SOME STRUCTURAL PROPERTIES OF GYPSUM AND OF REINFORCED GYPSUM

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Recent developments in building construction requiring a light, cheap fire-resisting building material have brought about investigation of the structural properties of gypsum.

Nearly twenty years ago a reinforced gypsum floor was approved by the City of New York after a fire test at Columbia University Testing Station.[1] Similarly, load tests were made on gypsum floor construction early in the history of floor tests.[2] These tests made a creditable showing, but for some reason attention was directed away from gypsum toward Portland cement concrete, and it is only recently that investigation of gypsum has been receiving the attention to which the importance of the subject entitles it.

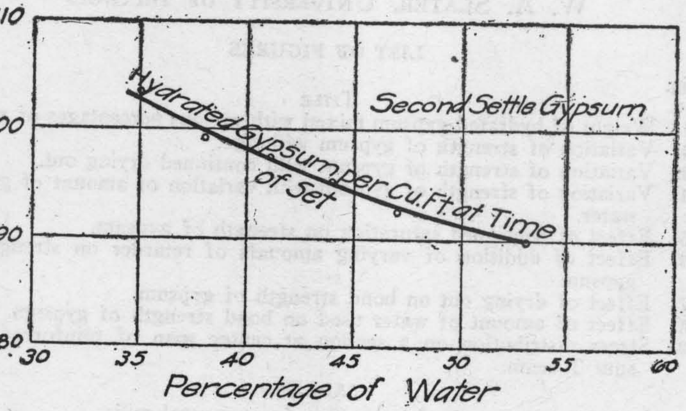
Engineers' opinions of gypsum seem usually to be based on observations of the gypsum block used for partitions. This block is used only in places where strength is not required and consequently it is designed to secure lightness rather than strength. Of the wet mixture used for this block over 50 per cent by weight is water.

Fig. 1 shows that such a mixture gives a very light wall, approximately three-eighths the weight of Portland cement concrete. Fig. 1 also shows that even with the smallest

[1]Test of Metropolitan floor system, May 20, 1897. See International Association of Testing Materials, Paper XXVII, by Ira H. Woolson and Rudolph P. Miller.

[2]See Eng. News Vol. XXXIV, page 333, Nov. 14, 1895.

amount of water practicable (about 35 per cent) the weight of dry gypsum is only slightly more than half that of concrete.



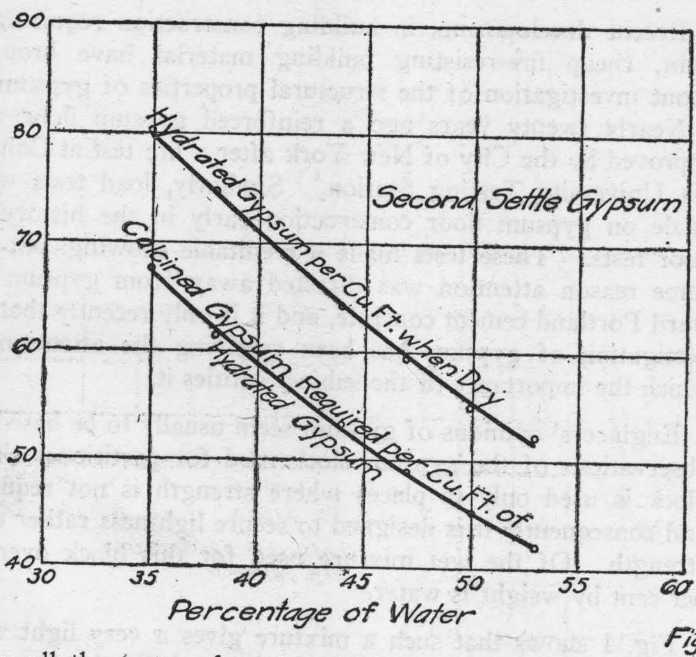


Fig. 1.

In all the tests referred to in this paper, except as otherwise noted, the amount of retarder used was 0.1 per cent, and the amount of water used was such as would give the same consistency to the mixtures for all specimens. This consistency, termed "standard consistency," required that the percentage of water used in gaging the mixtures be from 37 to 39 per cent by weight of the total weight of the water and gypsum used in the specimen.

