out of the material and does not mix to the bottom of the base

5 Water should be applied with power driven distributors properly tachometered whenever possible At least all water distributors should have spray bar length control and adjustable valves so that the spread of water can be controlled at all times and under all conditions

6. Rolling with sheepsfoot rollers should be completed while the base mixture is at the optimum moisture content

Enough rollers should be used so that the required density is reached in 2 to $2\frac{1}{2}$ hours

7 During the initial compacting, or sheepsfoot rolling, only tractors of the track laying type should be used for operating the rollers Pneumatic tires should not be used at this stage as they compact the base unevenly

8 For final compaction the pneumatic roller should be operated by pneumatic tired tractors as a uniform surface, free from tracks, is desired Where track laying tractors are used, track marks are left in the base and extra rolling and blading are required to remove them

One pneumatic roller will take care of about 1500 ft per day The job should be equipped with two rollers of this type as this final compaction is important to the finish of the base In case of extra footage or breakdown of roller, the additional machine would be available to complete the day's run

9 For removing compaction planes on final shaping and packing, a fine spike tooth harrow should be used This type of harrow should have more and finer teeth than the common farm harrow so as not to leave too large ridges in the top mixture

10 Where bitumen is used for curing, it appears advisable to give the completed base one or two light applications of water before priming The first application should be about five hours after the base has been completed and the second 5 hours later, with about the same lapse of time before the prime coat is applied

FINISHED ROAD

The soil-cement stabilized base was surfaced with a bituminous wearing mat of inverted penetration type, 22 ft wide applied in two courses The binder was SC-7 bitumen applied at 0 3 gal. per sq yd for each course Crushed lime stone was applied at 30 lb per sq yd for each of the two courses

EXPERIMENTAL SOIL-CEMENT ROAD IN WISCONSIN

By Guy H Larson

Senior Assistant Engineer of Materials

An experimental soil-cement stabilization project was undertaken in Wisconsin during the fall of 1936, and early summer of 1937 The project consisted of a 3 3-mile section, located on State Highway 13, immediately north of Friendship in Adams County, 1 65 miles were built in 1936 and the project was completed in 1937. The work was done by county forces at the expense and under the supervision of the State Highway Commission of Wisconsin, working in cooperation with the Portland Cement Association, who also conducted the preliminary tests and designed the proportions.

The region is an old glacial lake bed and while the sandy soil deposited by the lake waters lent itself to some easy manipulation during construction, it also presented some unexpected problems during the preliminary tests The soil was graded largely between the 30 and 100-mesh sieves and appeared very uniform throughout the project A limited number of representative samples of the soil occurring on the road were obtained for preliminary tests Determination of grain size distribution and physical test constants showed the soil in these samples to be very similar Because of this similarity and the uniformity of the soil, one of the samples (No 36) was selected for the preliminary tests of strength and durability of the sand in combination with various percentages of cement

Durability tests consisted of wetting and drying, and freezing and thawing, conducted on specimens molded at the optimum moisture content The specimens were cured for 7 days in a covered container having free water in the bottom, before the tests were started. Wetting and drying tests were conducted by placing the specimens in an oven at a temperature of 160°F for 42 hr, after which they were removed, wire brushed and weighed, then placed in individual cans containing tap water After soaking for 5 hr the specimens were removed and weighed, then replaced in the oven Freezing and thawing tests were conducted by setting the specimens on blotters in the carriers so as to insure maximum capillary absorption of water during thawing They were then placed in the refrigerator where they were frozen in 3 hr. and reached a temperature of −15°F. in 20 hr Upon removal from the refrigerator the specimens were weighed and then placed in the moist room in containers holding sufficient water to submerge the blotters beneath the specimens, where they were permitted to thaw and absorb water for 24 hr After this, the specimens were brushed with a wire brush, re-weighed and again placed in the refrigerator The specimens thus brushed and weighed in each test gave data on the soil loss Twelve cycles constituted a complete test in either the wetting and drying or freezing and thawing tests unless the material slaked to its angle of repose before the twelve cycles were finished Compressive strength tests were made on 2 by 2-inch cylinders molded with a sand-molding machine regulated so that the density of the specimens approximated that obtained in the durability specimens

These preliminary tests showed unsatisfactory results with pure sand and cement mixtures Table 1 shows results of strength tests of various mixtures of sand and cement

