Soil Stabilization Field Trials, Primary Highway 117, Jasper County, Iowa

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This paper presents the methods of construction, and the evaluation of three years of field and laboratory observations of 6,000 ft of stabilized soil base and subbase courses of primary highway 117, Jasper County, Iowa. The 6-in. subbase test sections were constructed by using the in-place subgrade loessial soil materials stabilized with lime, lime-fly ash, and commercial organic cationic chemical. The 7-in. base course test sections were constructed using a sand-loess soil mixture stabilized with lime-fly ash, lime-fly ash-accelerating agent, and type I portland cement. The fly ash was obtained from two sources. Sodium carbonate and sodium chloride were used as accelerating agents in two sections of lime-fly ash base course. The surface course was 3 in. of an asphaltic concrete mix.

The evaluation program of the test sections was divided into three phases: (a) laboratory analysis and development of project specifications before construction; (b) construction of base and subbase courses, accompanied by sampling and specimen molding of field mixed materials for laboratory testing; and (c) field and laboratory testing, and evaluation of the test sections under existing traffic and weather conditions covering the first three years of performance.

As far as possible, conventional construction practices were used: scarification, blading, spreading of stabilizing agent, single- and multi-pass mixing, sheepsfoot and rubber-tired compaction. Water for standard Proctor optimum moisture content was applied through the spray bar of the single-pass mixer. The chemical was applied in a water solution through the spray bar at a rate and water concentration necessary for desired optimum moisture content and chemical concentration in the soil.

Performance evaluation was accomplished through testing of laboratory specimens, core samples, Benkelman beam tests, crack studies, weather information, traffic volumes and road roughness measurements. Results indicate all sections of the test road have given three years of excellent service. The road has sustained severe freezing and moisture conditions and is in an equally excellent condition to the non-experimental sections of the road immediately adjacent which employ a 6-in. soil-aggregate subbase; 7-in. soil-cement base course, and a 3-in. asphaltic concrete surface course.

Appended to this paper are the results of soil-bacterial counts made on the chemical-treated subbase section. The results indicate that the presence of the chemical in the treated soil material has resulted in no net increase or decrease in the quantity of microorganisms present at the time of the study, approximately 3½ years after construction.

• DURING THE SPRING of 1957, the Iowa Highway Research Board, the Iowa State Highway Commission, and the Iowa Engineering Experiment Station Soil Research Laboratory, in joint effort, initiated a field trial of stabilized soil base and subbase courses at a test site on Primary Highway 117, Jasper County, Iowa (Fig. 1). The test program incorporated both generally accepted construction procedures, and laboratory-proven methods of soil stabilization.

The test site was a 6,000-ft portion of an otherwise 12-mi long soil-cement-base soil-aggregate subbase highway. The test sections were integrated into the regular construction, for a comparative analysis and examination between the experimental and the regularly designed sections.

During the life of the road, Iowa has had some of its coldest winters in over two decades. Adding to this severe condition is the fact that all occurring cracks have been left unsealed for the penetration of snow and rain. Since completion, traffic density has almost doubled. Increasingly heavy loads are being experienced, as trucking firms are using this route from US 30 to Interstate 35, which opened for traffic in early 1961.

The experimental program was set up in three phases:

1. A simplified laboratory analysis of the field materials, and a general development of project specifications.
2. Construction of the subbase and base course sections.
3. An analytical report covering the first three years' performance under existing traffic and weather conditions.

Since completion of construction in November 1957, the road has been under study by IEES Soil Research Laboratory personnel with assistance by the Iowa State Highway Commission in obtaining core samples, traffic data, and road roughness studies. Although some studies will necessarily continue for years to come, the preliminary studies for this test road were completed in 1961. The tests and observations to that time have indicated the positive effectiveness of the various stabilizing agents, their method of incorporation with the soil and the total design of the various experimental sections. The cost of materials used in the test sections, though not reported in this paper, were relatively low and reasonable.

The purpose of this paper is to present the background and results of the testing program, and the general evaluation of the experimental sections following three years of in-place service.

DESIGN

Timing on the experimental sections was such as to permit little opportunity for detailed laboratory studies and planning. Subsequently all mix design for the base and subbase sections were formulated on the experience with similar soils by personnel of the IEES Soil Research Laboratory. Soil stabilization research in the Laboratory indicated satisfactory stabilization with the mix design shown in Figure 2.

Preliminary Field and Laboratory Investigation

Preliminary investigation of the test sections was begun by using a soil survey made by the Iowa Highway Commission during 1955. This survey developed the AASHO classification of the subgrade soils and other information pertinent to design and construction of the subgrade (Table 1). Rather than locating the 6,000 ft of experimental sections by laboratory and statistical means, a visual inspection of the road was conducted jointly by Iowa State Highway Commission and IEES Soil Research Laboratory personnel to select a test area where terrain and subgrade soils would be relatively uniform. Some variations were unavoidable as the entire length of the road is in fairly rolling terrain involving a Tama-Muscatine soil series complex. The selected 6,000-ft test sector began at station 190 + 00, about 2 mi north of Colfax and ended at station 250 + 00 (Fig. 2). Subgrade soil variation had a pronounced effect on the subbase test sections, because the in-place subgrade soil was mixed with the various stabilizing agents, creating a subbase course. Nearby sand and loess "borrow" materials were decided on as a mixed base course soil.

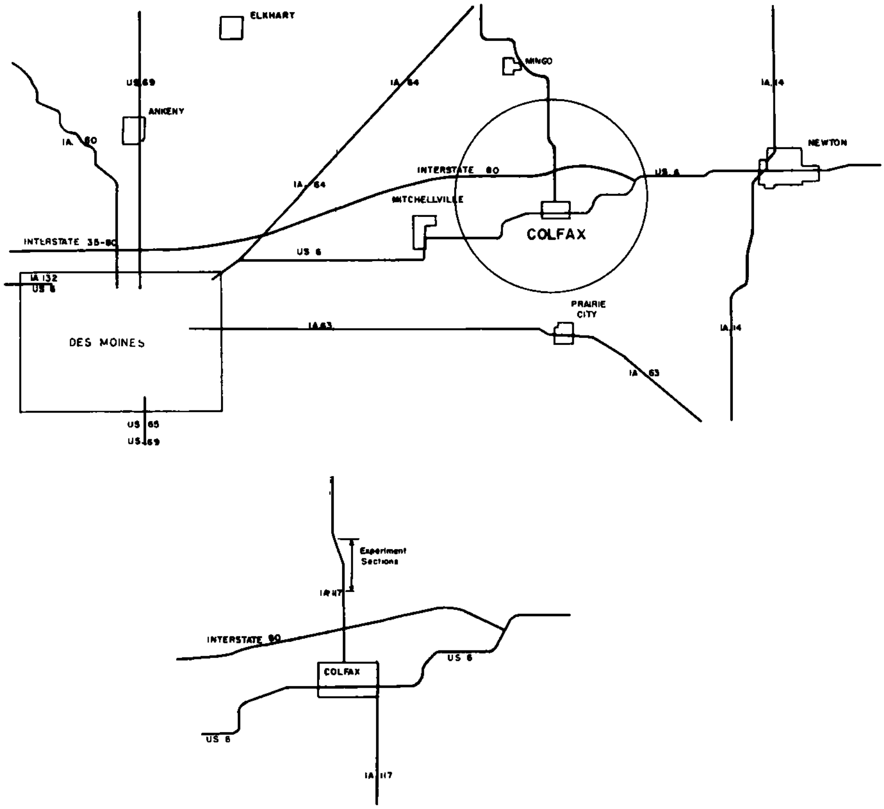

Figure 1. Soil stabilization field trials conducted at a site on Primary Highway 117 in Jasper Co., 2 mi north of Colfax, Iowa.

The in-place soil material used in the subbase test sections was predominantly a medium plastic loess: generally susceptible to capillary moisture from a fairly high water table, and by virtue of its location, subject to a major portion of the freeze-thaw cycles each winter. The in-place soil also included some gravel that had been used as a surfacing following completion of the subgrade in 1956.

The selection of the base course soil materials was primarily based on local availability and economy of utilization. Waste sand from a sand and gravel pit adjoining Highway 117 at the north edge of Colfax was the basic material finally decided on. To improve its workability for construction, and to create a near optimum sandy soil material for cement stabilization (for economical stabilization by portland cement as recommended by the Portland Cement Association, 17), the addition of a medium plastic loess was determined necessary. The sand-loess mixture adopted contained 18 percent loess by dry soil weight. This somewhat cohesive mixture did not have sufficient all-weather stability to serve as a base material without addition of some stabilizing agent.

Representative soil samples were removed from the in-place material in each subbase test section and from the base course borrow materials. Typical AASHO-ASTM analyses of the subbase soil and the base soil mixture are given in Tables 2 and 3, respectively.

Stabilizing Agents

Selection of the various stabilizing agents was based on previous research with soil materials similar to those in the experimental sections. The major consideration for

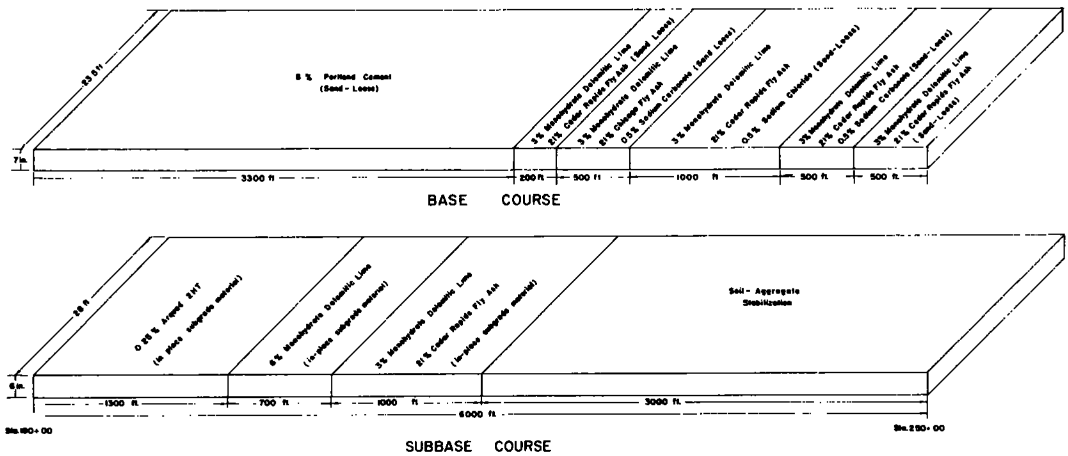

Figure 2. General layout and locations of soil stabilization sections constructed in field trials, Primary Highway 117, Jasper Co., Iowa.

TABLE 1

SOIL SURVEY OF SUBGRADE IN AND NEAR EXPERIMENTAL PORTIONS OF HIGHWAY 117[a]

Property	Station					
	192+00	196+00	221+00	180+00	183+00	184+00
Depth (ft)	0.0-2.4	2.4-12.0	5.6-10.0	7.2-9.0	0.0-3.0	2.6-16.0
Mechanical analysis (%)						
Gravel (over 2.0 mm)	0	0	0	5	0	0
Sand (2.0 - 0.074 mm)	1	0	1	36	1	0
Silt (0.074 - 0.005 mm)	68	70	81	25	62	71
Clay (0.005 - 0.0 mm)	31	30	18	34	37	29
Atterberg limits (%)						
Liquid limit	41	39	32	48	39	42
Plastic limit	25	20	21	26	25	21
Plastic index	16	19	11	22	14	21
Soil type	Silty clay	Silty clay loam	Silt	Clay	Silty clay	Silty clay loam
AASHO class.	A-7-6(11)	A-6(12)	A-6(8)	A-7-6(11)	A-6(10)	A-7-6(13)
Color	Br blk.	Mod yel br.	Lt. yel. br	Mod. br	Blk. br	Mod. yel. br

[a]From Iowa State Highway Commission Plan and Profile of Proposed Improvement of Primary Highway 117, Jasper County, Project F.772 (B) Date February and August, 1955.

stabilization of the in-place subbase material was the addition of agents known to arrest the shrinkage-swelling characteristics of the soil, and to waterproof it against moisture intrusion from either the surface or the subgrade.

