ENGINEERING
RESEARCH

ENGINEERING
RESEARCH
ENGINEERING
RESEARCH
ENGINEERING
RESEARCH
ENGINEERING
RESEARCH

PROGRESS REPORT

SURFACE IMPROVEMENT AND DUST PALLIATION OF UNPAVED SECONDARY ROADS AND STREETS

James M. Hoover

June 1971

ISU–ERI–AMES 99991
Project 856-S

ENGINEERING RESEARCH INSTITUTE
IOWA STATE UNIVERSITY AMES

SURFACE IMPROVEMENT AND DUST PALLIATION OF UNPAVED SECONDARY ROADS AND STREETS

Introduction

For many years, engineers have sought means of providing the public with low-cost all-weather road surfaces. Such surfaces have not been achieved, since most studies were concerned with actual pavements and involved performance-serviceability criteria more closely associated with high-type surfaces; nor has this form of criteria provided all-weather surfaces within the economical capabilities of most counties and cities. Therefore, it has become apparent to many county engineers that a means of improving the serviceability of unpaved roads is potentially the most effective and practicable method of coping with: (1) public indignation of dust; (2) costs of maintenance coupled with annual replacement of crushed stone or gravel surfacing; and (3) rising costs of high-type surfaces.

The objective of this research project is a combined study of dust control and low-cost surface improvements of soil and aggregate materials for immediate (and intermediate) use as a treated surface course. Three concurrent phases of study are included in the project: (1) laboratory screenings study of various additives thought to have potential for long-lasting dust palliation, soil-additive strength, durability and additive retention potential; (2) test road construction, using those additives from the screening studies that indicate promise for performance-serviceability useage; and (3) observation and tests of constructed sections for evaluation of the additive's contribution to performance and serviceability as well as relationship to initial costs.

The research program is expected to provide much information on the effects of various agents as low-cost surface improvements and dust palliatives of unpaved secondary roads and streets utilizing existing in-place soil-aggregate materials. These include: (1) performance of low-volume traffic surfaces not considered for eventual paving; (2) performance of similar surfaces, in use on an intermediate basis while awaiting higher-type surface improvements; and (3) procedures for engineers and field personnel showing processing steps, relating traffic volume, environmental conditions, soil types and quantity of additive for producing desired results.

The purpose of this report is to illustrate the rational development of the project objectives and goals through a broad overview, and to report on progress to date. Consequently, a brief review will be made of: (1) the problem, (2) some methods of measurement of the problem, (3) means of handling the problem which have basically been in existence prior to the start of the project, (4) project field tests and a portion of the results thus far, and (5) portions of the laboratory work accomplished in the screening studies.

The Problem — Dust and Loose Aggregate

The concentration of silt-sized particles in air 100 ft behind a car moving at 35 mph on a moderately dusty crushed-rock road is about 100 times the pollution concentration in industial city air. Nationwide, 2.3 times more people are killed per vehicle mile of travel on unpaved roads and streets than on the paved primary system. Unpaved road dust detracts from the ultimate useful life of public and private vehicles. Hazards in driving on unpaved surfaces include reduction of sight distance, with a consequent reduction of safe speeds (See Fig. 1). Loose surface aggregate produces skidding and swaying of vehicles, less positive steering response, longer stopping distance, and broken windshields from flying rock (See Fig. 2). Dust from unpaved surfaces infiltrates homes and destroys the esthetics of both rural and urban living (See Fig. 3). Dust and loose aggregate contribute to severe maintenance and aggregate replacement costs — such costs are illustrated by blade grading of 20 or more times per year and one known Iowa county whose aggregate replacement costs exceed $500,000.00 annually.

Present design and construction standards provide adequate means of either improvement of grade and cross section of secondary roads followed by immediate road metal surfacing, or eventual high-type surfacing. The first provides a recognizable dust and loose aggregate nuisance with dangerous destructive and costly effects. Regarding the second alternative, most Iowa counties do not have many high traffic volume roads, and are consequently limited on the mileage of high-type pavement that can be built and maintained annually due to initial construction costs. Provisions for intermediate forms of surface improvement which at least retard, and preferably eliminate, dust and loose aggregate hazards as well as losses of aggregate, are an economic necessity.

The Problem — Dust Measurement

Standard provisions for collection and analysis of dustfall are contained in ASTM designation D1739. In an effort to determine acceptability of this method as generally applied to road dust, a simplified procedure using plastic frozen food containers attached to wood lath and placed 3 ft above ground surface was used as shown in Figs. 4, 5, and 6. Each container was half-filled with distilled water and remained in place exactly 7 days. A traffic counter was installed for the same period of time with average traffic recorded slightly over 110 vpd. The containers were checked daily for water level* and after the 7 day period were sealed and returned to the laboratory. Following removal of all organic matter, including bugs, chaff, and seeds, the contents of each box were oven-dried, weighed, and examined under a microscope. The average daily accumulation of dust over the bottom area of each box was calculated in pounds per acre per day of dust, and are shown in Fig. 7. Microscopic examination indicated that the dust was composed predominantly of limestone particles.

Additional installations of dust samplers have been made on the various test road sections in Linn and Clinton Counties and will be made this summer in Floyd, Lee, Pottawattomie and other counties. These samplers are more consistent with ASTM D1739 and were constructed by the ERI shop. Though incomplete at this point of the project, the added samplings indicate both greater and lesser amounts of dust than shown in Fig. 7 due to both traffic and rainfall. Depending on prevailing wind conditions during periods of sampling, slightly higher dust quantities are noted immediately adjacent to one side or the other of the roadway, but from approximately 100 to 300 ft from the roadway centerline, the values remain roughly constant regardless of wind direction. Also, data thus far indicates that the preponderance of dustfall is within 100 ft of the road centerline.

---

* It has since been found that only one- to two-week checks of water level are needed, depending of weather conditions.

Figure 7 also compares the preliminary sampling data with both normal U.S. conditions and 1954 Kansas "dust bowl" conditions. Figure 8 compares the preliminary sampling data with agricultural field dust data from across the U.S.

Volumetric sampling has also been obtained from several test areas throughout the state. This procedure utilizes a portable, battery operated vacuum pump system, equipped with a variable flow meter, calibrated in cubic feet per minute. Two of these units are placed with their intake collectors in line with, and to the rear of, the field lab van's rear tires. The truck is driven at a constant forward speed. As the rear wheels cross the beginning of a test section, the vacuum pump is switched on and a stopwatch is started; both are stopped as the van crosses the end of the section. The amount of dust collected within the time period noted, coupled with the pump rate of flow, determines the weight of dust per million cubic feet of air sampled. Trials determined that the most satisfactory vehicle speed was not over 30 mph, with the intake collectors one foot above the roadway and about six feet behind the vehicle. Portions of the results using this system will be shown in a succeeding section.

Means of Handling the Problem

Over the years, engineers have tried various methods of controlling dust and reducing quantity of aggregate replacement. Typically, surface applications of calcium and sodium chlorides have assisted in "laying the dust" for very short periods of time. Surface oiling definitely provides longer periods of dust palliation while also holding aggregate in place (See Figs. 9 and 10). Most counties will provide surface oiling to the petitioning rural dweller at a nominal charge though retaining the right to blade grade the treated surface at their discretion. The obvious reason for this policy is that surface oiling occasionally ravels and develops potholes, with limited quantities of aggregate thrown to the edges. However, Shelby County has oiled with SC250 covered by a sand blotter for better than 20 years with considerable success, maintaining a satisfied public.