All the compression specimens tested were cylinders having a height of twice the diameter. These were used because it has been found[3] that with specimens of this form slight variations in the dimensions of the specimen cause less variation in the strength than with specimens whose height is equal to the diameter. Also it is believed that the specimens used give strengths more nearly representative of what may be developed in a structural member than would a shorter specimen. A specimen whose height is equal to its

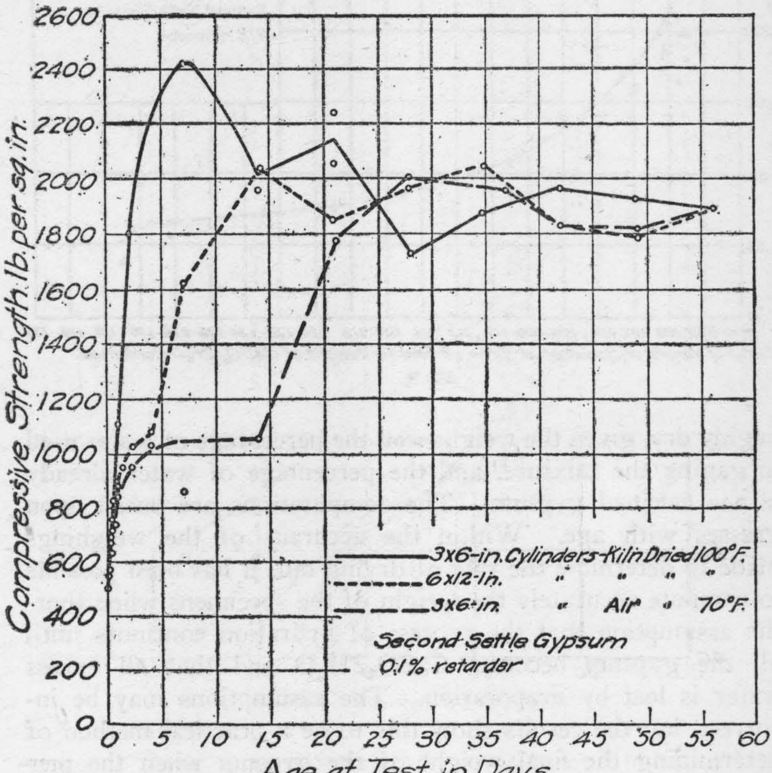


Fig. 2.

[3]See Journal of American Concrete Institute, Vol. 11, No. 6, October-November 1914, p. 424.

diameter probably would have a strength about 35 per cent greater than the strength of a specimen whose height is equal to twice its diameter.

Fig. 2 shows the increase in strength of gypsum with increased age after hydration. Each value given is the average strength of five 3x6-in. cylinders. Fig. 3 uses the same strengths as Fig. 2, but in Fig. 3 the strengths are plotted against the ratios of the weights of the specimens tested, to the weight of a thoroughly dry specimen. This indicates that the age affects the strength only as evaporation pro-

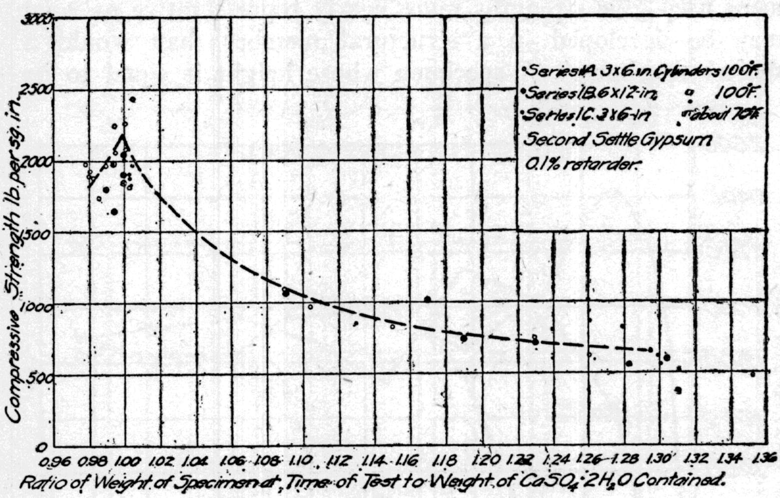


Fig. 3.

oughly dry, given the weight wet, the percentage of water used in gaging the mixture, and the percentage of water already in the calcined gypsum. The computations are based upon gresses with age. Within the accuracy of the weighings made to determine the rate of drying out, it has been possible to compute accurately the weight of the specimens when thor- the assumption that the process of hydration continues until all the gypsum becomes $CaSO_42H_2O$ and that all excess water is lost by evaporation. The assumptions may be incorrect, but the results show this to be a practical method of determining the final weight of the gypsum when the percentage of gaging water used and the percentage of water in the calcined gypsum are known.