Arquad 2HT.—An organic cationic chemical derived from meat packing wastes, Arquad 2HT has been found to waterproof and significantly reduce the shrinkage and swelling characteristics of many silty and clayey soils (4, 5, 6, 11, 14). The natural strength characteristics of a soil are little affected by the introduction of trace amounts of Arquad 2HT. However, silty or clayey soils treated with this chemical retain much of their load-bearing capacity under adverse moisture or freeze-thaw conditions.

TABLE 2

PROPERTIES OF UPPER 6 IN OF IN-PLACE SUBGRADE SOIL

Property	Soil
Geological description	Wisconsin-age loess, plastic, leached, thinly covered with surface dressing of gravelly sand
Location	Jasper Co , Iowa, 2 mi north of Colfax on Iowa 117
Soil series and horizon	Tama-Muscatine complex, silt loam, C-horizon
Textural composition (%)	
Gravel (>2.00 mm)	23.5
Sand (2 00-0 074 mm)	8.0
Silt (0.074-0.005 mm)	39.5
Clay (<0.005 mm)	29.0
Colloids (<0 001 mm)	24.0
Predominant clay mineral	Montmorillonite
Chemical properties	
Cat. exch. cap (meq/100 g)	21 9
Carbonates (%)	2.0
pH	7.5
Organic matter (%)	0.2
Atterberg limits (%)	
Liquid limit	40 5
Plastic limit	23.6
Plasticity index	16.9
Classification	
Textural[a]	Gravelly clay
Engineering (AASHO)	A-6(9)
Standard AASHO density (with 0.25% Arquad 2HT)	
Optimum moisture (%)	15.7
Maximum dry density (pcf)	114.0

[a]By triangular chart used by U S Bureau of Public Roads (19)

TABLE 3

PROPERTIES OF SAND-LOESS BASE COURSE SOIL MIXTURE

Property	Soil
Geological description	Loess—Wisconsin-age, plastic, leached, Sand—washed concentrate from Skunk River Valley
Location	Loess—borrow pit northeast edge of Colfax, Sand—Van Dusseldorp sand and gravel pit, 0 5 mi north of Colfax
Textural composition (%)	
Gravel (>2.00 mm)	0.5
Sand (2 00-0 074 mm)	57.5
Silt (0 074-0.005 mm)	30.0
Clay (<0.005 mm)	12.0
Colloids (<0 001 mm)	10 5
Predominant clay mineral	Montmorillonite
Chemical properties	
Cat. exch. cap. (meq/100 g)	11.0
Carbonates (%)	11.6
pH	8 3
Organic matter (%)	0.2
Atterberg limits (%)	
Liquid limit	18.9
Plastic limit	16.4
Plasticity index	4.0
Classification	
Textural[a]	Sandy loam
Engineering (AASHO)	A-4(1)
Standard AASHO density (with 3% lime, 21% fly ash)	
Optimum moisture (%)	18.0
Maximum dry density (pcf)	103.2

[a]By triangular chart used by U S. Bureau of Public Roads (19).

TABLE 4

ANALYSIS OF MONOHYDRATE DOLOMITIC LIME[a]

Property	Value
Physical (%):	
Loss on ignition	21.0
Fineness	92.1[b]
Chemical (%):	
CaO	45.36
MgO	36.29
SiO_2	0.40
R_2O_3	0.63

[a]Information furnished by manufacturer.
[b]Passing No. 200 sieve.

Lime.—In general, lime causes a reduction in plasticity, an increase in granulation, a reduction in swelling and shrinkage, and an increase in the strength characteristics of silty and clayey soils. Monohydrate dolomitic lime (Table 4) was selected for use in the lime-subbase section because previous investigations had shown it to be superior to other limes for soil-lime stabilization in Iowa, where the dominant soil clay mineral is montmorillonite (15, 16).

Fly Ash.—Fly ash, collected at power plants burning powdered coal, is predominantly composed of spherical particles of noncrystalline silica and alumina, and rounded particles of magnetic iron oxide, Fe_3O_4. Calcium oxide occurs alone or in combination with other ingredients of fly ash. Unburned porous bits of carbon act as a diluent in the pozzolanic reaction with lime; the content of carbon varying with the efficiency of fly ash production, but normally less than 10 percent in what is presently considered good quality ash. The pozzolanic activity of fly ash also appears to depend partly on fineness; normally 80 percent of a good-quality ash passes the No. 325 U.S. Standard sieve (13).

The fly ash used in the experimental sections was obtained from two producers; one located at Cedar Rapids, Iowa, and the second located at Chicago, Ill. (referred to in this report as Cedar Rapids fly ash and Chicago fly ash, respectively). Analyses of these fly ashes are given in Table 5.

Monohydrate Dolomitic Lime-Fly Ash.—The use of lime-fly ash as a stabilizing agent with clayey soils depends largely on the type and amount of clay present. The strength characteristics of montmorillonitic or kaolinitic clays may be improved to a higher degree with lime-fly ash than with lime only. The strengths of illitic-chloritic clays and non-cohesive sandy soils (generally too coarse to react with lime alone) stabilized with lime-fly ash are materially increased over those stabilized only with lime (16). Laboratory trials are necessary to determine the feasibility of stabilization of

TABLE 5

TYPICAL ANALYSES OF FLY ASH USED IN FIELD TRIALS

Property	Fly Ash	
	Chicago[a]	Cedar Rapids[b]
Chemical analysis (% by wt)		
SiO_2	49.8	43 72
Fe_2O_3	14.1	18 37
Al_2O_3	24.9	16.87
CaO	3.1	6 04
MgO	0 38	1.32
SO_3	1 2	1.09
S	---	---
Na_2O	---	---
$CaCO_3$	---	---
CO_2	---	---
SiC	---	---
C	0.36	8.75
Physical property		
Specific gravity	2 50	2.04
Specific surface (Blaine) (cm^2/g)	3,000	3,112
Passing No. 325 sieve (% by wt)	90.00	51.3

[a]Analysis furnished by Chicago Fly Ash Company, Chicago, Ill.
[b]Analysis furnished by Walter N. Handy Co., Springfield, Mo.

TABLE 6

ANALYSIS OF SODIUM CHLORIDE AND SODIUM CARBONATE[a]

Chemical Composition	Accelerator	
	Sodium Chloride	Sodium Carbonate
Compound (% by dry wt)		
$CaSO_4$	0.11	---
$CaCl_2$	0.02	---
NaCl	99.87	---
$(C_{18}H_{34}O_2)_2Ca$	0.022	---
$NaCO_3$	---	99.0
Na_2O	---	58.3
$NaHCO_3$	---	0.1
Na_2SO_4	---	0.02
Element (ppm)		
Fe	---	10
Al	---	5
Ca	---	130
Cu	---	1
Mg	---	30
Si	---	15

[a]Manufacturer's analyses.

silty soils with lime-fly ash rather than lime alone. Granular soils and crushed stone possess inherent mechanical stability, needing only slight improvement to meet requirements of a base course; however, the introduction of lime-fly ash is generally beneficial (7).

Fly ash is used primarily as a pozzolanic stabilization material with lime when the soil to be stabilized contains insufficient natural pozzolans. The benefits thus achieved are increased compressive strength, durability, and waterproofing improvements (7, 16).

Soil-lime and soil-lime fly ash base courses must be protected from traffic abrasion by a wearing surface, and for best results should be constructed and cured during the time of year when the air temperature averages 70 F or higher; the rate of hardening is a direct function of temperature. For proper moist curing as well as protection from carbonation by CO_2 in the air, lime or lime-fly ash-stabilized soil bases should be covered with a bituminous seal coat until such time as a permanent surfacing can be laid (7).

Accelerators.—Because the rate of pozzolanic hardening was expected to be slow due to the late season construction, sodium carbonate (covered by U.S. Patent No. 2,942,993) and sodium chloride were selected for evaluation as accelerators in three of the soil-lime-fly ash base course sections (8, 13). Analyses of the two accelerating agents used are given in Table 6.

Portland Cement.—Soil-cement is the hardened, freeze-thaw resistant material formed by curing a mechanically compacted uniform mixture of pulverized soil, portland cement, and water (9). A proven paving material, it was used in the experimental sections as a standard of comparison for other base course materials.

Type I, ordinary portland cement was used in both the experimental and non-experimental soil-cement portions of the road.

Final Design

Evaluation of all information obtained through field and laboratory investigations of the soils to be stabilized, provided a basis for the final design of the various test sections (Fig. 2). To compare the performance of the base and subbase test sections to the design employed by the Iowa State Highway Commission for the remainder of the 12-mi long road, all base test sections were underlain by the regularly designed soil-aggregate subbase, whereas the subbase test sections were overlain by the regularly designed soil-cement base.

TABLE 7

FINAL MIX DESIGN OF STABILIZING AGENT USED IN FIELD TRIALS

Course	Soil	Approx. Location by Stationing	Test Section Length (ft)	Stabilizing agent (% by dry wt.)[a]
Subbase	Using in-place soil material	190+00 to 203+00	1,300	0 25 (Arquad 2HT[b])
		203+00 to 210+00	700	6 (monohydrate dolomitic lime)
		210+00 to 220+00	1,000	3 (monohydrate dolomitic lime), 21 (Cedar Rapids fly ash)
Base	Sand-loess mixture	190+00 to 223+00	3,300	8 (Type I portland cement)
		223+00 to 225+00	200	3 (monohydrate dolomitic lime), 21 (Cedar Rapids fly ash)
		225+00 to 230+00	500	3 (monohydrate dolomitic lime), 21 (Chicago fly ash), 0. 5 (sodium carbonate)
		230+00 to 240+00	1,000	3 (monohydrate dolomitic lime), 21 (Cedar Rapids fly ash), 0 5 (sodium chloride)
		240+00 to 245+00	500	3 (monohydrate dolomitic lime), 21 (Cedar Rapids fly ash), 0. 5 (sodium carbonate)
		245+00 to 250+00	500	3 (monohydrate dolomitic lime), 21 (Cedar Rapids fly ash)

[a]Of soil-agent mixture.
[b]As supplied by manufacturer, Arquad 2HT is 75 percent active in isoproponal. Thus, 0.25 percent of 75 percent active Arquad 2HT would supply 0. 1875 percent of pure Arquad 2HT by dry soil weight. Amount of Arquad used in field trials referred to herein as 0.25 percent by dry soil weight, as received in 75 percent active form from manufacturer

Thickness.—Design-compacted thicknesses of the subbase and base sections as selected by the Iowa State Highway Commission (largely on the basis of experience) were 6 and 7 in., respectively. The wearing surface was 3 in. of Type B asphaltic concrete constructed in accordance with Article 2304, Iowa State Highway Commission Specifications (12). The surface course was included as an integral part of the soil stabilization field trials only as the base and subbase courses might affect its performance.

