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FINAL REPORT

MISSION-ORIENTED DUST CONTROL AND SURFACE IMPROVEMENT PROCESSES FOR UNPAVED ROADS

Principal Investigator
J. M. Hoover

Contributors
J. M. Pitt M. T. Lustig
D. E. Fox

May 1981

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Department of Transportation,
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ERI Project 1308

DEPARTMENT OF CIVIL ENGINEERING
ENGINEERING RESEARCH INSTITUTE
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PURPOSE AND OBJECTIVES

Six subject areas prompted the broad field of inquiry of this mission-oriented dust control and surface improvement project for unpaved roads:

- DUST--Hundreds of thousands of tons of dust are created annually by vehicles on Iowa's 70,000 miles of unpaved roads and streets. Such dust is often regarded as a nuisance by Iowa's highway engineers.
- REGULATIONS--Establishment of "fugitive dust" regulations by the Iowa DEQ in 1971 has created debates, conferences, legal opinions, financial responsibilities, and limited compromises regarding "reasonable precaution" and "ordinary travel," both terms being undefined judgment factors.
- THE PUBLIC--Increased awareness by the public that regulations regarding dust do in fact exist creates a discord of telephone calls, petitions, and increasing numbers of legal citations. Both engineers and politicians are frustrated into allowing either the courts or regulatory agencies to resolve what is basically a professional engineering responsibility.
- COST--Economics seldom appear as a tenet of regulatory strategies, and in the case of "fugitive dust," four-way struggles often occur between the highway professions, political bodies, regulatory agencies, and the general public as to who is responsible, what can be done, how much it will cost, or why it wasn't done yesterday.

- CONFUSION--The engineer lacks authority, and guidelines and specifications to design and construct a low-cost surfacing system are nebulous, i.e., construct something between the present crushed stone/gravel surface and a high-type pavement.
- SOLUTION--The engineer must demonstrate that dust control and surface improvement may be engineered at a reasonable cost to the public, so that a higher degree of regulatory responsibility can be vested in engineering solutions.

Originating from the above subject areas were three primary questions:

1) What is an acceptable, easily measured, and quantifiable level of dust control which will lower dust emissions outside the Right of Way (ROW) to levels acceptable to the public, the engineering profession, and regulatory agencies?
2) What products and techniques can be utilized, and demonstrated, to decrease (and/or eliminate) exterior ROW dust emissions?
3) What will such techniques cost the public?

The following objectives have arisen from the preceding subject areas and questions, as being desirable for implementation in a mission-oriented project on dust control and surface improvement processes for unpaved roads:

1) Quantify minimal levels of dust within the ROW, which will lower exterior ROW emissions to acceptable levels.
2) Identify current practices producing economically acceptable levels of dust abatement.

3) Identify products and techniques from prior or ongoing research which have the potential of achieving acceptable levels of dust abatement.

4) Plan, design, and construct a series of in-place field experiments and demonstration test sections in four to six geographic, geologic regions of the State of Iowa.

5) Evaluate materials and construction costs, performance, and potential cost-benefits of all field demonstration test sections.

PREVIOUS STUDIES

Gravel or crushed stone surfaces have been a significant part of U.S. road and street systems for the better part of a century [1]. Since traffic-generated dust from aggregate-surfaced roads involves public economics and environmental quality, as well as occasional irritation to the public user, highway engineers have sought the cure-all for dust control and surface improvement. As early as 1909, the "Office of Public Roads" suggested clay-bound stone as the surfacing for roads in order to alleviate dusting and raveling [1]. Portland cement and asphaltic concretes further stimulated technical solutions to mud, dust, and surface improvements. Historically, however, the combination of high initial costs and low traffic volumes did not provide sufficient cost-benefits, a situation which has not significantly changed. Short-term relief from dust, raveling, and washboarding of aggregate-surfaced roads has thus been accomplished through trial and error technology by use of a variety of palliatives and additives, such as calcium chloride, asphaltic compounds, oils, and lignins [2,3]. Such methods have generally been limited in scope and success, with the vast majority of unpaved roads receiving only intermittent blading and occasional aggregate replacement.

In the past ten years, increased public awareness of environmental pollution, conservation of natural resources, and increased user costs have occasionally spawned renewed interest in the status of low-volume, aggregate-surfaced roads. Since 1975, the Transportation Research

Board has sponsored two international conferences on low-volume road technology [4,5].

In 1978, Iowa's 99 county secondary road departments spent $32,267,661 for aggregate replacement, a condition due in large part to traffic abrasion losses from crushed limestone [6,7]. Loss of aggregate in the form of dust produces an unsightly nuisance, as well as a safety hazard due to impaired visibility. In addition, recent studies by a task force of the United Nations cited this type of particulate pollution as a human health hazard [8].

Iowa Highway Research Board Project HR-151 quantified dust sources and emissions created by traffic on unpaved roads and identified several possible solutions for low-cost dust control and surface improvement [6]. Average dust generation from unpaved roads was found to be 1 ton/mile/year/vehicle of average daily traffic within a 1000-ft-wide corridor centered on the roadway. Over half of the dust generated from limestone-surfaced roads was calcium carbonate, the major mineral of limestone.

Stabilization of in-situ materials has long been recognized as the most promising method of achieving dust abatement and surface improvement within reasonable economic constraints for unpaved low-volume roads. Many palliatives and additives have been used for such stabilization goals, including chlorides, Portland cement, lime, lignin, lime fly ash, organic and inorganic chemicals, and various formulations of bitumen. Flexibility of application and/or incorporation of such products, particularly with respect to labor and use of commonly available equipment, enhances applicability of stabilization for unpaved roads.

In-situ stabilization is also appealing in light of conservation of energy and re-use or recycling of materials, particularly in regard to extremely limited funding associated with more conventional high-type design and construction techniques.

Two primary application methods are commonly used for stabilization: 1) surface or topically sprayed and 2) mixed-in-place. Calcium chloride, lignin, and cutback asphalts (in the form of road oils) have long been used as dust suppressant palliatives with varying degrees of success. Advantages of initial cost, speed, and simplicity have been associated with these products [2,3,9]. However, the short effective life results in the need for repeated applications during a single season, resulting in lowered cost-benefits.

Mixed-in-depth additive treatment of in-situ road materials [2,3,9,10] not only achieves palliation, but provides improved roadway surfacing, resulting in reduced maintenance costs from continued palliative applications and/or aggregate surfacing replacement [6,7]. In addition, in-depth stabilization may provide the sub-base or base course for future higher type pavements, a benefit often overlooked in the planning programs for low-volume roads [6,7].

Within the laboratory studies of HR-151, twenty-two products, or combinations thereof, were tested as potential dust palliatives or surface improvement agents for low-volume, low-load-bearing roads. These products ranged from asphalts and elastomers, to lignosulfonates and secondary additives, to various soil-chemical additives. Over one-half of these products were recommended for project field trials, of which only six were ultimately placed in test sections in Poweshiek, Linn, and Clinton Counties for controlled experimentation. These sections involved use of MC-800 cutback asphalt, a cationic asphalt emulsion, lignin, lignin plus alum, lignin plus lime, and a residual waste product of the Chemplex Plastics Co., Clinton, Iowa. Of the remaining products recommended for field trials, two appeared most promising, i.e., Petro-D-Dust and Stypol 40-5020, a proprietary product of unknown origin, and a polyester resin, respectively. Observations were conducted on several applications of lignin as utilized by additional counties but these observations were made without benefit of control (untreated) sections.

Of the projects constructed and observed during HR-151, dusting was reduced from approximately one-third to more than 80% of that of untreated surfaces, depending on method of treatment, i.e., surface palliation, or mixed-in-place application of the various additives. Primary dust reductions occurred within 30 to 60 ft of the roadway centerline. Aggregate pullout (loose surface aggregate) was reduced to as little as one-fourth of that of the untreated soil/aggregate test road surfaces, again dependent on treatment methods, with the mixed-in-place application effecting the greatest improvement. Thus, it was illustrated that dust could be controlled, and annual aggregate replacement could be reduced by a factor of 2 to 4, the latter alone offering a potential annual cost savings of several thousand dollars per mile. Reduction of dust and aggregate losses were also coupled with significant reductions of normal weekly to monthly blade grading for the palliation sections, and generally no blade operations were required on the mixed-in-place applications, a definite maintenance cost saving.

Carbonate data from dust measurements of HR-151 indicated that lignin mixed-in-place treatment preferentially held limestone, probably due to clay migration to the surface during wet weather, forming an observable protective patina when dry [6,7]. The patina produced a slippery surface in wet weather, but the use of more limestone in the mix not only reduced slipperiness but also reduced dust, suggesting that mechanical stability and low dusting go hand-in-hand.

Comparative data from several surface-applied aggregate sections with mixed-in-place soil/aggregate sections after one year indicated that an unpaved road does not mean that it must be a major dust source. One of the surface-applied aggregate sections had a topical lignin palliative application, while several of the mixed-in-place sections had been treated with one percent lignin solids. The best mixed-in-place section lost rock at the rate of 3.3 kg/km/vpd/year, while the worst surface-applied aggregate section lost 2185 kg/km/vpd/year or more than 600 times as much [6,7]. Furthermore, the amount of stone used to construct the low dusting road equaled the amount of rock lost as dust from the worst road in 3.1 years. This would appear to be a strong economic, as well as environmental argument, for improving aggregate-surface roads by mixing aggregate and stabilizing agent. This treatment might have to be repeated every five years.

The HR-151 study also indicated that loss of limestone in the form of dust may account for up to 80% of the annual consumption of crushed stone used in the U.S. for surfacing of unpaved roads [7].

Those mixed-in-place test sections of HR-151 that showed effectiveness in reduction of dust and loose aggregate also indicated improved stability through varying amounts of compressive strength, bearing values, and deflection/stiffness characteristics.

A laboratory traffic simulator environmental test was developed during HR-151. Correlation between observed field performance and laboratory results using the traffic-simulator test were reasonably good.

A cooperative research project in affiliation with 19 chemical stabilization agent producers was undertaken in 1973 in Linn County, Iowa [11]. Volumetric dust sampling measurements were made on six of the fifteen test sections. Five of the six sections were mixed-in-place treatments utilizing 4- to 6-in. depths of the existing crushed limestone road materials coupled with lignin, lignin plus a herbicide, two cationic emulsions, and a proprietary chemical termed Kelpak. None of the mixed-in-place sections were provided with a seal coat or other form of surface. The sixth section was a surface-applied palliative of calcium chloride. The dust measuring unit was mounted 6 ft behind the right rear tire of the vehicle, about 1 ft above the roadway, and all measurements were taken at a constant vehicle speed of 30 mph.

Several weeks after construction, the lignin and lignin plus herbicide sections produced less than 10 lbs of dust per million cubic ft of air. Both cationic asphalt emulsion sections produced less than 3 lb/million cubic ft of air, though prior to construction one of these sections showed in excess of 55 lb. The proprietary chemical produced a reduction of about 50% from the 13 lbs of dust/million cubic ft of air within the control (untreated) section.

Approximately one year after construction, the lignin, lignin plus herbicide, and both cationic asphalt emulsion sections received an asphalt surface. Just prior to surfacing, each was producing significantly less dust than their respective controls, with the emulsions showing the greatest amount of continued control. At the same time, the proprietary chemical was producing dust about equivalent to its control.

Measurements were periodically obtained from the calcium chloride palliative and an adjacent control section. Initially, the treated and control sections produced about 12 and 27 lbs of dust/million cubic ft of air, respectively. Following several weeks of dry weather, the control section had increased to about 54 lbs of dust, while the chloride treatment increased to only 14 lbs/million cubic ft of air. However, in less than six months, effectiveness of the chloride palliative was negligible.

Laboratory tests, including moisture-density, unconfined compressive strengths, freeze-thaw, erosibility, trafficability (as developed under HR-151), and Iowa Continuous K-Tests, were conducted on the 15 untreated and treated soils. The latter test is a patented quick test for determination of shear parameters cohesion and angle of internal friction, vertical deformation modulus, and lateral pressure ratio (an indicator of lateral stability) [12,13]. Field performance, in addition to dust levels, was monitored with Benkelman beam deflection and stiffness evaluations and spherical bearing value tests, as well as subjective observations. After six years of monitoring, the mixed-in-place sections consisting of cationic asphalt emulsions, lignin plus lime, lime, and lime-fly ash, have shown quite adequate field performance under a seal coat surfacing, with virtually no dusting. A similarly placed calcium chloride section has indicated small quantities of deterioration. Similarly constructed proprietary additive sections have indicated little long-term benefit.

As with HR-151, the Linn County studies have indicated the superiority of mixed-in-place versus topically-applied palliative techniques.

In 1948, the Iowa County Engineer's Association initiated a program that was purported to provide a surfaced road to every farm home in the state within 20 years [14]. Dustless surfacing of secondary roads appeared feasible and easy to maintain in the future. A number of sections were constructed, consisting of various combination ratios of gravel, silt, and clay coupled with sodium and calcium chloride treatments. As was noted at time of construction, all sections were in good condition, though a 3 in. macadam section was not too smooth. The chloride sections produced hard base courses, though their surfaces became slippery following a rain.

In an American Road Builders Association publication, A. W. Johnson presented several road surface stabilization methods for soil materials ranging from coarse granular to clayey soils of high plasticity [15]. Products included chloride salts, road oils, and cut-back bitumens. Application techniques ranged from surface-applied to mechanical blending. Coarse granular materials suggested chloride salts with mechanical blending. Fine granular soils were recommended for stabilization with or without mechanical blending when chloride salts, road oils, or cut-back bitumens were the additives. Mechanical blending was recommended for chloride salts in silts having some cohesion, but where cohesion was absent, the soil should have a mechanically stabilized surface with chloride salt. Mechanical blending with a chloride salt was recommended for clayey soils of low plasticity, but high plasticity clays should be covered with a mechanically stabilized granular surface containing an effective chloride salt. For dust control of unsurfaced roads, road oils and bituminous surface sprays were recommended in arid regions, calcium chloride in humid regions.

