A STUDY OF MAP CRACKING IN SAND-GRAVEL PAVEMENTS

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SYNOPSIS

The appearance of cracks, indicative of disintegration in sand-gravel aggregate concrete pavements after four years' service prompted this investigation Sand-gravel is the local name of a siliceous material found principally in the valleys of the Kaw, Arkansas and Platte rivers Approximately 90 per cent passes the No 4 sieve and the maximum size is one inch or less

The brand of cement and method of curing and subgrade conditions were eliminated as possible sources of the difficulty

Specimens of concrete were subjected to freezing and thawing, and wetting and drying tests in connection with measurements of strength and volume changes in an attempt to produce similar disintegration in the laboratory The specimens did not show signs of disintegration under freezing and thawing but the characteristic map cracking developed in the wetting and drying tests

Similar tests on conventional mixtures of fine and coarse aggregate did not produce disintegration or map cracking

Several states in the middle west have built considerable mileage of portland cement concrete pavement using a sand-gravel aggregate This aggregate is siliceous, containing not more than four per cent limestone particles and is fairly uniformly graded from one inch to number one hundred mesh size Sand-gravel from the Kaw and Arkansas Rivers has developed more severe map cracking in Kansas than sand-gravel produced from other sources Sand-gravel taken from the Platte River in Nebraska has developed map cracking in Missouri, Kansas and Nebraska

In Kansas this particular type of map cracking has not developed in concrete pavement constructed with coarse and fine aggregate, unless it is developing in a section of pavement which is eighteen years old, and which is constructed of fine and coarse aggregate

The type of map cracking developing in some sand-gravel pavement in this section usually is noticeable when the pavement is four years old and can be easily detected when the pavement begins to dry after a light rain The first symptoms of this type of cracking are the closing of expansion joints, and appearance of longitudinal and horizontal cracks forming parallelograms approximately three by six inches The cracking is predominately parallel to the center line The first cracks are from ¼ to 1 in in depth and later they deepen through the entire thickness of the pavement with formation of scale on top of the pavement to a depth of ½ to ¾ in

This map cracking is not confined to pavement but has developed in sidewalks, bridges, garage floors and flumes constructed of sand-gravel aggregate

The first sand-gravel pavement in Kansas which developed this disintegrating map cracking was constructed in 1927 and 1928, and bad cracking had developed by 1931 See Figure 1 for top view of pavement and Figure 2 for bottom view of pavement

This pavement is a 9–6–9 in section 18 ft wide It has ¾-in plain round edge bars, V-type center joint with one-half round bars 4 ft long spaced at 5-ft centers The ¾-in expansion joints are spaced at 100-ft intervals

The green concrete consisted of a dry and rodded mix by volume of 1:3 37 with a slump of ¾ in The mix had 5 gal of water per sack of cement, which yielded concrete containing seven sacks of cement per cubic yard