Mix.—The soil-cement base and the soil-aggregate subbase mixtures were designed by the Iowa State Highway Commission: the soil-cement by ASTM method D 560-57; the soil-aggregate in accordance with Art. 4118, Provision 41.06, Iowa State Highway Commission Specifications (12). All other mixes were designed by personnel of the Iowa Engineering Experiment Station, based on soil stabilization research using similar soils. Final mixes are given in Table 7 and Figure 2.

CONSTRUCTION

Subbase Course

The general construction and curing procedures used for the subbase sections were as follows:

1. Surface of subgrade was scarified to required depth, then bladed smooth.
2. The stabilizing agent was spread, with the exception of the Arquad 2HT.
3. AP & H single-pass stabilizer was used with the cutter depth established to produce enough processed material for a compacted depth of 6 in. Water was applied through the spray bar of the machine during mixing at a rate which produced standard Proctor optimum moisture content in the mixture. The Arquad 2HT was applied as a water dispersion through the spray bar, bringing the soil to the desired moisture content and chemical concentration.
4. Initial compaction was accomplished with a tamping foot roller.
5. After the tamping foot had walked out of the mixture, a blade grader was used to smooth the surface of the course, after which compaction was done with a Duopactor rubber-tired roller.

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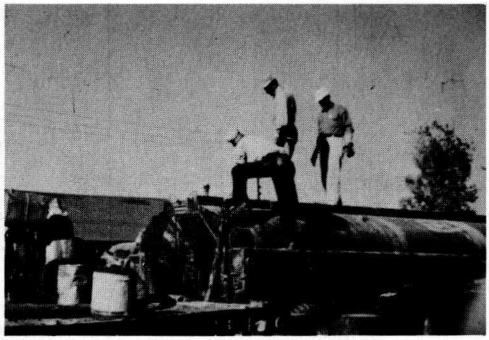

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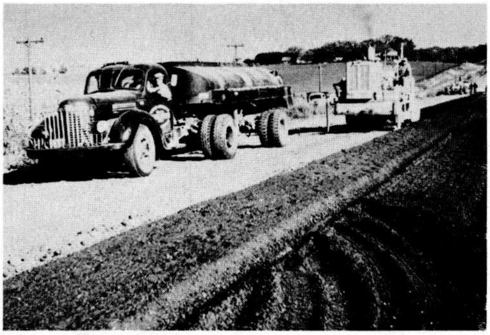

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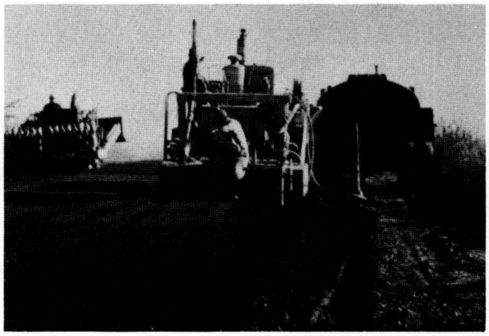

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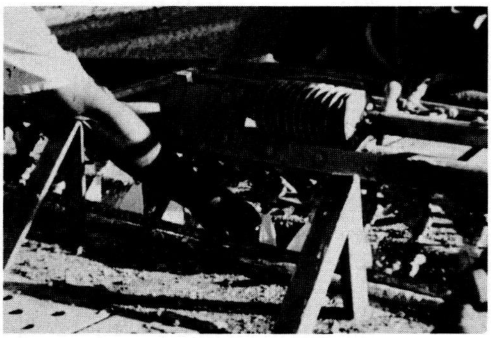

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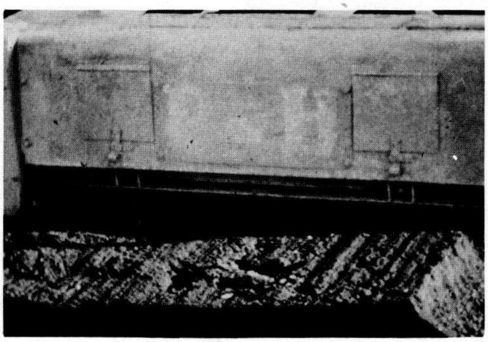

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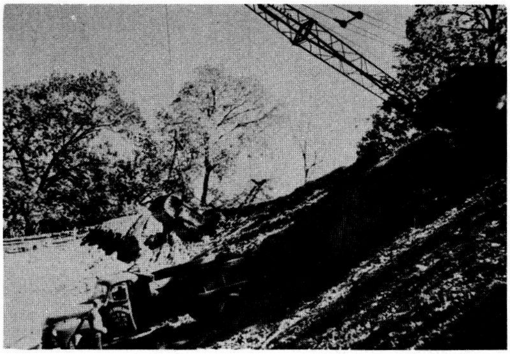
Figure 3. Mixing operations for Arquad 2HT subbase section. (a) Initial mixing of Arquad 2HT in 55-gal drums in which it was received, preparatory to pouring into tank truck. (b) Mixing Arquad 2HT with water in tank truck, using 3-in. centrifugal pump shown at left. (c) Tank truck and P & H single-pass stabilizer. (d) General procedure of mixing subbase materials with stabilizer. (e) Spray bar of stabilizer, showing Arquad 2HT-water dispersion being sprayed into subbase soil for mixing. (f) Tail strike-off of stabilizer, showing mixed material coming out of mixer box.



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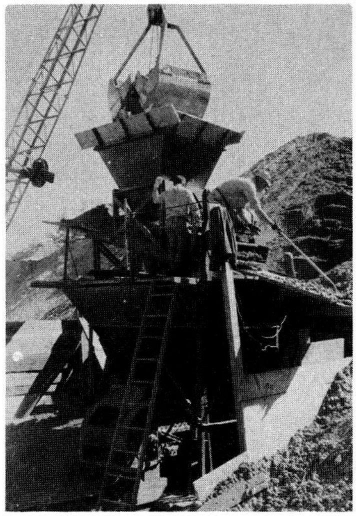

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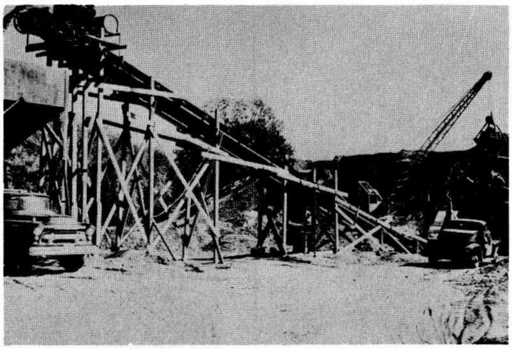

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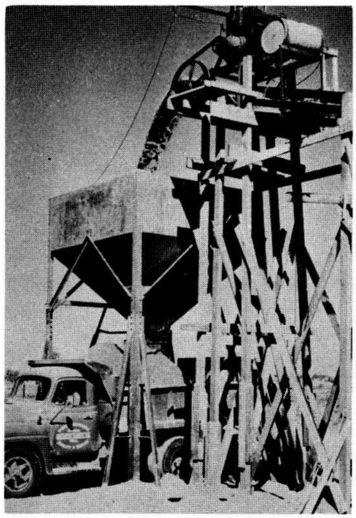

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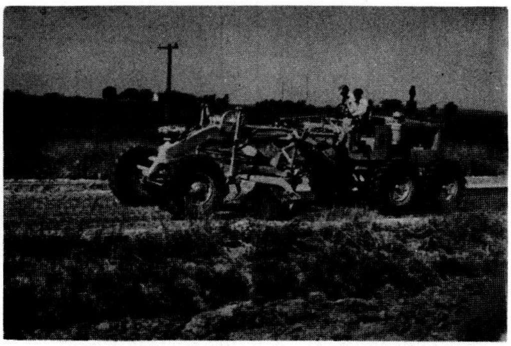

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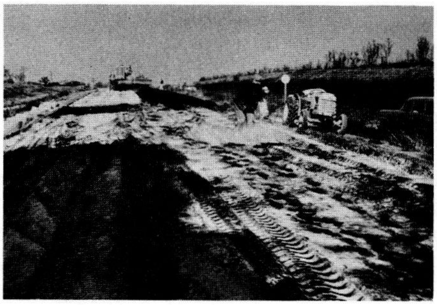
Figure 4. Preparation of sand-loess mixture for base course stabilization. (a) Loess in borrow pit at northeast edge of Colfax, Iowa, being loaded for hauling to mixing plant. (b) Feed hopper: Loess dropped into hopper, screened (to right) to 3/4-in. maximum lump size, and dropped into bottom of hopper containing a calibrated opening for discharge onto belt conveyer for proportioning of loess with sand. Conveyer deposited loess on belt carrying waste sand from pile in background. (c) General view of sand-loess mix plant, showing from right to left waste sand pile, loess hopper and screen, and belt conveyor to storage hopper. (d) Loading sand-loess mix for trucking to construction site. (e) After truck dumping, loess spread by blade grader to desired width and loose thickness before spreading of stabilizing agents.



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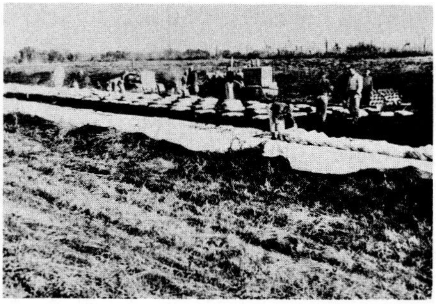

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Figure 5. Soil-lime-fly ash base course construction. (a) Fly ash was truck dumped, then spread by blade to desired width and loose thickness. In sections containing accelerator agents, sodium chloride and sodium carbonate spread on contrasting fly ash to aid uniform distribution. (b) Spotting and opening lime bags in the lime-fly ash section. Spike-tooth harrow drag used to spread transverse rows of lime. (c) Tractor-drawn Seaman Pulvi-mixer mixing 200-ft base section of soil-lime-Cedar Rapids fly ash. All other mixing accomplished with P & H single-pass mixer.

6. The blade grader shaped the course to the desired grade and crown.

7. A wire brush was used to roughen the surface slightly and a light self-propelled rubber-tired roller was used to seal the surface of the course.

8. Each test section was moist cured for 7 days, with the exception of the Arquad 2HT section which was allowed to air-dry for 7 days. Moist curing was accomplished by means of several surface applications of water daily.

One of the problems faced in the field trials was the preparation of the Arquad 2HT water dispersion. In the laboratory, this organic cationic chemical is normally mixed with water heated to approximately 140 F (60 C) to facilitate dispersion of the chemical. Not having a readily available supply of heated water in the field necessitated trying several methods of mixing. Because the quantity of Arquad 2HT used in the field trials was rather small, it was supplied in 55-gal drums. Each drum was given an initial mixing to insure uniformity throughout the depth of the drum. The required quantity of Arquad was then added to each tank truck to produce approximately a 4 percent Arquad concentration in water. This concentration was necessary to give the amount of Arquad desired (0.25 percent by dry soil weight) in the soil-Arquad mixture.

Several methods of mixing the chemical in unheated water in the tank truck were tried. An outboard motor was tried as a stirrer but produced excessive foaming. A compressed air line was next introduced into the tank but again excessive foaming resulted. A 3-in. circulating centrifugal pump was then tried, laying the intake line at the top of the tank and the exhaust at the bottom. This produced a satisfactory dispersion, though some fine particles of undispersed chemical remained, necessitating an occasional cleaning of the filter screen in the pump line of the P & H machine on the job site. Extremely fine air bubbles were also noted in the unheated dispersion which appeared to affect the pressure obtainable from the pump on the P & H machine, necessitating a slower rate of travel with the machine to insure that the proper amount of Arquad 2HT-water dispersion was added to the soil. The air bubbles broke immediately on contact with the soil and did not appear to affect the remainder of the construction procedure or the desired compacted density.

