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Progress Report

of the

Engineering Research Division

of the

Bureau of Economic Geology and Technology

BY

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

PROGRESS REPORT
ENGINEERING RESEARCH DIVISION

SECTION I

INTRODUCTION

The work of the Engineering Research Division includes independent research by members of the staff, coöperative research with other organizations, routine testing for the State Highway Department, and testing and research for others when conditions justify it.

In the course of this work it happens occasionally that new facts are discovered which are of importance to the engineering profession, but not of sufficient importance to justify the immediate publication of a special bulletin. In order to bring such new information promptly to the attention of the practicing engineers and in order to secure a general coöperation of the engineering profession with the Engineering Research Division, Progress Reports describing the Division's work will be sent out from time to time. It is desired to send the Progress Reports to all who are interested; the names and addresses of such persons are solicited.

SECTION II

THE INFLUENCE OF STRENGTH OF COARSE AGGREGATE ON THE STRENGTH OF CONCRETE WHEN THE COARSE AGGREGATE IS NOT LARGER THAN ONE-HALF INCH

In the summer of 1920 City Engineer H. Helland of San Antonio inquired whether the soft limestone in the municipal quarry was of sufficient strength to be used in concrete construction and stated that if it were the City of San Antonio could save a considerable sum of money by using local stone instead of shipping in harder coarse aggregate.

To answer the question, a quantity of soft limestone was sent from the San Antonio quarries and tested in the Engineering Research Laboratory in comparison with some of the harder limestone from Comal County.

The tests showed that, while soft limestone from San Antonio had a unit compressive strength of about 6000 pounds and the harder Comal County limestone had a unit compressive strength of about 18,000 pounds, the 28-day strength of concrete made with the soft stone was as great as that made with the harder stone, so the Division advised the San Antonio officials that "The stone from the San Antonio quarry is suitable for concrete aggregate other than for wearing surfaces of roads and pavements."

The results of this investigation differed considerably from those expected, particularly since the Final Report of the Joint Committee on Concrete and Reinforced Concrete, published in 1917, recommended that the strength of concrete made with hard limestone be assumed about one-third higher than similar concrete made with soft limestone.

To throw more light on this question, it was decided to make a thorough investigation and to test practically the entire range of Texas stones, from soft limestone to trap, in order to determine how the strength of concrete varies with the strength of its coarse aggregate.

Six different aggregates were selected, namely, trap, porphyry, dolomite, and three grades of limestone; five different proportions of cement were employed for each aggregate, and ten specimens were made for each aggregate and each proportion of cement, five to be tested at 28 days and five at 3 months. The five specimens constituting a group were made on five different days in order to avoid accidental variations which might affect the whole group.

The test specimens were prepared according to A. S. T. M. specifications for compressive strength of Portland cement mortars, but they were tested with cardboard, about 1/16 inch thick, on each end of the specimen in order to obtain a more nearly uniform distribution of the load over the entire surface of the specimen than is possible without the use of cardboard or similar material.

The test specimens were 2 by 4-inch cylinders. The aggregates were Colorado River sand, and crushed rock of two sizes, the smaller size passing the 1/4-inch mesh sieve and retained on the 1/8-inch mesh sieve and the larger size passing the 1/2-inch mesh sieve and retained on the 1/4-inch mesh sieve.

The aggregates were combined so that one volume of sand was used with every two volumes of crushed rock; the crushed rock was composed of one part of the smaller size to two parts of the larger size.

The cement was a blend of Texas cements which passed the A. S. T. M. specifications and had a tensile strength of 282 pounds at 7 days and 360 pounds at 28 days in a 1:3 standard mortar.

The cement was proportioned so that the richness of the mixes varied from about eight to about fifteen sacks of cement per cubic yard of concrete.

The two principal reasons for using such rich mixes were that the hard rocks are better able to develop a strong concrete in a rich mix than in a lean one, and that aggregates of the small sizes used need richer mixes to develop ordinary strengths than aggregates of a larger size. The effect of maximum size of aggregate on the strength of concrete of a given richness is discussed in University of Texas Bulletin No. 1855.

The total mixing water was equal, by weight, to 21 per cent of the cement, plus 8 per cent of the sand, plus 4 per cent of the crushed stone. In order to make proper allowance for the difference in the quantity of water absorbed by the different kinds of crushed stone, the following method was used: Immediately before preparing a mix, the crushed stone was immersed in water for 15 minutes and then centrifuged in a Rotarex Extractor for 70 seconds. By this method the crushed stone had no surplus water on the surface and was saturated sufficiently not to extract water from the mix. As well as could be judged by the appearance, the consistency was exactly the same for all mixes.