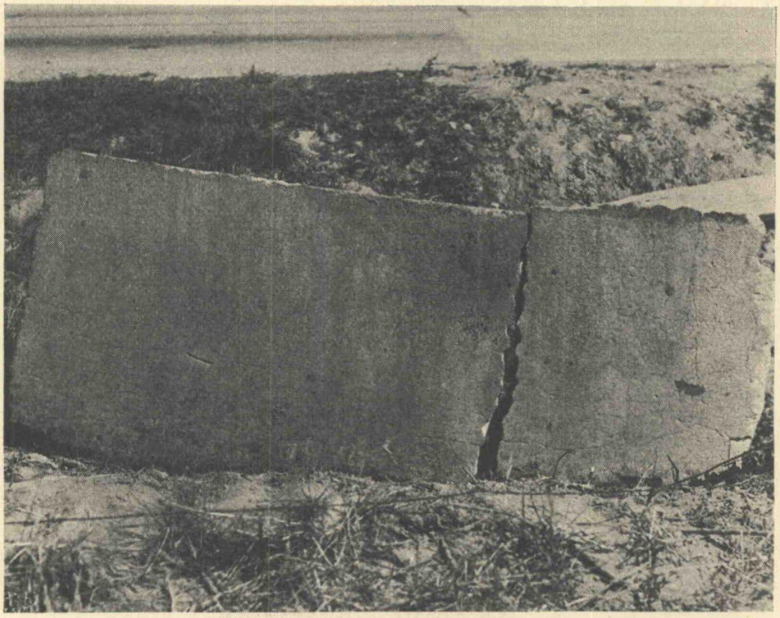

Figure 1. Top View of Pavement Slab Showing Map Cracking

Figure 2. Bottom View of Pavement Slab Showing Map Cracking

The aggregate was washed sand-gravel from the Kaw River and had approximately the following gradation

Sieve	Per Cent Retained
¾ in	1
⅜ in	3
No 4	9
No 8	28
No 16	56
No 30	81
No 50	97
No 100	100
G F	3 75

The pavement was laid on A–2, A–4, A–6, and A–7 subgrades Chemical tests proved that the subgrade in no way contributed to the cracking No subgrade paper was placed underneath the slab The pavement was cured with calcium chloride The calcium chloride curing was found not to be responsible for the cracking since another section of pavement placed in 1928 and cured with water and damp earth also cracked in the same manner

This cracking cannot be attributed to any one brand of cement as the difficulty has developed with several brands when used with this type of sand-gravel aggregate Chemical tests on the water prove it to be very satisfactory for human consumption and further tests show that it contains no ingredients harmful to concrete

The first research work in which an effort was made to develop this type of cracking was started in 1932, at the Road Materials Testing Laboratory of The Kansas State Highway Department A series of tests was made in which concrete specimens were subjected to different curing conditions and cycles of freezing and thawing but no cracking developed in the specimens until they were given a series of wetting and drying tests These tests extended from 1932 to 1935 [1]

Series 6 of these tests which is still in progress consisted of molding 3 by 6-in cylinders containing stainless steel gage points in each end for measuring elongation Six-inch by six-inch beams were cast of the same mix At the end of four days, the beams were broken into blocks 8 in long to form prisms 6 in by 6 in. by 8 in It was felt that large specimens might react differently than small ones, because the expansion and contraction could equalize more easily in a small specimen than in a large one

Nine brands of normal portland cement are being used in this series with Kaw River sand-gravel Cylinders and prisms were cured for 28 days in the moist room at 70°F Part of these specimens are being subjected to freezing and thawing, part to a combination of freezing and thawing and wetting and drying, part to wetting by submerging in water at 70°F for 16 hr and drying by placing in an oven for 8 hr at 125°F , and part to wetting by submerging in water at 70°F for 16 hr and drying in front of an electric fan for 8 hr at room temperature Control specimens for each brand of cement have been curing in the moist room for purpose of comparison of loss in strength due to various treatments and for comparisons of elongations The physical properties of the sand-gravel used in this series of tests are given in Table 1

The proportions by weight, the slump and the weight per cubic foot of the green concrete for the various cements are shown in Table 2

[1] In December of 1935 the author made a trip to the West Coast and found the same type of map cracking in concrete pavements located in a section of the country that has never had freezing conditions since the pavement was constructed

This was proof that the map cracking which is developing in sand-gravel pavements in Kansas and other states is being initiated by some cause other than freezing and thawing, although freezing and thawing is certainly speeding up the action after it has once started

TABLE 1

SAND-GRAVEL USED IN TESTS SERIES 6
Weight per cu ft 115 5. lb
Specific gravity 2 61
Percentage soluble in HCl 3 4

SIEVE	PER CENT RETAINED
¾ in	0
⅜ in	2
No 4	10
No 8	28
No 16	57
No 30	79
No 50	95
No 100	100
G F	3 71