For one tank truck load of chemical dispersion 1,500 gal of water heated to approximately 50 C were obtained. By using a 2-in. pump, integrated to the lower rear of the truck, the dispersion was circulated continuously throughout the tank for a short period, producing excellent homogeneity. No undispersed chemical was noted and no air bubbles appeared. The construction effects noted at the P & H machine when this tank load was sprayed into the soil were extremely good.

The Arquad 2HT section of the subbase contained a rather plastic soil which was not pulverized with the P & H machine as effectively as was thought needed. Consequently, a tractor-drawn Seaman pulvi-mixer was used for further pulverization after the P & H machine had made its pass.

The lime used in the field trials was contained in 50-lb bags. The bags were spotted, opened, and dump-spread in rows transverse to the centerline of the roadway, adjacent rows being approximately 5 ft apart. A spike-tooth harrow was then used to drag-spread the lime uniformly over the surface of the subbase course. Mixing with the in-place soil was then accomplished with the P & H machine. Water added from a tank truck through the spray bars of the P & H machine brought the moisture content of the mix to near the standard Proctor optimum content.

Moistened fly ash was dumped from uncovered trucks, then spread with a blade grader to the required loose thickness and width. The lime was then spotted and opened as previously described. Premixing of the lime and fly ash was done with a spiked-tooth harrow, and final mixing and addition of water was accomplished with the P & H machine.

Base Course

The general construction and curing procedures used for the base course sections were the same as for the subbase, with the following exceptions:

1. The sand-loess mixture was hauled in and dumped according to the required spread for each stabilized section. Following blading to the full width of the base course, the various stabilizing agents were spread on top of it.
2. To provide moist curing, an RC-O cutback asphalt was applied at approximately 0.2 gal per sq yd immediately after final compaction.

The loess for the sand-loess mixture was hauled from the borrow pit to the sand and gravel plant where it was combined with the waste sand. A clam shell bucket loaded the loess into a hopper, from which it was screened and dropped onto a moving belt and delivered to a second belt coming from under the sand pile. The relative speeds of the two belts were adjusted to proportion the sand-loess mixture properly. The mix was then carried to a hopper from which it was dumped into trucks for transportation to the job site.

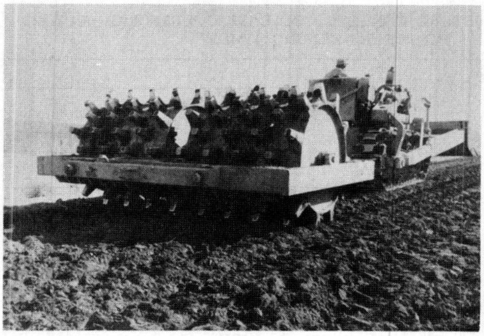
The lime-fly ash base course sections containing the two activating agents required an additional step from that previously described. After the fly ash had been spread, the sodium carbonate or the sodium chloride additive was spread uniformly over it; the former by a hand-seeding method, the latter by a whirlwind seeder. The contrast between the white color of the activators and the black fly ash facilitated uniform spreading.

The last 700 ft of fly ash construction, immediately north of the soil-cement section and including the 500 ft of Chicago fly ash (Fig. 2), was "dry" mixed with the tractor-drawn Seaman pulvi-mixer, after which the desired quantity of water was sprayed on the surface of the mixture from a tank truck equipped with pump and spray bar. Final mixing was done with the Seaman machine.

Mixing, compaction, and finishing procedures used for the 3,300 ft of soil-cement base were the same as in the lime and fly ash base course sections. However, the portland cement was spread with a conventional cement spreader.

General Remarks

Though it was originally thought that the experimental sections would be constructed in June or July, construction did not begin on the subbase sections until September 30, 1957. The final base course section was laid on November 1. In Iowa this is not a satisfactory time of year to obtain proper curing.



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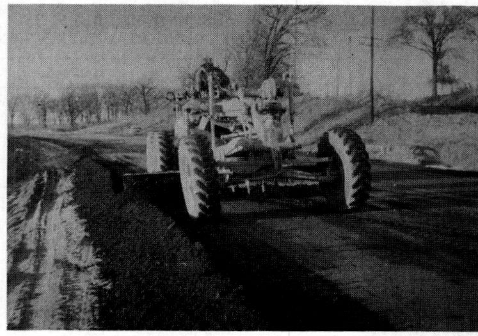

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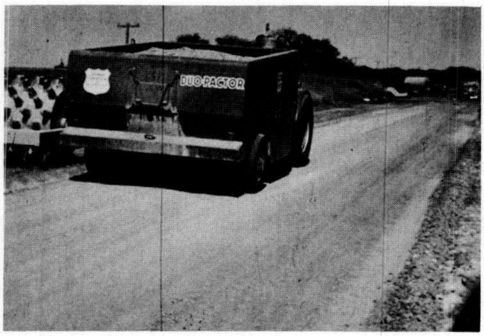

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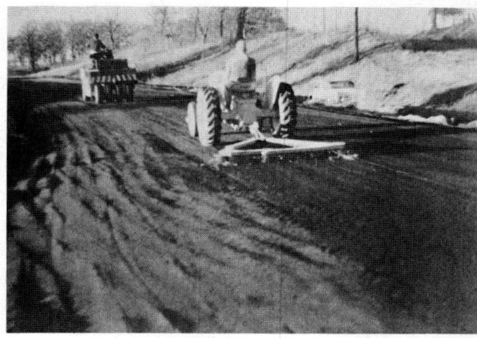

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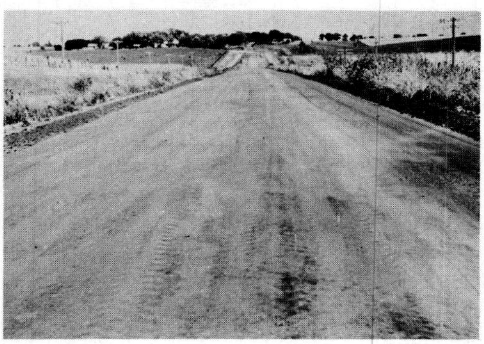

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f

Figure 6. Compaction and finishing operations. (a) Tamping foot roller used for initial compaction. (b) Blade grader used to shape moderately cross-section before final compaction. (c) Final compaction accomplished by Duo-Packer rubber-tired roller. (d) After final blading to grade and cross-section, surface of course broom-dragged, then rolled by light rubber-tired roller. (e) Finished subbase course, looking north. In foreground, Arquad 2HT section, followed by lime section, and lime-fly ash section. (f) Finished lime-fly ash base course, looking south across soil-lime-Cedar Rapids fly ash-sodium carbonate base section.

TABLE 8

UNCONFINED COMPRESSIVE STRENGTHS, DENSITIES, AND MOISTURE CONTENTS OF BASE COURSE LABORATORY- AND FIELD-MIXED STABILIZED SPECIMENS AT DIFFERENT CURING TIMES[a]

Stabilizing Agent[b]	Curing Time (days)	Lab Mixed, Lab Molded: Avg. Unconf. Compr Str. (psi)	Lab Mixed, Lab Molded: Dry Density[c] (pcf)	Field Mixed, Lab Molded: Avg. Unconf. Compr. Str. (psi)	Field Mixed, Lab Molded: Dry Density[c] (pcf)	Field Mixed, Lab Molded: Moist. Content[c] (% by dry wt.)
8% Type I	14	---	---	420	---	7.3
portland cement	26	---	---	550	---	6.2
	45	---	---	655	---	5.3
	183	---	---	834	---	4.0
	365	---	---	720	---	6.5
3% monohydrate	7	115	102.2	---	---	---
dolomitic lime, 21% Cedar	14	180	99.9	---	---	---
Rapids fly ash	17	---	---	195	123.2	13 8
	28	273	99 7	294	116.8	---
	45	---	---	545	109.4	18.5
	48	329	99 8	---	---	---
	60	231	---	---	---	---
	61	---	---	582	108.4	9.0
	183	166	---	605	---	6.2
	365	---	---	365	---	14.7
3% monohydrate	14	351	115 9	---	---	---
dolomitic lime,	17	---	---	609	117 9	8.5
21% Chicago fly ash,	28	383	115.5	878	117 0	8 5
0.5% sodium carbonate	45	488	117.7	1,320	116.7	6 3
	61	---	---	1,480	---	---
	183	---	---	1,710	---	3.8
	365	---	---	1,240	---	11 3
3% monohydrate dolomitic	7	77	109.3	163	112.8	15 6
lime, 21% Cedar Rapids	14	150	---	---	---	---
fly ash, 0 5% sodium	27	---	109.0	354	112.8	14 8
chloride	28	275	---	---	---	---
	45	274	110 0	420	113.8	10.2
	60	319	110.5	480	113.0	11 8
	183	---	---	512	---	5.0
	365	---	---	519	---	15.5
3% monohydrate dolomitic	7	---	---	170	---	13 5
lime, 21% Cedar Rapids	28	---	---	235	---	12 8
fly ash, 0.5% sodium	45	---	---	315	---	10 3
carbonate	60	---	---	360	---	6.2
	183	---	---	497	---	3 5
	365	---	---	220	---	21 2
	7	---	---	125	---	14 5
3% monohydrate dolomitic	28	---	---	238	---	12 8
lime, 21% Cedar Rapids	45	---	---	370	---	10.3
fly ash	61	---	---	440	---	7 0
	183	---	---	491	---	4 0
	365	---	---	409	---	16 5

[a]Laboratory specimens mixed and molded using representative sand-loess mix soil material and stabilizing agents Field specimens were molded from representative samples obtained immediately following construction mixing of sand-loess mix soil material and stabilizing agents. In each case 2-in. diameter by 2-in. high specimens were molded to near standard Proctor density, wrapped and sealed in waxed paper, and cured in a humidity cabinet for indicated periods at 70 F and near 100 percent relative humidity, molding and curing conditions approximately the same for lab- and field-mixed specimens.
[b]See Figure 2 for layout of experimental base course sections.
[c]At time of test.

The construction methods adopted for the test sections were the most effective means for the short sections involved and the consequent small quantities of materials used. Soil stabilization projects of larger scope might necessitate employing methods of construction other than those used on this project. For example, lime could be spread by a conventional cement or bulk spreader rather than from 50-lb bags. Figures 3, 4, 5, and 6 show the various phases of construction and the equipment used.

EVALUATION OF PERFORMANCE

Preliminary studies of the performance of the test sections cover the period from time of construction through January 1961, slightly over three years.