From the average values of the 28-day and 3-month tests, curves like those shown in Fig. 1 were drawn for each of the six aggregates and from those curves the strengths for mixes of 6, 8, 10, 12, and 14 sacks of cement per cubic yard of concrete were obtained and plotted against the ultimate compressive strength of the coarse aggregate, as shown in Fig. 2.

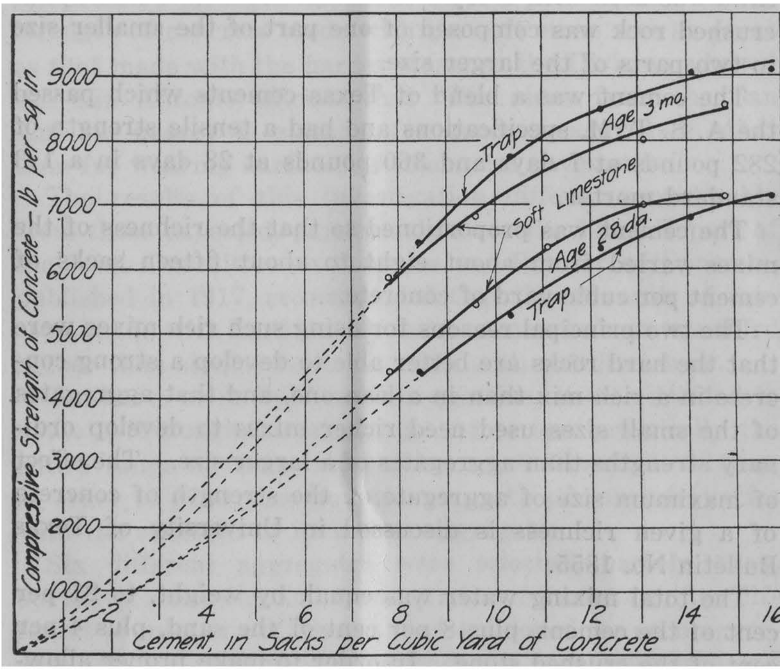

Figure 1

Showing the strength of concrete made with soft limestone and of similar concrete made with trap rock. Each of the 20 points represented in the diagram is the average of five experimental determinations.

It is evident from this figure that, for the materials tested and for the proportions of cement ordinarily employed in practice, the strength of concrete varies only slightly with the strength of its coarse aggregate. For very rich mixes and at an age of 3 months the strength of concrete increases slightly with the strength of its coarse aggregate,