Tests of specimens gaged with varying amounts of water (see Fig. 4) show that for cases in which strength is important a high strength can be reached by using a small amount of water. Results shown here are not for materials selected as the best, but for a good grade of second settle calcined gypsum and are shown in order to give an idea of the great increase in strength going along with a decrease in the percentage of water.

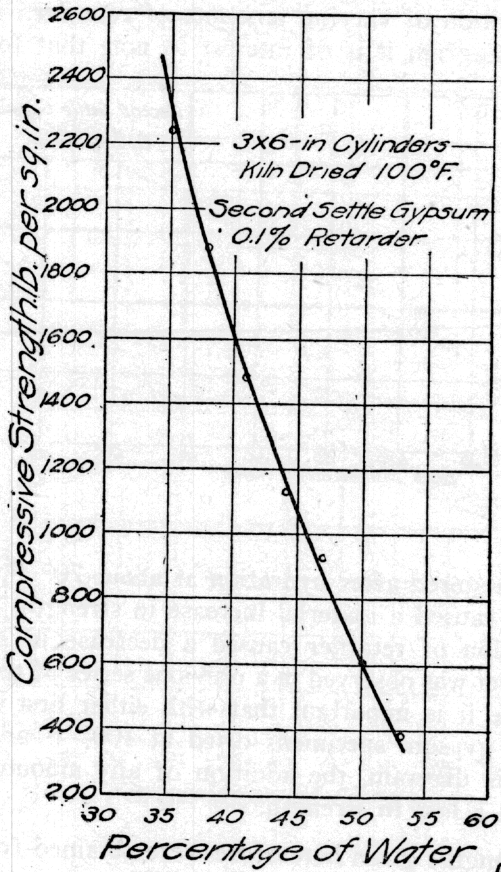


Fig. 4.

Tests made to determine the effect of water on the strength of specimens previously dried show that the absorption of a small amount of moisture by a thoroughly dry specimen reduced its strength materially. No further loss of strength seemed to be caused, however, by further exposure indefinitely to a very moist air. Immersing in water caused the strength to fall off rapidly to about 50 per cent of the strength of the dry specimen, but remaining in the water after this for an indefinite time (up to 176 days) caused little further loss in strength. Obviously this is more severe treatment than gypsum in actual service may be expected to receive. Fig. 5 shows the effect of standing in water for various lengths of time.

The time of set of gypsum may be controlled by the addition of a retardant. Fig. 6 shows the variation in strength due to the addition of varying amounts of retarder. In the study of this diagram it is of interest to note that for[4] first

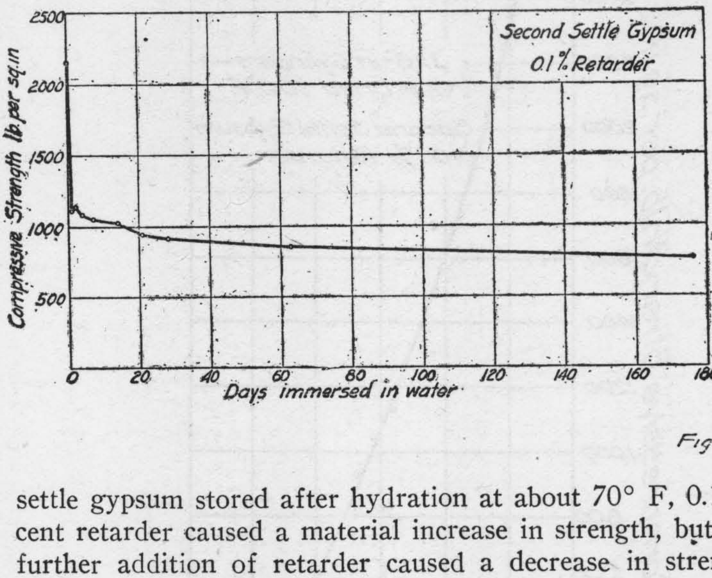


Fig. 5

settle gypsum stored after hydration at about 70° F, 0.1 per cent retarder caused a material increase in strength, but that further addition of retarder caused a decrease in strength. The same effect was observed in a previous series of tests. At the same time it is important that with either first settle or second settle gypsum specimens dried at 100° F or less, as shown by this diagram, the addition of any amount of retarder caused a loss in strength.