A study conducted by the Swedish Royal Institute of Technology [16] compared calcium and magnesium chloride as dust palliatives. Since magnesium chloride can form a solution with smaller amounts of water than can calcium chloride, it was found that 18% more magnesium chloride was needed than $CaCl_2$ in order to achieve equal amounts of solution for equal lengths of effective time. No significant differences were found in general corrosive effects, except that magnesium chloride was more aggressive to concrete. The author concluded that calcium chloride was more acceptable as a dust binding agent than magnesium chloride.

In a study conducted in Seattle's Duwamish Valley, Roberts [17] reported that dust emissions on 19 miles of gravel roads and 110 miles of dusty paved roads contributed 2700 tons/year of particulates, of which 700 tons were of a particle size of less than 10 microns (0.010 mm). It was suggested that paving of gravel roads having an average daily traffic (ADT) over 15 was the least costly method for reducing particulates, and was a good investment when the traffic exceeded 100 ADT. Paving or oiling the roads was estimated to produce benefits of nearly $3.9 million yearly in household cleaning, health care, vehicle operation, sewer and road maintenance costs, coupled with increased property values.

In 1975, the Taylor County Engineer T. R. Blunck reported on three test sections utilizing 0.75, 1.00 and 1.25% by soil weight of Bindtite, a lignosulfonate, constructed in 1973-74 [18]. The sections ranged from 1/4 to 1-1/4 miles in length, and prior to treatment were experiencing complaints of dust, potholes, washboarding, frost heaving, and general deterioration of the surface. Calcium and sodium chlorides as well as lignins were originally considered for the test sections. Sodium chloride was discarded due to lack of experience within the area. Calcium chloride was discarded due to FOB job site costs being approximately twice that of the lignin. Application rates of the chosen lignin were determined on the basis of HR-151 studies, without field or laboratory testing. Pre-construction consisted primarily of blade dressing the roadway shoulders and ditch lines and reclaiming surface rock lost to traffic. Ultimately scarified and mixed to a compacted depth of six inches, the lignin treated bases did not receive a seal coat surface until the summer of 1975. All sections remained nearly free of dust, no pothole or washboarding problems developed, and the surfaces remained relatively dry and solid after each rain. On the basis of a 1% lignin solids content, the cost of materials, labor, and equipment was $6600/mile for a 6 in. stabilized base. With application of a single surface, total cost was approximately $11,000/mile. Blunck concluded that "this appears to be an economical way to improve a road with local manpower and equipment and still provide the type of roadway the public is demanding."

Roads and Streets magazine [19] described a program of dust control on heavily traveled, gravel-surfaced plant haul roads. Using a proprietary product called Coherex applied as a dust palliative, a savings was provided in terms of truck time, labor, and use and maintenance of blade graders when compared with use of water only for dust control.

The U.S. Forest Service utilizes emulsified asphalts for dust control on gravel roads through either surface treatment or modified blade mix operations [20]. By binding in-place surface aggregate materials with emulsions, both cold mix operations and lack of fuel eligible volatiles were found advantageous in energy conservation.

In 1976, Sultan [21] reported preliminary evaluations of an Arizona study on 46 commercial chemicals tested under both laboratory and field conditions. Portions of this study were patterned after IHRB Project HR-151. The study was conducted on two soils and involved tests related to control of dust from a nontrafficked, wind erodible dune sand and a gravel-surfaced, granitic subgrade soil roadway. Simulated wind erosion tests at 45 and 90 mph were performed on the untreated and treated dune sand following cycles of freeze-thaw, wet-dry, and rain-dry on specimens cured at 50% relative humidity for 1, 3, and 7 days. Laboratory traffic abrasion tests were performed at 30, 45, and 60 psi contact pressure on the granitic subgrade soil, untreated or treated with the various chemicals as either a surface palliative or mixed-in-place application, following similar cycles and curing periods as in the wind erosion tests.

Eleven chemicals were selected from laboratory tests for wind erosion evaluation on the dune sand. Five chemicals were selected as dust palliatives for the gravel-surfaced granitic subgrade soil, while seven were selected for mixed-in-place application. Of the latter seven, five were lignosulfonate-based, and consequently only one of the five were evaluated in the field.

Preliminary field results indicated that five of the eleven wind erosion control agents were performing satisfactorily at application costs of less than 9 cents/sq yd. These products were predominantly a latex emulsion, oils, a lignosulfonate, and Coherex. Of the five dust palliative chemicals, an oil and a lignosulfonate ranked as first and second within the preliminary performance ratings. Preliminary results from the three mixed-in-place chemical applications ranked a cationic asphalt emulsion first, the lignosulfonate second, and an oil third. Though the mixed-in-place field trials appeared as having less direct correlation between laboratory tests and field performance than the wind erosion control agents, treatment costs were indicated at less than 60 cents/sq yd.

A research project completed at Iowa State University for the Federal Highway Administration, U.S. Department of Transportation, involved a study of about 30 chemicals, as compaction aids for fine-grained soils obtained from locations over the contiguous 48 states [22]. While the effect of the chemicals on compaction was a prime objective, effects of the chemicals on such properties as shearing strength parameters, bearing capacity, various moduli, Atterberg limits and other engineering and physico-chemical properties were also studied.

Though such analyses as freeze-thaw elongation, trafficability, or erosibility were not performed as a part of this research, several of the chemicals appeared suitable as mixed-in-place surface improvement agents, based on the aforementioned tests. Field trials involving two of the chemicals (termed Claset and Thinwater) and an identically constructed untreated control section were conducted in Marion County, Iowa, through cooperation with A. B. Davis, County Engineer. In general, both laboratory and field treatments of this glacial derived A-7-5 soil improved moisture-density relations. As predicted from lab tests, however, in-situ strength and stability properties of the soil were not improved over a 10-month period of monitoring. Both products appeared to act as dispersants, as observed through textural as well as physical parameters; i.e., the products produced physico-chemical reactions within the soil aggregations (clods), which caused the aggregations to disperse into their more natural finer grained particle sizes. Both products are described in Volume I of Reference 22.

In a further field trial with a highly calcitic SC soil near Villanueva, New Mexico, 0.10% by dry soil wt of a proprietary product termed Petro-S was incorporated into the upper 6 in. of an unpaved primary highway. As anticipated from laboratory tests, the product did not increase density from that obtained in an identically constructed control section, but substantially reduced optimum moisture content for compaction. One month after construction, the treated-base bearing capacity was in excess of five times that of the untreated control. From all lab and field evidence, it appeared that a texturization of the soil was achieved; i.e., an alteration of the materials into cluster units which produced size variances with apparent well-graded particle size distribution.

The dispersion, flocculation, and texturization characteristics noted in the two preceeding FHWA project [22] examples are of importance in understanding the required mechanisms for an effective dust palliative. Large particulates will be airborne only short distances from their source, while very fine particulates (such as silt, clay, and colloidal sizes) may be airborne extremely long distances. Masses of finer particles generally show increased surface area coupled with larger potential for physico- and surface-chemical activity, including electric potential at the faces of the particle, plus capillary attraction between two or more particles due to minute quantities of water (sometimes termed capillary cohesion). Variations in physico- and surface-chemical activity change, due to even minor differences in mineralogical composition. The Clapak and Thinwater used in Marion County interrupted the continuity of the clay-water bonding, decreasing sliding friction between particles, and thus reducing any flocculant effects. If such response would occur with a chemical dust palliative, further dispersion of aggregated fine particles would result in increased particulates further from the source. An effective chemical dust palliative must therefore provide significantly increased physico- and surface-activity in order for the fine particulates to remain in an aggregated form under adverse conditions of both weather and traffic. For example, calcium chloride and lignins improve capillary cohesion so long as rain does not occur. When mixed-in-place, the lignins and calcium chloride have already been noted as showing greater longevity.

As will be shown later in this report, the electric potential created by varying the type of emulsifier within an asphalt emulsion produces variations in strength, as well as potential effectiveness as a dust stabilizer for a given soil.

In addition to Petro-S, Coherex also indicated a possible use as a dust palliative from the FHWA study [22]. While Coherex appeared less susceptible to water (particularly after 7 days curing) it also appeared somewhat more susceptible to mineralogy and the accompanying physicochemical properties of the soils originating therefrom.

A publication by the Road Research Laboratory, Crowthorne, England, indicated that the quantity of fine silt and clay lost from an unsurfaced road could be of the magnitude of 60 to 300 Mg per kilometer (100 to 500 tons per mile) per year [23]. They suggested that the objective of treating an unpaved road was "to cause the finer particles, which when detached from the road become the dust, to be bound firmly with the other constituents of the road material." Where a road had a stable base, a thin wearing course was considered adequate. However, adequate base stability did not appear in most instances, particularly for roads carrying heavy traffic, in which cases treatments were considered effective for varying lengths of time, and cost of treatment had to be weighed against its useful life.

The RRL [23] classified dust-laying agents under the following:

1. Water, fresh or sea.
2. Deliquescent and hygroscopic chemicals.
3. Other inorganic chemicals.
4. Organic, non-bituminous binders.

5. Tar and bituminous materials.

Several light applications of water were looked upon as providing short-term relief, with seawater being more effective than fresh water due to inclusion of deliquescent chemicals, primarily magnesium chloride. A waste product of the salt industry, brine liquor, was considered more effective than seawater since it contained larger quantities of magnesium chloride.

Calcium, magnesium, and sodium chlorides were considered the most common deliquescent and hygroscopic chemicals [23]. Deliquescent salts absorb atmospheric moisture, liquifying when the vapor pressure of their saturated solution is less than that of water in the atmosphere. Calcium chloride was cited as ceasing to absorb moisture when the relative humidity was less than 30 to 40%, a condition which can occur at temperatures ranging from near freezing to near 100 °F. A hygroscopic salt such as sodium chloride was noted to absorb water only when the humidity exceeded 75%.

Salts were noted by RRL [23] for both surface or in-depth application. Water spray was recommended prior to application of dry, flake form salts, in order to ensure adequate moisture. Penetration was noted as usually less than 1/2 in. Mixed-in-depth applications were recommended after scarification to 3 to 4 in., with additional soil added if improved mechanical stability was needed. Spread rates were shown to vary from 1/2 to 2-1/2 lb/sq yd depending on soil, climate, and intended purpose. The cost of calcium chloride treatment per mile at a 21-ft width and 2 lb/sq yd application rate was about £165 exclusive of processing, with 1/2 lb/sq yd added treatment twice a year creating additive costs only, of about £1000 (about $2500) over a 10-year period.

Sodium and potassium silicates were noted to precipitate aluminum or calcium silicates. When combined with solutions of aluminum or calcium salts, the precipitates formed insoluble binding agents [23]. Disadvantages of such techniques are chemical costs as well as a two-stage application.

Organic nonbituminous binders included a variety of industrial waste products, animal fats, and vegetable oils, generally available in limited quantities, or near the source of manufacturing [23][*]. Of the industrial products, RRL considered sulphite liquor (one form of lignin) and molasses residues the most important. Gradation of the road material indicated clay should be present if sulphite liquor was to be an effective dust-laying agent.[†] Surface applications were noted as about 0.5 gal./sq yd in liquid form, or 1 to 2 lb/sq yd in dry powder form. In-depth application and processing of sulphite liquor appeared to be more satisfactory due to the mixture remaining slightly plastic for a period of time. This allowed continued reshaping and traffic compaction reducing voids and provided greater strength and less rain penetration. As with use of salts, RRL noted that surface-applied sulphite liquor may require additional treatments due to rain-destroyed binding action.

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[*] Several such products were also noted within the HR-151 study, including lignin, Residual, and Petro-D-Dust [6].

[†] Similar lignin effectiveness was also noted where fines were present in the roadway mix within HR-151 [6].

Cost of a 0.5 gal./sq yd surface application of the liquor only, per mile length and 21-ft width, was noted as about £350 ($800-$900).

Tars and bitumens, when combined with varying quantities of distillates, produce a wide range of viscosities for dust-laying purposes [23]. Where the road base is adequate for traffic, a surface treatment of such products may consist of either a sand-blotted application, or a prime followed by a sand-blotted application. Either may be short-lived, but can be extended with a seal coat. Mixed-in-depth treatments are best achieved where the roadway material gradation is already mechanically stable. Low viscosity binders appeared to provide the best coatings at normal ambient temperatures. Where the road materials contained fines, particularly clays, the fines were noted to absorb the binder, reducing the fines' natural cohesion, and necessitating binder contents of 5% or greater.

The RRL noted little success where bituminous emulsions were utilized for surface dust-laying, primarily due to a quick break occurring upon contact with the dust, prior to penetration of the surface [23]. Slow breaking emulsions were noted as the most satisfactory, with a water dilution of the emulsion providing a more satisfactory distribution of the bitumen. Regardless of type of bituminous binder, the cost was noted as high.

According to the RRL, the cost of controlling road dust is dependent on climate, materials available, and economics of the region [23]. In an area where materials are susceptible to freeze-thaw and/or high water tables, the cost will be high. Where materials are more frost stable or drainage is good, reduced thicknesses of construction are possible. From the soil materials standpoint, low plasticity, low fine content gravels are best, and more amenable, to low-cost dust-laying techniques. Within some areas therefore, dust-laying may be more expensive and require greater maintenance than adopting higher type roadway design and construction techniques.

Governmental directives have accelerated the rate of air quality monitoring and control [24,25]. McKee [26] indicated evidence exists that suspended particulates have the potential to alter weather patterns and affect human health. A study commissioned by the American Petroleum Institute in 1971 estimates that soil dust from tillage and unpaved roads contributes approximately 10% of the annual total of particulate emissions on a global scale [27].