TABLE 2

MIXTURES

No. Cement	Cement	Water	Sand-gravel	Slump	Green Concrete
	lb	lb	lb	in	lb per cu ft
32945	94	48	460	0 38	142 0
32946	94	48	460	0 31	142 2
32968	94	48	460	0 50	142 0
32982	94	48	460	0 31	143 0
33001	94	48	460	0 31	142 0
33006	94	48	460	0 50	142 3
33040	94	48	460	0 75	139 0
33059	94	48	460	0 50	143 0
33138	94	48	460	0 31	140 0

TABLE 3

PHYSICAL TESTS OF CEMENTS

Cement No	Normal Con-sistency	Per cent Ret 200	Surface Area	Weight Per Liter	Specific Gravity	Sound-ness	Autoclave Per Cent	Time of Set		Tensile Strength	
								Initial	Final	7 day	28 day
32945	24 0	0 58	1560	2161	3 16	O K	+0 1815	2–45	4–05	313	373
32946	24 0	1 12	1740	2186	3 22	O K	+0 1590	3–30	6–00	357	430
32968	24 5	3 28	1680	2189	3 14	O K	+0 1590	2–45	4 45	380	497
32982	23 0	4 52	1760	2213	3 16	O K	+0 0605	3–30	5–50	320	442
33001	23 0	6 04	1690	2189	3 13	O K	−0 0085	2–30	4–45	327	432
33006	23 0	1 52	1650	2175	3 15	O K	+0 0175	3–00	5–30	320	452
33040	28 0	1 00	1670	2126	3 14	O K	+0 1650	3–35	5–20	307	386
33059	23 5	0 22	1700	2195	3 15	O K	+0 0695	2–15	4–15	348	470
33138	24 5	1 86	1780	2183	3 15	O K	+0 0470	2–40	5–00	365	425

TABLE 4

CHEMICAL ANALYSIS OF CEMENTS

Cement	Ignition Loss %	Sulfuric Anhydride	Silica	Ferric Oxide and Alumina	Calcium Oxide	Magnesium Oxide	Insoluble Residue	Free Lime	Ferric Oxide
32945	0 81	1 80	21 39	8 73	62 86	3 88	0 94	1 13	2 91
32946	1 63	1 44	19 90	9 32	64 24	3 31	0 29	1 83	3 38
32968	1 45	1 68	20 62	9 24	63 77	2 56	0 45	0 98	3 07
32982	0 62	1 67	20 89	9 68	63 84	3 06	1 13	0 47	2 99
33001	1 45	1 68	21 84	8 42	65 02	1 19	0 18	1 20	2 73
33006	0 91	1 65	20 52	10 53	63 24	2 32	0 15	0 57	4 57
33040	2 12	1 53	21 05	8 54	65 26	0 98	0 37	3 78	3 07
33059	0 88	1 71	20 52	9 64	63 98	3 03	0 20	0 44	3 55
33138	1 41	1 90	20 36	10 59	64 12	1 04	0 31	1 95	3 65

The physical tests of the cement are shown in Table 3

The chemical tests of the cements are shown in Table 4 and the calculated compounds are shown in Table 5

After the specimens were subjected to the above treatment they were tested for strengths and elongation and the results tabulated in Tables 6 to 8

Table 9 deals with a sand and stone

TABLE 5

Calculated Compounds—Cement

Cement No	$CaSO_4$	C_4AF	C_3A	C_2S	C_3S	CaO(Free)	MgO
32945	3 05	9 00	10 50	30 50	41 00	1 13	3 88
32946	2 45	10 30	10 00	16 50	54 00	1 83	3 31
32968	2 80	9 30	11 10	22 40	48 70	0 98	2 56
32982	2 80	9 10	12 50	25 20	45 90	0 47	3 06
33001	2 80	8 30	10 30	26 50	47 70	1 20	1 19
33006	2 75	13 80	8 00	22 50	48 00	0 57	2 32
33040	2 60	9 40	9 30	26 50	45 00	3 78	0 98
33059	2 90	10 80	10 20	20 00	52 00	0 44	3 03
33138	3 25	11 00	12 10	26 50	42 00	1 95	1 04

