VOLUME CHANGES IN CONCRETE SLABS IN THE FIELD

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SYNOPSIS

Observations of the changes in volume of 14 concrete slabs, each 81 feet long, 24 inches wide and 6 inches thick, exposed out of doors are presented The purpose of the tests was primarily to determine the effects of different curing methods upon volume changes Seven curing methods were used Interesting data were also secured on the relative volume changes of concrete made with two different coarse aggregates

The paper also includes observations from crack surveys of 2,380 miles of concrete pavement which also show characteristic differences in volume changes of concrete made from different aggregates

The Department of Materials and Tests of the Iowa State Highway Commission has made some observations of volume changes in concrete slabs built for this special purpose out of doors upon the earth It is recognized that these slabs represent only a few specimens made up of certain particular materials and subjected to a certain set of conditions which may be peculiar to one time and place However, the results are interesting in themselves, and, supplemented by further data, may form a basis for predicting the behavior of concrete in the field from the study of free bodies of concrete in the laboratory

Observations have also been made as to the effect of volume changes on 2,380 miles of concrete pavement constructed without joints

OBSERVATIONS OF VOLUME CHANGES IN EXPERIMENTAL CONCRETE SLABS

There are 29 slabs 81 feet long, 24 inches wide and 6 inches thick They are located out of doors near the laboratory on practically level ground The first six were built in August, 1929 The arrangement of the measuring apparatus was not so well worked out as was desirable, hence, accurate and continuous observations of changes in length in these six slabs have not been possible. However, it may be said that such measurements as could be expected to be reliable, check the measurements made on similar slabs built at later dates.

The data reported in this paper are limited to 14 slabs built in August, 1930, and 9 slabs built early in September, 1931.

The particular reason for making this study was to determine the effect of curing conditions upon the volume changes in concrete pavements. The measurements are made with dials of the common "Ames" type having a minimum graduation of 0.001 inches One of these is mounted at each end of each slab Each dial is supported on a concrete pier which has a footing placed below the frost line. From a point well below the frost line to the surface of the ground, the pier is protected from movements of the surrounding soil by a casing of drain tile In the top of the pier is set a stainless steel rod to which the dial is clamped The moving plunger of the dial is in contact with a stainless steel rod anchored into the end of the concrete slab In these rods are holes to which a strain gage may be applied so that if any dial should be disturbed it can be re-set to the proper reading

The concrete in the slabs is similar to that used in concrete paving work in Iowa The proportion by absolute volume was that which would correspond to a weight proportion of 1:1 95:2 92 if the

TABLE I

	Per Cent
Granite	42
Fine Grained, Dark Colored Igneous Rocks	15
Quartz	21
Total Igneous Rocks	78
Sand Stone	10
Limestone	9
Very Soft Sedimentary Rocks	1
Total Sedimentary Rocks	20
Metamorphic Rocks	2
	100

TABLE II

Clear Square Opening, Inches	Percentage Passing	
	Limestone	Gravel
1 49	99	93
0 742	47	54
0.371	11	25
0 185	3	1

specific gravity of the aggregates were 2 65 The water-cement ratio was 4 92 gallons per sack of cement for the concrete in which the coarse aggregate was gravel; and 5 4 gallons per sack of cement in the limestone concrete This concrete contains approximately 1 71 barrels of cement per cubic yard

The fine aggregate was washed, screened sand from the Des Moines River. In half of the 14 slabs built in 1930 the coarse aggregate was crushed limestone having a percentage of wear of approximately 5 7 Its specific gravity is approximately 2 66 and its absorption is approximately 1 5 per cent In the other seven slabs built in 1930 the coarse aggregate was washed screened gravel from the same source as the sand used. A lithological classification of the particles in this gravel is given in Table I

A sieve analysis of the coarse aggregates is given in Table II.

Of the nine slabs built in 1931 three were built of the limestone concrete described above; three of the gravel concrete described above; and three of concrete in which the only aggregate was Platte River "Sand-Gravel," a material which is entirely siliceous. This Platte River material is essentially a very coarse sand containing approximately ten per cent of pebbles which will be retained on a sieve having 0 185 inch square openings These pebbles have a maximum size of about ¾ inch The concrete in which this aggregate was used was mixed in the proportion 1: 3 90 by weight with a water cement ratio of 5 25 gallons per sack of cement, and contains 1 9 barrels of cement per cubic yard

The concrete was mixed for 2 minutes in a Blystone Mixer It was transported from the mixer in wheel barrows The rate of placing the concrete in one-third of the slabs was approximately 100 lineal feet per hour or about the same as is common on highway paving work The rate of placing concrete in the other two-thirds of the slabs was a little more than half this figure There is no evidence that the rate of placing the concrete in the slabs has affected the volume changes

The concrete was consolidated by means of a puddling tamper composed of a number of ⅝ inch round rods fastened to a board to which a vertical handle was attached This tool was operated by hand to give the concrete the rodding equivalent to that prescribed in the A S T M specifications (C31-27) for molding concrete specimens in the field.