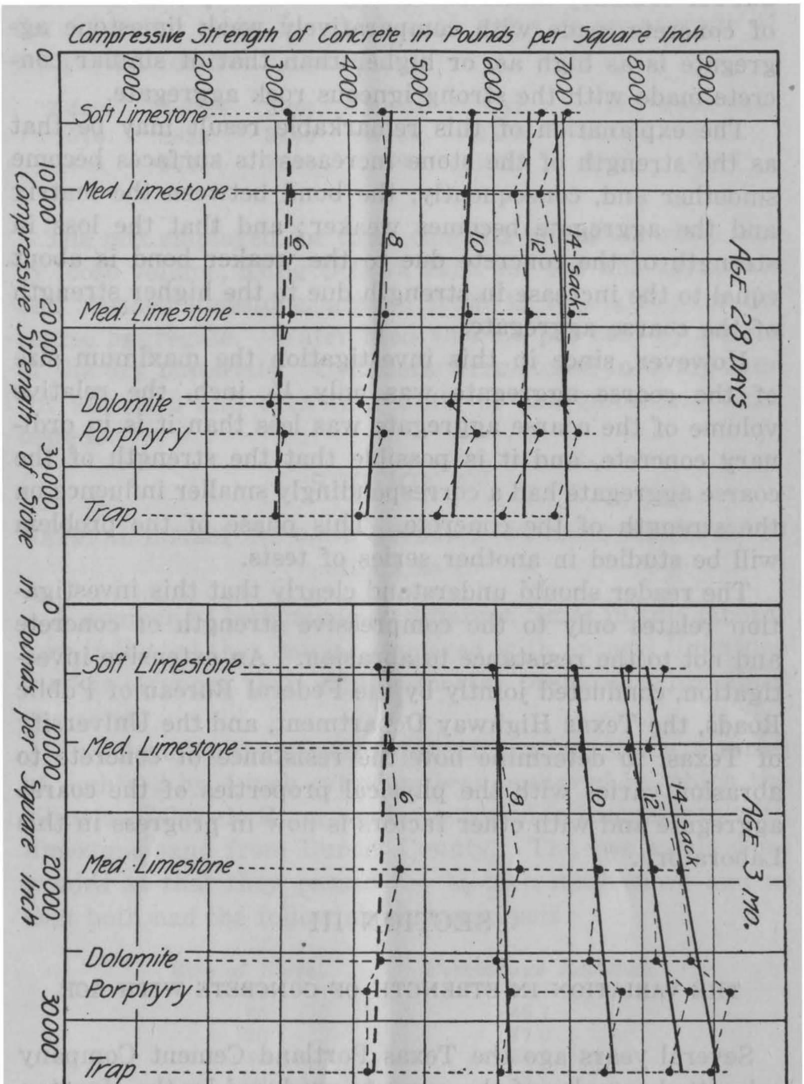

Figure 2

Showing the variation in the strength of concrete with the richness of the mix, with the strength of the coarse aggregate, and with age, as determined from curves like those shown in Figure 1, the coarse aggregate being not larger than one-half inch.

but for ordinary mixes and an age of 28 days, the strength of concrete made with comparatively weak limestone aggregate is as high as, or higher than that of similar concrete made with the strong igneous rock aggregate.

The explanation of this remarkable result may be that as the strength of the stone increases its surfaces become smoother and, consequently, the bond between the matrix and the aggregate becomes weaker; and that the loss in strength of the concrete due to the weaker bond is about equal to the increase in strength due to the higher strength of the coarse aggregate.

However, since in this investigation the maximum size of the coarse aggregate was only ½ inch, the relative volume of the coarse aggregate was less than it is in ordinary concrete, and it is possible that the strength of the coarse aggregate had a correspondingly smaller influence on the strength of the concrete. This phase of the problem will be studied in another series of tests.

The reader should understand clearly that this investigation relates only to the compressive strength of concrete and not to the resistance to abrasion. An extensive investigation, conducted jointly by the Federal Bureau of Public Roads, the Texas Highway Department, and the University of Texas, to determine how the resistance of concrete to abrasion varies with the physical properties of the coarse aggregate and with other factors is now in progress in this Laboratory.

SECTION III

THE VARIATION IN STRENGTH OF CONCRETE WITH AGE

Several years ago the Texas Portland Cement Company submitted samples of the cements produced by the Houston and Dallas mills for tests extending over a long range of time.

The variation with age in the compressive strength of concrete cylinders made with these two cements is shown in the following table, in which each value is an average of the results for five cylinders:

7 days	28 days	3 mo.	6 mo.	1 yr.	2 yr.	5 yr., 4mo.
1570	2830	3400	3180	3110	3260	3740
1775	3565	3310	3305	2995	3025	3390

The mix employed for these concrete cylinders was 1:2:4 by loose volume, using Ottawa sand for the fine aggregate and crushed limestone, graded from ¼ to 1¼ in., for the coarse aggregate. Water used was 8.4 per cent by weight of the dry materials. Cylinders were stored in damp sand for six days and then in the air of the laboratory until tested.

SECTION IV

NATURAL LIMESTONE SAND SUPERIOR, IN SOME RESPECTS, TO SILICA SAND

A number of tests made at different times in this laboratory indicated that mortar prepared with natural limestone sand is stronger than similar mortar prepared with siliceous sand.

To determine the relative value of the two sands, a series of eighty 2 by 4-inch cylinders was prepared in which the siliceous Colorado River sand was tested in comparison with limestone sand from Burnet County. The two sands were graded so that they passed the ¼-inch mesh sieve and so that both had the following sieve analysis:

Size of Sieve	Percentage Retained
10	22.7
20	49.1
30	77.0
40	88.0
50	95.7
60	98.1
80	99.1
100	99.4
200	99.7

Four types of mortar, differing from each other in richness, were made with each sand, the proportioning being by volume.

The results of the 28-day and 3-month tests are shown in Fig. 3. It is evident from this figure that mortars made from the limestone sand are stronger than those made from the siliceous Colorado River sand. At 28 days the limestone sand mortar averaged 17 per cent stronger than the silica sand mortar and at 3 months it averaged 11 per cent stronger.