TABLE 6

3-in by 6-in Cylinder Specimens Measured Saturated at 70°F, Sand-Gravel Aggregate

Cement No	Gage length at 28 days age moist room normal	Change in gage length at 64 days age moist room normal	Change in gage length at 64 days age after 25 cycles wet and dry	Change in gage length at 100 days moist room normal	Change in gage length at 100 days age after 50 cycles wet and dry	Change in gage length after 233 days age moist room normal	Change in gage length after 233 days age after 75 cycles wet and dry
32945	4 7000	+0 0003	+0 0031	+0 0004	+0 0036	+0 0011	+0 0038
32946	4 7000	+0 0004	+0 0026	+0 0004	+0 0028	+0 0011	+0 0033
32968	4 7000	+0 0001	+0 0021	+0 0001	+0 0026	+0 0008	+0 0033
32982	4 7000	+0 0001	+0 0006	+0 0004	+0 0013	+0 0009	+0 0018
33001	4 7000	+0 0001	+0 0004	+0 0004	+0 0008	+0 0008	+0 0011
33006	4 7000	+0 0002	+0 0003	+0 0004	+0 0010	+0 0009	+0 0016
33040	4 7000	+0 0001	+0 0007	+0 0006	+0 0012	+0 0005	+0 0017
33059	4 7000	+0 0000	+0 0001	+0 0006	+0 0006	+0 0008	+0 0012
33138	4 7000	+0 0000	+0 0008	+0 0009	+0 0013	+0 0010	+0 0023

TABLE 7

Compression Tests of 3-in by 6-in Cylinders, Sand-Gravel Aggregate

Age 233 Days

Cement No	Moist Room	75 Cycles Wetting and Drying		50 Cycles Freezing and Thawing		50 Cycles Freezing and Thawing Wetting and Drying	
		Strength	Ratio to Normal Strength	Strength	Ratio to Normal Strength	Strength	Ratio to Normal Strength
	lb per sq in	*lb per sq in*		*lb per sq in.*		*lb per sq in*	
32945	5411	4151	0 77	3784	0 70	2021	0 37
32946	5280	4113	0 78	2701	0 51	3406	0 65
32968	4408	3978	0 90	3834	0 87	3374	0 77
32982	5301	4814	0 91	3047	0 57	3893	0 73
33001	5652	4983	0 88	2790	0 50	3526	0 62
33006	5606	4326	0 77	5039	0 90	2917	0 52
33040	6012	4832	0 80	4187	0 70	3240	0 54
33059	5828	4799	0 82	4640	0 80	2586	0 44
33138	5090	4697	0 92	3412	0 67	2513	0 49

mix and Figure 8 shows the specimens after 75 cycles of wetting and drying.

Series 7 deals with strengths at various temperatures comparing sand-gravel aggregate concrete with fine aggregate Kaw River Sand and Bethany Falls

TABLE 8

COMPRESSIVE STRENGTH OF 6-IN BY 6-IN BY 8-IN PRISMS, SAND-GRAVEL AGGREGATE
Age 233 Days

Cement No	Moist Room Strength	75 Cycles Wetting and Drying		50 Cycles Freezing and Thawing		50 Cycles Freezing and Thawing Wetting and Drying		150 Cycles Wetting and Drying in Front of Fan at Room Temperature	
		Strength	Ratio to Normal Strength	Strength	Ratio to Normal Strength	Strength	Ratio to Normal Strength	Strength	Ratio to Normal Strength
	lb per sq in	*lb per sq in*		*lb per sq in*		*lb per sq in*		*lb per sq in*	
32945	4605	3342	0 73	4477	0 97	3403	0 74	4993	1 08
32946	4731	3805	0 81	5000	1 05	3871	0 82	4847	1 02
32968	4800	3369	0 70	5514	1 13	4259	0 89	5111	1 06
32982	4397	3364	0 77	4912	1 11	4305	0 98	4507	1 02
33001	4697	2791	0 59	4861	1 03	3935	0 84	4993	1 06
33006	4986	2722	0 55	5435	1 08	3662	0 73	4563	0 92
33040	4842	3331	0 69	3861	0 80	3408	0 70	4014	0 83
33059	4703	2633	0 56	5495	1 16	3911	0 84	4701	1 00
33138	4697	4108	0 87	4870	1 03	3273	0 70	4417	0 94