Literature concerning atmospheric pollution from dust appears to center on two areas of study: 1) atmospheric modeling and prediction, and 2) field measurement and quantification. Several studies have proposed mathematical models for generation and distribution of particulate emissions from various sources [27,28]. Becker [28] examined a Gaussian plane model applied to dust generated from unpaved roads in Iowa and Kansas. Included were limited field measurements using a high volumetric sampler and mechanical analysis of collected particulates. Becker concluded dust levels of 60 mg/cu m were not exceeded outside limits of approximately 20 ft from either side of unpaved roads. Robinson and Robbins [27] utilized digital computer modeling to estimate global particulate emissions from various sources including industry, petroleum, mining, and agriculture. This work resulted in an estimate of 2×10^9 tons/yr of dust from agricultural tillage and unpaved roads on a global scale. However, they acknowledged that the reliability of these estimates was subject to criticism due to lack of field verification.

Several investigators [29,7,30] have published results of dust quantification research based on field measurements. Smith et al. [30] investigated the effects of agricultural and climatic variables on particulate deposition in several locations across the U.S. Average ambient dust level determined from this work was 1.5 lbs/acre/day, while a known dust bowl condition produced levels of 14 lbs/acre/day. This study has been useful in determining ambient air quality levels for different regions of the country. Other researchers have focused attention on the contribution of unpaved roads to the level of particulates in the atmosphere. Hoover et al. [6] found that stationary collectors adjacent to unpaved roads provided reliable measurement of dust levels in a range of 6 to 110 lbs/acre/day. Handy et al. [7] provided an analysis of dust level versus distance from the centerline of unpaved roads, indicating that dust deposition decreased linearly with the logarithm of distance from the source. The study also concluded that the majority of particulate emissions from unpaved roads, approximately 63 lbs/acre/day, were confined to the public ROW.

While dustfall has long been considered a nuisance, several authors have expressed concern for human health with regard to dustfall levels. Battigelli [31] documented several hypotheses for the mechanism of particulate human respiratory system interaction. This work also brings to light the importance of particle size, in that smaller particles become trapped in the lungs due to the inability of the respiratory system to filter all particulates. A report by the United Nations concluded that particles smaller than 3 microns in diameter have the greatest frequency of being retained in the lungs and in cases of extreme exposure cause silicosis [8].

A recent Environmental Protection Agency report documents emission rate estimates of particulates from open sources in the U.S., as based on emissions and sources noted within the published literature [24]. Sources and their estimated rates of emission, in millions of tons per year, were unpaved roads, 3×10^2; construction activities, 3×10^1; cropland wind erosion, 4×10^1; paved roads, 8; wildfires, 3; agricultural tilling, 3; and mineral extraction, 3. For comparison, point sources were estimated at about 20 million tons per year. The study concluded that the major contribution to total suspended particulates (TSP) was soil-like material, with unpaved roads, especially in cities, and construction activity as the primary sources. In order to reduce TSP levels, the report generally recommended paving roads and controlling emissions from construction. It was shown that the paving of unpaved roads would cost "--an average of less than $0.01 per pound--." However, estimated costs of control for Iowa's unpaved rural and municipal roads were respectively $0.025 to $0.030 and $0.015 to $0.020 per lb. It was noted for comparison, however, that costs of point source emissions were approximately $0.01 to $0.18 per lb. This report implied that emphasis be placed on open source emissions before further industrial source controls are considered. Midrange cost-efficiency ratios for various unpaved road treatments are noted in the following table:

Control Method	Estimated Cost-Efficiency Ratio, Total Annualized Cost, \$/mile/% reduction	Treatment Efficiency, % Reduction of emissions
Paving	\$89	86 to 99.98
Oiling	2906	50 to 98
Watering	1302	40
Calcium Chloride	491	60
Speed reduction, 40 to 30 mph	1.096 × ADT	25 to 60
Speed reduction, 40 to 20 mph	3.355 × ADT	50 to 84

Total annualized cost was defined as "--the average yearly cost of items which involve repeated yearly expenditures, such as maintenance, plus a yearly pro-rating of costs which do not, in fact, occur yearly, such as initial capital investment." All costs were adjusted to levels prevailing in mid-1977.

Critique

Road dust research has been active for several decades, but it has been only in the past few years that environmental concerns have emphasized the need for control and have awakened an urgent public demand for control. Thus, despite all of the money and effort spent in the past, the road dust problem looms worse than ever. The reason appears to be twofold.

1) Quantitative measurements of dust from roads have been practically nil. Yet it is quite impossible and borders on the absurd to assess the economics and lasting value of dust palliation methods without monitoring the dust. Furthermore, it is not sufficient to merely measure dust from the treated section; a competent evaluation requires the use of control sections that are identically constructed except for the single variable, nontreatment, because only then can that variable be evaluated. Thus, to evaluate a palliative it is not sufficient to mark off an adjacent section of road and label it "control," if the test section is to be scarified, mixed with palliative, and recompacted, because these other parts of the treatment should also affect performance. Where proper controls have been used, as in HR-151, some surprising conclusions result; for example, (a) the discovery that mixing in rock alone, without any chemical additives, is an effective palliation measure, and (b) some chemicals are relatively ineffective as surface treatments.

2) The second major problem common to all research is implementation of the results. This problem is particularly severe where implementation requires effective communication to a multitude of responsible practitioners--in this case practicing state, county, and municipal engineers. The problem is communication; written reports are not sufficient. In the past, communications also depended on salespersons with vested interests. Unfortunately, until a technology becomes

well established, salespeople may not always act in the best public interest.

CURRENT PRACTICE

Current practice varies from those recommendations and conclusions noted in the previous section of this report, to nonexistent. Dominant surface-applied palliatives, in a generalized decreasing order of usage, appear to be calcium chloride and various road oils (including waste oils), followed by localized usage of sodium chloride, lignosulfonates and emulsified asphalts.* Application rates appear more a matter of judgment, often at rates suggested by the supplier, even though criteria for application of such products may be specified by the Iowa Department of Transportation [32]. A supplier of aqueous calcium chloride (35% $CaCl_2$ in a water solution) suggests an application rate of 1/3 gal./sq yd. Lignin suppliers often recommend up to 1-1/2 gal./sq yd depending on lignosulfonate solids content. Suggested applications of oils may range up to about 0.25 gal./sq yd.

Frequency of application of a palliative ranges from an annual oiling, to specific programs of twice a season for calcium chloride and/or lignin, to strictly on demand. Many counties have a program of palliation based on an annual petition and payment by the individual property owner. In some areas the property owner is allowed to contract directly with a palliative supplier for placement of a product on the roadway adjacent to his/her property. Some counties have designated locations for application of a palliative, without cost to the adjacent

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*Major price increases in bituminous products since January 1981 may significantly affect further future usage of road oils. One county in Iowa has used oiling for many years and is presently attempting to abandon such a process.

landowner, as based on safety aspects and traffic counts. For example, in such locations where sight distances and various safety hazards occur, and where vehicular traffic is in excess of 200 ADT, Linn County applies calcium chloride at a rate of 8 dry tons/mile in an aqueous solution of 4000 gal./mile. Cost of the 1981 chloride treatment within Linn County is projected at about $195 per dry ton, or $1500-1600 per mile [33].

Though the practice has significantly diminished in Iowa, particularly over the past decade, calcium chloride has been mixed with granular surfacing materials at the quarry or gravel pit, the combined product then transported to the surfacing project site, spread, and compacted. Periodic light applications of calcium chloride to the surface then provide additional dust control. In general, this process has a greater span of effectiveness since it is less susceptible to leaching, particularly where the aggregate is well-graded and a tight, mechanically stable mix is attained. Such processing is provided for within Iowa DOT specifications [32].

The City of Des Moines has been using a CSSI emulsified asphalt palliative treatment for several years. Inspection of several of these projects indicated primary benefit where the surfacing materials were sandy to mechanically well-graded. The generalized processing basically involves the development of about a 2-in. in-depth palliation. Initially, the roadway is tight bladed. This is followed with a 9:1 water dilution of emulsion, fog sprayed at an application rate of about 0.1 to 0.15 gal./sq yd. One to several re-applications of the 9:1 dilution may be done periodically, each preceeded by a tight blading.

Following the fogging(s) of the 9:1 dilution and an additional tight blading, a 3:1 water dilution of the emulsion may be applied at the same rate. Where a mechanically stable surfacing material was apparent, after several months the surface was still tight enough to visually identify traffic smoothing of aggregates. In late 1977, it was indicated by an official of the City of Des Moines, that the cost per application was on the order of 2-1/2 to 3 cents/sq yd, including materials, equipment, and labor.

Prices of surface aggregates vary considerably throughout the state, depending primarily on source, processing, and transportation distance. Arbitrarily assuming a price of \$4.00 per ton delivered, the cost of aggregate per mile, at a spread rate of only 1000 tons per mile, would be \$4000. If it is also assumed that aggregate replacement is accomplished every three years, the cost per year would thus be about \$1300 to \$1400, a cost not totally dissimilar from the Linn County projections of palliation with calcium chloride.

HR-151 showed that the simple addition of mixing limestone aggregate into the roadway surface reduced dusting by a factor of 10 [8,9]. In-depth addition of one percent lignin further reduced dusting by one-half, but was of only short-term benefit when surface applied. Furthermore, the amount of stone used in construction of the lowest-dusting road within HR-151 equaled the amount of rock lost from the worst-dusting road in 3.1 years.

Thus, when coupling aggregate replacement costs with environmental considerations, there appears a strong economic discussion for implementing improvement of aggregate-surfaced roads by mixing aggregate and a stabilizing agent even though the treatment might have to be repeated every five years or so.

SELECTION OF DEMONSTRATION SECTIONS

Demonstration sections were the major impetus of this project and the primary evaluation mechanism for the research objectives. Demonstration sections were looked upon as potentially providing the intermediary knowledge between research already accomplished and interim specifications, which in turn could be used to assist in defining dust regulatory responsibilities. In addition, demonstration sections were to assist in furthering the development of design and construction of low-cost surfacing systems, i.e., something between the present crushed stone and gravel surface and a high-type pavement.

Demonstration sites were to be selected as representing geographic and geologic regions of the state, including parent material soils, soil association areas, and crushed stone or gravel sources. Input to the selection was attained from literature sources, as well as discussion with Iowa Geological Survey and Iowa DOT personnel, to ensure general areal representation of both soils and aggregates.

Six primary regions and their generalized soil/aggregate characteristics were initially selected:

1) Northwest Iowa: Sioux-Plymouth-O'Brien-Cherokee counties, loess/gravel.
2) Southwest Iowa: Pottawattamie-Shelby-Cass-Montgomery-Adams counties, loess/limestone.
3) Central Iowa: Story-Polk-Warren counties, glacial till/ some loess/limestone-gravel.

4) North Central Iowa: Kossuth-Hancock-Humboldt-Wright-Franklin counties, glacial till/gravel-limestone.

5) Northeast Iowa: Bremer-Black Hawk-Buchanan, glacial till/loess/limestone.

6) Southeast Iowa: Keokuk-Wapello-Jefferson-Washington counties, loess/glacial till/limestone-dolomite-chert.

Site selection was strongly dependent on a county's willingness to incorporate demonstration section construction into its respective scheduling and budgets. In addition, selections involved consideration of balancing such factors as metropolitan versus rural counties, availability of county equipment,* the general potential for county participation, and site factors such as profile, cross-section, traffic, topography, soil series, and aggregate characteristics. Therefore, one or more counties within each region were contacted by letter, explaining the objectives of the project and requesting a meeting with the County Engineer and Board of Supervisors. (The latter was requested as a means of illustrating the problem and explaining what accomplishments might be produced through the project.) Each presentation involved a showing of the ISU educational movie "Stabilization--Holding the Roads," a discussion of project objectives, a request for participation, and generally answering innumerable questions, many of which could only be answered through the completed project.

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*It was desirable that demonstration section construction be accomplished by county forces using their own available equipment, with project research personnel assisting in construction supervision, and all required tests prior to, during, and following construction.

Several demonstration sections were sought within each regional site. The sections were divided into three principal categories, each category utilizing the existing in-place soil/aggregate roadway material:

1) Surface-applied dust palliatives.
2) Mixed-in-place dust palliation and surface improvement products, no additional surfacing.
3) Mixed-in-place base stabilizers with seal coat surfacing.

Products for possible adaptation in each category were to be selected in conjunction with the county after each site was chosen, sampled, and design tests performed. The latter were performed with more products than would likely be placed in the field.

As might be anticipated, site selection was a slow process. However, Figure 1 and the following discussion illustrate the final participating locations:

1) Plymouth County: beginning at Iowa Highway 3, about 1/2 mile east of LeMars, continuing two miles north along the west boundary, Sec. 34, Elgin Twp. and Sec. 3, America Twp. This road services a sanitary landfill near its northern extremity.
2) Pottawattamie County: termed the Honey Creek site, county road L-19 begins at the I-29 exit, proceeds west about 1/2 mile and north about 1/4 mile, ending adjacent to a KOA Campground, Sec. 33, Rockford Twp.
3) Pottawattamie County: the 1100-ft-length Mud Hollow site beginning at the intersection with Iowa Highway 183 is located in Sec. 18, Garner Twp.