All the strengths given heretofore were obtained from gypsum calcined at one of the mills of the United States Gypsum Company. Attention was given to carrying out the calcining

[4]When a charge of ground gypsum is subjected to a steadily increasing temperature, it goes through alternate stages of quiescence and of boiling due to the more rapid ejection of water as steam at certain stages than at others. Gypsum whose calcination stops with the end of the first boiling stage is termed here first settle gypsum and gypsum whose calcination stops with the end of the second boiling stage is termed second settle gypsum. See pp. 55 and 59, Bulletin No. 11, Oklahoma Geol. Survey, "Gypsum and Salt of Oklahoma," by L. C. Snider, and p. 107, Mines Branch Bulletin No. 84, "Gypsum Deposits of the Maritime Provinces," Mines Department, Ottawa, Canada.

process in such a way that at any future time a similar batch could be calcined and results of any of the tests checked or carried out more in detail. However, no attention was paid to selecting the strongest gypsum, and in order that a comparison might be possible betwen this and the company's regular practice, test specimens were made from samples of second settle gypsum taken from five mills of the United States Gypsum Company.

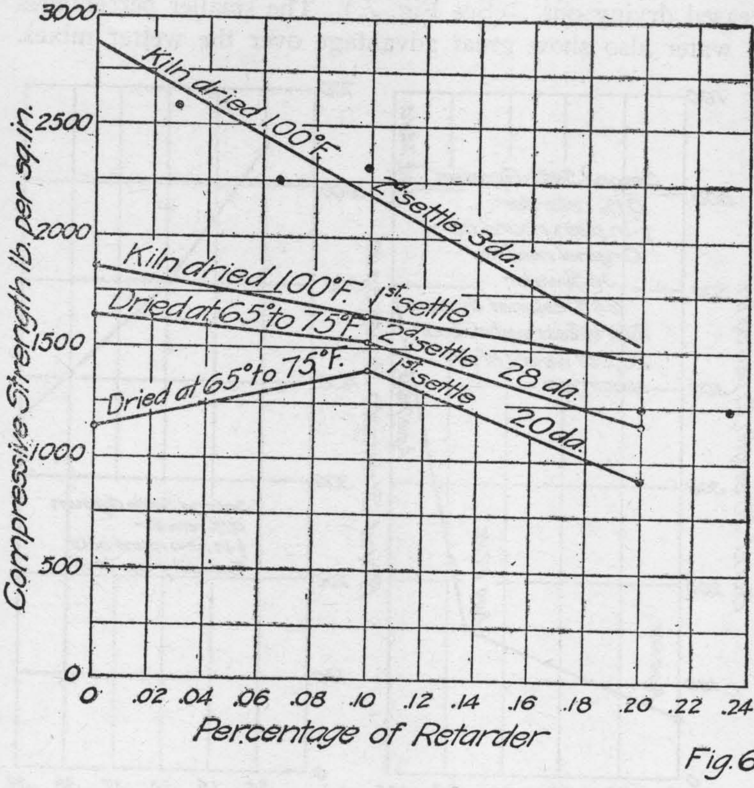


Fig. 6

The strengths of these specimens are given in Table 1, in which Gypsum No. 1 represents the specially calcined gypsum from which all the specimens previously discussed were made. These materials represent a geographical distribution covering five states and show a satisfactory uniformity in strength. In all these specimens 0.1 per cent retarder was used. The specimens were dried at 100° F and were tested at an age of four days.

TABLE 1.—STRENGTH OF SECOND SETTLE GYPSUM FROM VARIOUS MILLS

Gypsum No.	Compressive Strength lb. per sq. in.
1	2250
2	1590
3	1560
4	1720
5	1710
6	1860

Bond tests of specimens made by embedding ½-in. bars in 8-in. gypsum cylinders 8 in. long, showed a very satisfactory bond strength. A very great increase is shown with increased drying out. (See Fig. 7.) The smaller percentages of water also show great advantage over the wetter mixes.