Lee County now has over 140 miles of road surface treated with lignin, some of which have been treated annually for better than 10 years with quite reasonable success (See Figs. 11 and 12). Lee County also has the advantage of having a local pulp mill as a source of lignin at about 11% solids concentration.

Since lignins are water soluble, periodic replenishment is needed. Studies by Demirel and Davidson[1] indicated either lime, or salts of aluminum, iron, chromium and manganese appeared applicable as secondary additives to potentially eliminate the need for lignin replenishment. Figure 13 shows a lignin plus aluminum sulfate (alum) treated roadway in an urban residential area. Constructed in Linn County in 1969, the roadway was scarified, windrowed, treated with combined lignin and alum, bladed to crown and cross section, and compacted. Following compaction, a light topshot of lignin/alum was surface sprayed. Since construction, dusting has been about 10% of original and only slight amounts of aggregate pullout have occurred, primarily on the curves. Lignin leaching appears to have been at least retarded over the two year period since construction.

Similar in-depth treatments have been used by several counties for a number of years, incorporating cut-back asphalts to a depth of two or more inches with the inplace soil and aggregate (See Figs. 14-17). In the figures noted, dusting has been nearly eliminated (volumetric dust measurements on the roads noted in Figs. 15 and 16 were so small as to be undetectable on an analytical balance) though very small amounts of aggregate pull-out may be observed. Practicable quantities of the cut-back asphalt appear to be 4% or less, however, as may be noted by comparing the shoving in Figs. 15 and 16.

Project Field Tests and Results

Experimental sections have been constructed in Floyd, Clinton and Linn Counties as a part of this research project. Only the Linn County project has involved additional funding through an Iowa Highway Research Board recommended grant. All other projects were constructed solely out of available county funds.

The Floyd County projects include three sections:

1. From Rockford, northwest, about 1 mile in length, 4 in. depth treatment with 50% solids concentration of lignin providing about 1% solids by dry soil weight in place (See Figs. 18 and 19). As of mid-May, 1971, the section was slightly less than one year old, little dusting is occurring except on the curves where some aggregate pullout is observable, some of the matrix surface aggregate is actually showing polishing due to traffic, and as far as is known by the researchers, the road has received no maintenance since construction.
2. From Rockford, southeast, about 1½ miles in length, same treatment level and similar observed results.
3. Southeast of Charles City, near the YMCA camp, about 1/4 mile in length, same treatment level. The surface as of mid-May 1971 had definitely been bladed as observed from

stone gouges and fractured matrix embedded aggregates. Dusting is visibly higher on this than on the other test sections and has probably been due to surface disturbance by blading.

The Clinton County project begins near the Hawkeye Chemical plant west of Clinton and includes three test sections of about 1000 ft each, up to the Camanche city limits. Additives contained in the three sections from south to north included: (1) 1% by dry soil weight lignin solids plus ½% lime; (2) 1% by dry soil weight lignin only; and (3) 4% by dry soil weight of what we have termed "Chemplex Residual." The latter is a waste product containing various oils and tar, from the Chemplex Plastic Co. plant west of Clinton. Laboratory screening studies indicated the residual's potential for test section application at about the 4% dry weight level.

Figure 20 illustrates dusting on the residual section prior to construction. Figure 21 illustrates the residual section surface characteristics this spring, indicating some fines plus aggregate pull-out which appear to be the result of construction problems. Construction processes followed by the county crews were worked out between the County Engineer and the researchers. This included scarification to provide 6 in. compacted depth, windrowing scarified material to each side of road, tamping foot rolling of subgrade trench, pulling one-half the material back into the trench, mixing of the required quantity of additive, tamping foot rolling, repeating mixing and rolling with final half of windrowed material, blading to crown, and rubber rolling. The lignin-lime, and the lignin-only sections were completed, but only the first lift of the residual section was completed prior to a deluge of rain. Water ponded in the remaining trench of the residual section, thus allowing thorough saturation of the subgrade and remaining windrowed material. Drying was never accomplished prior to completion of construction several days later. A number of soft spots thus appeared and some frost heaving was noted during the winter. This spring, however, the section has returned to fairly good shape, though slightly potholed, but with an overabundance of fines on the surface and some aggregate pullout as noted in Fig. 21. The other two sections have thus far encouragingly survived with little dusting and aggregate pullout.

Figure 22 illustrates the average variations in volumetric dust data obtained from the Floyd and Clinton County tests as well as dust sampling data from the spray on surface treatments used in Lee County. Data shown in this figure was taken from about two weeks to up to six months after construction. It will be noted that the various additives reduced the amount of dust to about 10-20% that of typical untreated dusty roads.

In-place tests have been, and will continue to be, conducted in the various test sections. These tests include the following:

1. Spherical Bearing Value Test. Figures 23 and 27 illustrate this test, using a 6 in. diameter sphere. The SBV test is a reasonably quick field test for analyzing the relative bearing capacity of the various sections. Though requiring about the same time to conduct as an inplace CBR test, it has been shown to have far better reproducibility than either CBR or plate bearing tests and has been correlated with the CBR test for use in design of pavements.[2]
2. Benkelman Beam Deflection Test. Figure 24 shows the test being conducted within the outside wheel path of an untreated section in Linn County. Deflections are determined under a 17,280 lb

rear axle load with the truck moving. Deflections may be converted to what has been termed a "stiffness" factor,[3] which is the wheel load in thousands of pounds (kips) divided by the maximum deflection. Deflection and stiffness values from other roads within the state will provide comparisons with more common pavement materials.

Figure 25 presents a portion of the SBV and B beam field test results from the Clinton test sections. The effect of softening due to construction (and the extremely wet conditions during construction of the residual section) are particularly evident with the SBV values. Maximum Benkelman beam deflections in all cases is less than 0.04 in. Stiffness is in general about a quarter to a third that of a test roadway consisting of 6 in. lime treated subbase, 7 in. soil-cement base, and 3 inch asphaltic concrete surface.[3] The effect of softening immediately following the spring thaw is also evident. Results of beam and SBV tests taken June 3, 1971 were not computed prior to preparation of this report but appear to show increases in SBV and stiffness, with subsequent decreases in deflection from those taken early this spring. A minimum of one more series of tests will be taken prior to late fall 1971.

The Linn County project is about 1 1/4 miles in length and is located on a new grade, constructed during the summer of 1970, north of Marion and about 2 miles due west of the Linn County maintenance garage. Carrying about 100 vpd, the road consists of 12 test sections, each at least 500 ft in length and of 4 in. depth, and constructed using the same procedure previously described for the Clinton test sections with the exceptions that it was constructed in one lift; and lime and alum were spread dry prior to mixing rather than dissolved in the lignin concentrate. In addition, one of the major purposes of this road is to ascertain the effect of varying crushed stone contents on lignin treatments. Beginning with a new grade, crushed stone was spread at the rates noted in Table 1, prior to scarification. Table 1 also presents the quantities of additives, by dry soil weight used in each section. No scarification was used in the untreated sections, instead the crushed stone was applied at the rates noted and bladed to crown thus providing sections utilized for comparison with the remaining sections as untreated and prior to surface improvement construction.

Table 1. Crushed stone rates and additive quantities, Marion Test Road, Linn County.

Test section number	Crushed stone application, Tons/mile	Additives, % dry soil weight		
		Lignin	Alum	Lime
1	400	2	0	0
2	400	0	0	0
3	400	1	0	0
4	400	1	½	0
5	400	1	0	½
6	1000	1	0	0
7	1000	1	½	0
8	1000	1	0	½
9	1800	0	0	0
10	1800	1	0	0
11	1800	1	½	0
12	1800	1	0	½

Figure 26 shows section 2 in the foreground and section 1 in the background, shortly after the spring thaw this year. Rutting is quite evident in the untreated section, while the treated 400 Ton/mile sections showed little or no rutting.