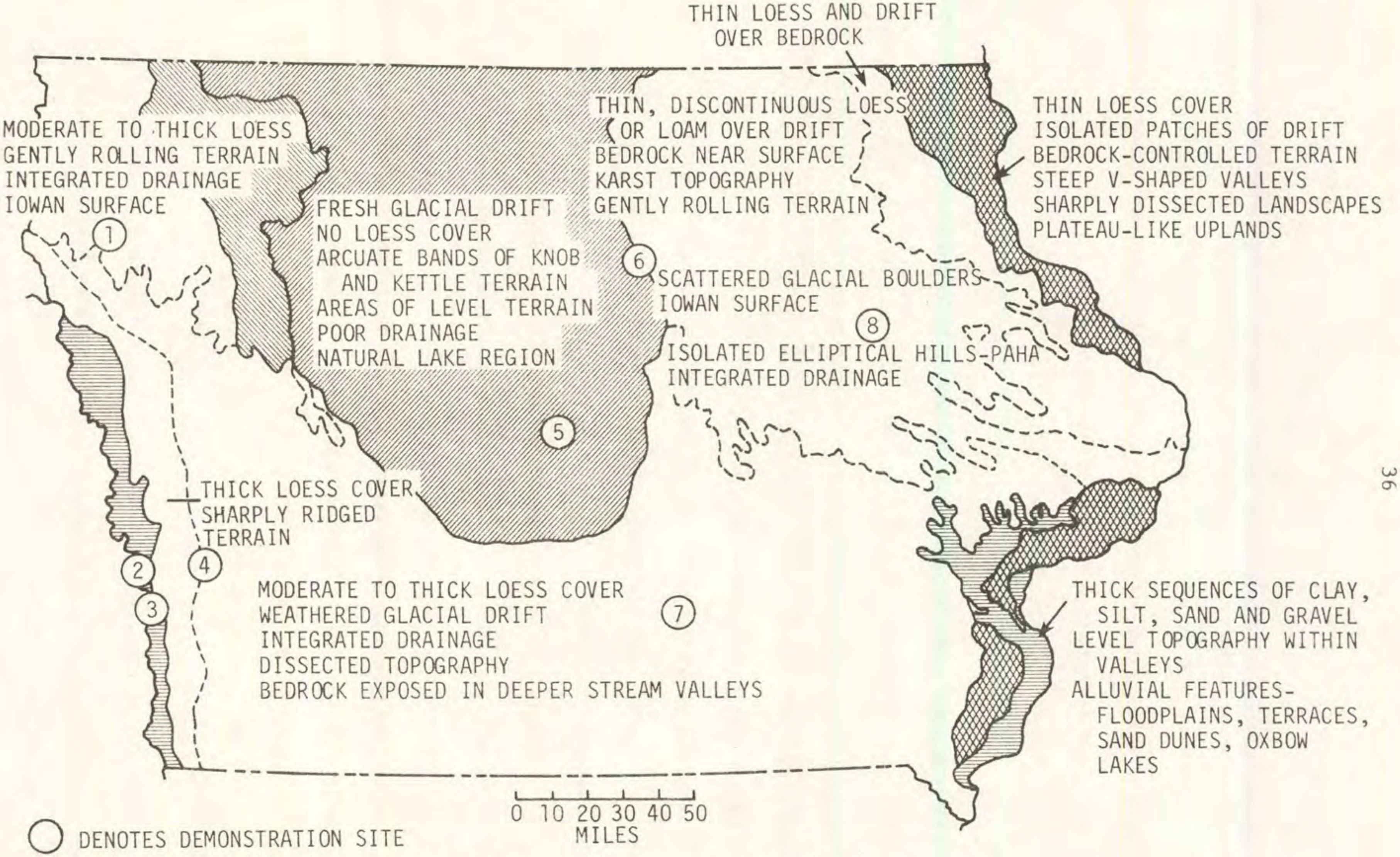

Fig. 1. Demonstration site location in relation to the Quaternary of Iowa. (Adapted from Prior[34])

4) Pottawattamie County: referred to as the Neola site, a 3/4 mile length of county road L-55, beginning adjacent to the exit of I-80, ending adjacent to the entrance of Arrowhead Park, and located in Sec. 30, Minden Twp.

5) Story County: just over one mile in length, an extension of Mortenson Road, between State Ave. and South Dakota Ave. at the southwest edge of the City of Ames. Portions of the road are under the jurisdiction of Iowa State University, the City of Ames, and Story County, though all maintenance is performed by Story County.

6) Franklin County: about one mile in length, located in Sec. 11, Reeve Twp., southeast of Hampton, providing access to several gravel pit operations 1 to 2 miles to the east.

7) Marion County: located on a portion of county road G-62, beginning near the intersection of T-17, and extending easterly, adjacent to the district shop and sanitary landfill, Sec. 29, Clay Twp.

8) Buchanan County: consisting of a one-mile long portion of county road D-47, located along the north edge, Sec. 9, Homer Twp., and intersecting with Iowa Highway 150.

All of the above sites were extensively monitored for dust, roadway samples were removed for laboratory testing, and products were evaluated for each of the three categories of stabilization. Due primarily to a change in County Engineer, no construction was accomplished within Buchanan County. Three sites were monitored for dust and roadway samples were removed for laboratory testing within Polk County. Due to various contributing factors, each Polk County site was ultimately abandoned. Sites within the Southeast Iowa region were never obtained. Responses within this region ranged from negative, to not interested, to no reply.

MATERIALS

Soils

Soil and aggregate samples were obtained to a depth of six inches from several randomly selected locations within each site. All bags of material from each site were thoroughly combined to form a representative composite sample. Table 1 presents the results of the various standard property and index tests performed on each material for classification purposes.

Examination of the AASHTO classifications indicates the variability of secondary road materials within the state. Buchanan, Franklin, and Marion sites each classified as A-2-4, rated as good subgrade materials. The Plymouth and Mud Hollow sites classified as A-4, considered to be only a fair roadway construction material. Honey Creek and Story sites could be rated as generally poor roadway soils; i.e., A-6. A high percentage of plastic fines (71% passing the No. 200 sieve) in the Neola site resulted in an A-7-5(12) classification, indicative of a very poor roadway construction material. While the range of material quality was very broad, it was also indicative of the vast range of in-situ roadway materials which many counties may encounter within their own boundaries. Therefore, the use of these materials within the research project was considered representative of a broad range of classifications which exist throughout the state. Aggregates encountered in each site's soil followed the anticipated regional geologic types previously presented, ranging from gravels to limestones.

Table 1. Properties and classification of representative roadway site soil materials.

					Pottawattamie County			
Location	Buchanan County	Franklin County	Marion County	Plymouth County	Honey Creek	Mud Hollow	Neola	Story County
Textural Composition, % by weight:								
Gravel, > 4.76 mm	20	26	35	17	23	13	10	7
Sand, 4.76 - 0.074 mm	60	51	47	42	30	26	19	47
Silt, 0.074 - 0.005 mm	8	14	10	25	31	46	33	25
Clay, < 0.005 mm	12	9	8	16	16	15	38	21
Index Properties:								
Liquid limit, %	16.1	18.8	16.6	18.5	27.2	30.8	46.4	33.5
Plastic limit, %	N.P.	14.9	16.4	16.1	11.2	28.0	25.0	17.7
Plasticity index, %	N.P.	3.9	0.2	2.4	16.0	2.8	21.4	15.8
Moisture-Density, Standard AASHTO T-99:								
Maximum density, pcf	131.5	130.0	137.0	125.4	124.8	117.9	113.5	108.2
Optimum moisture content, %	7.8	8.5	7.5	9.8	10.0	13.0	15.0	17.5
Engineering Soil Class:								
AASHTO	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-4(0)	A-6(4)	A-4(0)	A-7-5(12)	A-6(4)
Unified	SM	SM	SM	SM	SC	SM	CL	SC
Dominant Soil Series:								
SCS	Sparta	Dinsdale	Ladoga	Wadena	Sarpy	Wabash	Marshall	Clarion

Products

Following is a description of dust palliative and stabilization additives used in the laboratory studies with the various site soils:

1) Asphalt emulsion. Four cationic slow-set mixing grade asphalt emulsions were obtained from Armak Highway Chemicals Department, McCook, Illinois. Each emulsion was selected to provide a range in the zeta potential* of the emulsifying agent, a material property which influences the adhesion and coating of the soil-emulsion mixture. The following table summarizes the range of emulsion properties:

Emulsion Designation	Emulsion Type	Asphalt Content, %	Emulsifying Agent	
			Zeta Potential, Millivolts	pH
E-4868	CSS-1	61	0-5	1.7
E 65	CSS-1	60	10	varies
E 55	CSS-1	60	30	5.0-6.0
E 11	CSS-1	57	60-80	varies

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*Zeta potential is a means of identifying the electrical potential existing between colloidal particles and a bulk aqueous solution. Most soils and aggregates are negatively charged, but vary quantitatively from low to high negative values. Cationic slow set asphalt emulsions (CSS) are positively charged, but are produced with varying quantities of such charges. Thus (-) attracts (+) and hopefully the most effective marriage conditions of soil and asphalt are attained.

2) Coherex. This product is manufactured by Golden Bear Division, Witco Chemical, Bakersfield, California. According to the manufacturer's literature, Coherex is a concentrated highly-stable emulsion of petroleum oils and resins, consisting of about 60% resins and 40% wetting solution. The wetting solution keeps the petroleum resin dispersed and readily miscible with water. Coherex is primarily a palliative, coating dust particles and forming cohesive membranes that attach adjacent particles, resulting in large agglomerates. The size increase in particles immobilizes the dust and prevents it from remaining in air suspension. The resinous components provide longer palliation than conventional dust oils, gradually forming a hardened coating which becomes more permanent with subsequent applications. Ratios for all applications of Coherex to water range from 1:4 to 1:15, with application rates varying from 1/2 to 1-1/2 gal./sq yd.

3) Polybind Acrylic DLR 81-03. This product is produced by Celtite, Inc., Cleveland, Ohio. It is described as a co-polymer resin emulsion soil stabilizer and dust control agent, providing a binding effect on soil and a means of controlling erosion. It may be highly diluted with water, drying to a colorless, transparent, and flexible film. Polybind Acrylic DLR is stated as resistant to alkaline materials. It may be diluted as needed depending on application conditions but is typically applied at a rate of 40 gal./acre in a 1:20 water dilution particularly when used for hydro-mulching.

4) Amsco Res AB 1881. This product is described by the producer, Amsco Division, Union Oil Company of California, La Mirada, California, as a styrene butadiene latex "plastic" binder for demanding soil stabilization problems. The product contains 50% solids at a pH of 9.0 but is not recommended for use in mixtures where the pH is less than 6.0 due to coagulation of the latex. It is readily miscible in water, with dilutions approaching 1:50. Applications have generally been about 500 lb/acre of dry solids.

5) Ammonium lignosulfonate. A by-product of the paper pulp industry, this form of lignosulfonate was provided by Edwards Spraying and Contracting, Hampton, Iowa.

6) Type I Portland cement.

7) Fly ash. Three sources of ash were obtained for use in the laboratory studies: (a) Port Neal III, Iowa Public Service Co., Sioux City; (b) Iowa Power, Council Bluffs; (c) Ames Municipal Power Plant, Ames. The following table presents typical chemical and physical properties of the three ashes as summarized from information provided by Power Plant Aggregates of Iowa, Sioux City, and conducted by the Coal By-Products Utilization Institute, Engineering Experiment Station, University of North Dakota, Grand Fork, N.D., in accordance with ASTM designation C-618.

Property	IPS Port Neal III	Iowa Power	Ames Municipal
Silicon dioxide, %	66.0	44.6	33.4
Aluminum oxide, %	12.9	22.5	18.7
Iron oxide, %	5.8	5.6	27.5
Sulfur trioxide, %	0.68	2.56	2.93
Calcium oxide, %	10.8	20.4	10.2
Magnesium oxide, %	N.D.	3.5	1.0
Moisture content, %	0.03	0.07	0.02
Loss on ignition, %	0.06	0.53	1.74
Available alkalies			
Na_2O, %	0.18	1.19	0.41
K_2O, %	0.46	0.30	0.76
% retained when wet sieved on No. 325	30.0	21.0	23.3
Pozzolanic Activity Index:			
w/Portland cement at 28 days, % of control	75	94	75
w/lime at 7 days, psi	1385	805	1013
Autoclave expansion or contraction, %	0.174	0.12	0.024
Specific gravity	2.30	2.54	2.77

LABORATORY STUDIES

Test Methods and Results

Laboratory testing was conducted through the following generalized approaches for each of the composite samples removed from the in-place soil-aggregate surfacing of each demonstration site:

a) Particle size distribution, Atterberg limits, standard AASHTO T-99 moisture-density, and engineering classifications.

b) Based on previously conducted research for Iowa DOT (Primarily HR-151), FHWA, and other agencies and industries, a broad range of potential application rates for each product, or combinations thereof, was established for trial mix screening tests conducted on 2-in. high by 2-in. diameter cylinders. This screening process allowed a qualitative evaluation of the many products, a wide variation of application rates, and a variety of curing and environmental testing conditions to be conducted in a relatively short amount of time with a minimum quantity of soil-aggregate sample.

c) Upon completion of the screening tests, the data were analyzed and narrowed, in order to select the more satisfactory products with limited range of application rates for further, but more refined testing.

d) Refined testing consisted primarily of freeze-thaw durability, trafficability, and Iowa K-Test.

e) Final evaluative analysis was based on maximum effectiveness of lab test results as applied to each categorization previously defined.

No attempt will be made herein to present all of the laboratory testing data due to their volume, with eight site materials, seven basic products, and various combinations thereof. Instead, methods of tests, typical results from each, and evaluative criteria are presented in the subsequent discussion. This is followed by a section on demonstration section recommendations, as presented to each county.

Trial Mix Screening

Use of 2-in. high by 2-in. diameter cylindrical test specimens for various soil stabilization screening techniques has previously been documented [6,35,36,37,38]. Specimen preparation and curing conditions were varied in accordance with type of additive utilized, but no less than duplicate specimens were molded for each variable considered in order to obtain an average of all results.

Where any asphalt emulsion was used, sufficient material to mold at least six 2 × 2 specimens was mixed with distilled water to approximate the untreated optimum moisture content. The desired quantity of emulsion was added to the moistened material, then alternately mechanically and hand mixed for three minutes, and the specimens were molded. Following molding each specimen was weighed and the height measured. Duplicate specimens were then wrapped, sealed, and stored for 24 hrs in a moist cure room at about 72 °F and 100% relative humidity. Duplicate specimens were also allowed to air cure at room temperature for 24 hrs. A third set of specimens were air cured for 24 hrs, then immersed in distilled water for 24 hrs. Following each curing condition, specimens were again weighed, measured, and then unconfined compression tested. Moisture content and volumetric shrinkage and/or expansion changes could be noted through the variations observed in weight and height measurements.