After being consolidated the concrete was struck off with a straight edge floated and belted.

In order to secure a uniform subgrade condition for all slabs, the natural soil was carefully prepared to provide a smooth surface at the proper elevation A light coating of sand was then placed on the soil and struck off to provide a smoother surface than could be secured from the natural soil On the subgrade thus prepared was placed a single layer of slater's felt or tar paper which covered the subgrade and extended up on the wooden side forms three or four inches The paper was fastened to the side forms by small roofing nails

None of the slabs are reinforced. No visible cracks have appeared except in one slab built in 1929 which was given no artificial curing treatment

The concrete was placed at times when the weather could be expected to be as uniformly hot and dry as is likely to occur in Iowa In order to reduce variations in exposure conditions during the first few hours life of the concrete, the placing of concrete was done only between 10 a m and 3 p m Six slabs were built on August 25, 1930, six on August 26, and two on August 27

Since the principal object in view at the time these slabs were built was to determine the effect of curing treatment upon volume changes in concrete pavements, the 14 slabs built in August, 1930, were subjected to curing treatments

1. Wet burlap 24 hours Wet earth 8 days
2. " Hunt Process " bitumen applied to fresh concrete
3. Wet burlap 24 hours.
4. Wet burlap 24 hours followed by " Curcrete."
5. Wet burlap 72 hours
6. Wet burlap 24 hours followed by calcium chloride
7. " Curcrete " applied to fresh concrete.

Of the nine slabs built in 1931, one in which each kind of aggregate was used was cured with earth and water, one with a bituminous coating and one with a bituminous coating to which a coating of whitewash was applied

The observations of changes in length of the slabs have consisted of hourly readings of the dials for 24 hours each day for 21 days after placing During the next 21 days the dials were read hourly for 12 to 16 hours each day Since that time the dials have been read each working day a sufficient number of times to determine the maximum and minimum length of slab At intervals of about one month when the concrete is assumed to be normally dry, hourly readings have been taken for a 24 hour period Each time the dials are read records are made of the air temperature in the sun and in the shade, and of the temperatures of the concrete one-half inch from the top surface, at the center and one-half inch from the bottom surface of the slab Records of relative humidity and rain fall are also available.

The mass of data thus accumulated is so great that no considerable part of it could be included in a paper of this kind. Therefore only certain data which seem to be most interesting will be presented at this time

Since these slabs are not free bodies but rest upon the earth and are subject to changes in moisture condition, a change in the length and the corresponding change in temperature cannot be used to compute a true thermal coefficient of expansion for the concrete A change in the length in any slab will be a function not only of the temperature change and the thermal coefficient of expansion of the concrete but also a function of the restraint of the subgrade and changes in the moisture condition of the concrete The effect of the restraint of the subgrade will depend upon the coefficient of subgrade friction and the modulus of elasticity of the concrete

Table III shows some of the data recorded for six slabs for two different days, one day when the slabs were approximately one month old, and one day when the slabs were approximately eleven months old.

TABLE III

COMPARISON OF CHANGES IN LENGTH OF CONCRETE WITH VARIATIONS IN TEMPERATURE, TYPE OF COARSE AGGREGATE, CURING AND AGE

Slab No	Coarse Aggregate	Method of Curing	Concrete Temperature			Variation from Original Slab Length			Apparent Thermal Coefficient of Expansion
			Max	Min	Change	Max In	Min In	Change In	
(September 22, 1930—Air Temperature in Sun—Max 95, Min 41)									
7	Gravel	Wet Earth	90 5	60 8	29 7	+ 0520	− 1144	1664	00000577
9	Limestone	Wet Earth	90 5	61 7	28 8	+ 0460	− 0583	1043	00000373
18	Gravel	Calcium Chloride	88 7	60 8	27 9	+ 0262	− 1217	1479	00000546
17	Limestone	Calcium Chloride	90 5	60 8	29 7	− 0380	− 0639	1019	00000353
8	Gravel	Curcrete	100 4	62 6	37 8	− 0613	− 2597	1984	00000541
10	Limestone	Curcrete	98 6	62 6	36 0	+ 0031	− 1329	1360	00000337
(July 15, 1931—Air Temperature in Sun—Max 96 0, Min 74 5)									
7	Gravel	Wet Earth	105 8	77 9	27 9	+ 1966	+ 0629	1337	00000464
9	Limestone	Wet Earth	105 8	78 8	27 0	+ 1435	+ 0566	0869	00000332
18	Gravel	Calcium Chloride	104 0	77 0	27 0	+ 1974	+ 0740	1234	00000470
17	Limestone	Calcium Chloride	104 0	77 0	27 0	+ 1758	+ 0884	0874	00000333
8	Gravel	Curcrete	118 4	80 6	37 8	+ 1280	− 0530	1810	00000493
10	Limestone ..	Curcrete	118 4	80 6	37 8	+ 1442	+ 0185	1257	00000342

