	141.60	5	1565	2833	358	58	4.372	7.913	1.810	-8.96	-0.28	-13.10	3.80	13.66	9.30
4	0.88	144.40	6	1862	2877	499	58	3.731	5.766	1.545	8.32	1.27	21.11	-11.42	-17.18	-6.70
5	0.88	144.00	7	1818	2904	376	57	4.835	7.723	1.597	5.76	2.22	-8.73	14.79	10.93	-3.56
6	0.88	144.80	6½	1792	2949	445	56	4.027	6.627	1.646	4.25	3.80	8.00	-4.39	-4.81	-0.60
7	0.88	144.40	6½	1960	3107	470	55	4.170	6.611	1.586	14.02	9.36	14.07	-1.00	-5.04	-4.23
8	0.88	144.40	6	1381	2231	304	53	4.543	7.339	1.615	-19.66	-21.47	-26.21	7.86	5.41	-2.48
9	0.88	144.48	6½	1330	2381	333	57	3.994	7.150	1.790	-22.63	-16.19	-19.17	-5.18	2.70	8.09
10	0.88	144.00	6½	1733	2536	369	56	4.696	6.873	1.463	0.81	-10.74	-10.43	11.49	-1.28	-11.65
Average				1719	2841	412	56½	4.212	6.962	1.656	10.26	9.72	15.58	7.59	6.55	5.87

TABLE VII

ORIGINAL DATA
BRAND "B" CEMENT

l. 1 mple mber	Col. 2 Water-Cement Ratio	Col. 3 Unit Weight	Col. 4 Slump in.	Col. 5 7-day Strength	Col. 6 28-day Strength	Col. 7 Cube Strength	Col. 8 Moist-room Temperature	Col. 9 Col. 5 / Col. 7	Col. 10 Col. 6 / Col. 7	Col. 11 Col. 6 / Col. 5	Col. 12 Col. 5 % Deviation	Col. 13 Col. 6 % Deviation	Col. 14 Col. 7 % Deviation	Col. 15 Col. 9 % Deviation	Col. 16 Col. 10 % Deviation	Col. 17 Col. 11 Deviati
11	0.65	146.24	6	2669	3912	1070	73	2.494	3.656	1.466	-1.44	-1.39	-10.01	8.91	8.84	0.00
12	0.65	145.52	6½	2634	4070	1153	74	2.284	3.530	1.545	-2.73	2.60	-3.03	-0.26	5.09	5.39
13	0.65	147.60	5½	2782	4131	1168	73	2.382	3.537	1.485	2.73	4.13	-1.77	4.02	5.30	1.30
14	0.65	146.80	5½	2808	4063	1443	76	1.946	2.816	1.447	3.69	2.42	21.36	-15.02	-16.17	-1.30
15	0.65	147.60	5½	3010	4216	1355	73	2.221	3.111	1.401	11.15	6.28	12.28	-3.01	-7.38	-4.43
16	0.65	146.88	5	2765	4043	1264	75	2.188	3.199	1.462	2.10	1.92	6.31	-4.45	-4.76	-0.27
17	0.65	146.80	5¼	2589	3963	1083	73	2.391	3.659	1.531	-4.39	-0.10	-8.92	4.41	8.93	4.43
18	0.65	146.48	5½	2545	3772	1045	72	2.435	3.610	1.482	-6.02	-4.92	-12.11	6.33	7.47	1.09
19	0.65	146.88	5½	2659	3693	1119	72	2.376	3.300	1.389	-1.81	-6.91	-5.89	3.76	-1.76	-5.25
20	0.65	147.04	5	2730	3755	1133	71	2.410	3.314	1.375	0.81	-4.84	-4.71	5.24	-1.34	-6.21
21	0.65	146.04	5¼	2747	3833	1337	74	2.055	2.867	1.395	1.44	-3.38	12.45	-10.26	-14.65	-4.84
22	0.65	146.20	4½	2615	3816	1198	72	2.183	3.185	1.459	-3.43	-3.81	0.76	-4.67	-5.18	-0.48
23	0.65	146.32	4¼	2660	4043	1168	72	2.277	3.461	1.520	-1.77	1.92	-1.77	-0.57	3.04	3.68
24	0.65	146.72	5	2704	4226	1116	74	2.423	3.787	1.563	-0.15	6.53	-6.14	5.81	3.96	6.62
rage				2708	3967	1189	73	2.290	3.359	1.466	3.12	3.65	7.68	5.48	6.71	3.24
11	0.88	143.92	8	1751	2740	507	73	3.454	5.404	1.565	3.00	4.34	-8.31	11.74	13.15	1.03
12	0.88	144.20	7	1538	2642	548	74	2.807	4.821	1.718	-9.53	0.61	-0.90	-9.19	0.94	10.91
13	0.88	144.40	7½	1862	2948	553	73	3.367	5.331	1.583	9.53	12.26	0.00	8.93	11.62	2.19
14	0.88	144.36	7	1698	2713	624	76	2.721	4.348	1.598	-0.12	3.31	12.83	-11.97	-8.96	3.16
15	0.88	145.20	7¼	1933	2722	657	73	2.942	4.143	1.408	13.71	3.66	18.80	-4.82	-13.25	-9.10
16	0.88	144.92	7	1835	2519	527	75	3.482	4.780	1.373	7.94	-4.07	-4.70	12.65	0.08	-11.36
17	0.88	143.84	6½	1645	2597	510	73	3.225	5.092	1.579	-3.24	-1.10	-7.77	4.34	6.62	1.94
18	0.88	143.88	6½	1627	2492	466	72	3.491	5.348	1.532	-4.29	-5.10	-15.73	12.94	11.98	-1.10
19	0.88	144.12	7	1680	2440	524	72	3.206	4.656	1.452	-1.18	-7.08	-5.24	3.72	-2.51	-6.26
20	0.88	144.48	6¼	1662	2536	608	71	2.734	4.171	1.526	-2.24	-3.43	9.94	-11.55	-12.67	-1.48
21	0.88	144.00	8	1758	2615	533	74	3.298	4.906	1.487	3.41	-0.42	-3.61	6.70	2.72	-4.00
22	0.88	143.68	6¼	1654	2589	608	72	2.720	4.258	1.565	-2.71	-1.41	9.94	-12.00	-10.85	1.03
23	0.88	144.48	6	1556	2572	535	72	2.909	4.807	1.653	-8.47	-2.06	-3.25	-5.89	0.65	6.71
24	0.88	144.36	6½	1600	2633	548	74	2.920	4.805	1.646	-5.88	0.27	-0.90	-5.53	0.61	6.26
rage				1700	2626	553	73	3.091	4.776	1.549	5.38	3.51	7.28	8.71	6.90	4.75