TABLE 9

SEVEN 6-IN BY 6-IN BY 7-IN PRISMS MADE OF STONE (No 33075), KAW RIVER FINE AGGREGATE, AND CEMENT No 32946

The prisms were cured in the moist room for 28 days, then five were wet and dried for 75 cycles of 8 hours drying in oven at 125°F and 16 hours submerged in tank of water in moist room at 70°F Two prisms remained in the moist room 233 days [1]

Gradation				Concrete Mix	
Stone		Fine Aggregate			
Sieve	Per Cent Retained	Sieve	Per Cent Retained		
2-in	00	⅜-in	00	Cement	23 5 lb
1½-in	2	No 4	3	Fine aggregate	57 5 lb
1-in	17	No 8	18	Stone	83 3 lb
¾-in	42	No 16	46	Water	12 0 lb
⅜-in	83	No 30	69		
No 4	98	No 50	94		
		No 100	100		
		G F	3 30		

Stone	Fine Aggregate	Green Concrete
Weight per Cubic Foot Dry and Rodded	Weight per Cubic Foot Dry and Rodded	Weight per Cubic Foot
98 0 lb	112 5 lb	150 5 lb

Compressive Strength

Age	Moist Room	After 75 Cycles Wet & Dry	Ratio of Strength after Wetting and Drying to Normal Strength
days	*lb per sq in*	*lb per sq in*	
233	5548	5211	0 94

[1] See Figure 9 specimens after 75 cycles wetting and drying

TABLE 10
Series 7

Sieve	Grading											Fineness Modulus	Wt per Cu Ft Dry and Rodded	Specific Gravity
	2-in	1½-in	1-in	¾-in	⅜-in	No 4	No 8	No 16	No 30	No 50	No 100		lb	
Fine Aggregate retained, %				0	0	2	12	35	60	90	99	2 98	111 0	2 60
Mixed Aggregate retained, %				0	2	7	26	54	76	94	99	3 58	115 5	2 60
Coarse Aggregate retained, %			0	56	87	98	100	100	100	100	100	7 41	91 5	2 58

Concrete Mix

Aggregate	Cement	Water	Fine Aggregate	Sand-gravel	Stone	Slump	Bbl per Cu Yd
	lb	lb	lb	lb	lb	in	
Coarse and fine	94 0	48 0	220 0		332 0	2 0	1 44
Mixed	94 0	48 0		430 0		0 5	1 67

Strength

	Age	Av Modulus of Rupture	Av Compressive Strength	Ratio to Modulus of Rupture at 70°F	Ratio to Compressive Strength at 70°F
	days	lb per sq in			
Coarse and fine aggregate beams frozen, temp −5°F	28	1743	7471	2 28	1 55
Coarse and fine aggregate beams moist room cured, temp 70°F	28	766	4829		
Coarse and fine aggregate beams hot, temp 135°F	28	575	5201	0 75	1 08
Mixed aggregate beams frozen, temp −5°F	28	1670	6516	2 85	1 81
Mixed aggregate beams moist room cured, temp 70°F	28	585	3597		
Mixed aggregate beams hot, temp 135°F	28	388	3642	0 66	1 01

Note All specimens held at respective temperatures for 16 hours and broken at these temperatures