Chemical tests revealed that the soil contained 11,000 parts of organic matter per million, and study of the grain size distribution indicated a shortage of fine material It was concluded that these factors were largely responsible for the unsatisfactory test results Fines could be provided by adding clay to the sand, and it was felt the clay might react to overcome somewhat the effects of the organic matter

TABLE 1

EFFECT OF ADDING INCREASED AMOUNTS OF CEMENT TO WISCONSIN SOIL No 36, SAND

Cement Content, Percent By Dry Weight	Compressive Strengths of 2-in Cylinders, lbs per sq in Average of Two Cylinders	
	2 days	7 days
12	25	38
14	25	43
16	29	40
18	33	46
20	37	57

Additional samples of the sand (No 66) and two clays (Nos 75 and 76, and No 77) were obtained for further tests Soils 75 and 76 came from the same deposit, one superimposed upon the other, so they would be mixed in approximately equal parts, and they were used in combination as one soil Table 2 gives the grain size distribution and physical test constants of these new samples and those of the original sample of soil, No 36

A comparison of the grain size distribution and test constants of soils 36 and 66 shows them to be very similar Chemical tests showed the organic content of soil No. 66 to be approximately 11,000 parts per million, which checks that of soil No 36

Strength and durability tests of mixes using varying proportions of clay and cement showed very beneficial effects from the addition of clay The general effect on strength of various additions of clay, and using varying cement contents is shown very clearly in the Table 3

Moisture-density relations were determined as shown in Figure 1, and the data in Table 5 were calculated from the curves

Durability specimens were molded using these data The tests gave satisfactory results and the mixture recommended for construction of the project was as follows

20 per cent by dry wt of either clay Nos 75 and 76, or No 77 to be added to the sand,

TABLE 2

GRAIN SIZE DISTRIBUTION

P C A Laboratory Sample No	Smaller than 2 00 mm , %	Coarse Sand, 2 00-0 25 mm , %	Fine Sand, 0 25-0 05 mm , %	Silt, 0 05-0 005 mm , %	Clay, 0 005-0 000 mm , %	Colloids,* 0 001-0 000 mm , %	Classification
36	100	52 0	36 0	7 0	5 0	2 5	Sand
66	100	54 0	40 0	3 0	3 0	1 0	Sand
75 & 76 (50-50 mix)	100	1 0	28 0	48 0	23 0	8 0	Clay-loam
77	100	4 0	8 0	50 0	38 0	12 0	Clay

* Also included in clay fraction

PHYSICAL TEST CONSTANTS

P C A Laboratory Sample No	L L	P I	F M E	S L	S R	Classification
36	15 3	0	14 8	16 6	1 80	Sand
66	13 0	0	18 2	18 2	1 66	Sand
75 & 76 (50-50 mix)	24 5	7 1	20 0	17 5	1 78	Clay-loam
77	30 6	13 9	18 9	17 2	1 85	Clay

These strengths were high in comparison with those obtained with sand and cement alone and compared very favorably with those obtained with soils encountered on similar projects which gave satisfactory results It was noted during the series of tests that mixes in which the clay was pulverized to pass a No 10 sieve gave better results than those in which the clay passed the one-fourth-inch sieve

The mixtures (Nos 5 and 6) shown in Table 4 were then made up, using 10 percent cement by weight

10 per cent by dry wt of cement to be added to the sand-clay mixtures

The optimum moisture content and maximum density of this mixture were given as 9 5 percent and 126 lbs per cubic foot, respectively

EQUIPMENT

Since equipment had not been developed especially for this type of construction, it was necessary to select such units as were available and appeared likely to function satisfactorily That

TABLE 3

EFFECT OF ADDING VARIABLE PERCENTAGES OF SOILS 75 AND 76 (50-50 MIX), CLAY-LOAM, AND NO 77, CLAY, TO WISCONSIN SOIL NO 66, SAND

(Admixed soils pulverized approximately to pass No 10 sieve)

