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DETERMINATION OF CEMENT CONTENT OF PAVEMENT CONCRETE
Construction Project F 62031, C2U, C3R

C. C. Rhodes, M. H. Janson, W. L. Frederick, and S. W. Ruis

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Michigan State Highway Department
John C. Mackie, Commissioner
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DETERMINATION OF CEMENT CONTENT
OF PAVEMENT CONCRETE
Construction Project F 62031, C2U, C3R

In the period April 29 to May 9, 1958, inclusive, concrete was placed in a 4-ft base widening about 9 mi long on M 37 north of Newago by the Rieth-Riley Construction Co under Construction Project F 62031, C2U, C3R. Concrete for the project was air-entraining Grade B with a cement content of 5 sacks per cu yd. During construction, discrepancies began to appear between the estimated and actual amounts of cement used. This discrepancy was first mentioned by the plant inspector in his daily report for May 6. Until this time, the records indicated overruns of cement on all pours, but at the same time an excess of unused cement was accumulating at the plant. Subsequent check of the cement inventory revealed an apparent shortage of some 1,100 bbl for the whole project, which represented an average underrun of about 15 percent.

On August 14 a meeting was held in the Road Construction office with the contractor to discuss the penalty to be assessed for the apparent cement shortage. At this meeting it was decided to have cement content determinations made on cores taken from the project for the purpose of determining the limits of the penalty. As a result of this decision, Mr. H. J. Rathfoot in a memorandum to Mr. W. W. McLaughlin dated August 19 requested that cores be taken at random in increments of 1,000 ft throughout the project, and that cement content be determined on two cores from each day's pour.

In accordance with this request, 50 cores were taken and subsequently delivered to the Research Laboratory Division on August 25, 1958. No cores were taken from the pour of May 9, which consisted of 1952 ft of 2-ft widening and two gaps totalling 55 ft. Samples of the 6A coarse aggregate and 2NS sand used in the project, both from Gillesse Construction Company Pit 41-50, were also delivered with the cores. All of the cores were tested for compressive strength, and two from each day's pour, 18 cores in all, were selected for chemical analysis.

PROCEDURES

All cores were prepared by sawing off the bottoms and then tested for compressive strength using corrugated paper on the ends rather than conventional capping to avoid contamination of the crushed concrete with capping material. Those selected for chemical analysis were further reduced in a jaw crusher to about 1/4-in. maximum size, then passed once through a pulverizer which reduced the size to almost 100 percent passing the No. 30 sieve. After this first pass, the pulverized concrete from the entire core was quartered through a sample splitter to about 500 g. This sample was then reduced in the pulverizer until it all passed a No. 100 sieve, and a portion taken for chemical analysis.

Cement content was determined by ASTM Method C85-54, using both silica and lime contents as bases for conversion. Samples of the aggregates, about 10 lb each, were crushed, quartered, pulverized, and tested in the same way to determine the corrections to be applied. Huron Type IA cement was used on this project, but no sample was obtained at the time of construction. However, the records of several previous chemical analyses of this brand indicated an average silica content of 21.4 percent and 63.6 percent lime; these values were used to convert analytical determinations to cement content.

TREATMENT OF ANALYTICAL DATA

Two conversions of laboratory data are necessary to determine cement content of the original concrete in terms of sacks per cu yd. The first involves computing the cement content, by weight, of oven-dry, pulverized concrete from the silica or lime determination; the second involves computing the cement content of the original concrete in sacks per cu yd from the cement content of the dry pulverized concrete.

Cement Content of Oven-dry Concrete

In making the first conversion, let

x = dry, unhydrated cement fraction in oven-dry concrete,

y = dry aggregate fraction in oven-dry concrete,

z = water in oven-dry concrete.

Then

$$x + y + z = 1.00 \qquad (1)$$

and

$$y = 1.00 - x - z.$$

Now let

a = silica fraction in oven-dry concrete,

b = silica fraction in dry aggregates (blank), and

c = silica fraction in dry, unhydrated cement.