TABLE 9

UNCONFINED COMPRESSIVE STRENGTHS, DENSITIES, AND MOISTURE CONTENTS OF SUBBASE COURSE LABORATORY- AND FIELD-MIXED STABILIZED SPECIMENS AT DIFFERENT CURING TIMES[a]

Stabilizing Agent[b]	Curing Time (days)	Lab Mixed, Lab Molded: Avg. Unconf. Compr. Str. (psi)	Lab Mixed, Lab Molded: Dry Density[c] (pcf)	Lab Mixed, Lab Molded: Moist. Cont.[c] (% dry wt.)	Field Mixed, Lab Molded: Avg. Unconf. Compr. Str. (psi)	Field Mixed, Lab Molded: Dry Density[c] (pcf)	Field Mixed, Lab Molded: Moist. Cont.[c] (% dry wt.)
0.25% Arquad 2HT	7	220	109.3	4.3	---	---	---
	9	---	---	---	309	109.8	6.4
	14	300	---	3.6	---	---	---
	28	307	108.6	3.2	---	---	---
	30	---	---	---	435	110.2	3.5
	60	---	---	---	520	109.2	2.2
	63	216	108.0	2.9	---	---	---
	183	211	---	---	412	---	2.4
	365	---	---	---	372	---	3.4
6% monohydrate dolomitic lime	7	86	123.2	---	---	---	---
	10	---	---	---	69	121.6	---
	14	141	122.4	---	---	---	---
	28	188	---	---	---	---	---
	31	---	---	---	140	122.0	---
	60	228	121.7	---	---	---	---
	61	---	---	---	125	119.5	---
	183	141	---	---	261	---	---
	365	---	---	---	45	---	---
3% monohydrate dolomitic lime, 21% Cedar Rapids fly ash	7	52	104.9	21.0	---	---	---
	11	---	---	---	109	105.4	23.1
	14	61	107.2	20.5	---	---	---
	28	112	105.7	20.4	---	---	---
	32	---	---	---	116	117.5	23.0
	60	137	---	19.5	---	---	---
	62	---	---	---	137	111.4	22.8
	183	169	---	---	149	---	10.3
	365	---	---	---	100	---	20.5

[a]Laboratory specimens mixed and molded using representative in-place subbase materials and stabilizing agents Field specimens were molded from representative samples obtained immediately following construction mixing of in-place soil material and stabilizing agent. In each case, 4.0-in. diameter by 4.6-in high specimens were molded to standard Proctor density, wrapped and sealed in waxed paper, and cured in a humidity cabinet (Arquad 2HT specimens were not sealed and were air dried) for the indicated periods at 70 F and near 100 percent relative humidity, molding and curing conditions were approximately the same for lab- and field-mixed specimens

[b]See Figure 2 for layout of experimental subbase course sections.

[c]At time of test.

Laboratory Studies

Before construction, representative soil samples were removed from the base and subbase materials for laboratory mixing and molding of specimens containing the various stabilizing agents. During construction, immediately after mixing had been completed, samples of the soil-stabilizing agent mixture were taken from each major test section at the same locations represented by the laboratory-mixed samples, and were field-laboratory molded for subsequent testing. Compactive energy of molding was at standard Proctor density for all specimens. All base course materials were molded in 2-in. diameter by 2-in. high cylinders (18), whereas all subbase materials were molded in 4-in. diameter by 4.6-in. high cylinders (standard Proctor size). All specimens given moist curing were wrapped in waxed paper, sealed, and cured in a humid room at near 100 percent relative humidity and 70 F. The Arquad 2HT treated specimens were air cured.

Following curing, all molded specimens were tested to failure in unconfined compression (18). Average strengths of six or more specimens of mixtures from each stabilized section were determined for each curing period up to one year. The moisture content of each tested specimen was determined for comparison with the strength value obtained.

After three years of service, two 4-in. diameter core specimens were removed from the same locations in the base and subbase sections represented by the molded specimens. Each core was wrapped and sealed in waxed paper immediately after removal from the pavement and was stored in a humid room at near 100 percent relative humidity and 70 F until cut with a diamond saw to 4.6-in. height (Proctor size).

TABLE 10

AVERAGE UNCONFINED COMPRESSIVE STRENGTH AND MOISTURE CONTENT OF TWO OR MORE CORE SPECIMENS REMOVED FROM BASE AND SUBBASE COURSES, NOVEMBER 1960 (AGE OF TEST SECTION 3 YEARS)[a]

Course	Specimen	Station	Compr. Str.	Avg. Moist. Cont.[b] (% dry wt. of mix)
Base	Sand-loess mix, plus:			
	8% Type I portland cement	193+50	1,185	8.7
		198+50	1,670	8.5
		206+50	1,715	9.3
		212+50	2,263	7.7
		217+50	2,070	7.4
	3% monohydrate dolomitic lime, 21% Chicago fly ash, 0.5% sodium carbonate	227+50	1,840	9.4
	3% monohydrate dolomitic lime, 21% Cedar Rapids fly ash, 0.5% sodium chloride	232+50	690	29.8
	3% monohydrate dolomitic lime, 21% Cedar Rapids fly ash, 0.5% sodium carbonate	242+50	650	14.1
	3% monohydrate dolomitic lime, 21% Cedar Rapids fly ash	247+50	1,056	0.2
Subbase	In-place soil[c], plus 3% monohydrate dolomitic lime, 21% Cedar Rapids fly ash	212+50	668	25.4

[a]Core drilling accomplished by 4.0-in. inside diameter diamond bit core drill. One core removed from each traffic lane at locations indicated. Each specimen cut by diamond saw to 4.6-in. height and tested for unconfined compressive strength. Following testing, moisture content determined on duplicate samples from each specimen.

[b]At time of testing.

[c]Core specimens unattainable from lime and Arquad 2HT subbase sections though hard, lime subbase would not resist torsional effects of core bit, due to type of stabilizing agent, no cores anticipated from Arquad 2HT subbase section.

Unconfined compressive strengths and moisture contents of the core specimens were determined in the same manner as for the laboratory or field mixed, molded specimens.

Mixing.—The efficiency of field proportioning and mixing in base and subbase sections can be qualitatively evaluated by comparing the data on unconfined compressive strengths of field mixed, laboratory-molded specimens, and laboratory-mixed, laboratory-molded specimens given in Tables 8 and 9. Tables 8 and 9 also include some data on the densities and moisture contents of specimens at the times of testing.

Although the data are incomplete, a noticeable observance is that the strengths of field-mixed specimens exceeded the strengths of the comparable laboratory-mixed specimens with the exception of the specimens from the lime subbase. Because lab mixing is normally more efficient than field mixing, this relationship may be due to the higher density of the field mixed specimens. The field mixed specimens of the soil-lime subbase section generally had lower strength and density than the lab-mixed specimens.

The average 365-day cured strength of several of the mixes given in Tables 8 and 9 indicates a decrease from that at 183 days. This is believed to be due to the increase in moisture shown. During the last 60 to 90 days of curing, the waxed paper wrapping on specimens began to deteriorate allowing the specimens to absorb moisture from the humid air before this condition was discovered and the specimens were rewrapped.

In general, field proportioning and mixing appears to have been comparable to or even better than that done in the laboratory.

Carbon Content.—The superior strength values of the soil-lime-fly ash-activator specimens obtained with the low carbon content Chicago fly ash, as compared to strengths obtained with the high carbon Cedar Rapids fly ash, demonstrate the deleterious effect of high carbon content (Tables 8 and 10).

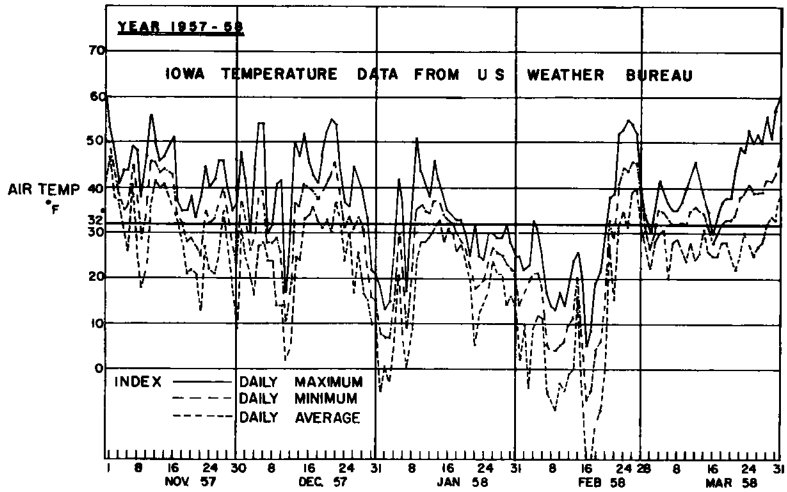


Figure 7. Winter 1957-58 temperature data compiled from U.S. Weather Bureau information.

Core Specimens.—Table 10 gives the unconfined compressive strength and moisture content data for the core specimens removed from experimental sections approximately 3 years after construction. (Removal of core specimens was attempted in April 1958, approximately 6 months following construction of the sections. With the exception of the soil-cement section, the remainder of the soil-stabilizing agent mixtures though hard and dense, would not withstand the torsional effect of the diamond core bit due to incomplete curing.) In comparing like sections, varying strength values seem to correspond directly with the moisture content of the cores. The lime-Cedar Rapids fly ash sections appeared the most adversely affected by the presence of high moisture. The increase in moisture above that at the time of construction was probably due to capillary moisture absorption from a high water table and/or infiltration of surface water.

The average moisture content in the soil-lime-fly ash sections was considerably higher than in the soil-cement base section, perhaps illustrating the relative permeability to moisture, or water-holding capacity, of these materials. However, the strengths of even the high moisture content specimens are indicative of high-bearing capacity-stabilized soil materials.

Visual inspection of core holes and specimens revealed close to design thicknesses and excellent contact between all courses of the pavement structure.

Inspection of cores taken to study surface cracks in the soil-cement and soil-lime-fly ash base and subbase sections, revealed that in some cases the cracks extended through the pavement structure to the subgrade. In two instances, the cores had broken normal to the vertical crack during drilling, revealing imprints of tamping foot roller teeth. The indentations had apparently provided planes of slight weakness which were not removed during construction by scratching the base with a spike-tooth harrow after each pass of the roller. Other cored cracks revealed from ½- to about 1½-in. thicknesses of soil material which had not been mixed with the stabilizing agent to the full, loose depth during construction. Although these conditions existed to a minor degree, and in general mixing was found to be efficient as well as effective, the importance of proper construction techniques cannot be overemphasized.

Curing

Time is required for lime and fly ash to react pozzolanically. The rate of reaction and hardening also depends on temperature, though the exact relationship has not been determined. The reaction most likely stops with temperatures at or below freezing (7).

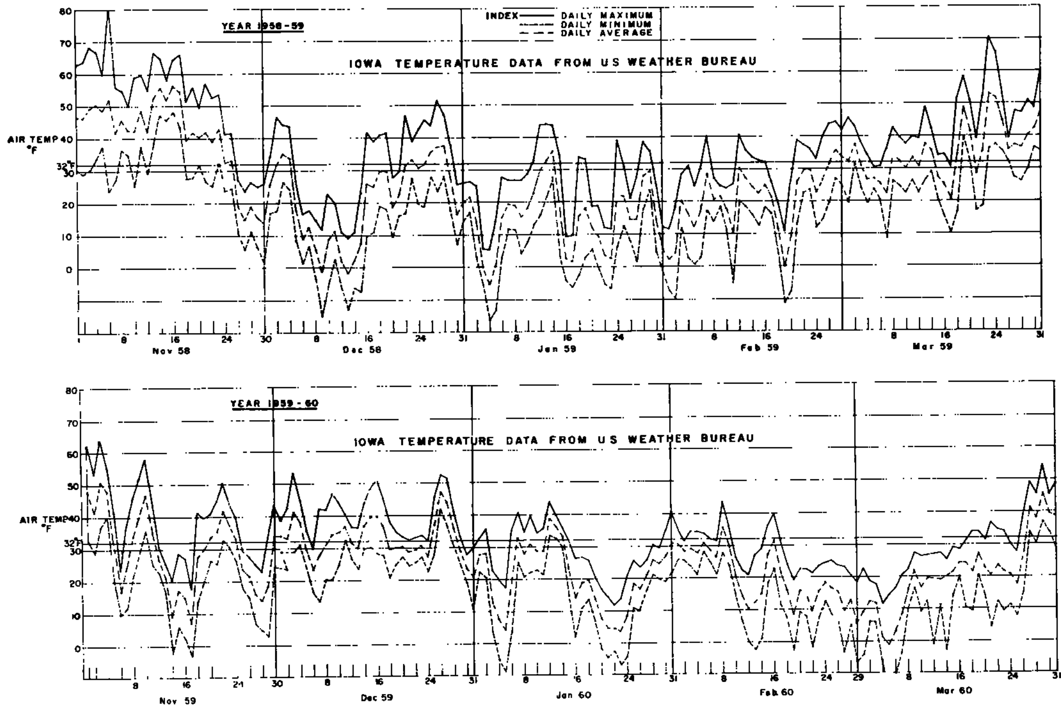


Figure 8. Winters 1958-59 and 1959-60 temperature data compiled from U. S. Weather Bureau information.