Figure 27 presents the average results of SBV tests approximately seven days after surface improvement construction and again early this spring. Additional tests were taken June 4, 1971, but are not included in this report. It is evident that SBV values decreased following construction and again early this spring due to moist subgrade conditions. An unexplained anomaly is apparent with the 2% lignin, 400 Ton/mile section, having a higher SBV value this spring than following construction. Laboratory screening tests indicated 1% lignin to be about optimum for all sections. Consequently, section 1 is being watched very closely.

Figure 27 also presently indicates a general trend of maximum reduction of SBV within the 1000 ton/mile crushed stone sections this spring, as well as a general trend of decreased SBV from 0-1% lignin, to 1% lignin plus the secondary additives.

This spring a definitive decrease in average stiffness and increase in average deflection developed, opposed to increasing aggregate content within the sections (See Fig. 28). Comparison of results from Figs. 27 and 28 indicate that the materials are generally capable of withstanding the traffic volume and the imposed loads, but deform to a greater extent with larger amounts of aggregate, i.e., are more flexible under moist subgrade conditions. This may be indicative of less bonding capabilities due to lower fines content and thus a lessening of the overall capabilities of the matrix surrounding the coarse particles.

Due to considerable delays in shipping, eight-day dual temperature recorders were finally installed in sections 6-9 of the Linn County road late this winter, just as the frost was leaving. Installations were made so that temperatures were measured 4 in. below the surface at the bottom of the treatment, and in three of the sections the thermocouples were also installed 4 in. into the subgrade or 8 in. below the surface. One thermocouple was allowed to remain exposed for recording ambient air temperatures.

Shown in Fig. 29 are a portion of the observed temperatures from sections 6 and 8, plus ambient air, for one 24 hr period in early April. In general, the 1% lignin plus lime surface improvement section (8B) appears to maintain a more uniform subgrade (8S) temperature and indicates a slightly lower thermal conductivity than does the 1% lignin treatment (6B) only. A lower thermal conductivity may be advantageous in lessening the number of freeze-thaw cycles of the surface material but does not necessarily indicate a lowering of the freezing point. Temperatures within sections 7 and 9 were intermediate between those values shown in Fig. 29, for sections 6 and 8.

Visual observations of the various lignin test sections in Floyd, Clinton and Linn Counties note a definite darkening of surface color from the lignin, to the lignin plus alum, and darkest with the lignin plus lime. At this point of the project the color darkening is unexplained but may be due to at least a limited amount of chemical activity indicative of polymerization.

One of the major portions of the lignin studies is the field effect of the secondary additives on prevention and control of leaching. The Linn County test sections are the primary location for the leaching experiments. Visually, some slight leaching has occurred in the lignin only sections, while little or no visible observations of leaching have occurred in the lignin plus lime sections. During construction, numerous Proctor-size specimens were molded from the field-mixed materials. During the winter, numerous 4 in. diameter cores were removed from the test sections including the untreated sections. A portion of the molded specimens and cores are being analyzed in the laboratory for additive retention. The test process involves literally raining on the specimens, whose sides only are sealed in a container, and catching the leachate at the bottom of each specimen. The leachate can then be analyzed quantitatively by comparison with control samples previously tested by colorimeter, X-ray diffractometer, or infra-red spectrophotometer. Test results are incomplete as of the time of this report.

Laboratory Screening Studies

Portions of the laboratory screening studies have been previously mentioned in this report. Unfortunately, this portion of the project is behind schedule due to two major factors: (1) more test road-construction last summer and fall than initially anticipated; and (2) the Indonesian chemical engineering graduate student hired last fall to develop the portion of the project involving polymeric compounds, synthetic resins and Guar derivatives was ordered to return to his country early this year due to visa problems. To this point, we have been unable to hire another graduate student with the necesary chemical and engineering background. This portion of the screening studies will be completed, however.

Prior to the above loss, the screening studies with the Guar derivatives and sodium silicate, were completed both separately and in combination with lignin. In all of the screening studies, 2 X 2 in. compacted specimens have been tested with varying quantities of additive(s), moisture contents, curing periods, and saturation by both immersion and capillarity. In general, the Guar derivatives do not appear promising and the sodium silicates appear even less satisfactory. The only favorable result observed in this study was the combined useage of 2% by dry weight of lignin plus ½% by dry weight of "Polymer J B," produced by Jaguar (a Guar derivative). However, these combined additives required 15 days of air curing before satisfactory saturated results were obtained. Such a process is not considered practicable for road construction.

A number of cutback asphalts, latex asphalt emulsions (including a high solids content emulsion), cationic emulsions and Peneprime have been screened using the 2 X 2 in. specimen process noted above. Most of these products appeared promising and have subsequently been tested in a trafficability simulator (See Figs. 30 and 31). This equipment magnifies many times the ravelling and rutting effects of traffic under a single wheel load within several thousand passes (approximately 1000/hour). After a number of trials, the test process environmental conditions shown in the upper portion of Fig. 32 was adopted, using a wheel contact pressure of 85 psi. Observations of this process show comparable stages of ravelling, rutting and final failure similar to those associated with in-situ pavements and previously observed surface improvement projects. No direct comparisons can be made with in-situ dust palliations, though the asphaltic additives noted previously in this report have shown no measurable dusting. In addition, it may be assumed that if the additive does not retard ravelling and rutting during periods of simulated rainfall, fine particles will accumulate at the surface following drying and dusting will occur.

Figure 32 presents only a limited portion of the trafficability results, with each of the additives noted, at 3% by dry weight concentrations. The soil material used in the study illustrated was a very poor quality crushed stone containing 20% passing the no. 200 U.S. standard sieve. The Petroset SB is a latex asphalt emulsion, while the Redicot E-36 is a cationic asphalt emulsion. Both of the emulsions can be applied cold, while the MC-800 required heating. However, it was found that if the cationic emulsion was heated to slightly more than 100°F, rutting was somewhat reduced from that noted following 3000 passes. The MC-800 has been satisfactorily used in Pottawattamie County as previously noted. The Petroset SB appears somewhat more satisfactory after 3000 passes than does the MC-800 but is outlandishly expensive. To be economically competitive with the two other products shown, the Petroset must be used at about 0.4% by dry soil weight with test results more comparable to MC-800. The Redicote E-36 cationic emulsion appears to be the most satisfactory asphaltic product thus far analyzed and is recommended for a field trial this summer. Preliminary discussions have been held with the Powshiek County engineer and road samples are presently being analyzed in the laboratory.

Summary

In general it is felt the project is fairly well on schedule, in that more test sections are presently under analysis than originally anticipated, though the screening studies are behind schedule. All aspects of the project are continuing to be studied, tested, and analyzed. It is anticipated that at least one additional test road may be constructed this summer or early fall, particularly for the purpose of field testing the cationic asphalt emulsions. This fall the project stages begin of producing procedural recommendations of useage of the various materials for surface improvement and dust palliation of unpaved secondary roads and streets.

References

1. Demirel, T., and D. T. Davidson, "Stabilization of Calcareous Loess with Calcium Lignosulfonate and Aluminum Sulfate," Proc. Iowa Acad, Sci., 67, 1960.

2. Butt, G. S., T. Demirel, and R. L. Handy, "Soil Bearing Tests Using a Spherical Penetration Device," Contribution No. 67-7, Soil Research Laboratory, Engineering Research Institute, Iowa State University, May 1967.