The cement content of the dry concrete is equal to the cement equivalent of the total silica minus the cement equivalent of the silica extracted from the aggregates, or

$$x = \frac{a - by}{c} \qquad (2)$$

Substituting the value of y from equation (1) and rearranging,

$$x = \frac{a - b\,(1.00 - z)}{c - b} \qquad (3)$$

Since b and z are both small, their product can be neglected and equation (3) reduces to

$$x = \frac{a - b}{c - b} \qquad (4)$$

Values for a, b, and c are readily determined with considerable precision by analytical procedures given in ASTM methods.

Cement Content of Original Concrete

The cement content of the dry, pulverized concrete must now be converted to cement content of the original, fresh concrete in terms of sacks per cu yd. The following chart quantities are given in Mix Design No. 58 MV-118 for a coarse aggregate unit weight of 101 lb per cu ft:

Cement	94.0 lb (1 sack)
Sand, 2NS	228.5 lb
Gravel, 6A	436.0 lb
Water	48.1 lb
Total	806.6 lb

This mixture is designed to yield 1 cu yd of concrete for every 5 sacks of cement used; therefore, the theoretical unit weight of the fresh concrete is

$$806.6 \times \frac{5}{27} = 149.4 \text{ lb per cu ft.}$$

Apart from the small shrinkage that occurs on hardening, the volume of the fresh concrete remains substantially constant through subsequent curing and drying out in air. From studies on water fixation by several investigators* and drying and absorption tests in this laboratory, it is known that about one-third of the mixing water in a mature concrete of this consistency remains fixed, or non-evaporable, on oven drying at 220 F. Removing two-thirds of the water in the above mix design results in a theoretical unit weight of dried-out, original concrete, of 143.4 lb per cu ft.

Since the fraction of cement by weight of the oven-dry concrete is known from the first conversion, the cement content in sacks per cu yd may now be determined by the relation

$$\text{Cement, sacks per cu yd} = \text{cement, \% by weight} \times \frac{143.4 \times 27}{94 \times 100} \quad (5)$$

or

$$\text{Cement, sacks per cu yd} = \text{\% cement} \times 0.412 \quad (6)$$

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* Powers and Brownyard, ACI Journal, October 1946 to April 1947, and Gause and Tucker, Journal of Research, NBS, Vol. 25, pp 403-16 (1940)

RESULTS AND DISCUSSION

Cement contents and compressive strengths of the cores tested are given in Table 1. As mentioned previously, no cores were taken from the pour of May 9. Lime analyses were run on most of the cores selected. The lime content of the aggregates constituted more than two-thirds of the total found in the concrete, thus making the correction from this source too high and uncertain. Subsequent petrographic examination of the coarse aggregate revealed that more than half was calcareous or calciferous. On the other hand, silica from the aggregates accounted for less than one-third of the total, except in the leanest mixes. Therefore, only silica content was used as a basis for conversion.

The plot of compressive strength against cement content is shown in Figure 1. From the correlation found, it appears safe to assume the cement determinations accurate to within ± 0.5 sack per cu yd.

A review of the project records provides the following data on pavement placed and cement used:

Lineal Feet Placed		Cement Factor, Sacks per lineal ft	Estimated Content Required, Sacks
2-ft	3,968	0.246916	979.8
3-ft	700	0.370374	259.3
4-ft	45,605	0.493832	22,521.2
Total	50,273		23,760.3

Total cement estimated, bbl	5940.1
Total cement actually used, bbl	5074.8
Total cement reported used, bbl	6232.6

The above data indicate a reported average overrun of 4.92 percent for the entire project, but an actual underrun of 14.57 percent.

Returning to Table 1, it is quite evident that concrete placed during the last two days, May 7 and 8, and part of May 6 is approximately normal in cement content and compressive strength. This area extends from approximately Sta. 152+45 to the end of the project. It is equally evident that with a few sporadic exceptions concrete placed in the period May 1 through May 5 is deficient in both cement content and strength. Concrete placed during the first two days, April 29 and 30, appears to be erratic, with occasional poor areas interspersed among good ones.