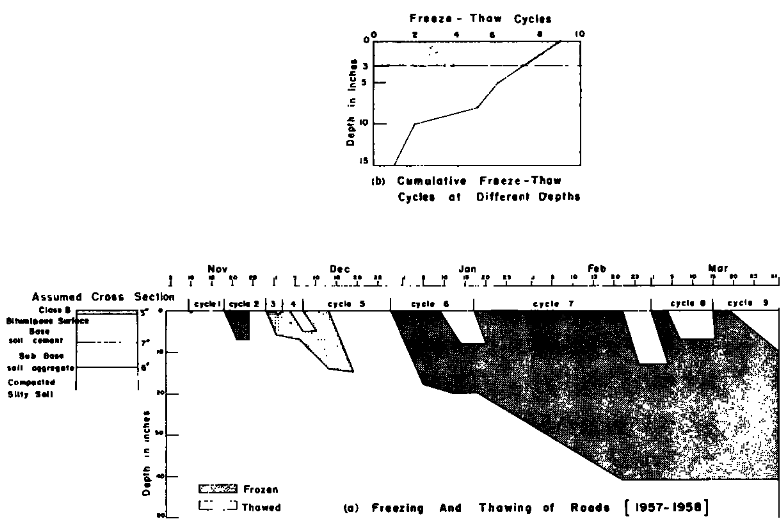


Figure 9. Winter 1957-58 computed freeze-thaw cycles.

At Colfax, the time from completion of the base course to the first freeze was about 6 days (Fig. 7). Except for several very brief intermittent periods, the average air temperature did not rise above freezing until mid-February 1958. Figure 8 shows the air temperatures to which the road was subjected during the winters of 1958-59 and 1959-60. Figures 9, 10, and 11 show the number of freeze-thaw cycles and depth of

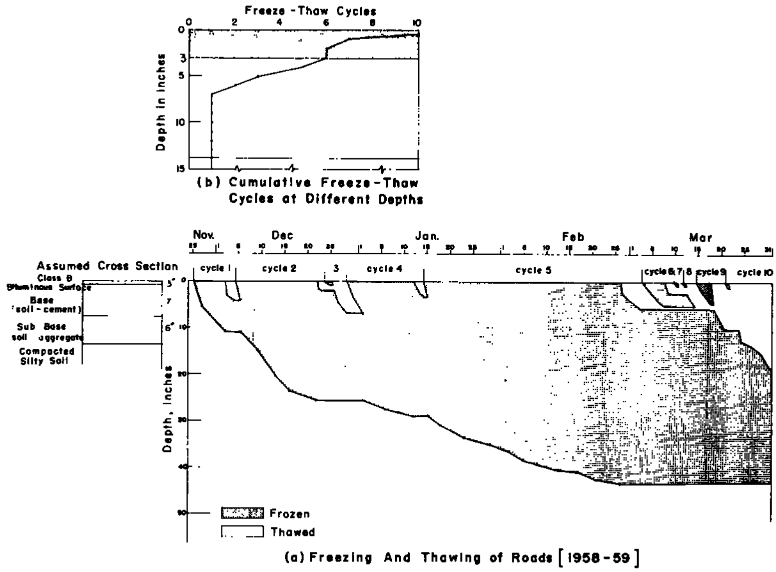


Figure 10. Winter 1958-59 computed freeze-thaw cycles.

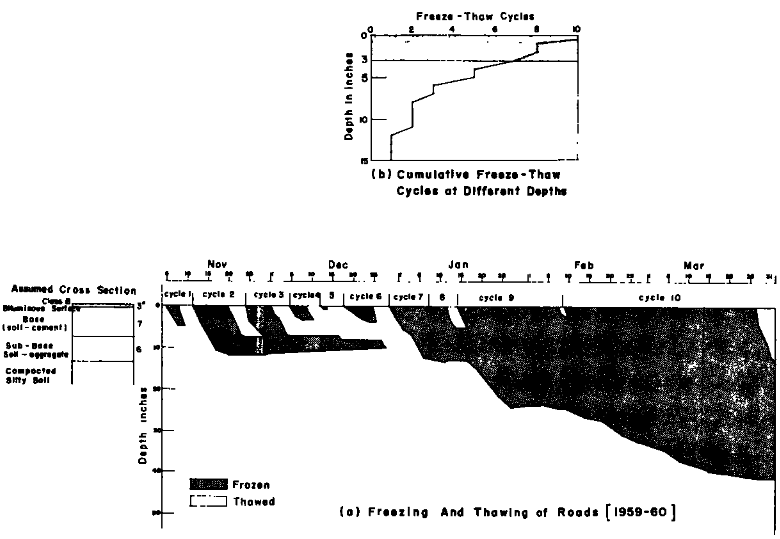


Figure 11. Winter 1959-60 computed freeze-thaw cycles.

freezing calculated for the assumed pavement using the temperature data shown in Figures 7 and 8, and the modified Berggren formula (1); these computations were considered sufficiently accurate for a qualitative analysis of the number of freeze-thaw cycles to which the test sections were subjected.

The qualitative effect of freezing on field curing can be estimated by a comparison of the unconfined compressive strengths of 6-mo and 1-yr laboratory-cured specimens molded from field mixes, to the strengths of the 3-yr field-cured core specimens from each test section (Tables 8, 9, and 10). In each case, core strength greatly exceeded laboratory-cured specimen strength, indicating that field curing of the pavement mixes continued over the 3-yr period even though interrupted by winter freezing.

TABLE 11

PAVEMENT[a] ROUGHNESS MEASUREMENTS[b]

Item	Section No.	Length (mi)	Run 1 Roughness (in. /mi)	Run 2 Roughness (in. /mi)
Terminus:				
Colfax RR tracks	1	1.00	71	72
	2	1.00	67	68
Approx. south end of test portion of hwy	3	1.00	58	72
Approx. north end of test portion of hwy	4	1.00	59	71
	5	1.00	55	60
	6	1.00	63	65
	7	1.00	61	70
	8	1.00	64	66
	9	1.00	66	67
	10	1.00	65	64
Jct. Iowa 64	11	0.98	63	68
Miles measured, total		10.98		
Average roughness				
Run			63	68
Test portion of pavement			65.00	
Regular pavement			65.26	

[a]May 9, 1958, from Colfax, Iowa, north to junction of Iowa 64 and Primary Highway 117.
[b]Information furnished by Iowa State Highway Commission.

During the winter of 1957-58 only a leveling course (1½ in. thick) of asphaltic concrete protected the experimental sections from traffic abrasion. This deficiency, coupled with the lack of cured strength in all the soil-lime-fly ash sections, was the cause of some isolated surface "alligator" cracking during the spring thaw of 1958. The most severe cracking occurred in the east lane of the soil-lime-Cedar Rapids fly ash-sodium carbonate base, approximately between stations 240+00 and 241+05. Before application of the additional 1½ in. of asphaltic concrete, the damaged areas of asphaltic concrete, were removed. Inspection revealed the base, in all cases to be free of cracks and in excellent condition, though in need of additional curing. The areas were resurfaced without further base treatment and no further difficulties have been observed.

TABLE 12

ROUGHNESS CRITERIA[a]

Roughness Index (in. /mi.)	Riding Quality
Old pavements:	
Below 60	Excellent
60-74	Good
75-90	Fair
91-150	Poor (possible resurfacing)
Above 150	Very poor (resurfacing required)
New pavements:	
Below 75	Good (acceptable)
75-90	Fair (acceptable)
Above 90	Poor (not acceptable)

[a]From Holloway (10).

Pavement Roughness

The Iowa State Highway Commission measured pavement roughness with a roughometer during May 1958 (Table 11). The roughometer is a device which, when towed over a paved surface, is assumed to stay in a relatively fixed plane due to its own inertia. Changes in elevation are measured by means of a floating wheel which follows the paved surface and deviates from the machine proper (19). Values of pavement roughness obtained are relative, therefore, it is necessary to correlate them with known surface behavior. Table 12 gives roughness criteria suggested by Holloway (10).

A comparison of data in Tables 11 and 12 indicates that the riding quality of all sections of the road would be classified as "good." The 65.00 mean inches of measured roughness per mile within the test

TABLE 13

RESULTS OF SURFACE CRACK STUDY OF VARIOUS EXPERIMENTAL SUBBASE AND BASE COURSE SECTIONS, AND 2,300 FT OF REGULARLY DESIGNED NON-EXPERIMENTAL 7-IN. SOIL-CEMENT BASE OVER 6-IN. SOIL-AGGREGATE SUBBASE

Surface Crack		Surface Cracking per 100 Lineal Feet of Pavement (ft)																	
		Subbase Sections						Base Sections											
Location	Class[a]	0.25% Arquad 2HT		6% Lime[b]		3% Lime[b] 21% Fly Ash[c]		3% Lime[b] 21% Fly Ash[c]		3% Lime[b] 21% Fly Ash[d] 0.5% Na_2CO_3		3% Lime[b] 21% Fly Ash[c] 0.5% NaCl		3% Lime[b] 21% Fly Ash[c] 0.5% Na_2CO_3		3% Lime[b] 21% Fly Ash[c]		Non-Experimental Section[e]	
		1959	1960	1959	1960	1959	1960	1959	1960	1959	1960	1959	1960	1959	1960	1959	1960	1959	1960
Longitudinal																			
Outside edge[f]	1	37.3	74.5	42.8	50.0	13.0	34.0	10.0	0.0	8.0	12.0	6.0	3.6	0.0	10.0	0.0	6.0	33.6	22.7
	2	1.2	40.0	15.7	50.0	0.0	9.0	35.0	95.0	0.0	40.0	2.8	10.8	2.0	14.0	0.0	0.0	3.6	1.0
	3	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Center of lane[g]	1	0.0	10.8	4.3	0.0	5.0	2.0	0.0	0.0	4.0	0.0	1.4	2.6	0.0	5.0	0.0	0.0	21.8	9.1
	2	0.0	1.9	0.0	5.7	4.0	23.0	0.0	0.0	0.0	18.0	0.0	1.4	0.0	0.0	0.0	0.0	36.3	35.4
	3	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2
Centerline[h]	1	4.6	29.6	37.2	11.4	11.0	13.0	0.0	0.0	0.0	0.0	2.2	5.0	0.0	3.0	0.0	0.0	37.3	42.7
	2	0.0	11.2	0.0	5.6	0.0	11.0	0.0	15.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	14.6	23.6
	3	0.0	2.3	0.0	0.0	0.0	4.0	0.0	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.3
Transverse	1	7.2	0.6	15.7	0.3	16.8	0.0	29.0	0.0	51.6	0.8	48.8	0.0	21.2	0.0	18.4	1.6	24.0	65.3
	2	59.5	69.1	54.8	10.6	44.4	1.4	67.0	11.0	30.0	36.8	21.6	49.0	39.6	18.4	51.6	20.4	54.3	24.0
	3	0.0	6.0	2.3	62.8	0.0	60.2	0.0	87.0	0.0	44.8	0.0	26.5	0.0	44.8	9.6	79.6	4.4	52.1

[a]All pavement surface cracks plotted on a scaled sketch of sections noted. Class indicates width of crack 1 = 0-1/8 in., 2 = 0-1/4 (with some raveling, 3 = 0-1/2 (with definite raveling).
[b]Monohydrate dolomitic type.
[c]Cedar Rapids fly ash.
[d]Chicago fly ash.
[e]Regularly designed 7-in. soil-cement base over 6-in. soil-aggregate subbase, 2,300 ft long, immediately adjacent to north end of experimental sections and including both cut and fill subgrade conditions.
[f]Outside edge indicates 0 to 3 ft from edge of each lane.
[g]Center of lane indicates 3 to 10 ft from pavement edge.
[h]Centerline indicates a strip 1 ft on each side of centerline.