3. Hoover, J. M., R. T. Huffman, and D. T. Davidson, "Soil Stabilization Field Trials, Primary Highway 117, Jasper County Iowa," Bulletin 357, Highway Research Board, NAS-NBC, 1962.

Fig. 1. Road dust at 40 mph behind a moving vehicle. A pickup truck is following, but hidden in the dust cloud.

Fig. 2. Loose surface aggregate and blowing dust.

Fig. 3. Road dust at 15 mph from vehicle through picnic area of an Iowa County Park.

Fig. 4. Road dust collector installation.

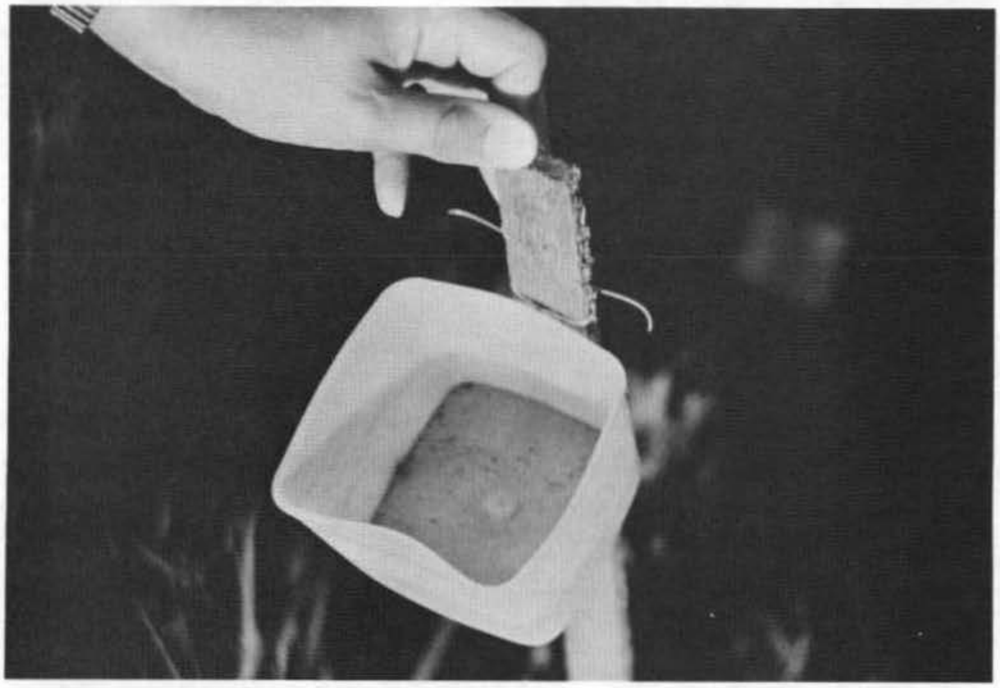

Fig. 5. Road dust collector after 24 hr on site.

Fig. 6. Road dust collectors installed at 20 ft intervals up to 140 ft each side of centerline.

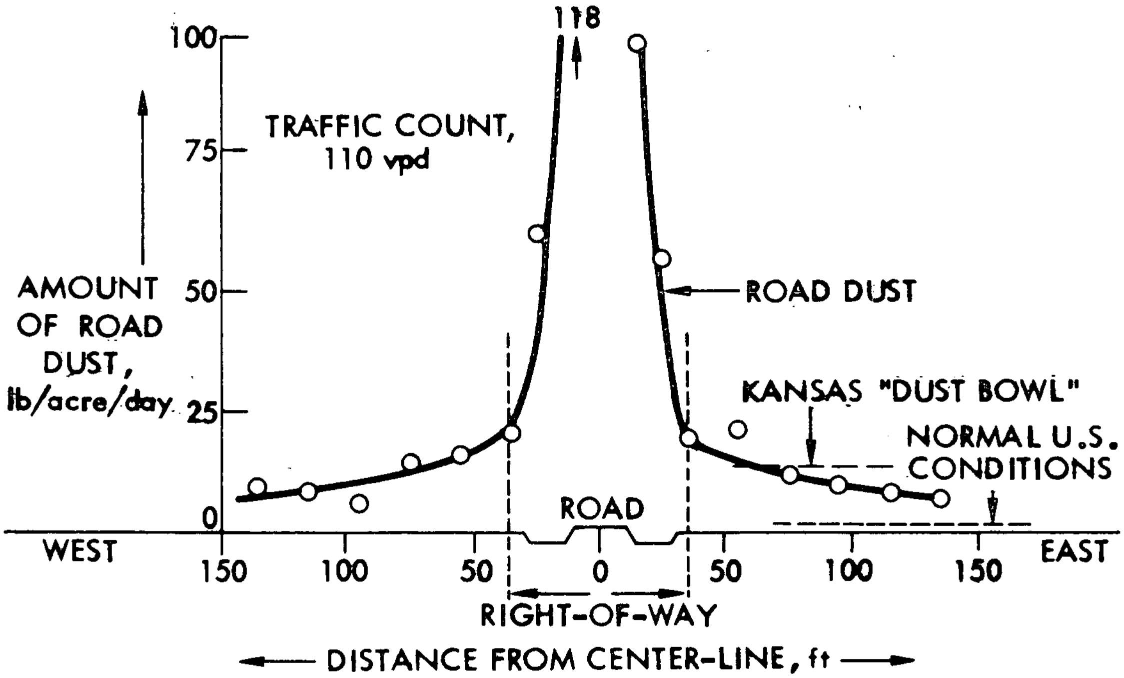

Fig. 7. Amount of daily road dust accumulation vs distance from centerline.

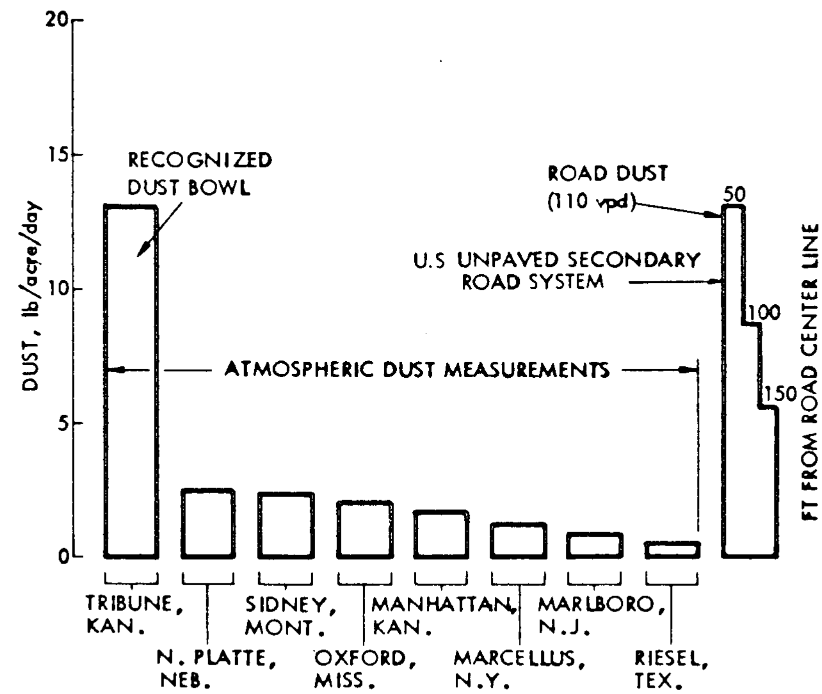

Fig. 8. Amount of daily road dust accumulation at 50, 100 and 150 ft from centerline compared with agricultural field dust data at various U.S. locations.