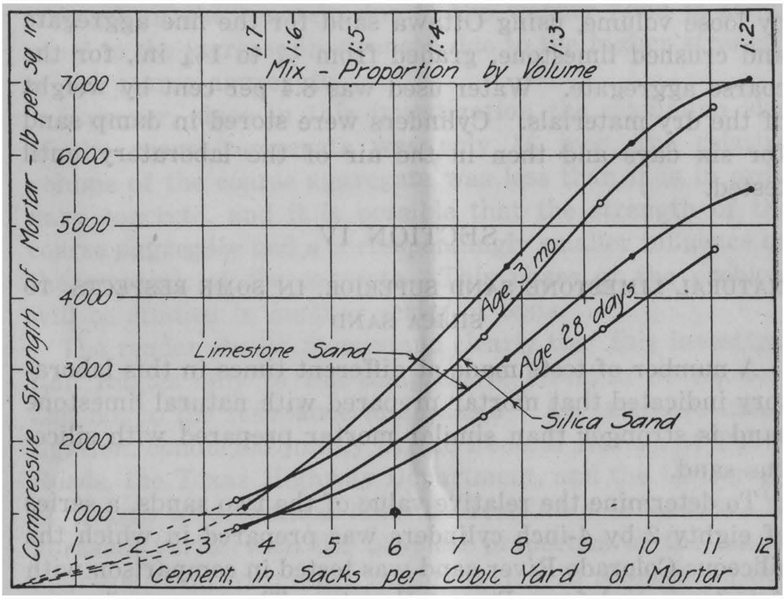

Figure 3

Showing the compressive strength of limestone sand mortars and silica sand mortars at ages of 28 days and 3 months. Each of the points shown in this diagram is the average of five experimental determinations.

SECTION V

IMPORTANCE OF TESTING FIELD CONCRETE

Very careful attention is given to the qualities of the cement and of the aggregate used in the production of concrete, but since many other factors also have an influence on the strength of the concrete, it is important to prepare and test samples of the type of concrete proposed for a new structure and, after the type of concrete has been selected, to make control tests of the field concrete at regular intervals during construction. Many engineers and architects realize this and are taking advantage of the facilities offered by this Laboratory for coöperation in tests of that kind.

The most complete set of field specimens received so far was sent in by the State Highway Department during the construction of Federal Aid Project 233, State Highway 36-B, in Burnet County. The samples submitted represented the concrete in about twenty structures. Seventy-two 6 by 12-inch cylinders were tested at an age of 28 days and gave compressive strengths ranging from 3400 to 1895, with an average of 2720 pounds per square inch. The weak specimens were samples of concrete poured and cured during cold weather; or from the footings for bents and abutments of bridges where, on account of the amount and location of the steel, more mixing water had to be used than in other portions of the structures. In all cases the concrete was composed of one part cement, two parts limestone sand, and four parts limestone gravel.

All field concrete was rodded with 1 by 2-in. or 2 by 3-in. pointed wooden sticks. The concrete in the test specimens was rodded with wooden sticks, and as nearly as possible like that in the structures.

SECTION VI

A DEFECTIVE CONCRETE FOUNDATION

The Central Texas Ice and Light Co., of Marlin, requested this Division to investigate the quality of the concrete foundation for its new Diesel engine. It was found that the concrete, which was about three months old at the time of test, had a compressive strength of 720 lb. per sq. in., when tested in the form of a cube. The mix used was found to have been one part of cement to 8 parts of pit-run sand and gravel.

A test in this Laboratory showed that by screening this pit-run material over a ¼-inch mesh screen and recombining the fine and the coarse materials so as to produce a 1:3:5 mix, the strength of the concrete at 28 days was increased 128 per cent over that obtained from a 1:8 pit-run mix, while the quantity of cement per cubic yard of concrete was increased only 20 per cent.

SECTION VII

CONCRETE PAVEMENT SUBJECTED TO FREEZING TEMPERATURE

A piece of concrete cut from a pavement was submitted for test by H. H. Batjer, City Engineer of Abilene, as it was feared that this concrete had been injured by a freeze which had occurred about 12 hours after pouring. This concrete was a 1:1½:3 mix. The section of the pavement was tested in the form of a prism at an age of 41 days and gave a compressive strength of 3880 lb. per sq. in. The high strength obtained indicated that the pavement had not been injured by freezing.

SECTION VIII

THE GROWTH OF THE ENGINEERING RESEARCH DIVISION

The work of the Division has been growing in value and in importance since its organization. This development is reflected partially by the number of samples tested during the past few years, as shown by the following table:

1919	482
1920	800
1921	1083

It should be noted that the number of samples tested, as shown in the table, does not indicate the total number of individual tests made, since a research project is listed as one sample. As an example of this, one project involved the testing of about 960 concrete cylinders.