It will be noted that the concrete in the slabs that were cured with bituminous material had a greater range in temperature during each day than did the slabs cured with wet earth or with a surface application of calcium chloride This is no doubt due to a difference in heat absorption caused by the difference in the color of the exposed surface This difference was greater on July 15 than on September 22. This may be due to the difference in the intensity of the sunlight.

The slabs in which gravel was used as coarse aggregate show a greater change in length per degree change in the temperature of the concrete than the slabs in which the coarse aggregate used was limestone.

The ratio of unit volume change per degree of temperature change in limestone concrete to that in gravel concrete on September 22, 1930, was approximately .64. On July 15, 1931, this ratio was approximately 71. This might be interpreted to mean that the difference in this ratio is approaching unity as the age of the concrete increases However the change in the ratio may be due to differences in moisture content or other conditions not measured. These data also indicate that the effect of temperature change decreased with the increasing age. This conclusion may also be in error since the result noted may be due to other causes not observed

The length measurements of the slabs cured with "Curcrete" show the effect of an initial shrinkage greater than that of slabs subjected to some other curing treatments

Laboratory determinations of the true thermal coefficient of expansion of the gravel concrete gave values of from .0000047 to 0000052. The data shown in Table III indicate that the apparent thermal coefficient in the gravel concrete slabs on September 22, 1930, was approximately 0000055 and on July 15 approximately 0000048

Laboratory determinations of the true thermal coefficient of expansion of the limestone concrete gave values of 0 0000033 to 0 0000037 The data from Table III indicate that the apparent thermal coefficient of expansion of the limestone concrete slabs was approximately 0 0000034 on September 22, 1930, and approximately 0 0000035 on July 15, 1931. These comparisons between laboratory data and field data indicate that the effect of the restraint of the subgrade upon the length change was either very slight or was overcome by the effect of some other condition

The effect of the two particular kinds of coarse aggregate upon the volume changes in the slabs has been shown

Laboratory determinations of the thermal coefficient of expansion of concrete in which the coarse aggregate was limestone from other sources indicate that if the limestone used as coarse aggregate had been secured from some other source the results might have been quite different

Table IV shows the laboratory determinations of the thermal coefficients of expansion of concretes made from coarse aggregates from various sources in Iowa:

TABLE IV

Source of Coarse Aggregate	Thermal Coefficient of Expansion
Des Moines Gravel	0 0000049
Dubuque Limestone	0 0000050
Alden Limestone	0 0000043
Linwood Limestone	0 0000035

This indicates that had the dense dolomitic stone from Dubuque been used in the slabs instead of the Linwood limestone, there might have been little or no difference in volume change between gravel concrete and limestone concrete.

OBSERVATIONS OF THE EFFECT OF VOLUME CHANGES IN CONCRETE PAVEMENTS

The observations on the effects of volume changes in concrete pavements built without joints consist of detailed crack surveys of the pavements

The longitudinal reinforcement in these pavements consists of four plain round bars five-eighth inches in diameter in pavements 18 feet wide

The information obtained from such surveys of 2,380 miles of pavement together with very complete reports made by inspectors at the time the pavements were built constitutes a great mass of data However, it does not seem safe to draw any but very general conclusions from them, for these pavements have been subjected to the effects of many unknown conditions Even though some of the conditions may be known their exact effects may not

Therefore, if the effect of any independent variable is to be deduced from these data there must be available observations on a considerable mileage of pavement to which the selected variable applies Otherwise, it may be that the effects observed are due to some other cause than the one under consideration