Fig. 9. Oiled road surface in foreground, untreated surface in background.

Fig. 10. Oiled road surface showing effects of ravelling and pot holing.

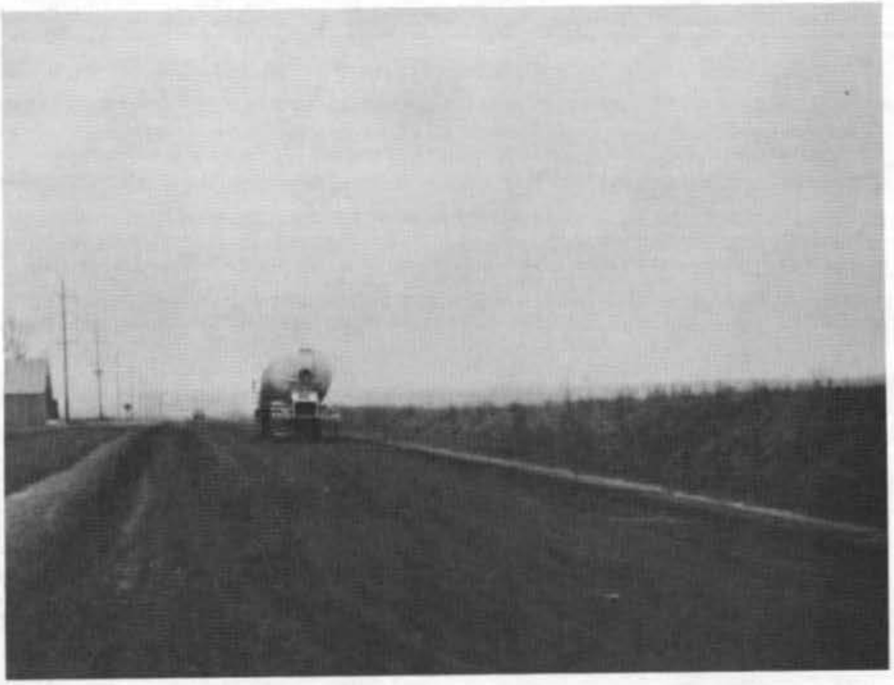

Fig. 11. Lignin-surface treated road. Treatment approximately two weeks old. Tank truck in background travelling at estimated 30 mph speed.

Fig. 12. Lignin-surface treated road. Treatment approximately 2 weeks old.

Fig. 13. Lignin plus aluminum sulfate in-depth treated roadway in urban residential area using in-place soil-aggregate. Vehicle speed 40 mph.

Fig. 14. MC-800 cutback asphalt in-depth treated surface improvement construction using in-place soil-aggregate. Treatment depths about 2-2½ in.

Fig. 15. Cut-back asphalt, in-depth treated surface improvement near De Soto Bend National Park using in-place soil-aggregate. Summer traffic, approximately 4000 vpd. Thickness about 2-2½ in. Age about 1 year.

Fig. 16. Cut-back asphalt, in-depth treated surface improvement using in-place soil-aggregate. Traffic, 700 vpd. Thickness about 2-2½ in. Age about 1 year.

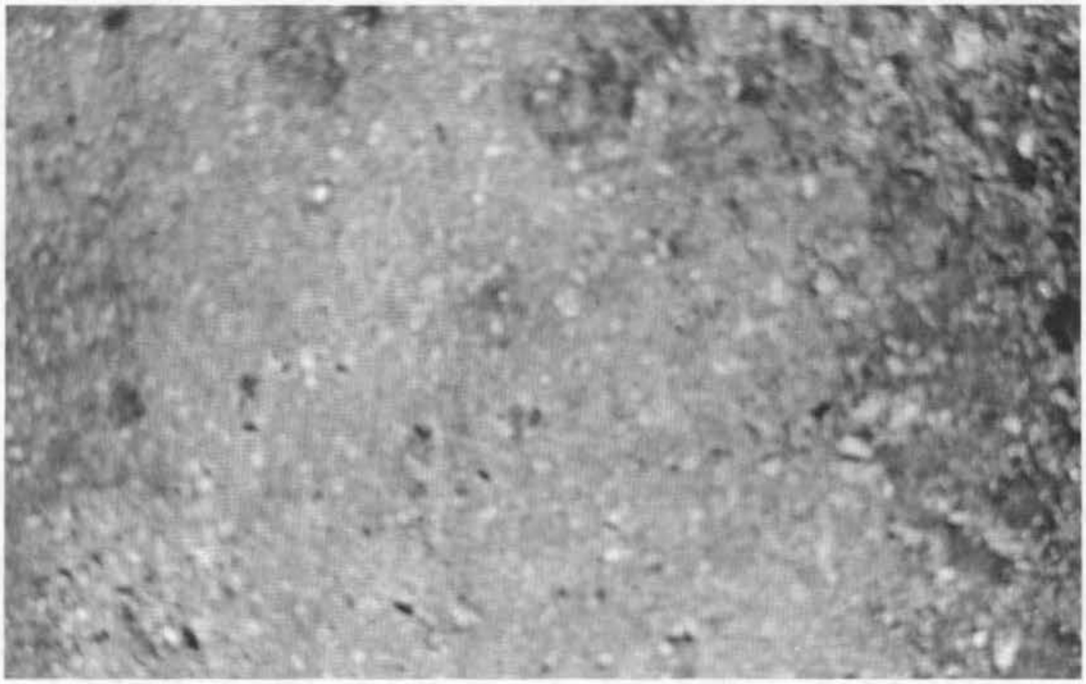

Fig. 17. Surface characteristics of cut-back asphalt section noted in Fig. 16.

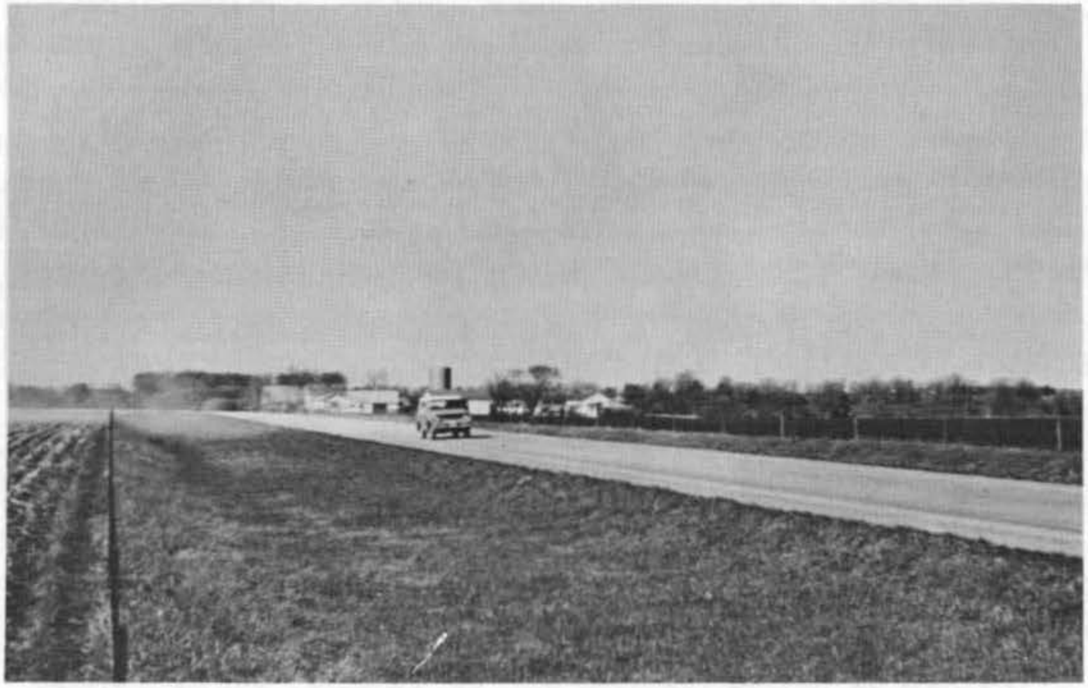

Fig. 18. Floyd County, 4 in. lignin treatment, about 1 year old. Vehicle had just left untreated area at 40 mph.