P C A Lab Sample No of Soil Admixed to No 66 Sand	Parts of Soil by Dry Wt Admixed to to 100 parts of Soil No 66, Sand	Cement Content Percent by Wt	Compressive Strength, lbs per sq in Av of Two Specimens	
			3 days	7 days
75 & 76 (50-50 mix)	15	8	120*	226
		10	115*	231
		12	99*	278
	20	8	184	274
		10	216	368
		12	280	609
	25	8	213	380
		10	312	571
		12	330	565
77	15	8	204	362
		10	198	420
		12	268	567
	20	8	257	410
		10	345	615
		12	377	716
	25	8	256	391
		10	360	584
		12	403	664

* These strengths are low due to an accident while handling the specimens

TABLE 4

MIXTURES OF SOIL 66, SAND, WITH NOS 75 AND 76 (50-50 MIX), CLAY-LOAM, PASSING ¼-INCH SIEVE AND WITH NO 77, CLAY, PASSING NO 10 SIEVE

P C A Laboratory Mixture Designation	Parts by Dry Wt of Soil No 66, Sand, in Mixture	Parts of Soil Nos 75 and 76 (50-50 mix), Clay-loam, in Mixture	Parts of Soil No 77, Clay, in Mixture
Mixture No 5	100	20	—
Mixture No 6	100	—	20

used on the Wisconsin project consisted of four tractors, 60, 40, 35, and 20, the lighter ones being used with the pulverizing and rolling equipment and the heavier ones with the mixing and grading equipment, two small 16-in tractor discs and spike-tooth harrows for pulverizing and breaking down the clay; four quack grass

TABLE 5

DATA CALCULATED FROM PROCTOR CURVES USED FOR MOLDING DURABILITY SPECIMENS HAVING PREDETERMINED CEMENT CONTENTS BY VOLUME

Admixed soil passed No 10 sieve

P C A Laboratory Mixture Designation	Percent Cement by Weight	Optimum Moisture, Percent	Maximum Density Lbs per cu ft
Mixture No 5	10	9 0	127 4
Mixture No 6	10	9 5	125 5

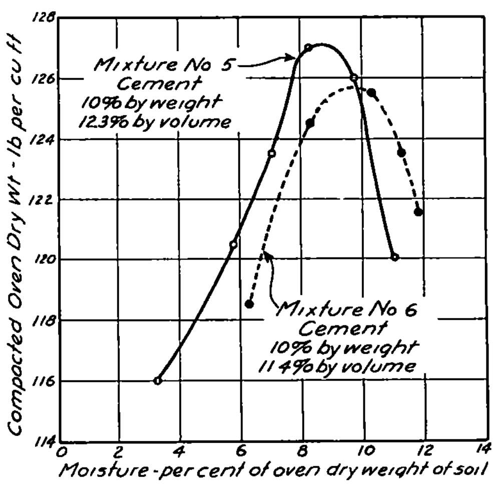

Figure 1 Moisture-Density Relations. Adams County, Wisconsin.

diggers, ranging from 7 to 10 ft. in width, for mixing operations, one large grader, one motor grader, two sheepsfoot rollers for compacting soil, one single and one double unit, four trucks for hauling cement and clay, and also for compacting, one 8-ton three-wheeled smooth roller, one 1,000-gal oil distributor for distributing water, one pump and pipe line for supplying water to the project, and field laboratory and testing equipment

SUBBASE

It was decided to place clay over a width of 24 ft, and to add cement over a 22-foot width and process to a compacted depth of 6 inches This required approximately 780 cubic yards of clay and 2,000 barrels of cement per mile

Since this project was built on a new roadbed consisting of loose sand which had been brought as nearly as possible to the desired shape and grade, no scarifying was necessary The clay was hauled and spread by means of trucks, supplemented by hand spreading when necessary The clay was pulverized and partially mixed with the sand by means of discs and spike-tooth harrows, after which it was mixed to the full depth by means of quack grass diggers traveling back and forth over the length of the section being worked. The quack grass digger is similar to a spring-tooth harrow mounted on wheels, and can be set to work at various desired depths

These quack grass diggers were an innovation in mixing equipment for this work They eliminated the necessity for blading the entire mass of material back and forth over the grade and replaced the large discs and blade graders used for mixing on previous projects of this character