Figures 2 and 3 illustrate the variation of curing conditions, residual asphalt content, and type of asphalt emulsion on the unconfined compressive strength of the Marion County site soil. The effect of the emulsifying agent zeta potential is quite obvious, the E4868 being most effective at about 2 to 4% residual asphalt content following immersion. Further evidence of waterproofing was exhibited by the E4868 specimens following immersion in that they absorbed only 2 to 3% moisture from that following air curing, while the E55 emulsion-treated specimens absorbed 4 to 7% additional water. Volumetric shrinkage and expansion of the E4868 specimens following air curing and immersion respectively, was minor, while that of the E55 specimens was considerably larger.

Where more cementitious products such as cement and fly ash were considered economically feasible within the region of a demonstration section, a modification of the preceeding 2 × 2 specimen screening technique was utilized. A group of at least six specimens were prepared for each point of a moisture-density curve. All specimens were weighed, measured for height, sealed, and stored in the moist cure room. Two specimens of each series were unconfined compression tested following (a) 24 hrs moist curing, (b) 7 days moist curing, and (c) 7 days moist curing plus 24 hrs immersion in distilled water. All specimens were weighed, measured, and moisture contents determined following each curing condition. Additive ranges were varied from 0 to 100% fly ash,

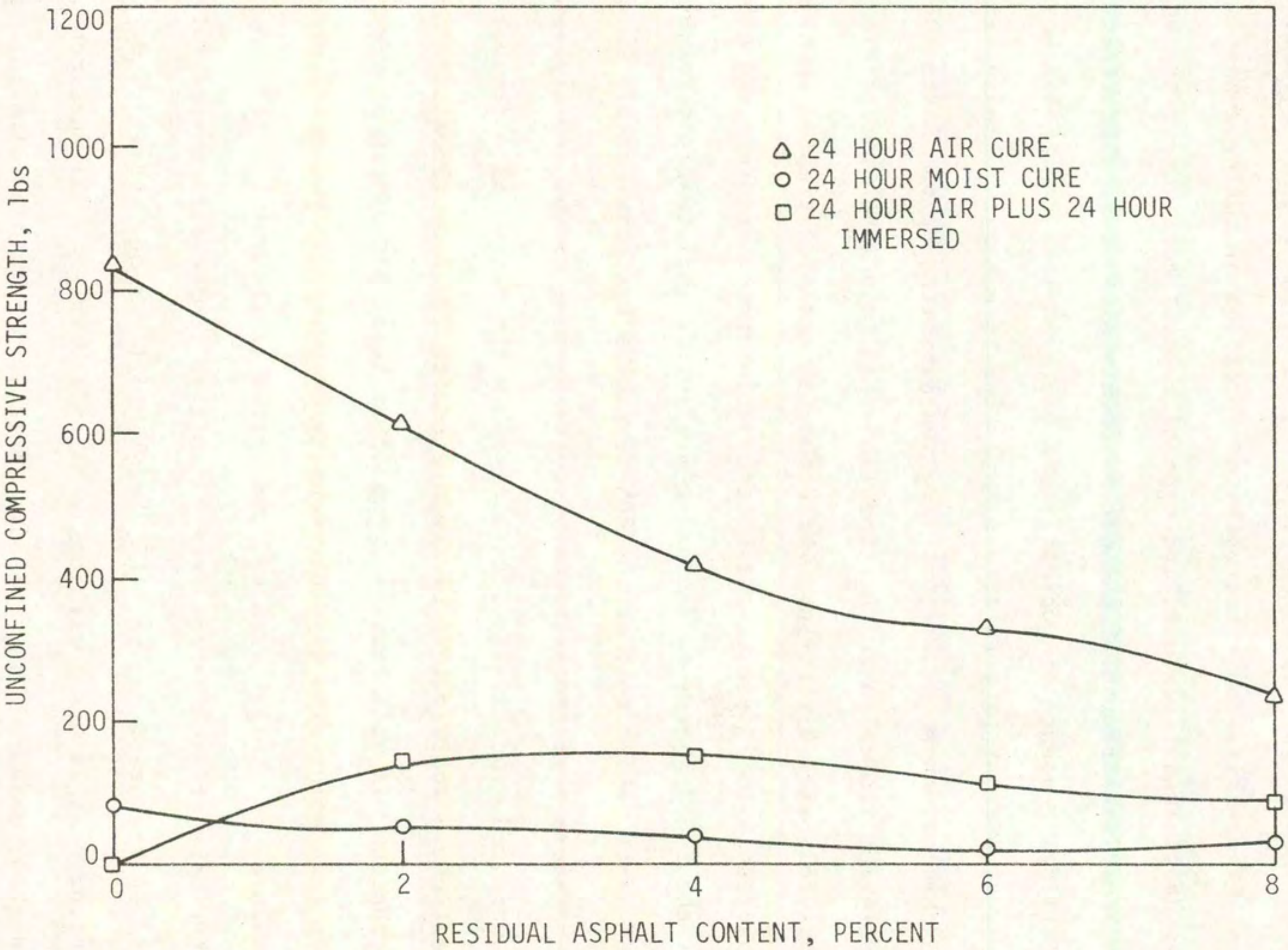

Fig. 2. Unconfined compressive strength versus residual asphalt content, Marion County soil and E4868 emulsion.

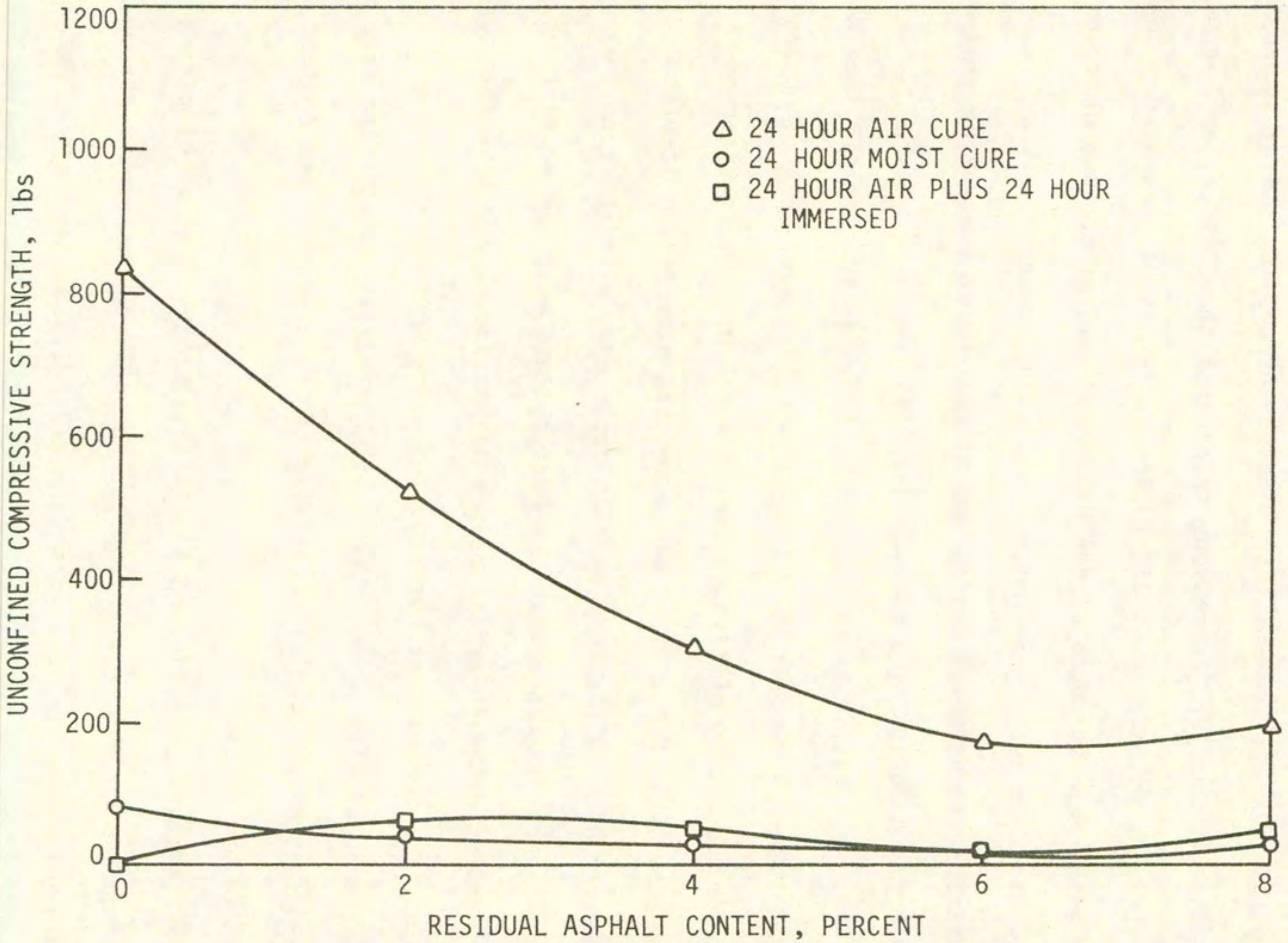

Fig. 3. Unconfined compressive strength versus residual asphalt content, Marion County soil and E55 emulsion.

as well as combinations of 2% cement and 6% fly ash to 4% cement and 20% fly ash, by dry soil weight. Figure 4 illustrates the moisture-density, and unconfined compressive strength results for the Plymouth County soil containing 3% Type I Portland cement and 9% Port Neal III fly ash. At optimum moisture content for molding, 24 hr strength approached 300 psi, increasing to greater than 380 psi at 7 days, decreasing by only about 15% following 24 hrs of immersion. Twenty-four hr moist cure strength of the untreated soil at optimum moisture content was about 30 psi. Near optimum molding moisture content, little or no shrink/swell occurred during any of the curing conditions, and moisture adsorption following immersion was less than 1.5%.

Application rates for Coherex, Polybind Acrylic DLR, and Amsco Res 1881 ranged from near 0 to only 1.0% by dry soil weight, while the maximum quantity of lignosulfonate was 2.0%. Where these products were utilized, the 2 × 2 trial mix screening process was identical to that associated with the four asphalt emulsions, with one minor exception; i.e., each mix was brought to near optimum moisture content in two stages in order to assure proper dispersion of additive throughout the mixture. One-half of the required water content was added to the soil and mechanically mixed. The small quantities of additive were then applied, mixed, and the remainder of the desired water content was added and mixed.

Figures 5, 6, 7, and 8 illustrate the variation of curing conditions and product content on the unconfined compressive strength of the Story County site soil with Coherex, Polybind, Amsco Res, and lignosulfonate. Effect of each chemical product on the compressive strength,

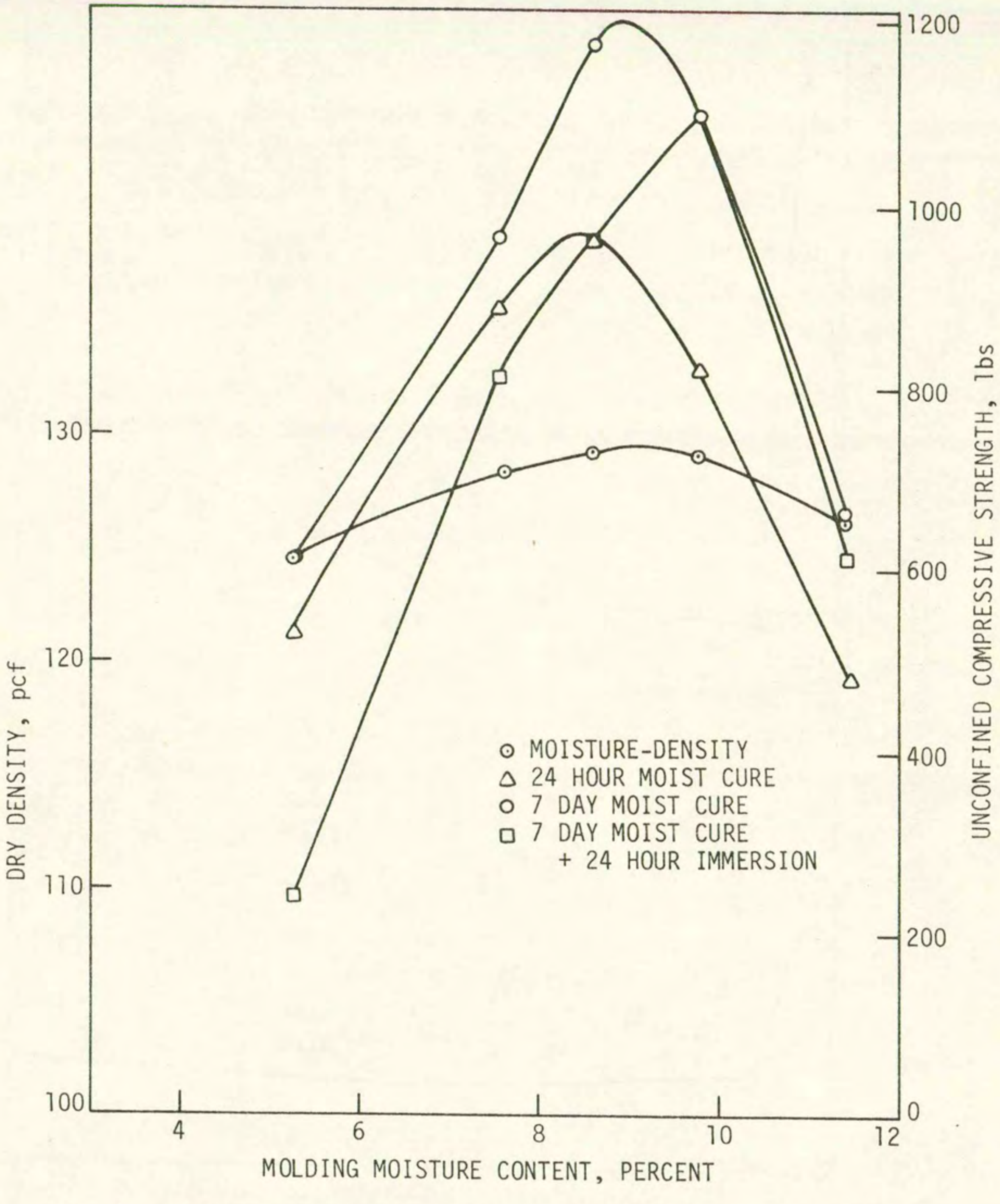

Fig. 4. Moisture-density and unconfined compressive strength, Plymouth County soils with 3% Type I Portland cement and 9% Port Neal III fly ash.