Fig. 19. Surface characteristics of road noted in Fig. 18.

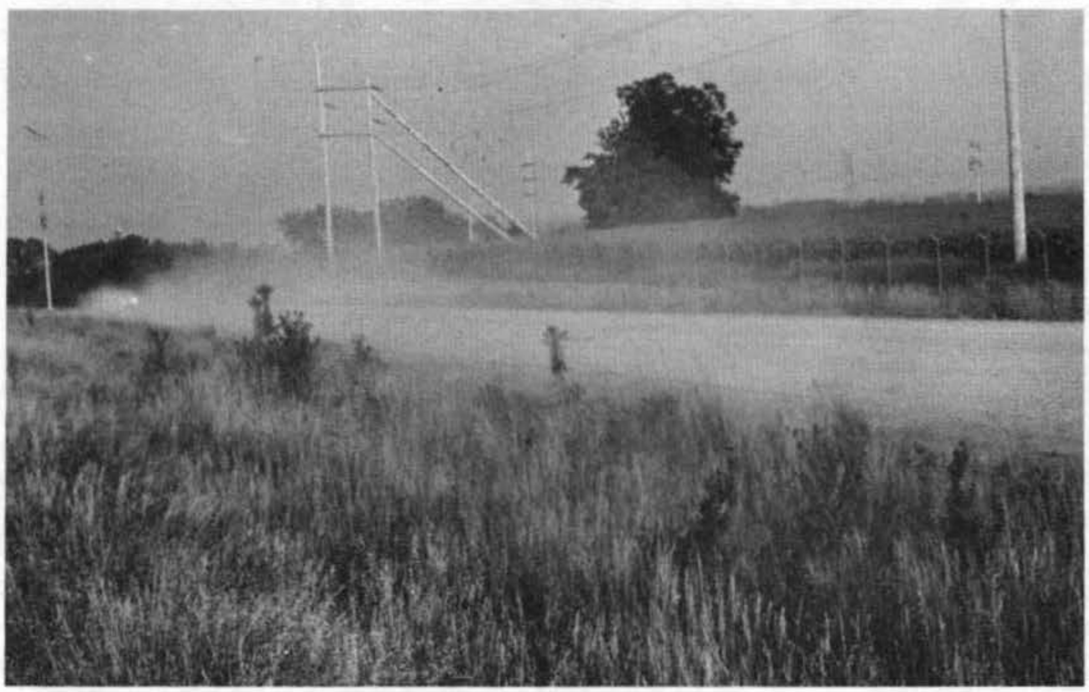

Fig. 20. Clinton county, residual test section dust prior to treatment. Vehicle speed, 40 mph.

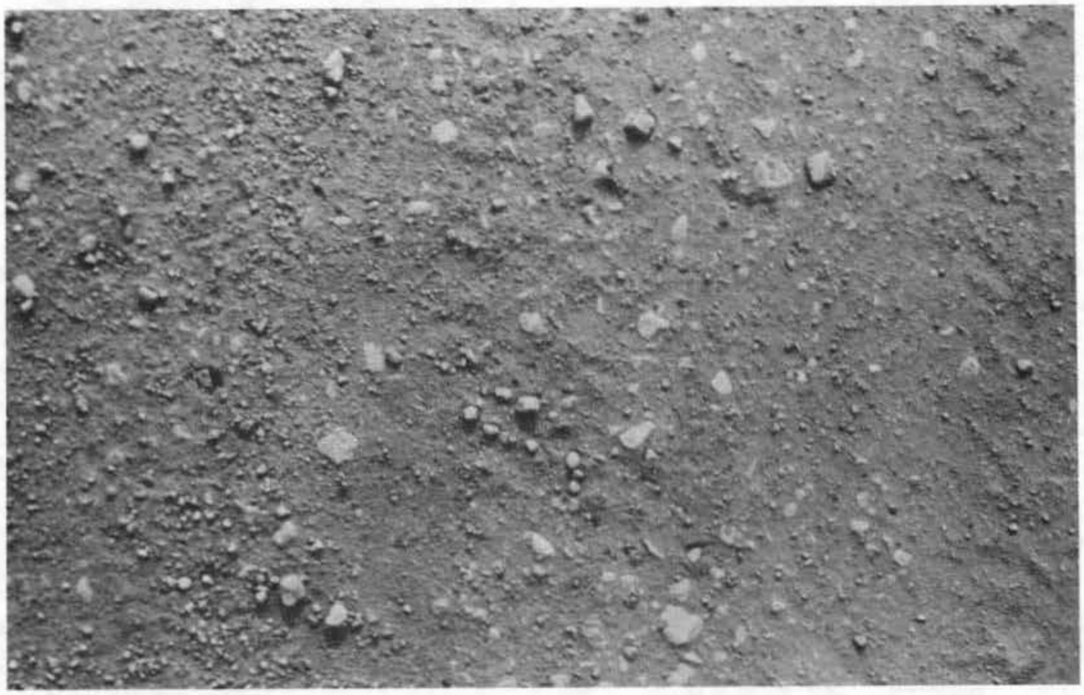

Fig. 21. Surface characteristics, Clinton County residual test sections, spring 1971.

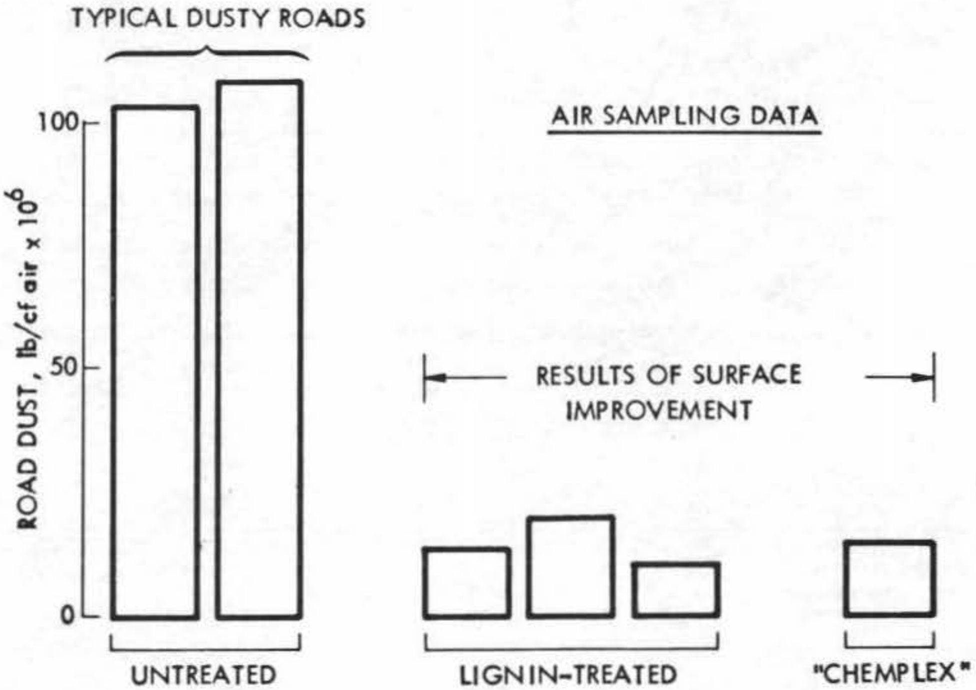

Fig. 22. Dust data by volumetric method. Average lignin treated data from left to right are Floyd, Lee and Clinton counties, respectively.