Assuming a normal cement content of concrete placed during the first two days and the last three days from Sta. 152+45 to the end of the project, the average underrun of the remainder is 28 percent, or 1.4 sacks per cu yd *. The average cement content from ten determinations in this same area (Table 1) is 3.5 sacks per cu yd.

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*	Lineal feet of equivalent 4-ft widening	48,114
	Lineal feet of "normal" concrete	22,398
	Lineal feet of deficient concrete	25,716

$$1.00\ (22,398) + x\ (25,716) = 0.8543\ (48,114)$$

$$x = 0.72$$

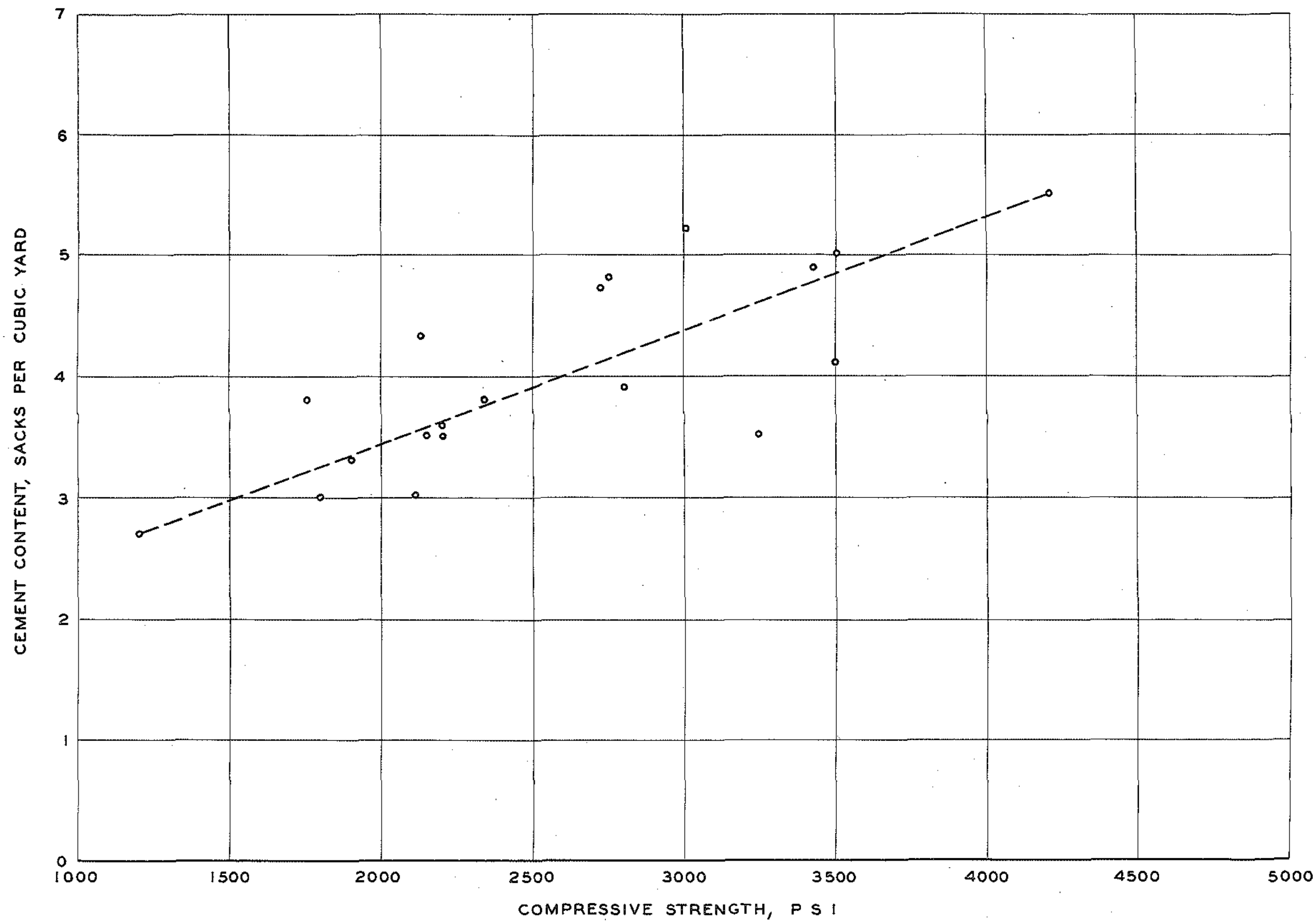

Figure 1. Relation of Compressive Strength to Cement Content.

Table 1. Pavement Core Cement Contents and Compressive Strengths

Date	Core No.	Station	Compr. Strength, psi[a]	Total Silica, Percent 1	2	Avg.	Cement Content Percent	Sacks per cu yd
May 8, 1958	854	96+11	3857					
	855	108+35	2382					
	Sta. Eq.	114+74 = 0+00						
	856[b]	2+04	2721	3.28	3.15	3.22	11.48	4.7
	857[b]	14+30	2627					
	858	22+35	2566					
May 7, 1958	859	37+97	2475					
	860	47+60	3223					
	861	56+14	3005	3.42	3.49	3.46	12.61	5.2
	862	68+13	3495	3.36	3.34	3.35	12.11	5.0
	863	76+15	2753	3.28	3.25	3.27	11.73	4.8
	864	89+55	3265					
	865	97+72	4196					
	866	106+13	3425	3.33	3.28	3.31	11.93	4.9
May 6, 1958	867	117+70	1616[c]	3.42	3.43	3.43	12.49	5.2
	868	126+30	3430					
	869	134+10	2925					
	870	143+96	3240	2.59	2.64	2.62	8.52	3.5
	871	152+45	1994[d]	2.64	2.63	2.64	8.66	3.6