TABLE 11
Strain Gage Measurements

Material				Elongation in 10 in			
Cement No	Sand-gravel Kaw river	Sand-gravel Blue river deposit	Kaw river fine agg Bethany Falls coarse agg	Moist room cured	25 cycles wet and dry 62 days age	42 cycles wet and dry 86 days age	50 cycles wet and dry 95 days age
32982	No	Yes	No	0 0004[1]	0 0020	0 0027	
33001	No	Yes	No	0 0004[1]	0 0026	0 0030	
32946	Yes	No	No	0 0009[2]	0 0023		0 0039
32968	Yes	No	No	0 0006[2]	0 0022		0 0032
33001	Yes	No	No	0 0004[2]	0 0019		0 0031
33006	Yes	No	No	0 0005[2]	0 0020		0 0031
32946	No	No	Yes	0 0003[3]	0 0010		
33006	No	No	Yes	0 0002[3]	0 0015		

[1] Moist room specimens at 86 days age
[2] Moist room specimens at 95 days age
[3] Moist room specimens at 62 days age

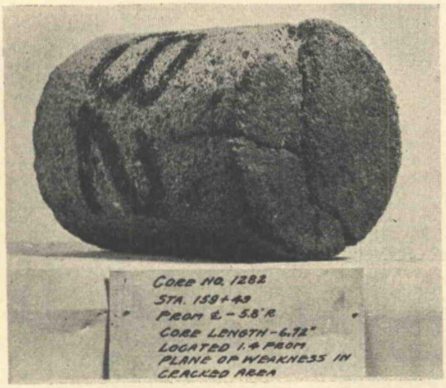

Figure 3. Core from Cracked Sand-Gravel Pavement

contraction. Specimens were made using sand-gravel aggregate from the Kaw River, sand-gravel aggregate deposited by the Blue River and specimens containing Kaw River fine aggregate and Bethany Falls limestone coarse aggregate.

These different aggregates were made up into 6-in. by 6-in. by 12-in. specimens using two brands of cement for each type of aggregate. The cements used in Series 8 were one in which slight or no cracking had appeared and one in which bad cracking developed in Series 6. The specimens were cured for 28 days in a moist room maintained at 70°F. At the end of 28 days control specimens were left in the moist room and companion specimens subjected to wetting and drying (16 hr. in water at 70°F., and 8 hr. in an oven at 125°F.)

The Kaw River sand-gravel specimens have a moisture loss of 0.26 per cent, the sand-gravel specimens made from the Blue River deposit have a moisture loss of 0.21 per cent and the fine and coarse aggregate specimens have a moisture loss

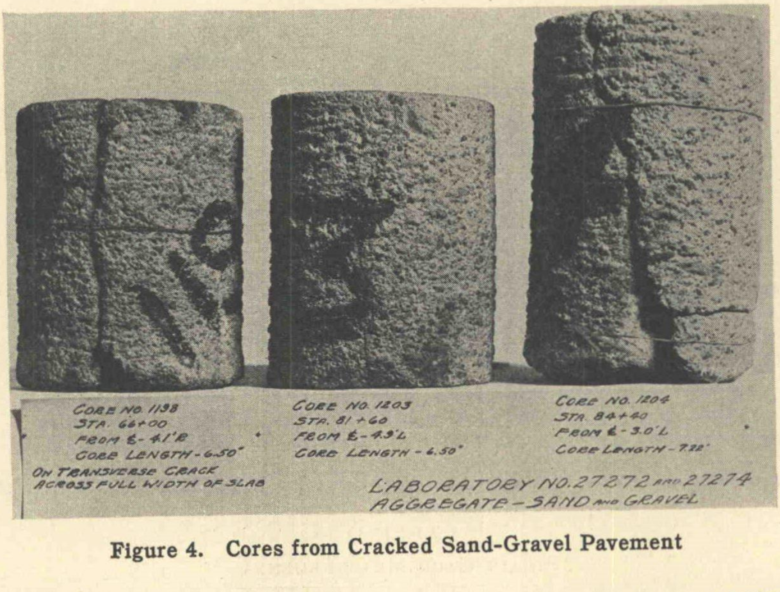

Figure 4. Cores from Cracked Sand-Gravel Pavement

stone coarse aggregate. The results of this series are tabulated in Table 10. Note that the modulus of rupture for the sand-gravel specimens tested at 135°F., have the lower ratio of strength to strength at 70°F. This may or may not have any bearing on this problem.