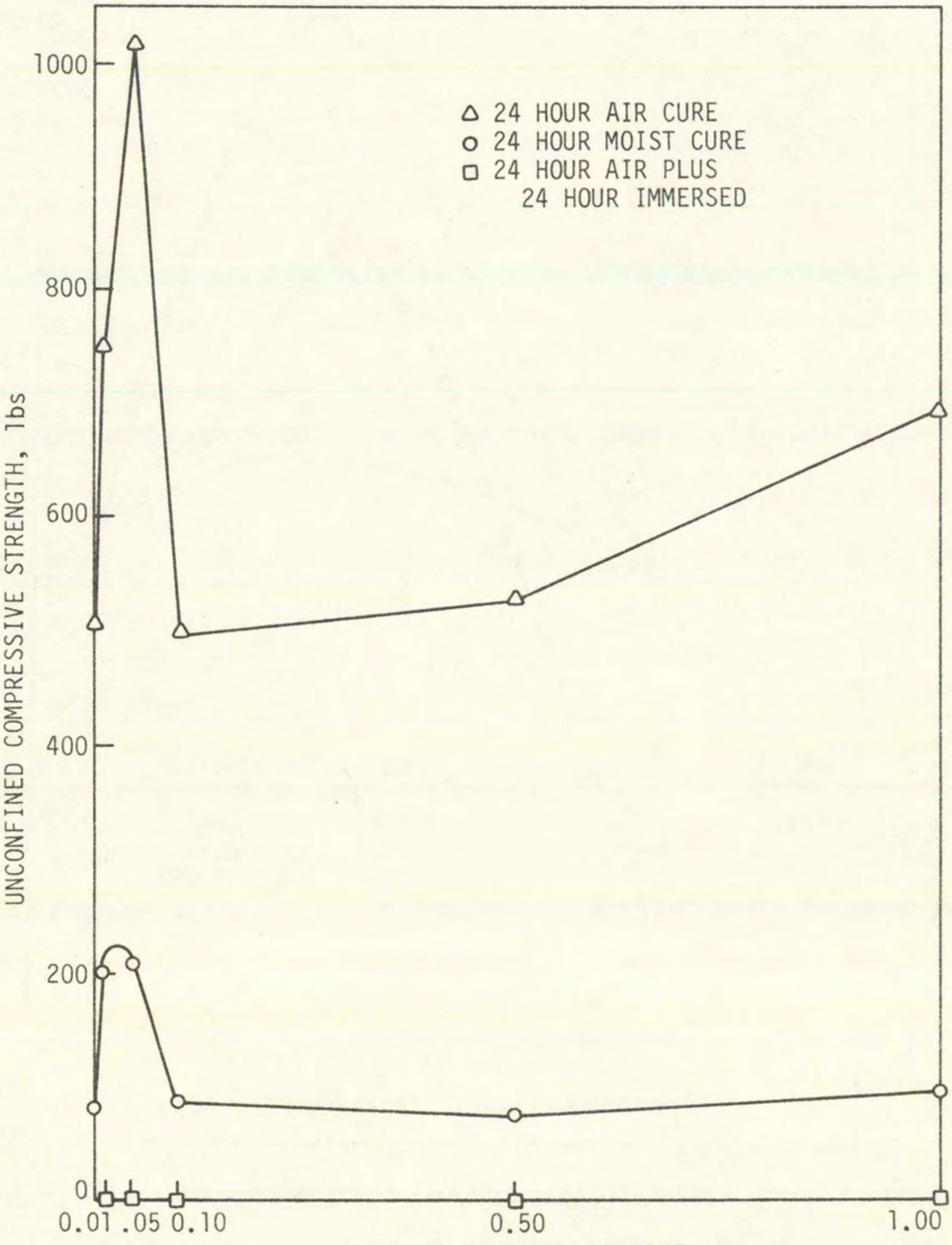

Fig. 5. Unconfined compressive strength versus Coherex content, Story County soil.

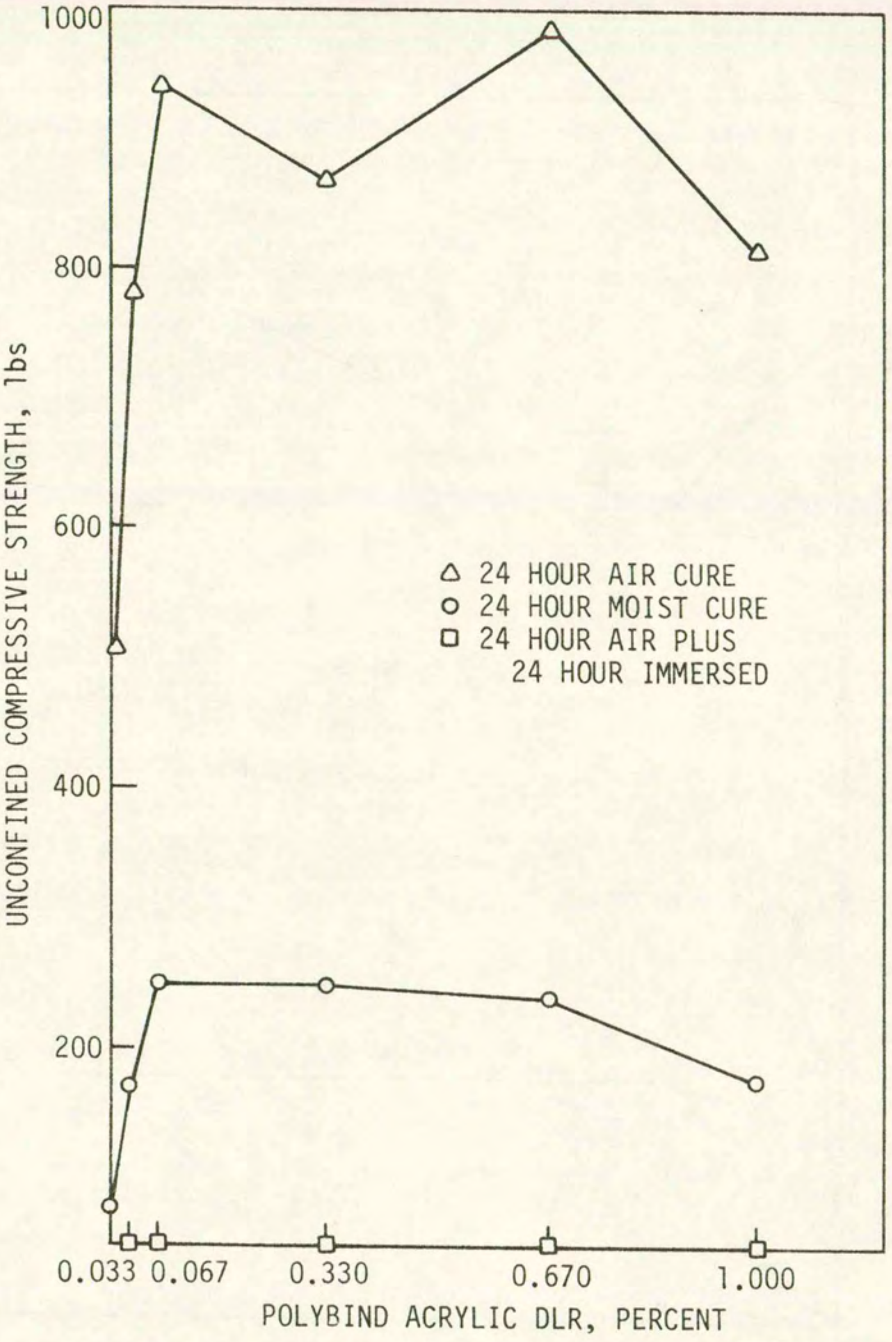

Fig. 6. Unconfined compressive strength versus Polybind Acrylic DLR content, Story County soil.

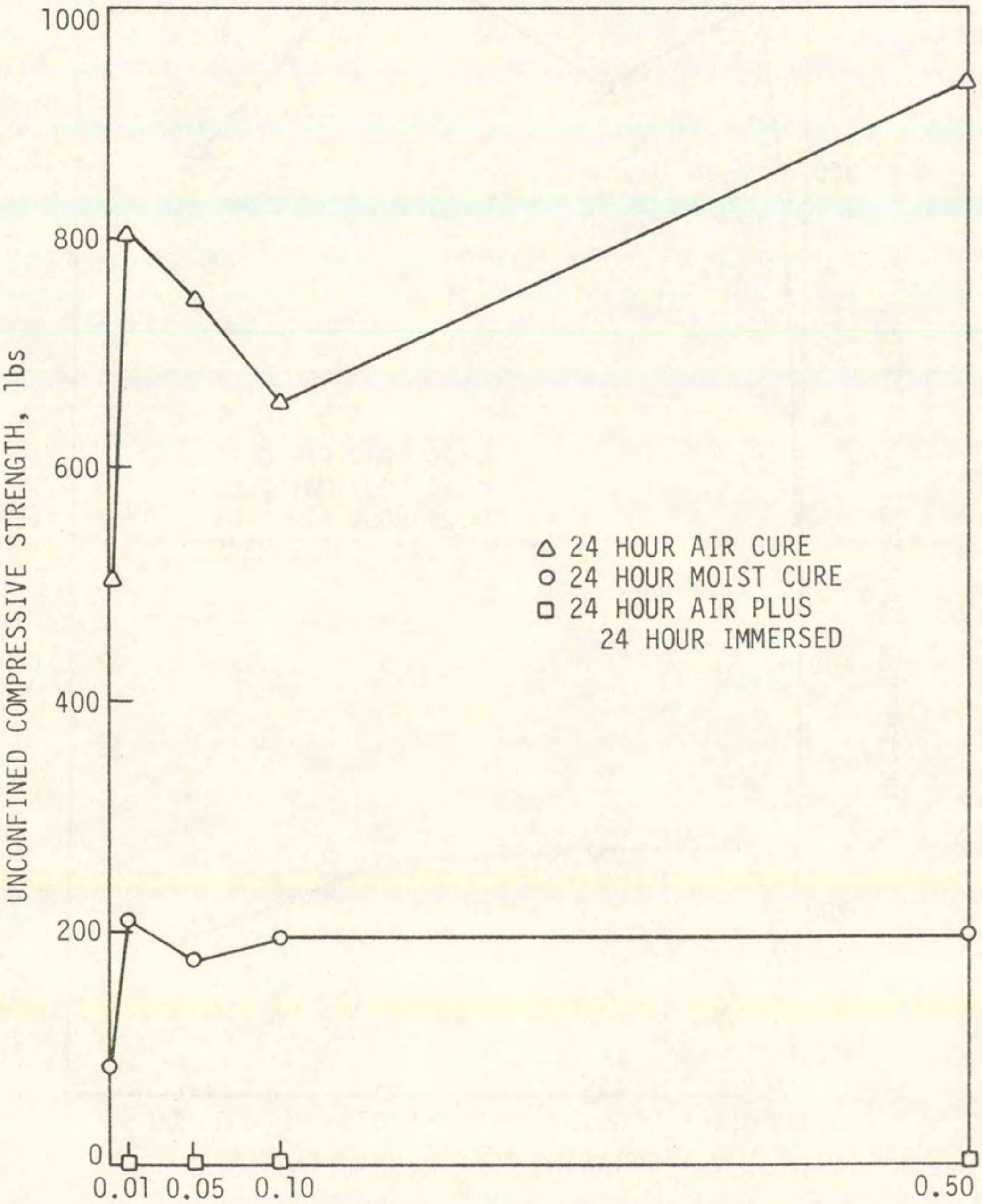

Fig. 7. Unconfined compressive strength versus Amsco Res AB 1881 content, Story County soil.