TABLE 14

SUMMARY OF CRACK STUDY

Agent	Section (ft)	Total Length of Cracking (ft/100 lin ft of pavement)					
		Longitudinal			Transverse		
		April 1959	Dec. 1960	Increase	April 1959	Dec. 1960	Increase
Subbase-stabilizing							
0.25% Arquad 2HT	1,300	43.1	170.2	127.1	66.7	75.7	9.0
6% lime	700	100.0	132.7	32.7	72.8	73.6	0.8
3% lime, 21% Cedar Rapids fly ash	1,000	33.0	99.0	66.0	61.2	61.6	0.4
Base-stabilizing							
3% lime, 21% Cedar Rapids fly ash	200	45.0	110.0	65.0	96.0	98.0	2.0
3% lime, 21% Chicago fly ash, 0 5% Na_2CO_3	500	12.0	70.0	58.0	81.6	82.4	0.2
3% lime, 21% Cedar Rapids fly ash, 0 5% NaCl	1,000	12.4	29.8	17.4	70.4	75.5	5.1
3% lime, 21% Cedar Rapids fly ash, 0 5% Na_2CO_3	500	2.0	32.0	30.0	60 8	63.2	2.4
3% lime, 21% Cedar Rapids fly ash	500	0.0	6.0	6.0	79.6	101.6	22.0
Typical non-experimental section[a]	2,300	147.2	176.0	28.8	82.7	141.4	58.7

[a]Includes cut and fill

sections compares favorably to the 65.26 mean inches of measured roughness for the portions of the road outside the test area.

Surface Crack Studies

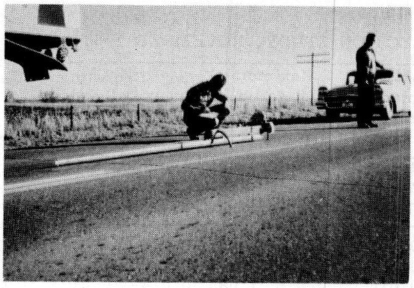
Two studies of pavement surface cracking were made on the experimental portions of the highway and on 2,300 ft of regularly designed pavement immediately north of the experimental sections. These studies were conducted during April 1959 and December 1960 as a means of measuring the comparative performance of the experimental pavement with that of the regularly designed pavement, and also as a means of evaluating possible pavement structural failure.

From visual examination and measurement the class and length of surface cracking in each test section was determined, differentiating between transverse and longitudinal cracks. Three designations were employed to classify the cracks by width: Class 1, 0 to ⅛ in.; Class 2, 0 to ¼ in. (with some raveling); and Class 3, 0 to ½ in. (with definite or pronounced raveling).

Table 13 gives a breakdown of the surface cracking according to the three classes, for both studies, and Table 14 gives a summary of the total cracking per each experimental section, and the increase in development of cracks over the 1½ years between studies.

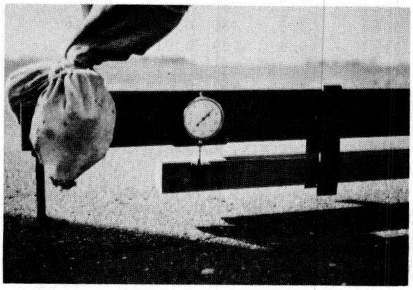
Comparison of the two studies, indicates increased longitudinal and transverse cracking in all surface areas of the experimental portion of the highway since the first study in April 1959. Comparison of the subbase test sections (overlain by the regularly designed soil-cement base) indicates surface cracking over the lime-fly ash portion was less than the surface cracking over either the Arquad 2HT or the lime-stabilized portions. The largest increase in total longitudinal cracking occurred in the surface over the Arquad 2HT-stabilized section, whereas the largest increase in total transverse cracking occurred in the surface of the regularly designed pavement. The greatest total surface cracking (that is, both longitudinal and transverse) as of December 1960 was in the regularly designed portion of the pavement north of the experimental sections.

Comparison of the soil-lime-fly ash-stabilized base sections indicates the least total



a

b



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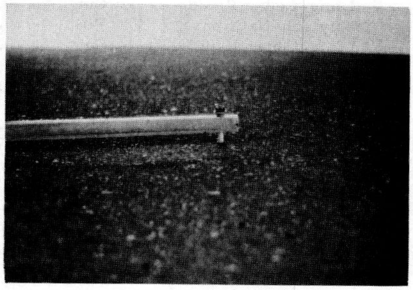

d

Figure 12. Benkelman beam deflection test. (a) Side view of beam. Deflection reading being taken with left rear dual of test truck at point 5 ft in front of probe of beam. (b) Zero reading being taken for outside wheel track. Beam placed between dual wheels of test truck having a rear axle load of 17,280 lb. (c) Rear view of beam showing extensiometer for determining deflections, and bag of lead weights for stabilizing beam carriage. (d) Probe of beam placed in direct contact with surface after surface is brushed free of loose material.

surface cracking in the sections where the Cedar Rapids, high carbon content, fly ash was used.

Some transverse and longitudinal cracking is to be expected in soil-cement, and to a more limited extent, in soil-lime fly ash if enough hardness is attained. The reasons are not yet completely known. Thermal expansion and contraction affect the width of cracks (widest in winter) whereas some cracking can be created by uneven settlement and/or shrinkage and swelling of subgrade materials. Soil-cement cracks are not regarded as failures unless structural evidence of failure can be attributed to the cracks (13). The principle objection to cracks is their reflection through a bituminous surface.

Some longitudinal cracking near the outside edges of the pavement was caused by heavy construction equipment, particularly scoops, which rode the pavement edges during shoulder construction in the spring of 1958. The overloading of the outside edges apparently caused shear and/or flexural failures, particularly along the slower curing portions of the experimental sections.

Lack of surface crack maintenance has undoubtedly permitted surface moisture to penetrate into and weaken the total pavement structure. However, an over-all observation of the test areas and the adjoining regularly designed roadway is that cracking is generally less in the test sections.

Flexural Strength Analysis

To analyze the flexural strength of the experimental sections, a Benkelman beam (2) was used to measure deflections induced by a 17,280-lb single rear-axle load of an Iowa

TABLE 15

RESULTS OF BENKLEMAN BEAM DEFLECTION STUDY, NOVEMBER 1960[a]

General Test Section[b]	General Subgrade Condition	Avg. Max. Benkelman Beam Deflection[c] (in.)		Maximum Relative Stiffness[d] (kips/in.)		Avg. Benkelman Beam Deflection 5 Ft Ahead of Probe (in.)	
		Outside Wheel Track	Inside Wheel Track	Outside Wheel Track	Inside Wheel Track	Outside Wheel Track	Inside Wheel Track
Arquad 2HT subbase	Cut	0.039	0.026	443	665	0 022	0.019
	Fill	0.029	0.022	596	785	0 016	0.012
Lime subbase	Fill	0.017	0.016	1,016	1,080	0 014	0.011
Lime-Cedar Rapids fly ash subbase	Cut	0.031	0.027	557	640	0.022	0.017
Lime-Chicago fly ash-Na_2CO_3 base	Cut	0.028	0.024	617	720	0.010	0.011
Lime-Cedar Rapids fly ash-NaCl base	Cut	0.028	0.022	617	785	0.008	0 006
	Fill	0.052	0.036	332	480	0.022	0.016
Lime-Cedar Rapids fly ash-Na_2CO_3 base	Cut	0 033	0.019	524	909	0.012	0.007
Lime-Cedar Rapids fly ash base	Cut	0.039	0.028	443	617	0.014	0 010

[a]Rear single-axle load of test truck, 17,280 lb, tire air pressure, 75 psi, tire contact pressure outside wheel track 79.4 psi, inside wheel track, 77.6 psi.
[b]See Figure 2 for detailed test section layout.
[c]Average of minimum of two deflection tests per wheel track, per traffic lane, per subgrade condition in each test section.
[d]Load divided by average deflection.

State Highway Commission test truck (Fig. 12). Because the maximum allowable single-axle in Iowa is 18,000 lb, deflections thus found were near maximum values.

With the rear duals of the test truck placed so that loading in each traffic lane occurred at points 2 and 9 ft from the pavement edge, the beam was placed between each rear dual wheel, in turn. Three readings were observed and recorded for the inside and outside wheel tracks at each of the following locations: at the point of placement (zero reading) at maximum deflection as the truck moved slowly ahead past the probe and at the point when the rear axle of the truck reached 5 ft in front of the beam probe. The deflection for each location was taken as twice the mean of the maximum reading minus the zero reading of each wheel track, because the deflection shown by the extensiometer is one-half the actual deflection. Air and pavement surface temperatures were recorded for each station; however, due to an overcast sky, temperature variance during the entire test operation was negligible, showing an average surface temperature of 60 F.

Table 15 gives the results of the Benkelman beam deflection studies as conducted in early November 1960. As expected, the outside edges showed the greatest deflection; that of the soil-lime-Cedar Rapids fly ash-NaCl section over fill showed an average maximum deflection of 0.052 in. A limiting deflection of 0.2 in. has been selected by the Navy Department for use in the design of flexible pavements (19). As a qualitative measure of the flexibility of an experimental section, a relative stiffness factor was computed by dividing the axle load by the maximum deflection; the more flexible the material, the lower the relative stiffness factor. Using the axle load of the test truck (17,280 lb), the maximum relative stiffness for the Navy Department design criteria (19) would be

TABLE 16

AVERAGE ATTERBERG LIMITS[a] OF SUBGRADE AND ARQUAD 2HT-TREATED SUBBASE SOILS SAMPLED OVER 3 YEARS FOLLOWING CONSTRUCTION

Arquad 2HT Additive (%)	Atterberg Limit (%) Liquid Limit	Plastic Limit	Plasticity Index
0.00 (subgrade)	45.6	21.1	24.5
0.25 (subbase)	38.9	22.5	16.4

[a]Performed on minus No. 40 sieve fraction in accordance with ASTM designations D423-59T and D424-59.

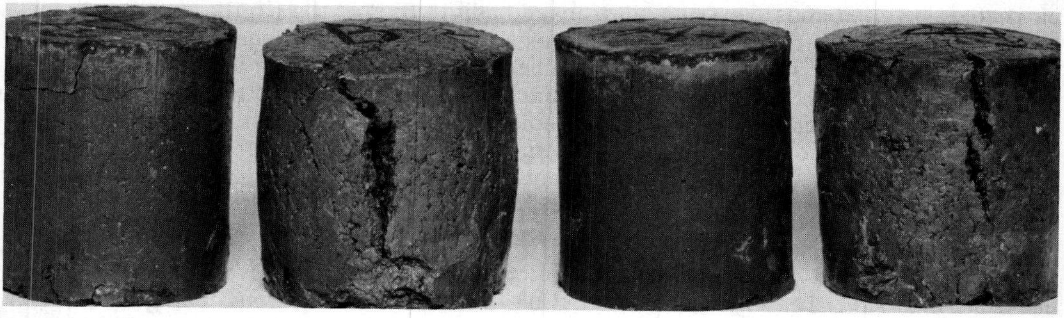

Figure 13. Alternately, 3-yr-old Arquad 2HT-treated subbase soil and untreated subgrade soil molded into 2-in. diameter by 2-in. high specimens. Specimens molded to standard Proctor density, air cured for 7 days, and subjected to capillary moisture absorption in open air for 7 days.