Fig. 23. Spherical Bearing Value (SBV) test in process.

Fig. 24. Benkelman beam deflection test in process.

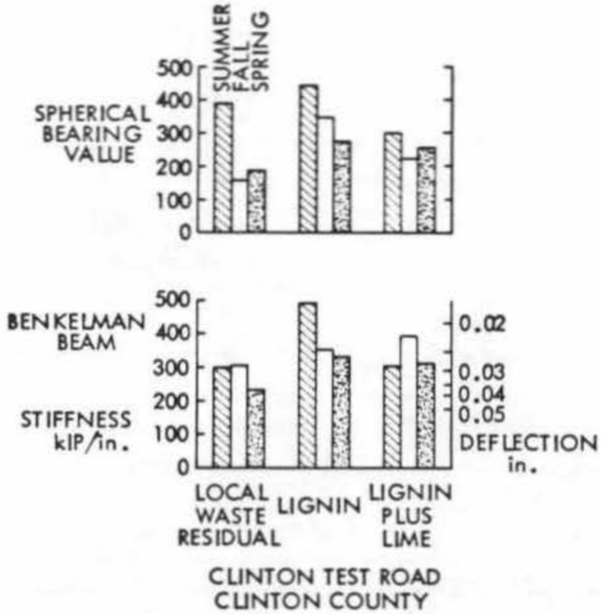

Fig. 25. Clinton county in-place test results. "summer" is prior to construction, "Fall" is about two weeks after construction, "spring" is shortly after thaw.

Fig. 26. Linn County, test section 2 in foreground, test section 1 in background, shortly after spring thaw.

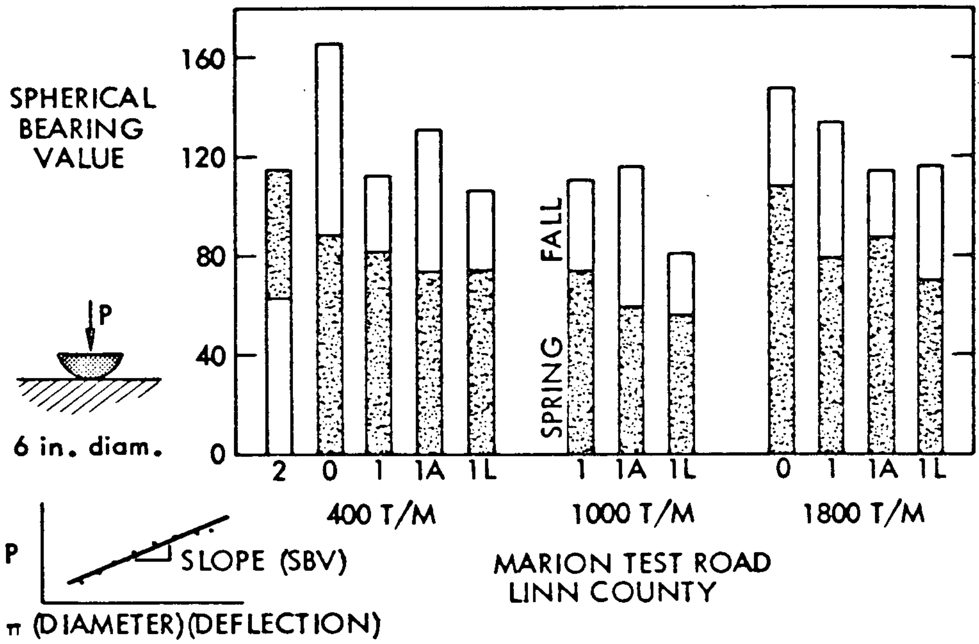

Fig. 27. Linn County in-place SBV test results. Also illustrated is the manner in which SBV values are obtained.

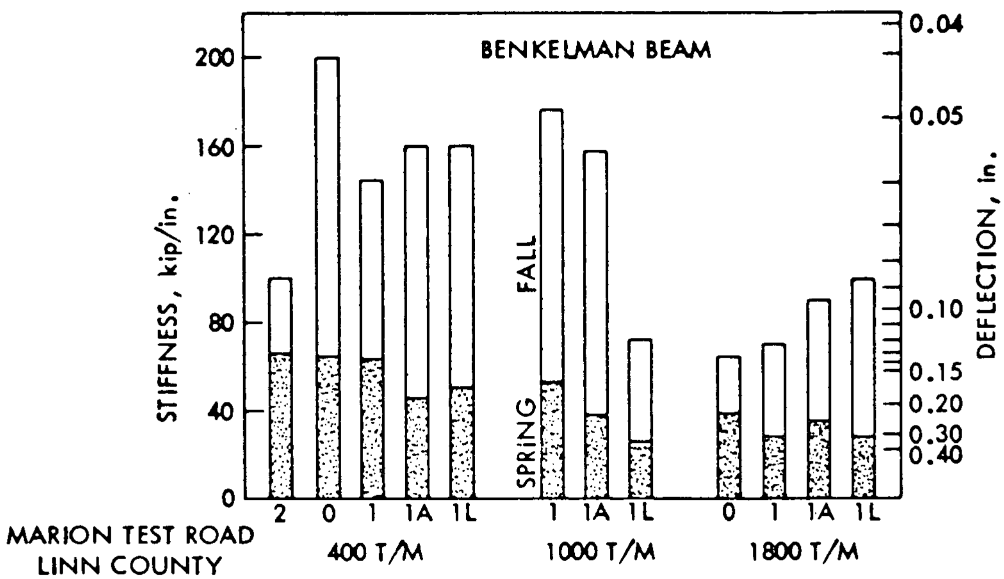

Fig. 28. Linn County in-place Benkelman Beam deflection test results.