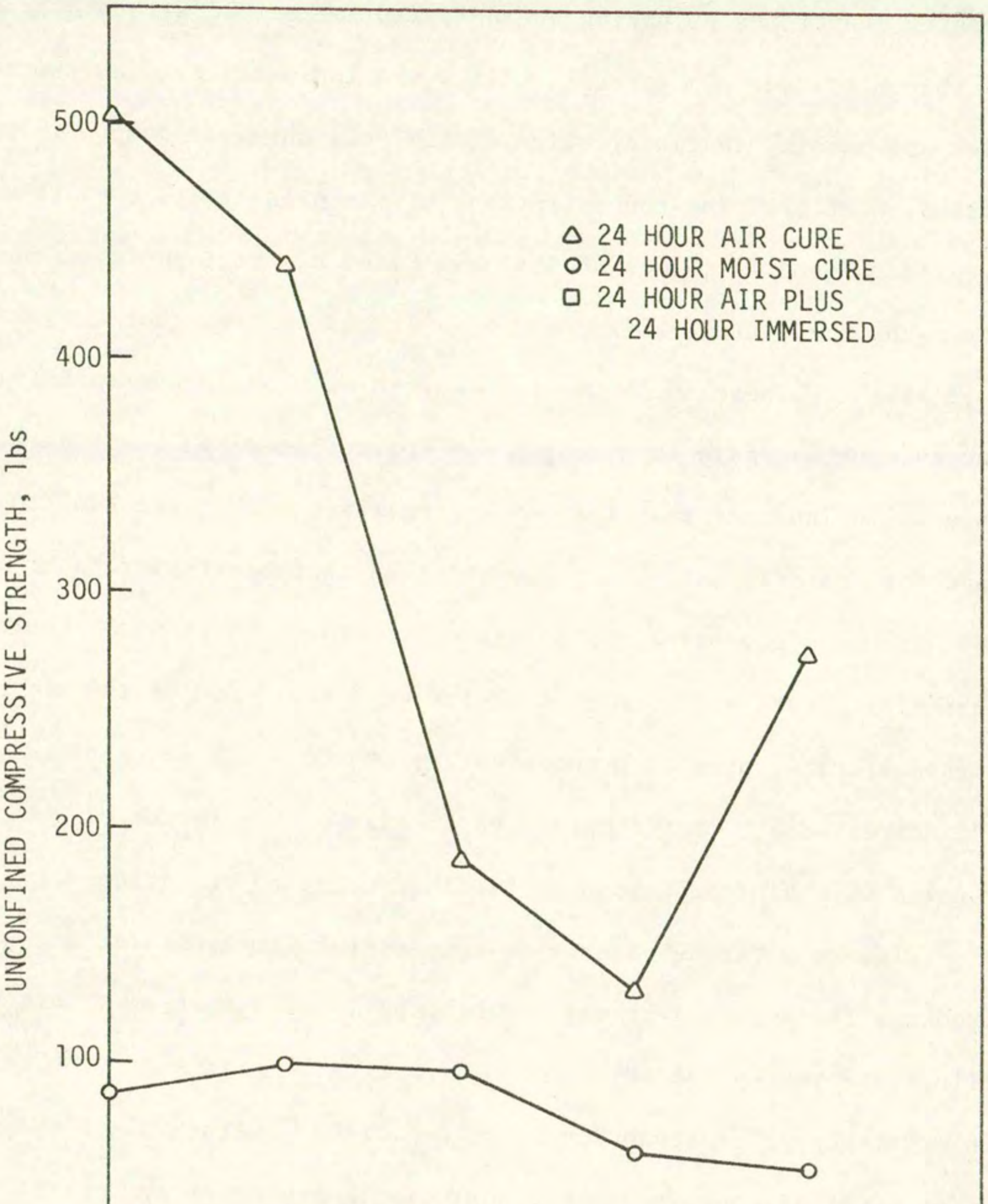

Fig. 8. Unconfined compressive strength versus ammonium lignosulfonate content, Story County soil.

and the potential variability of mechanism within the soil is quite apparent. Maximum effectiveness of Coherex occurred at less than 0.1%, greater quantities producing no basic improvement of strength from that of the untreated. In general, this would indicate that maximum absorptive and bonding characteristics of the soil-chemical composite were satisfied at very low concentrations of the product. The Polybind Acrylic DLR and Amsco Res AB 1881 exhibited distinct improved compressive strengths for both 24-hr air and moist cures at less than 0.1% by dry soil weight. These improvements occurred with no further primary increase or decrease in strength due to increased application rate. This would indicate that the low concentrations of these two products tended to satisfy any absorptive and bonding characteristics of the soil-chemical composite, with further increases in chemical concentration just filling the voids in an inactive capacity. Use of the ammonium lignosulfonate appeared unsatisfactory due to a distinct lowering from the untreated air cure compressive strength, by a factor of 2 to 3, coupled with no indications of bonding during moist curing.

Figures 5 through 8 show no compressive strengths for any of the products following 24-hr air curing plus 24-hr immersion. This would illustrate susceptibility to water, particularly if used with this soil in a Category 3 construction where capillary moisture might accumulate under a satisfactory seal coat surfacing. Degree of susceptibility to water, however, could be judged on the time required to slake during immersion, as observed during the testing process, and/or the moisture content of the specimens following immersion, if at least a substantial portion of the specimens remained. The Coherex specimens began slaking at about 2 hrs and were fully slaked at 24 hrs following immersion. Low concentrations of the Polybind Acrylic began slaking at about 3 hrs, while the higher concentrations were as much as 50% slaked during the same time period, and all specimens fully slaked at 24 hrs. Slaking of the Amsco Res specimens began within 15 minutes following immersion and were fully slaked within 1 to 1-1/2 hrs. Full slaking of all lignosulfonate specimens occurred within 20 hrs. No portions of the Amsco Res specimens were preservable for moisture content determinations. Each of the other products showed moisture increases of factors of 2 to 4 times that associated with the 24-hr air cure, the lignosulfonate specimens having absorbed the greater quantity of water.

Based on the preceding factors of compressive strength, as well as slaking time and/or moisture content increase following immersion, only the Coherex and Polybind Acrylic, at low concentrations, were considered for further testing with the Story County soil. In addition, these two products would be limited primarily to a Category 1 usage, with a marginal consideration for Category 2.

Trafficability

Most soil-aggregate surfaced roads are plagued with environmental and loading conditions which result in symptoms of instability such as washboarding, rutting, potholing and material losses. The traffic simulation test utilized within HR-151 [6] provides at least a qualitative evaluation of these stability factors for untreated, surface-treated, and treated (incorporated or mixed-in-depth) soil-aggregate materials. The test subjects replicate Marshall size specimens to simulated conditions of repetitive traffic loading and adverse environment.

All mixing procedures were as described for the trial mix screening. Duplicate Marshall size specimens (4.00-in. diameter × 2.75-in. height) were prepared at standard optimum moisture content and maximum dry density. With the exception of the cement and fly ash specimens, all untreated and treated specimens were air cured within their respective molds for 48 hrs, simulating field conditions following construction. All cementitious specimens were wrapped and sealed within their respective molds, then stored in the humid room for 48 hrs. All surface treated specimens were cured in two stages; (1) untreated specimens were molded and air cured within their respective molds for 24 hrs, then (2) the palliative was sprayed to the surface at the desired rate followed by an additional 24 hrs air curing.

The trafficability apparatus consists of a rigid steel frame with an electric powered travelling carriage moving longitudinally along the frame. Within the carriage, an 8-in. diameter by 1-1/4-in. wide solid rubber tired wheel is positioned to roll along a longitudinal wheel track containing six of the Marshall size specimens still within their respective molds. Contact pressure of the wheel is adjustable through a vertical pneumatic cylinder to which the wheel is attached. The cylinder also serves to automatically lift the wheel at the end of each loading pass. A water spray device is attached to the carriage, providing the capability of rain simulation either during, or without traffic loading.

Quantitative data consists of measuring wheel path, or rut depth development to the nearest 0.001 inch, at intervals of wheel load repetitions. The difference between the average of triplicate wheel path readings prior to and following load repetitions provides the quantity of rut depth, failure being defined as equal to, or greater than, 0.5 inch.

The following trafficability test procedure was used at a constant 85-psi wheel contact pressure for all specimens:

1) 1000 passes without rain; rut depth measurements at 50, 100, 250, 500, 750, and 1000 passes.
2) 1000 passes with a simulated rain of about 0.15 in./hr; rut depth measurements at 1100, 1250, 1500, 1750, and 2000 passes.
3) 2-hr fogging period consisting of a fine water mist; the top surface of all specimens was visibly wet during this interval.
4) 1000 passes with a simulated rain of about 0.15 in./hr; rut depth measurements at 2250, 2500, 2750, and 3000 passes, or until achievement of 0.5 in. rut depth, whichever might first occur.

Figures 9 through 13 illustrate typical traffic simulation test results for untreated, surface-treated, and treated soil-aggregate materials as might be applicable to Category 1, 2, and 3 applications, respectively. Rut depth measurements should be viewed from the mechanisms which occur during the testing process. Initially, a surface densification and seating of the specimen within the holding ring occurs within the first 50 to 100 passes. In general, there is little additional densification and deflection up to 1000 passes. During the initial period of rain, there is a near immediate "tracking-out" of any unbound fines coupled with some additional densification of the material within the wheel path, particularly for untreated specimens. As a visible rut may be formed, rain tends to puddle in the wheel path, resulting in further flushing and tracking-out of fines, a process normally occurring to lesser degrees with effectively stabilized specimens as compared to untreated specimens. This process may continue until the wheel path surface appears composed primarily of coarse particles with the fines removed, again most evident in untreated or unstable specimens. During the two periods of rain, unstable materials may also produce one or more forms of shear failure. Initially there is a general bulging and upheaval along the wheel path edges indicative of a plastic flow or local shearing. This process may continue to progress to development of full shear away from the wheel path, at or into the wall of the holding ring. This latter development may produce failure surfaces similar to those of the classic Prandtl-Terzaghi bearing capacity failure geometry [39]. Thus, while the primary measurements of the traffic simulator may be quantitatively observed as rutting depth, the test also provides qualitative indications of materials stability under moving load and imposed environmental conditions.

Figures 9 and 10 present traffic simulator results of untreated and surface-treated Franklin County site soil specimens. The Franklin County site was a low P.I. material containing only 23% silt and clay size binder, Table 1. With the first application of rain, Figure 9, the fines readily began to track out of the untreated material and rutting quickly proceeded to near 0.1 inch. The surface-applied calcium chloride provided some additional, but relatively short-lived binding, which was apparently flushed with increasing numbers of passes and the accompanying rain. The undiluted ammonium lignosulfonate appeared to

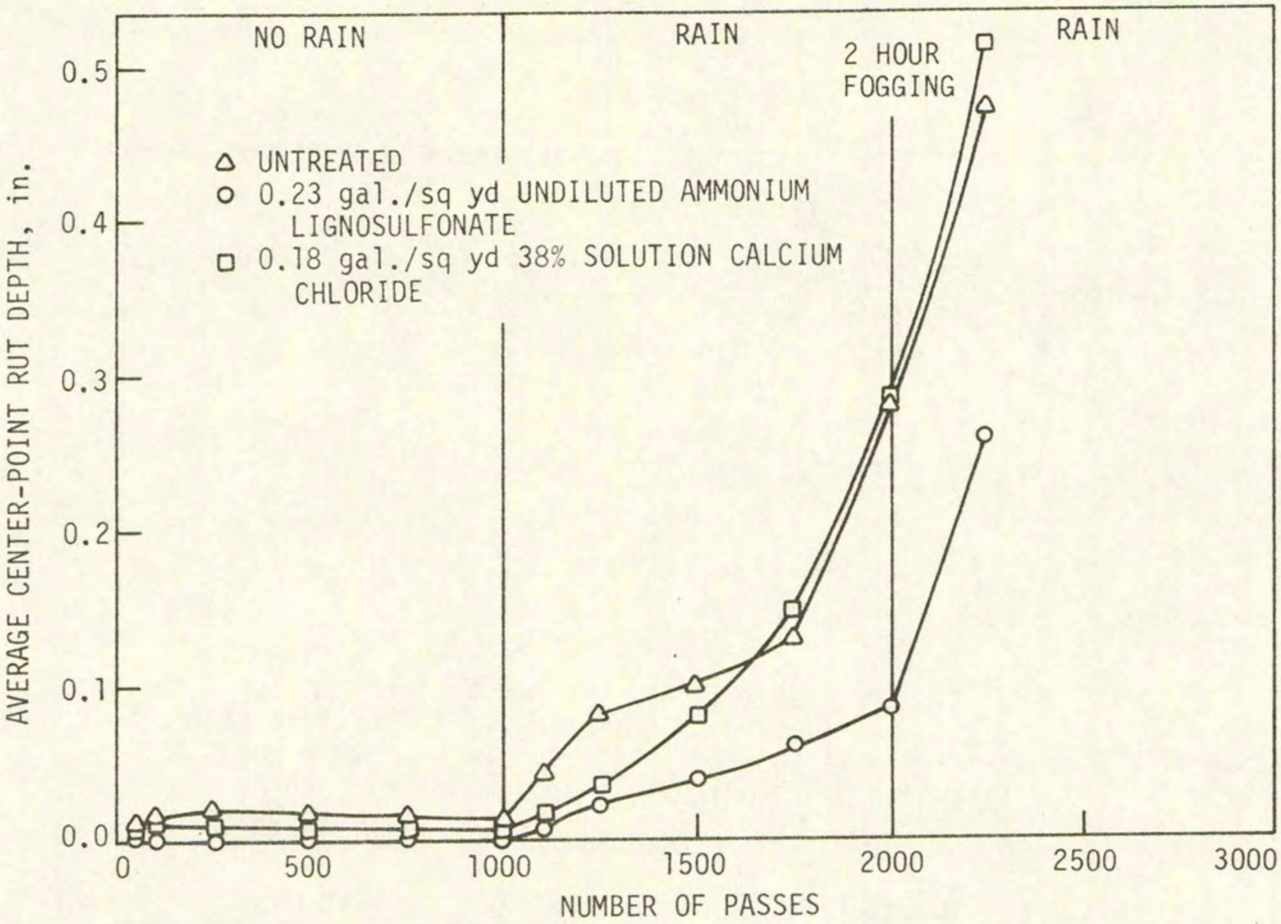

Fig. 9. Traffic simulator results, Franklin County soil.