APPLICATION OF CEMENT

Construction began each day with the application of cement on a section of road which the engineer estimated could be finished during the day Cement sacks were spotted at regular intervals so as to provide the required amount for a compacted depth of 6 in The sacks were opened and dumped, and the cement spread by hand labor using shovels and rakes As soon as the cement was spread uniformly over the surface of the road, mixing was started with the quack grass diggers, drawn by crawler tractors, and continued until the cement and soil were thoroughly mixed to the full depth as indicated by uniform color of the mixture The depth of mixing was controlled by means of reference stakes placed along the shoulder. It was necessary to maintain the edges of the road during processing by shoveling material back as the diggers worked it out

When the dry cement was thoroughly mixed with the soil, tests were made of the moisture content of the mixture, and the amount of water necessary to bring it up to the optimum determined The necessary water was added in several "shots", each at the rate of about two gal per sq yd with a 1,000-gal oil distributor. Water was brought to the work by means of a pump and pipeline, from which the distributor was filled at the side of the road Mixing with the diggers was continued until the mixture was again of uniform color, indicating that the water had been thoroughly and uniformly dispersed throughout the mass The mixture was then such that when squeezed firmly in the hand it could just be compressed into a ball which would withstand very light handling

COMPACTING AND FINISHING

Having brought the sand, clay, and cement into an intimate mixture and provided the proper moisture content, the mass was compacted with sheepsfoot rollers The bearing surfaces or "feet" of the roller were 3 by 4 in, and were so loaded as to exert a pressure of 100 lb. per sq in when the feet were in full contact with the soil This type of roller was used because its compaction had been correlated with the laboratory compaction At first the "feet" settled to their full depth in the soil, but as compaction proceeded they gradually worked out until they were riding near the surface

At this point it may be of interest to mention two factors, the moisture content and the clay, which had very noticeable effects on the success of the compacting operation The importance of the proper moisture content may be illustrated by the comparative compaction of spots having moisture contents different from the "optimum " A moisture content of 9 3 percent gave poor compaction, the soil being dry and crumbly, 10 5 to 11 5 percent gave good compaction, while a moisture content of 12 3 percent resulted in sponginess and a tendency of the soil to peel and stick to the smooth roller A short section of road processed with the same cement content but without the addition of clay could not be compacted with the sheepsfoot roller and the usual equipment It was necessary to resort to a cleatless crawler tractor and lighter equipment

The finishing procedure varied somewhat from that used on previous projects in other states When the sheepsfoot roller began to ride well up in the mass, shaping of the road was started by blading material from the sides toward the center so as to obtain some crown, the compaction process being continued as this blading was done When the roller ceased to "pack out" rolling was stopped, and the road dragged with a spike-tooth harrow to remove roller marks and to loosen and level the surface Compaction was then continued with a cleatless crawler tractor, followed with trucks and the distributor, starting at one side and working over the entire width of the road The reason for finishing compaction with the tractor and trucks was that the sheepsfoot roller could not be followed directly by the smooth roller because of its tendency to pick up the loose material

Immediately after compaction with the tractor and trucks, the surface was bladed and "shaved" with a motor grader to bring the road to final crown and shape This blading was started at the center, and continued toward either side Excess material was bladed off the road and wasted It was found more satisfactory to cut high spots completely down, with consequent waste of the excess material, than to attempt to cut them partially and fill in low spots Any material placed and compacted on the smooth and near-finished surface was almost certain to loosen and peel off The final shaping with the grader was followed by ironing and smoothing irregularities in the surface with an 8-ton three-wheeled smooth roller The finished surface was covered with damp sand to a depth of approximately one inch as a curing measure The usual curing time was from 7 to 10 days

PREPARATION FOR NEXT DAY'S WORK

At the end of the day, preparations were made for the following day's work. This included the construction of a "turn around" on the end of the completed section, the preparation of the end of the processed material for making the joint with the following day's work, and loosening up the soil in the section next to be processed The "turn around" consisted of a board mat 4 to 6 ft wide at the end of the completed section with wings about 3 ft wide extending back and covering the edges of the road This mat and the entire road was covered with sand or soil to a depth of 6 to 8 in for a distance of approximately 50 ft This protected the surface from the wheels of the equipment as it was turned around on the following day There was a certain amount of "dragging out" of the cement mixture at the end of the section processed and preparation for the joint consisted of cutting this back to sound, dense material and beveling off the end The joint was of the feather-edged or beveled type This joint was not satisfactory because the thin edge of the "overlap" would chip and spall off. Several vertical butt joints were tried. Certain difficulties in mixing and compacting the material right up to the vertical end of the previous day's work made this joint difficult to construct.