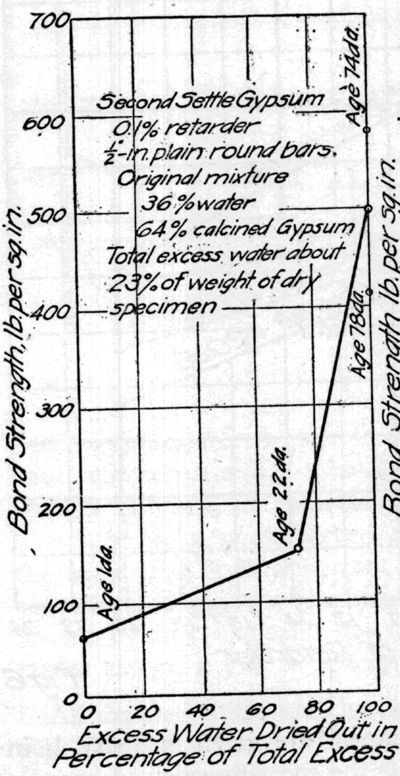


Fig. 7.

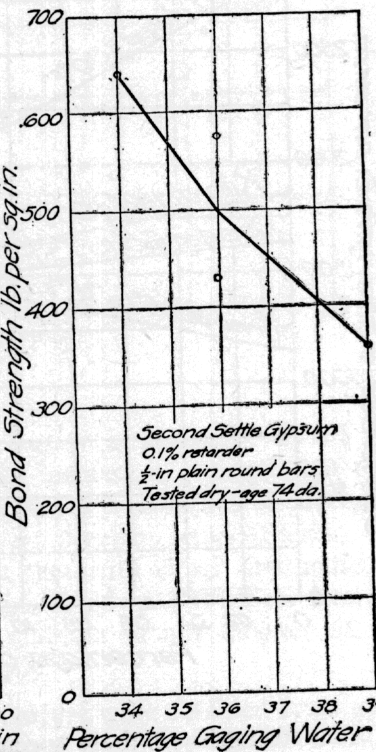


Fig. 8.

(See Fig. 8.) The driest mix shown, 34 per cent water, gave 640 pounds per square inch in bond strength. This mix may have been somewhat stiffer than could be handled in practical work, but that containing 36 per cent water was not too stiff for practical work and it gave a bond strength of 500 pounds per square inch.