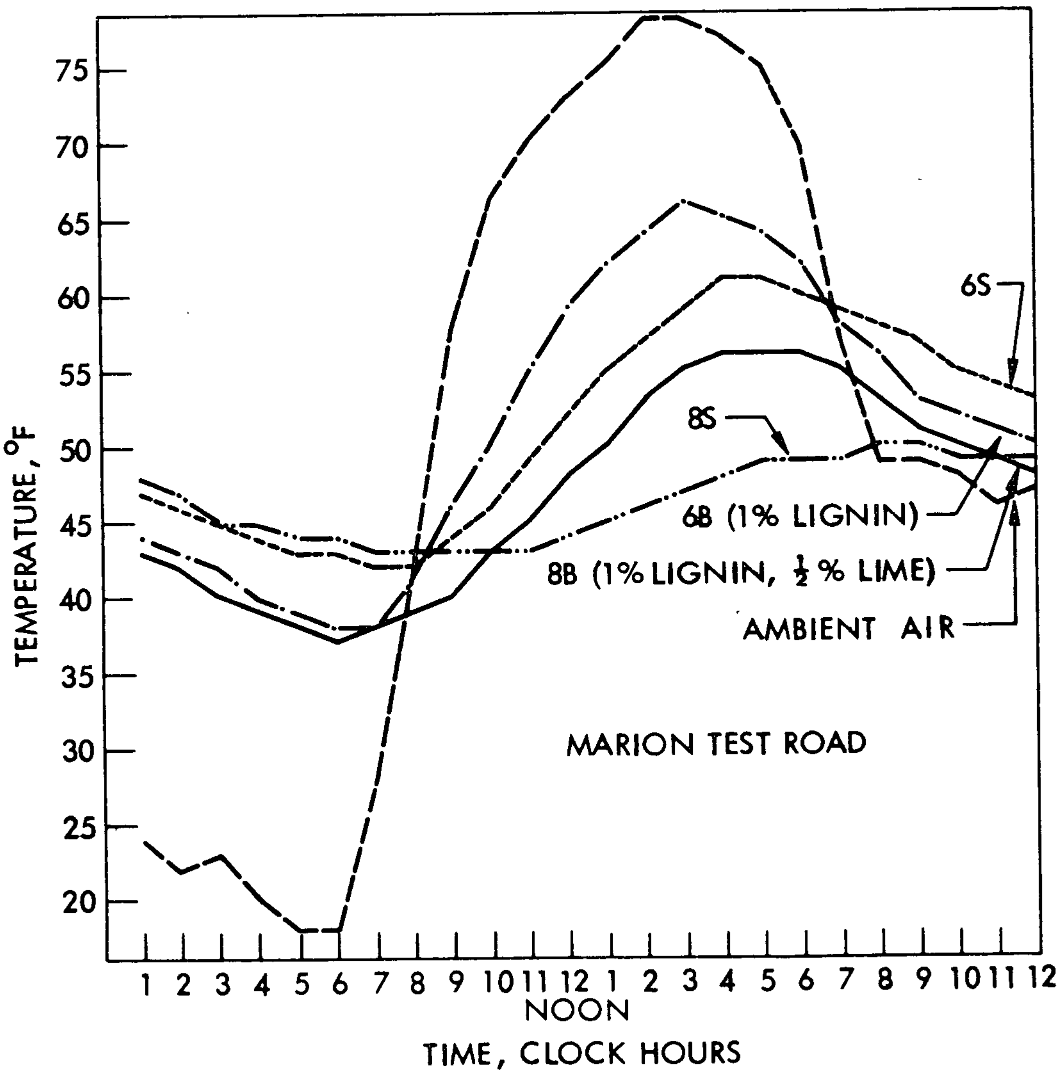

Fig. 29. Illustration of observed temperatures, sections 6, 8 and ambient air, Linn County.

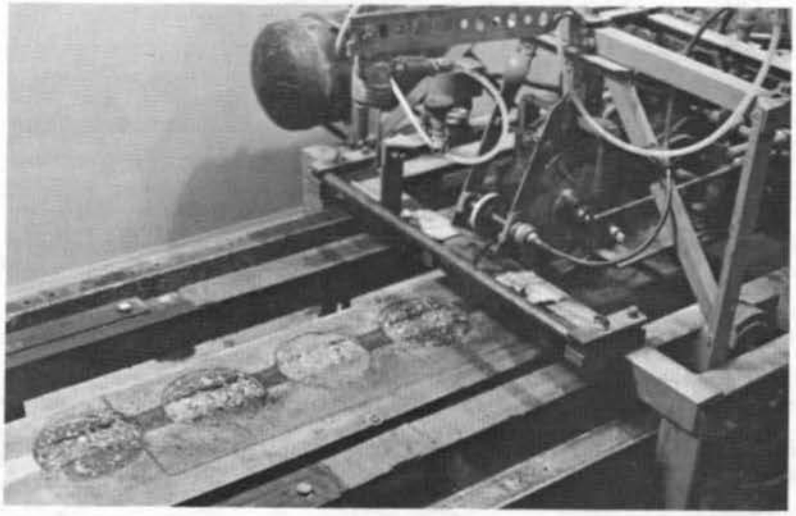

Fig. 30. Trafficability simulator with specimens in process of testing.

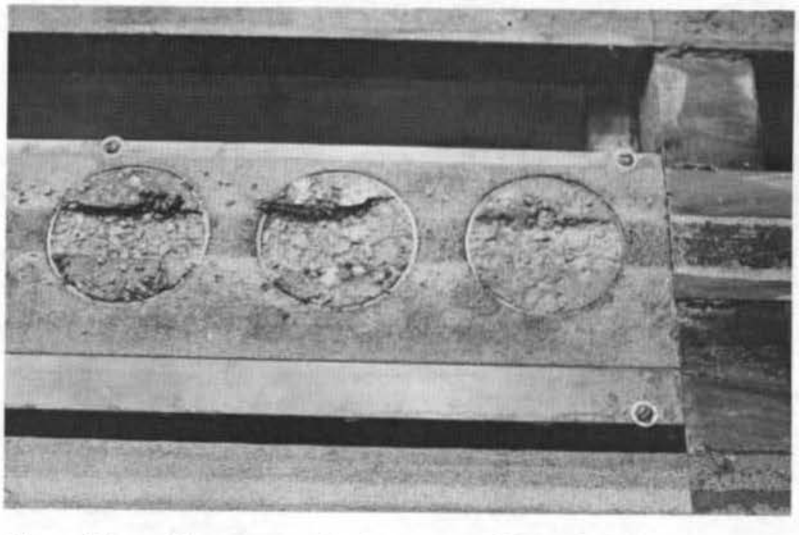

Fig. 31. Closeup of three trafficability simulator test specimens following failure.

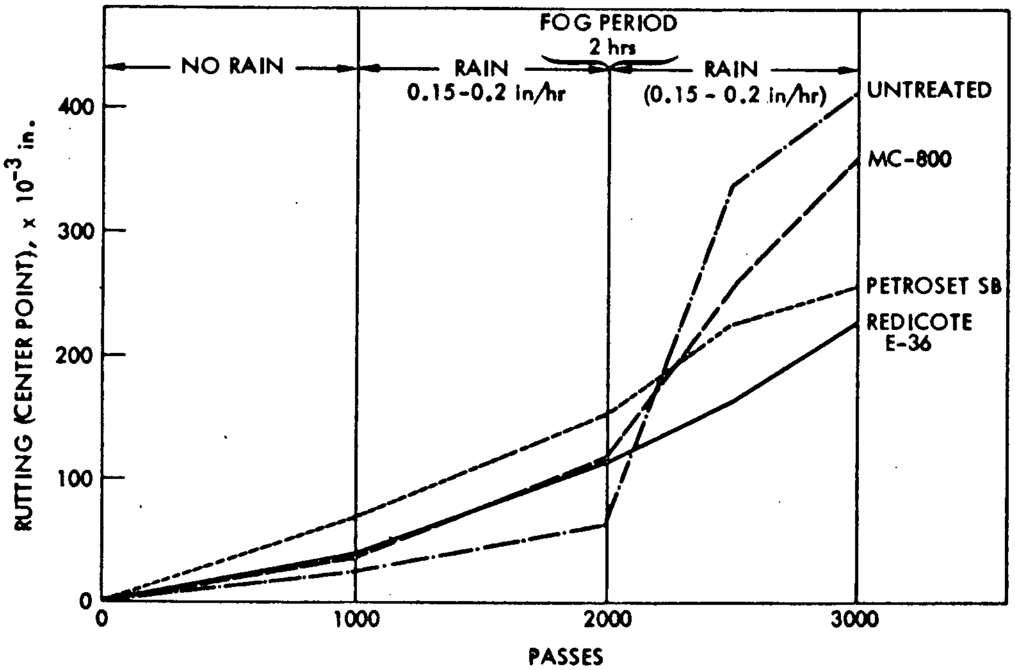

Fig. 32. Trafficability simulator test results. Generalized test environmental conditions noted at top of figure.