The average length of section processed per day in 1936 was 513 feet, with a

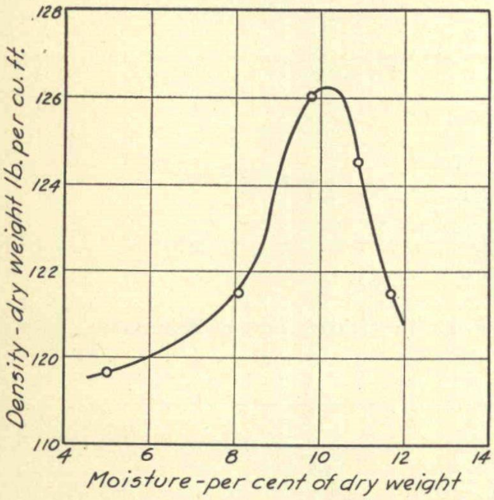

Figure 2. Moisture-Density Relations. Field Test. Station 153, Project 4758.

TABLE 6

TYPICAL SIEVE ANALYSES OF FIELD MIXTURES

Sieve No.	Percent by Weight Retained		
	Sand	Sand-clay	Sand-clay-cement
4	0	10.7	10.6
10	0.3	25.0	22.1
16	1.2	32.8	28.8
50	45.5	80.1	65.4
100	92.7	97.8	90.8
200	99.0	99.7	94.7
Pan	100.0	100.0	100.0

maximum of 660 feet. On the portion completed in 1937 the average was 728 feet, with a maximum of 900 feet. There naturally was considerable experimentation with equipment and procedure, particularly on the section processed in the fall. Of those available and tried, the ones described gave best results; they are not, however, to be taken as entirely satisfactory.

PROTECTIVE SURFACING

There was some shrinkage after final compaction, as evidenced by the formation of cracks noticed at intervals of ap-

Figure 3. Drilling hole for determining density of hardened road.

proximately 25 ft. upon the removal of the sand covering. Also, there was some scaling and spalling of the surface attributed to improper finishing and attempting to patch or fill low spots. The clay could not be completely pulverized with the equipment available, and small clay balls were apparent in the surface. It was, therefore, deemed advisable to protect the surface from abrasion with a light wearing surface, or armor coat. This consisted of an application of one-third gallon of a heavy tar, T H -4, and 20 lb of stone chips per sq yd field mixture and of the compacted and hardened material in the road were made, and the results compared with laboratory test results.