86.4 kips per in.; the lowest relative stiffness factor of the experimental sections was 332 kips per in. Thus the experimental sections appear to have adequate flexural strength for performance under 18,000-lb single-axle loads.

Traffic

Iowa State Highway Commission traffic information for the portion of Iowa 117 which includes the experimental sections is as follows:

From 1956 to 1959 the average daily traffic increased from 425 to 836 vehicles per day. Of the latter total, 556 were local passenger cars, 35 were foreign passenger cars, 42 were pickups and panels (subtotal, 633); 14 were 4-tire and 114 were 6-tire 2-axle single-unit trucks, 10 were 3-axle single-unit trucks; 19 were 3-axle truck tractor semi-trailer combinations, 36 were 2-axle TT, 2-axle ST truck tractor semi-trailer combinations, and 7 were 5-axle combinations, 3 were busses (subtotal 203). Total section length for 1959 was 3.43 mi, truck and bus vehicle-miles were 696, and total vehicle-miles were 2,867. In late 1960, Interstate 80 was opened between Des Moines and Newton with interchange facilities at Iowa 117. As of mid-1961 the average daily traffic over the experimental sections had increased to 874 vehicles per day.

Arquad 2HT-Treated Subbase

In May 1961 over three years after construction, the Arquad 2HT subbase section was given some additional testing and evaluation due to its more highly experimental nature.

Several 4-in. diameter core holes were opened in the soil-cement base overlying the Arquad 2HT subbase. Readings of a pocket penetrometer (Model CL-700, Soiltest, Inc., Chicago, Ill.) were used to qualitatively measure the general strength characteristics of the exposed subbase in each hole. The average unconfined compressive strengths thus determined were over 3.5 tons per sq ft.

Disturbed samples of the full depth of the subbase were removed by auger from each hole, sealed in containers, and returned to the laboratory for determination of Atterberg limits and capillary moisture absorption observations of remolded 2-in. diameter by 2-in. high cylinders compacted to near standard density. From each of the same holes the upper 6 in. of subgrade was also removed by auger, sealed in containers, and returned to the laboratory for tests duplicating those noted. Duplicate 5- to 10-g samples of these materials were removed directly from the auger for bacteriological studies reported in the Appendix. Table 16 presents the results of the Atterberg limits tests on the disturbed samples.

All remolded cylindrical specimens were air cured for 7 days and then placed on water soaked felt pads, subjecting them to capillary absorption in open air for 7 days. Figure 13 shows the effect of capillary moisture on four of the specimens. The remolded Arquad 2HT-treated soil specimens showed only slight swelling; the same soil, untreated, swelled considerably and cracked badly. During the capillary test, the untreated specimens became fully wetted in less than 30 min, whereas the 3-yr-old Arquad-treated soil, required 4 to 5 hr to become fully wetted due to its retained hydrophobic properties. During the performance of the plastic limit test, it was observed that the rate of drying of the Arquad 2HT soil was considerably faster than that of the untreated subgrade soil. At the time of removal of samples from the subbase and subgrade the average in-place moisture contents were 21.7 and 24.1 percent, respectively.

CONCLUSION

The experimental base and subbase sections of Iowa 117 have given over 3 years of excellent service. The experimental portion has sustained severe freezing and moisture conditions and has shown a general performance at least equal to that of the regularly designed pavement structure employing a 7-in. soil-cement base and a 6-in. soil-aggregate subbase.

ACKNOWLEDGMENTS

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REFERENCES

1. Aldrich, H.P., Jr., "Frost Penetration Below Highway and Airfield Pavements." HRB Bull. 135, 124-149 (1956).
2. Benkelman, A.C., and Olmstead, F.R., "A Cooperative Study of Structural Design of Non-Rigid Pavements." Public Roads, 25:21-29 (Dec. 1947).
3. Corning, L.H., Glodin, H.L., and McCoy, W.J., "Portland Concrete—Materials and Mix Design." In Woods, K.B., Ed., "Highway Engineering Handbook." pp. 17-3 to 17-40, McGraw-Hill (1960).
4. Davidson, D.T., "Experimental Methods of Chemical Soil Stabilization." Dept. of Civil Engineering, Iowa State Univ. (1960). (Mimeo.)
5. Davidson, D.T., "Portland Cement Stabilization of Soils." Dept. of Civil Engineering, Iowa State Univ. (1960).
6. Davidson, D.T., Demirel, T., and Rosauer, E.A., "Mechanism of Stabilization of Cohesive-Soils by Treatment with Organic Cations." (To be published in 9th Nat. Clay Conf. Proc., 1960).
7. Davidson, D.T., Katti, R.K., and Handy, R.L., "Field Trials of Soil-Lime-Fly Ash Paving at the Detroit Edison Co., St. Clair Power Plant, St. Clair, Michigan." Iowa Engineering Exp. Sta., Iowa State Univ. (1958). (Multilith.)
8. Davidson, D.T., Mateos, M., and Katti, R.K., "Activation of the Lime-Fly Ash Reaction by Trace Chemicals." HRB Bull. 231, 67-81 (1959).
9. "Soil Stabilization with Portland Cement." HRB Bull. 292 (1961).
10. Holloway, F.M., "Road Roughness Measurements on Indiana Pavements." Proc., Purdue Road School (1956). (Cited in ref. 19, p. 532.)
11. Hoover, J.M., and Davidson, D.T., "Organic Cationic Chemicals as Stabilizing Agents for Iowa Loess." HRB Bull. 129, 10-25 (1956).

12. "Standard Specifications for Construction on Primary, Farm to Market and Secondary Roads and Maintenance Work on the Primary Road System." Iowa State Highway Commission (1960).
13. Johnson, A.W., Moreland, H., Davidson, D.T., and Handy, R.L., "Soil Stabilization." In Woods, K.B., Ed., "Highway Engineering Handbook." pp. 21-7 to 21-85, McGraw-Hill (1960).
14. Kardoush, F.B., Hoover, J.M., and Davidson, D.T., "Stabilization of Loess with a Promising Quaternary Ammonium Chloride." HRB Proc., 36:736-754 (1957).
15. Lu, L.W., Davidson, D.T., Handy, R.L., and Laguros, J.G., "The Calcium-Magnesium Ratio in Soil-Lime Stabilization." HRB Proc., 36:794-805 (1957).
16. Mateos, M., and Davidson, D.T., "Further Evaluation of Promising Chemical Additives for Accelerating the Hardening of Soil-Lime-Fly Ash Mixtures. Iowa Engineering Exp. Sta., Iowa State Univ. (Jan. 1961). (Mimeo.)
17. "Soil-Cement Handbook." Portland Cement Association, Chicago (1959).
18. Viskochil, R.H., "Effect of Density on Unconfined Compressive Strength, Absorption and Volume Change of Lime-and-Fly-Ash Stabilized Soils." M.S. thesis, Iowa State Univ. (1956).
19. Yoder, E.J., "Principles of Pavement Design." Wiley (1959).

Appendix

BACTERIAL COUNTS OF ARQUAD 2HT-TREATED SUBBASE

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Materials and Methods

In May 1961, four core holes were opened in the soil-cement base exposing the Arquad 2HT subbase of Iowa 117. Two core holes were also opened exposing the soil-aggregate subbase immediately south of the experimental sections. From each of the six holes four 5- to 10-g samples were collected into sterile screw-cap test tubes for bacteriological analysis; one sample each, from near the top and bottom of the Arquad 2HT subbase, near the top of the subgrade and about 6 in. into the subgrade. The samples were kept cool until returned to the laboratory for storage at 4 C before plating about 6 to 11 hr later.

One gram of each sample was shaken 100 times with 99 ml of 0.1 percent peptone buffer (1). Subsequent dilutions were made in peptone buffer, after which appropriate dilutions were plated in duplicate into Trypticase soy agar (Baltimore Biological Laboratory, Inc., Baltimore, Md.) and inoculated in triplicate into tubes of steamed and cooled Thioglycollate medium (without indicator) (Difco Laboratories, Inc., Detroit, Mich.). In like manner, two media containing 0.25 percent added Arquad 2HT were inoculated, the pH of the Arquad media being adjusted so that it was 7.2 following sterilization of the media.

Trypticase soy agar plates were incubated for 4 days at 30 C. Tubes of Thioglycollate medium were incubated in candle jars for 7 days at 30 C. Total aerobic and anaerobic counts were calculated using 3-tube most probable numbers tables (2, p. 152).

Results

Data obtained from the tests are given in Table 17. Bacterial counts on the medium containing 0.25 percent added Arquad 2HT were negligible and thus were omitted from Table 18. Differences in moisture content of the various roadway samples would not have affected bacterial counts sufficiently to alter any conclusion made in this report.

It would appear that the vast majority of the microorganisms encountered in this study were susceptible to the presence of Arquad 2HT in the medium. In addition,

TABLE 17

BACTERIAL COUNTS ON SAMPLES OF ARQUAD 2HT-TREATED SUBBASE SOIL-AGGREGATE SUBBASE, AND UNDERLYING SUBGRADE, IOWA 117

Type of Bacteria	Sample Location		Type of Subbase[a]	Logarithm of Bacterial Count per Gram Wet Weight of Soil			
				Subbase		Subgrade	
	Station	Lane		Upper	Lower	Upper	Lower
Aerobes	193+50	East	A	4.54	4.78	5.48	4.28
	198+50	East	A	4.59	4.57	4.83	3.65
	200+50	West	A	4 60	4.66	4.78	4.66
	196+00	West	A	4.79	4.71	4.80	4.38
	187+00	West	B	4 68	4.86	4.40	4.49
	184+00	East	B	4.77	5.00	5.08	5.29
Anaerobes	193+50	East	A	3.40	5.04	4.40	3.65
	198+50	East	A	5.04	5.04	4.65	3.40
	200+50	West	A	4.65	4.65	4 40	4.65
	196+00	West	A	3.65	3.65	3 40	3.65
	187+00	West	B	4.65	>5.40	3.40	4.40
	184+00	East	B	4 40	4.65	>5.40	>5.40

[a]A = Arquad 2HT-treated subbase, B = soil-aggregate-stabilized subbase.

bacterial counts of all samples were rather uniform, indicating that the presence of Arquad in the subbase resulted in no long-term net increase or decrease in the quantity of microorganisms present.

The results, however, do not preclude the possibility that some inhibition or enrichment of the microbial population might have occurred early in the history of the road's construction and utilization. This possibility is suggested by the fact that slightly higher counts of aerobes were obtained in the upper portion of the subgrade, just under the Arquad 2HT-treated subbase, than in the other areas of sampling. Furthermore, substantial increases in bacterial counts were noted in Arquad-treated, but not in untreated, soil samples held for some time in the laboratory. Bacteria that were resistant to the Arquad could be isolated with ease from both types of samples using enrichment procedures where Arquad 2HT served as the sole carbon source.

REFERENCES

1. Straka, R.P., and Stokes, J.L., "Rapid Destruction of Bacteria in Commonly Used Diluents and Its Elimination." Applied Microbiology, 5:21-25 (1957).
2. "Standard Methods for the Examination of Dairy Products." 10th ed., Amer. Public Health Assoc. (1953).