Series 8 consists of concrete specimens 6 in. by 6 in. by 12 in. in size containing brass plugs set at a 10-in. gage length (See Fig. 9) for measuring expansion and

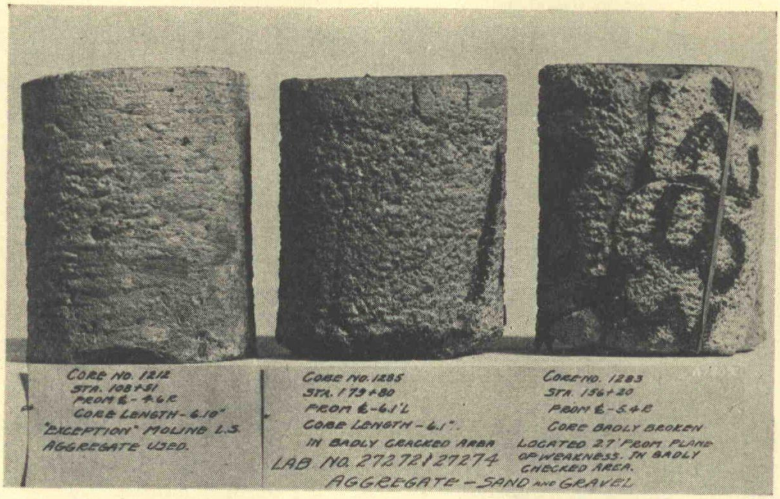

Figure 5. Cores from Cracked Sand-Gravel Pavement

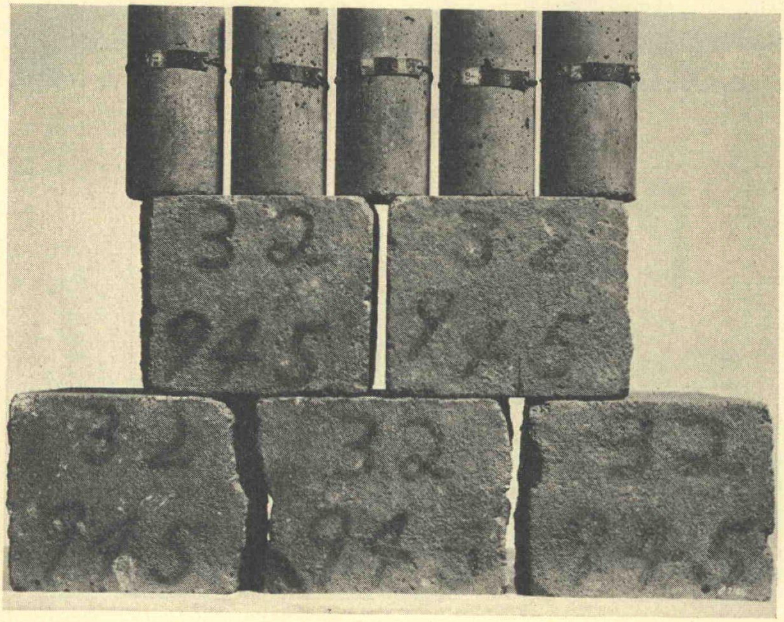

Figure 6. Specimens after 75 Cycles of Wetting and Drying, 5 of the Cements Included, Sand-Gravel Aggregates

of 0.22 per cent during the eight hour drying cycle.

Series 8 is still in progress but the strain gage results after 25 cycles of wetting and drying are tabulated in Table 11.

In Figures 3, 4, and 5 are shown cores $4\frac{1}{2}$ in. in diameter which were drilled from a concrete pavement that has developed map cracking.

In Figures 6 and 7 are shown cylinders and prisms after 75 cycles of wetting and drying.