It appears from these figures that the average distance between transverse cracks was less in the pavements in which gravel was used as coarse aggregate than in those in which limestone was used. If all the figures on the table are considered, the ratio of the distance between transverse cracks in gravel concrete to the distance between transverse cracks in limestone concrete is 63 This conforms quite closely to the apparent thermal coefficients of expansion determined on experimental slabs on a large scale

TABLE V

COMPARISON OF SLAB LENGTH OF CONCRETE PAVEMENTS BUILT WITHOUT JOINTS—CURED WITH EARTH AND WATER

Sand in Agg %	Cement Bbl per Cu Yd	Year Built	Limestone		Gravel		Ratio Slab Length Gravel to Limestone	Built in April and May Per Cent
			No Miles	Av Slab Length Ft	No Miles	Av Slab Length Ft		
33	1 63	1925	32 6	74 1	6 2	48 3	65	
40	1 71	1925	7 5	78 2				
45	1 78	1925	1 5	42 9				
50	1 85	1925	0 4	24 7	8 3	27 6	1 12	
Weighted Average			42 0	73 3	14 5	36 4	50	20 1
33	1 63	1926	34 4	67 9	18 2	30 8	45	
40	1 71	1926	1 5	65 1				
45	1 78	1926	6 9	82 1				
50	1 85	1926			1 2	24 2		
Weighted Average			42 8	70 1	19 4	30 4	43	13 2
33	1 63	1927	70 3	87 8	25 9	52 9	60	
40	1 71	1927	86 7	97 4	11 7	68 3	70	
45	1 78	1927	7 3	71 3	8 3	39 0	55	
50	1 85	1927	1 2	48 2				
Weighted Average			165 5	91 5	45 9	54 3	59	8 0
33	1 63	1928	41 8	73 4	35 2	53 9	72	
40	1 71	1928	198 2	70 1	134 1	59 7	85	
45	1 78	1928	57 5	60 3	57 2	39 4	65	
50	1 85	1928	19 9	52 8	35 4	35 0	66	
Weighted Average			317 4	67 6	261 9	51 2	76	25 7
33	1 63	1929	1 6	109 6	0 9	94 5	86	
40	1 71	1929	57 8	87 1	34 9	40 0	46	
45	1 78	1929	1 3	58 9	31 0	40 2	68	
50	1 85	1929						
Weighted Average			60 7	87 0	66 9	40 1	46	8 7
Grand Average, All Ages			628 8	76 3	408 6	48 3	633	

NOTE—Crack surveys of pavements built in 1925, 1926, 1927 and 1928 were made in 1929 Surveys of pavements built in 1929 were made in 1930

Thus it appears that the spacing of the transverse cracks that will occur in concrete pavements can be predicted of the thermal coefficient of expansion of the concrete is known

However, such a general rule fails to apply in one case that has been observed This is the case of pavements built of concrete in which the aggregate used was Platte River "Sand-Gravel" According to laboratory determinations this concrete has a thermal coefficient of expansion approximately the same as that of concrete made from Des Moines gravel However, a survey of 102 miles of pavement in which Platte River gravel was used shows an average distance between transverse cracks of only 25 3 feet

It seems logical to suspect that perhaps this unusually short distance between transverse cracks may be due to an unusually high modulus of elasticity However this does not seem to be the case since the Platte River gravel concrete has a modulus of elasticity of 4,360,000 while that of Des Moines gravel concrete is 4,640,000 Evidently some cause not yet determined is responsible for the unusually close spacing of the cracks in these pavements

Other interesting information regarding the use of Platte River gravel concrete is shown by a crack survey of 12.5 miles of pavement built in 1929 with expansion joints spaced at 40 feet Transverse cracks have developed between the joints in this pavement at an average distance apart of 17 8 feet Evidently a spacing of joints that might have been considered satisfactory, considering only the thermal coefficient of expansion and the modulus of elasticity of the concrete, was incorrect for this pavement.

DISCUSSION ON VOLUME CHANGES IN CONCRETE

Professor R E. Davis, *University of California.* With reference to the flow of concrete under continued compressive stress, it has been observed that dry concrete under the action of a given continuous compressive stress flows more rapidly over a longer period of time than does the same concrete when continuously wet. The reason therefore has not yet been explained

Professor Scholer suggested the necessity of making studies of the effects of the chemical composition and the fineness of grinding of cements upon volume changes. This is an opportunity for some real research work because up to date the efforts in that direction have been almost nil. From some experiments which as yet are incomplete, it appears that the quality of the cement has a very marked effect upon volume changes, both shrinkage in air and the swelling that takes place when concrete is kept perpetually wet. The evidence seems to be that other things being equal the finer the grinding the larger is likely to be the volume change