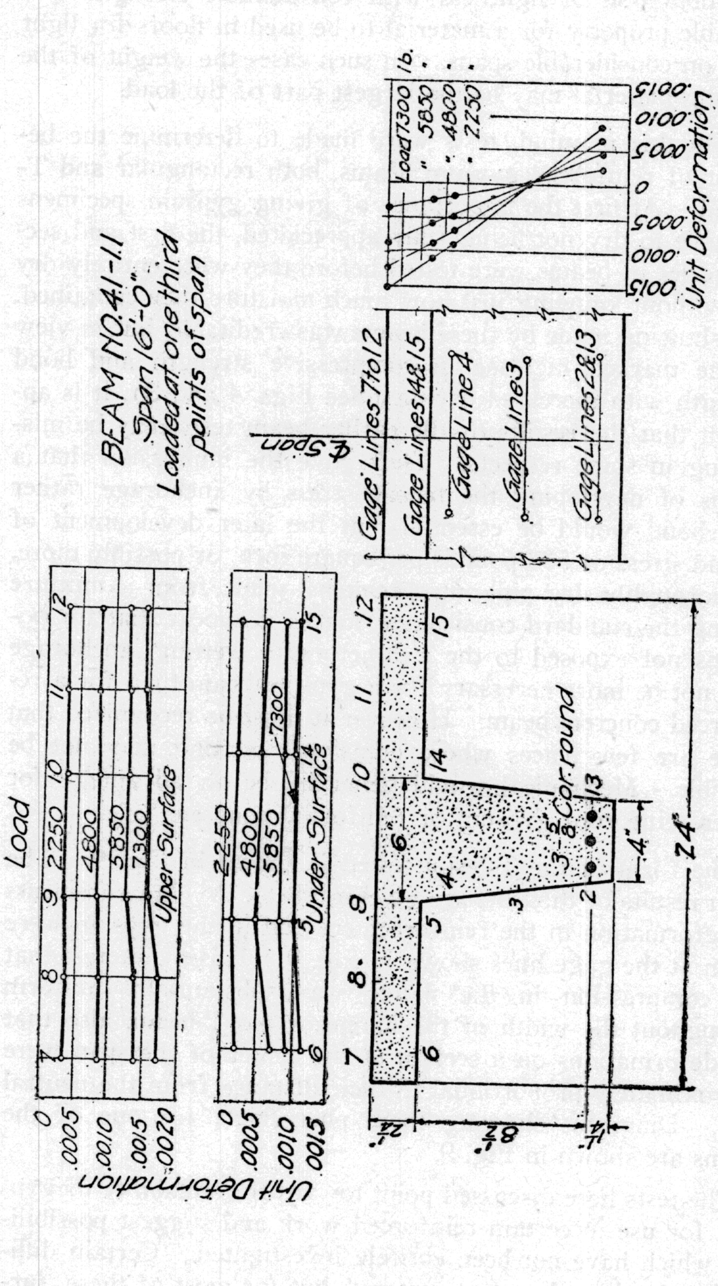

BEAM NO.41-1.1
Span 16'-0"
Loaded at one third points of span
Gage Lines 7 to 12
Gage Lines 14 & 15
Gage Line 4
Gage Line 3
Gage Lines 2 & 13
℄ Span
Load 7300 lb.
" 5850
" 4800
" 2250
Unit Deformation
Load
Upper Surface
Under Surface
3-5/8 Cor. round
24"

Fig. 9.

Combination of lightness with considerable strength is a desirable property for a material to be used in floors for light loads on considerable spans. In such cases the weight of the building material may be the largest part of the load.

With this in mind, tests were made to determine the behavior of reinforced gypsum beams, both rectangular and T-shaped. At first the importance of giving gypsum specimens a chance to dry not being fully appreciated, the first and second series of beams were tested before they were entirely dry and without knowing just how much moisture they contained. The showing made by these beams was creditable, but in view of the marked increase in compressive strength and bond strength with increased drying (See Figs. 4 and 8), it is apparent that the results of the earlier beam tests may be misleading in some respects. They gave the impression that a means of developing the tensile stress by anchorage rather than bond would be essential, but the later development of a bond stress of 500 pounds per square inch, or possibly more, in thoroughly dry pull-out specimens, made from a mixture having the standard consistency, makes it appear that for positions not exposed to the weather or to wetting, anchorage may not be more necessary for a gypsum beam than for a reinforced concrete beam. However it must be recognized that there are few places where occasional wetting may not be possible. Mechanical would generally be an advantage for either reinforced gypsum or reinforced concrete.

The form of the T-beam tested is shown in Fig. 9. The main results of the tests are given in Table 2. Measurements of deformation in the reinforcement and in the gypsum were taken at the gage lines shown in Fig. 9. It is of interest that the compression in the flange was substantially uniform throughout the width of the flange of the T-beam, also that the deformations on a section at the center of the span were approximately proportional to their distance from the neutral axis. Diagrams showing these phenomena for one of the beams are shown in Fig. 9.

The tests here discussed point toward the suitability of gypsum for use in certain reinforced work and suggest possibilities which have not been entirely investigated. Certain difficulties also have been encountered, but for most of these, further investigation has already offered a satisfactory solution.

TABLE II.—DATA OF T-BEAM TESTS

Beam No.	Reinforcement: Description	Reinforcement: Area Sq. in	Age at Test Days	Load at First Crack pounds	Observed Steel Stress at First Crack lbs. per. sq. in.	Maximum Load pounds	Stresses at Maximum Load lb. per. sq. in.: Vertical Shear	Bond	Tension Calculated	Tension Observed	Manner of Failure
4.1-1.1	Three 5-8 in.	0.92	20	5250	19000a	7850	87	74	29200	28600	Stripping of bars from stem
4.1-1.2	cor. round straight	0.92	17	6300	22000	6300	70	60	24400	23000	
4.1-2.1	Two ⅜-in. cor. round and one ¼-	0.27	19	3200	31500b 38000c	3700	41	70	48000	d	Tension in steel
4.1-2.2	in. cor. round, all bars straight	0.27	17	3150	25000b 29000c	3750	42	71	48000	d	
4.1-3.1	Two 5-8 in. cor.	0.61	Accidentally broken before test								
4-1-3.2	round, looped at ends for anchorage	0.61	15	6650	24000	6650e 7550f	74 86	95	39500 44800	36000 41000	Stripping of bars from stem

NOTES

a. This crack did not extend higher than the level of the reinforcement before failure.

b. Under load point (one-third point of 16-ft. span.)

c. At center of span.

d. Had passed yield point.

Span of all beams 16 ft. Loads applied at one-third points of span.

e. Load indicated by dial

f. Corrected load.