	872	165+85	3452					
	873	174+14	1793[d]					
May 5, 1958	874	184+17	1446[d]					
	875	196+15	2305					
	Sta. Eq.	204+70 = 226+20						
	876	227+75	2372					
	877	236+08	2125[d]	2.30	2.42	2.36	7.30	3.0
	878	244+20	1206[d]	2.21	2.17	2.19	6.48	2.7
	879	252+70	1860[d]					
	880	264+13	1645[d]					
	881	276+10	1706[d]					
May 3, 1958	882	282+28	1998[d]					
	883	294+10	1819[d]					
	884	308+80	1895[d]	2.51	2.54	2.53	8.13	3.3
	885	314+10	1803[d]	2.27	2.43	2.35	7.26	3.0
May 2, 1958	886	324+54	2067[d]					
	887	334+84	1175[d]					
	888	344+18	1442[d]					
	889	352+53	2192[d]	2.60	----	2.60	8.47	3.5
	890	365+30	2805	2.78	----	2.78	9.34	3.9
	891	374+21	1632[d]					
	892	384+90	2325					
May 1, 1958	893	396+25	2193[d]					
	894	404+25	2402					
	895	417+22	1753[d]	2.73	2.77	2.75	9.20	3.8
	896	426+00	2123[d]	2.97	2.99	2.98	10.32	4.3
April 30, 1958	897	436+12	2449					
	898	446+25	3089					
	899	456+30	4213	3.56	3.60	3.58	13.23	5.5
	900	464+08	1949[d]	2.55	2.66	2.61	8.52	3.5
April 29, 1958	901	474+09	3458	2.91	2.90	2.91	9.97	4.1
	902	482+05	2335	2.75	2.72	2.74	9.15	3.8
	903	96+68	1425[d]					

Notes:

(a) Corrected to conform to a cylinder whose height is twice its diameter

(b) Cores 856 and 857 combined for analysis

(c) This core was an extra selection for cement determination. Compressive strength indicates defective core.

(d) More than 10 percent below specifications minimum

Silica from aggregates combined in chart proportions - 0.86 percent

Silica content of cement - 21.4 percent