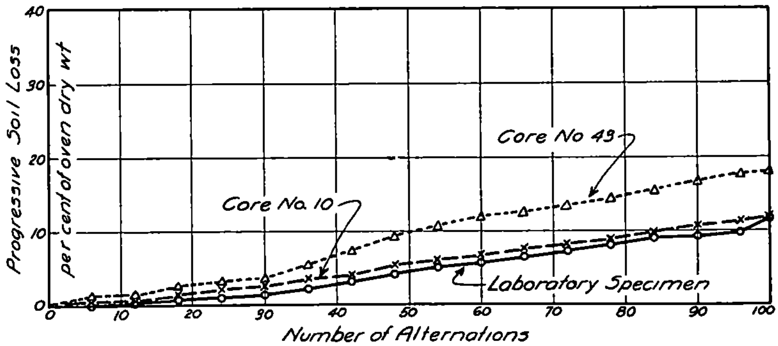

Figure 4. Wetting and Drying Tests. Progressive Loss of Material

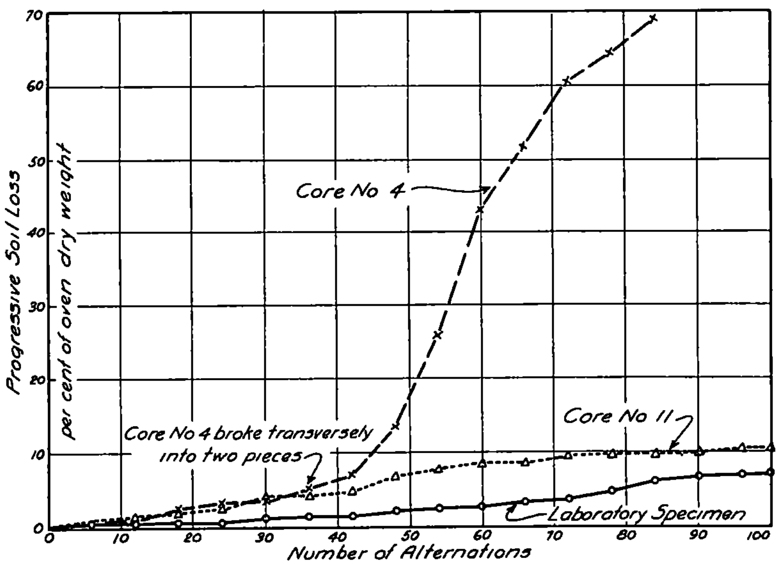

Figure 5. Freezing and Thawing Tests. Progressive Loss of Material

TEST RESULTS

In order to check the effectiveness of the field operations, certain tests of the

Typical sieve analyses of the sand, sand-clay, and sand-clay-cement mixtures are shown in Table 6.

The material retained on the Nos 10

and 4 sieves consisted of a clay core to which cement and fine sand were adhering; material between these sieves and the No. 100 was a mixture of sand, clay, and cement; that between the 100 and 200 mesh sieves consisted of fine sand, clay, and cement; and below the 200 mesh it was entirely clay and cement. Typical results of Proctor moisture-density relations obtained in tests on the field mixture are shown in Figure 2. The average moisture content of the mixture when compaction was started on the portion completed in 1936 was 10.3 percent, and the average of 48 field density tests made on the compacted material showed a dry weight per cu. ft. of 120 lb. Later a number of cores were taken from the road, and density tests made in the laboratory on them showed a weight of 123 lb. per cu. ft. These results compare favorably with the density of 126 lb. per cu. ft. obtained in the laboratory tests. Field density tests on the section processed without the addition of clay showed a weight per cu. ft. of 116.4 lb. Measurements of the thickness of the compacted material taken when field density tests were made showed an average of 6.3 in. for the middle of the road and 5.7 in. two to four feet from the edges. The cement content was reduced to 8 percent by weight on the portion built in 1937. The average moisture content at the beginning of compaction was 10.2 percent, and the density averaged 117 lb. per cu. ft.

Durability tests were conducted on certain of the cores taken from the road in parallel with companion laboratory specimens. The progressive soil losses in 100 cycles of wetting and drying, and 100 cycles of freezing and thawing, are shown graphically in Figures 4 and 5. Figures 6 to 9 show the condition of these cores at the end of 12, 48, 72 and 100 cycles. The agreement in results between laboratory specimens and field cores should be noted.

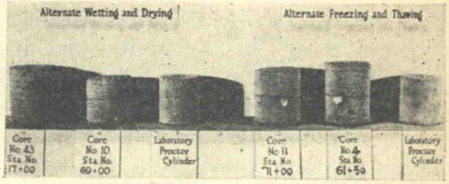

Figure 6. Condition of cores and cylinders after 12 cycles of durability tests.

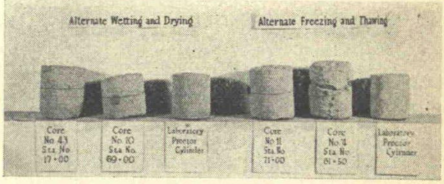

Figure 7. Condition of cores and cylinders after 48 cycles of durability tests.

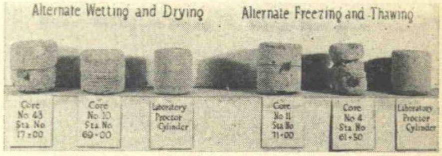

Figure 8. Condition of cores and cylinders after 72 cycles of durability tests.

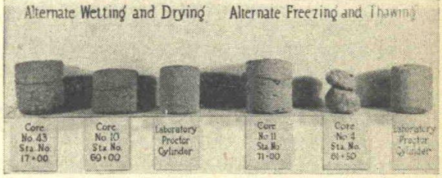

Figure 9. Condition of cores and cylinders after 100 cycles of durability tests.

The section built in the fall of 1936 came through the winter in good shape. It is rather early, however, to make any comment as to ultimate service behavior.