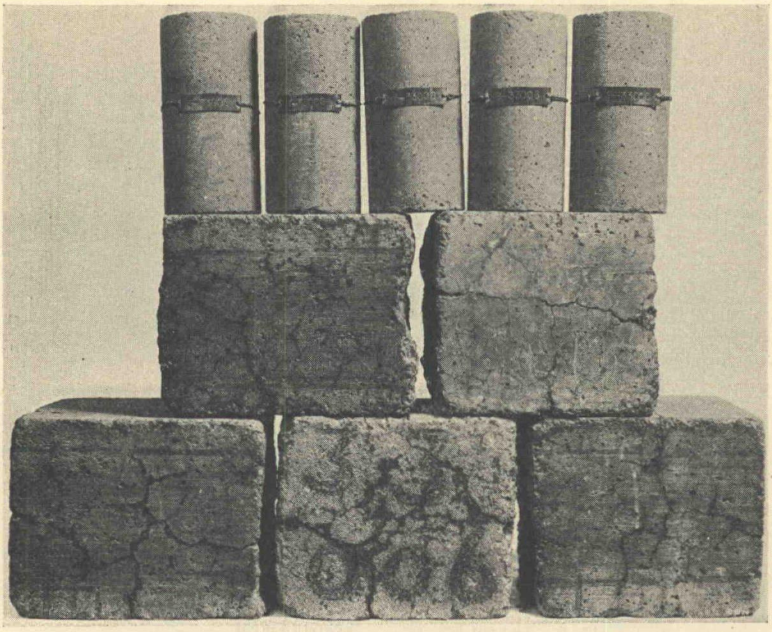

Figure 7. Specimens after 75 Cycles of Wetting and Drying, 4 Brands of Cement Not in Figure 6, Sand-Gravel Aggregate

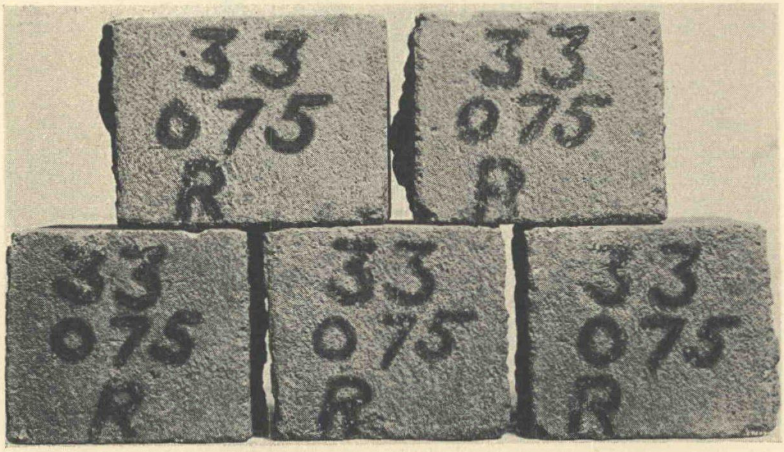

Figure 8. Concrete Specimens Containing Coarse and Fine Aggregate, after 75 Cycles of Wetting and Drying

Figure 6 is representative of five of the brands of cement and Figure 7 is representative of the other four cements after they have been through 75 cycles of wetting and drying.

TENTATIVE CONCLUSIONS

1. The information up to date does not indicate that map cracking in sand-gravel aggregate pavements can be foretold by the chemical analysis of the cement.

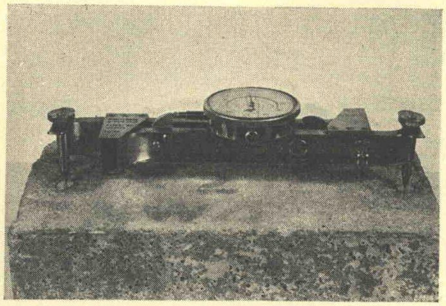

Figure 9. Strain Gage

2. This type of map cracking is predominately occurring in sand-gravel aggregate concrete pavements in Kansas.

3. The autoclave test as now made on cements is not a criterion as to whether or not map cracking will develop in sand-gravel aggregate concrete.

4. This disintegrating map cracking has been successfully reproduced in the laboratory.