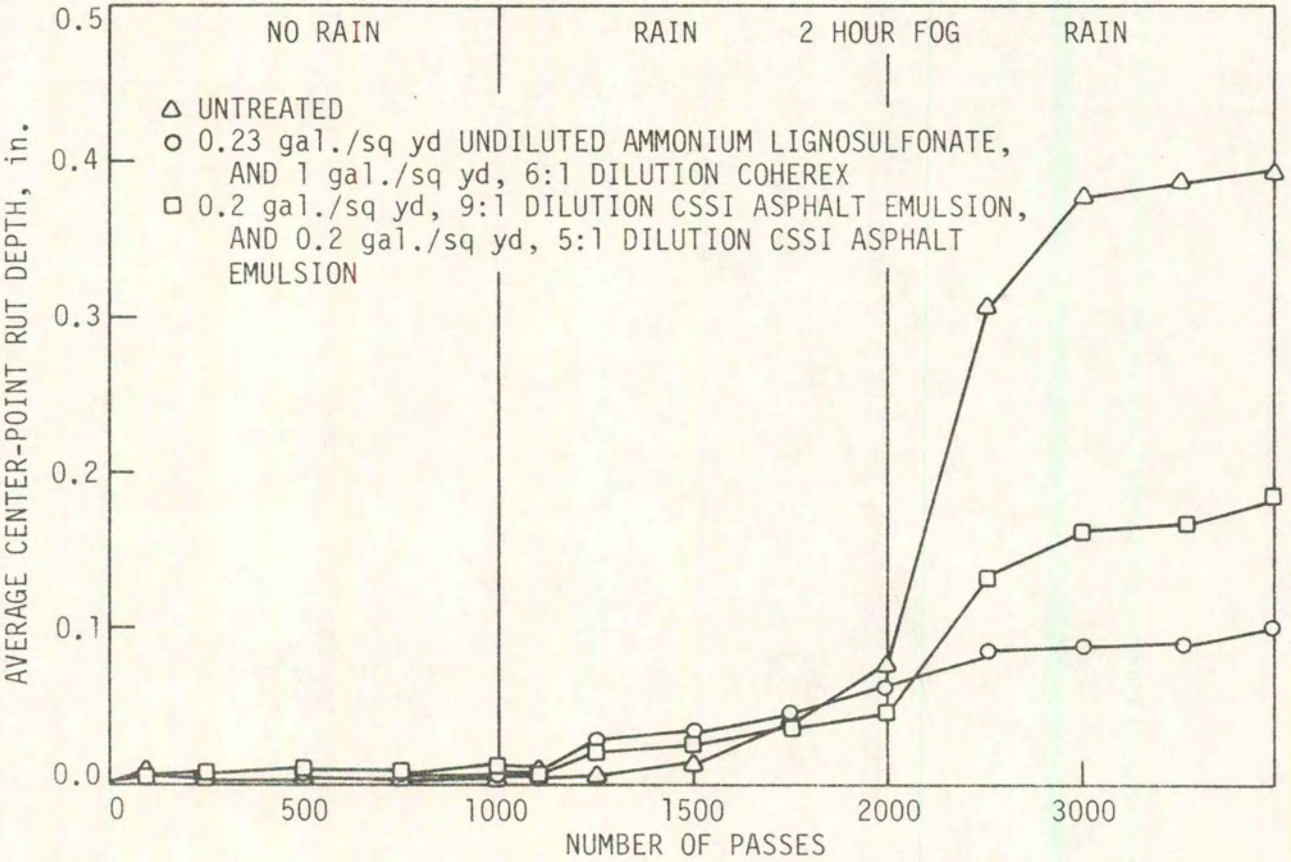

Fig. 10. Traffic simulator results, Franklin County soil.

produce a more firm surficial crust which was less affected by loading during the first period of rain. Following the 2-hr fogging, only the lignosulfonate continued to provide a small amount of binding stability. Of the two products presented in Figure 9, the lignosulfonate would therefore be considered as providing the greater surficial binding properties, the longest tolerance to traffic and environmental conditions, and in essence a longer term capacity for dust abatement for this particular soil.

While illustrating traffic simulator results of surface treatment of the Franklin County soil, Figure 10 also presents the effects of dual applications of surface palliatives. This particular laboratory evaluation resulted from decisions emanating from the actual demonstration section construction presented in a succeeding section of this report. The previously presented curing process was slightly changed, in that the undiluted ammonium lignosulfonate and the 9:1 water dilution of a Bitucote Products Co. CSSI asphalt emulsion were surface sprayed at the rates noted, following one day air curing. After a second 24-hr air cure, the Coherex and the final CSSI dilution were surface applied, after which an additional 24 hrs of air curing occurred prior to testing. The effect of the added 24-hr air curing is apparent in Figure 10 as compared to Figure 9, particularly for the untreated material. However, following the 2-hr fogging, the binding and stability effectiveness of the surface treatments are apparent. In general, it was projected that the combination lignosulfonate and Coherex would provide the greater surficial binding, longest tolerance to traffic and environmental conditions, and probability of longer term dust abatement for this particular soil, than would the emulsified asphalt. This projection was later affirmed.

Based on trial mix screening, the E-65 asphalt emulsion was selected for further testing with the Buchanan County soil for possible Category 1 and 2 construction. Figure 11 presents traffic simulator results for this soil containing 0, 2, and 4% residual asphalt contents. As noted in Table 1, this material contained only 20% non-plastic fines, being predominantly a sandy soil. Stability of all specimens during the first 1000 repetitions of wheel loading was excellent. During the first period of rain, the small quantity of binder fines was severely flushed and tracked-out of the untreated material, with a partial stability breakdown beginning to occur within the 2% asphalt treated specimens just prior to completion of the second thousand passes. Following the fogging period, and during the remainder of testing, severe bulging and local shear occurred with the untreated specimens. Specimens treated at 2% residual asphalt showed minor signs of bulging and local shear, though some fines were being flushed when testing was stopped at 2750 passes. Specimens containing 4% residual asphalt did not exhibit flushing of fines or local shear, though rutting was of about 0.3 inch upon termination of testing. In general, the 4% residual asphalt treatment of this soil would indicate improved waterproofing capability, relatively good tolerance to traffic and environmental conditions, and probability of long term dust abatement. However, the final quantity of rutting depth of the 4% treated specimens would indicate a limited lack of mechanical stability of the soil material,

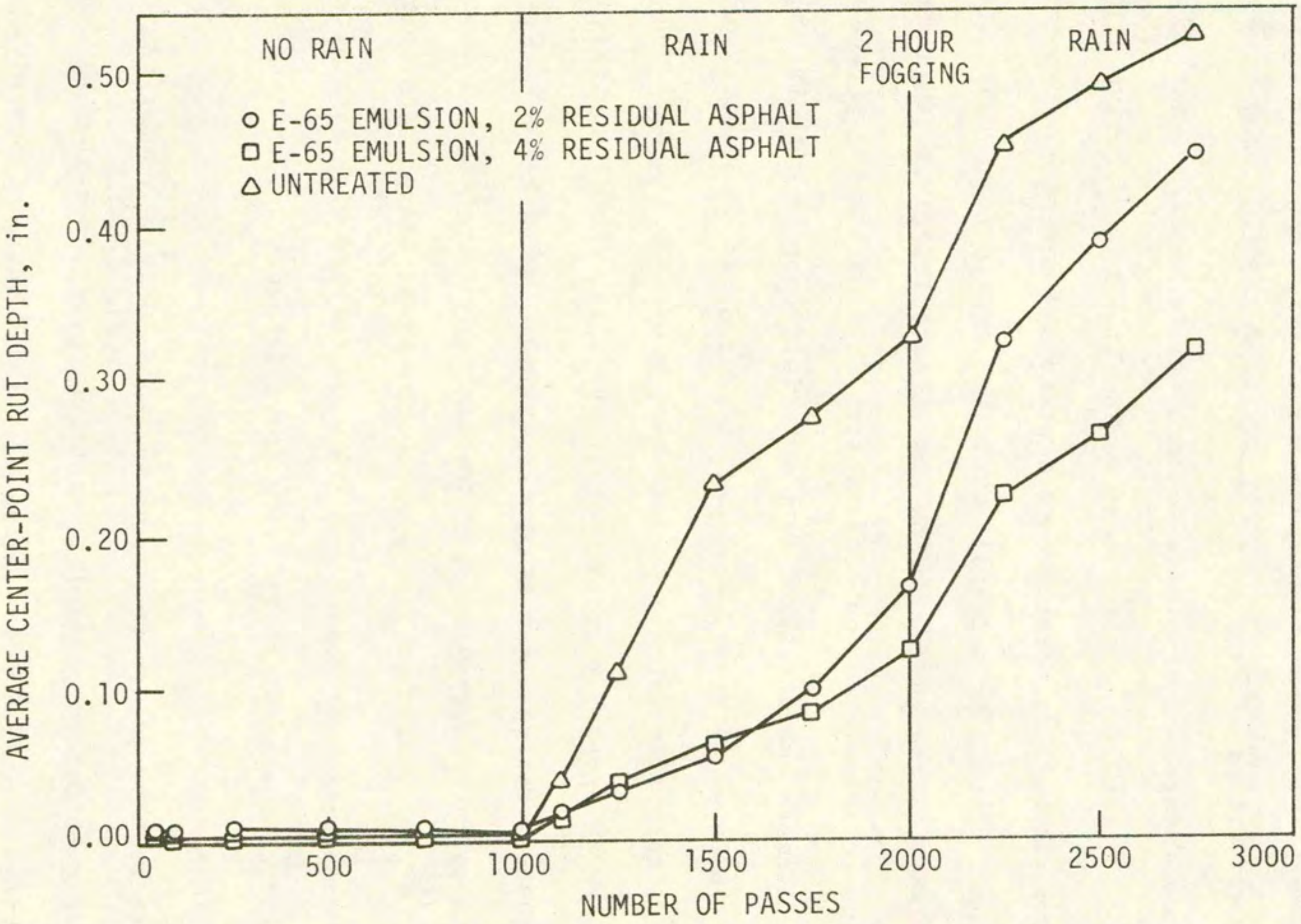

Fig. 11. Traffic simulator results, Buchanan County soil.

which might necessitate modifying its gradation to produce a more well-graded particle size distribution.

Figures 12 and 13 present traffic simulator results from two of the Pottawattamie County sites, Mud Hollow and Neola, when treated with varying quantities of Type I Portland cement and Iowa Power fly ash. While this Category 3 treatment would normally require a seal coat surfacing, the trafficability test would still be indicative of overall stability, as well as tolerance to traffic and severe environmental conditions. Both site materials contained considerable quantities of fines, Table 1, though Mud Hollow was of much lower P.I. than Neola, resulting in less untreated binding stability during the first 1000 passes. Treated stability of each material, coupled with its capability of environmental survival, was obvious regardless of quantity of fly ash. For both site materials, some very minor amounts of flushing of fines were observed during the periods of rain, though no bulging or local shear occurred. All treated specimens showed signs of polishing of bound surface aggregates upon termination of testing, indicating integrity of the cementitious matrix. Based on these tests only, either combination of cement and fly ash utilized with each site material would indicate general suitability for a Category 3 construction.

Freeze-Thaw

Freeze-thaw deterioration of soil and additive composites considered applicable to Category 2 and 3 construction were observed through use of the Iowa freeze-thaw and K-Tests. (The K-Test is presented in the next section of this report.) The quantity of heave occurring in a soil provides an indicator of strength of the thawed soil, in that the

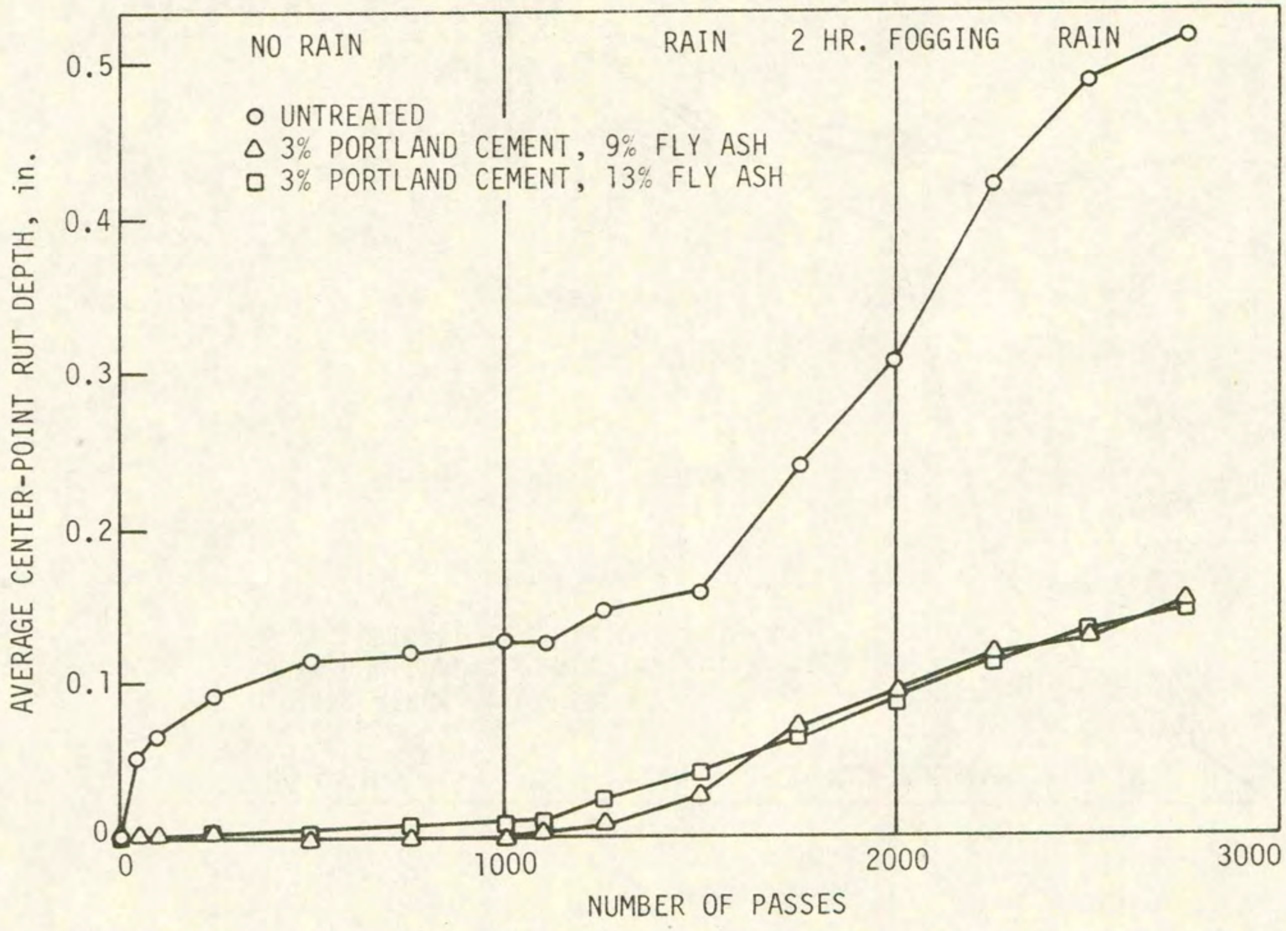

Fig. 12. Traffic simulator results, Pottawattamie County, Mud Hollow site soil.

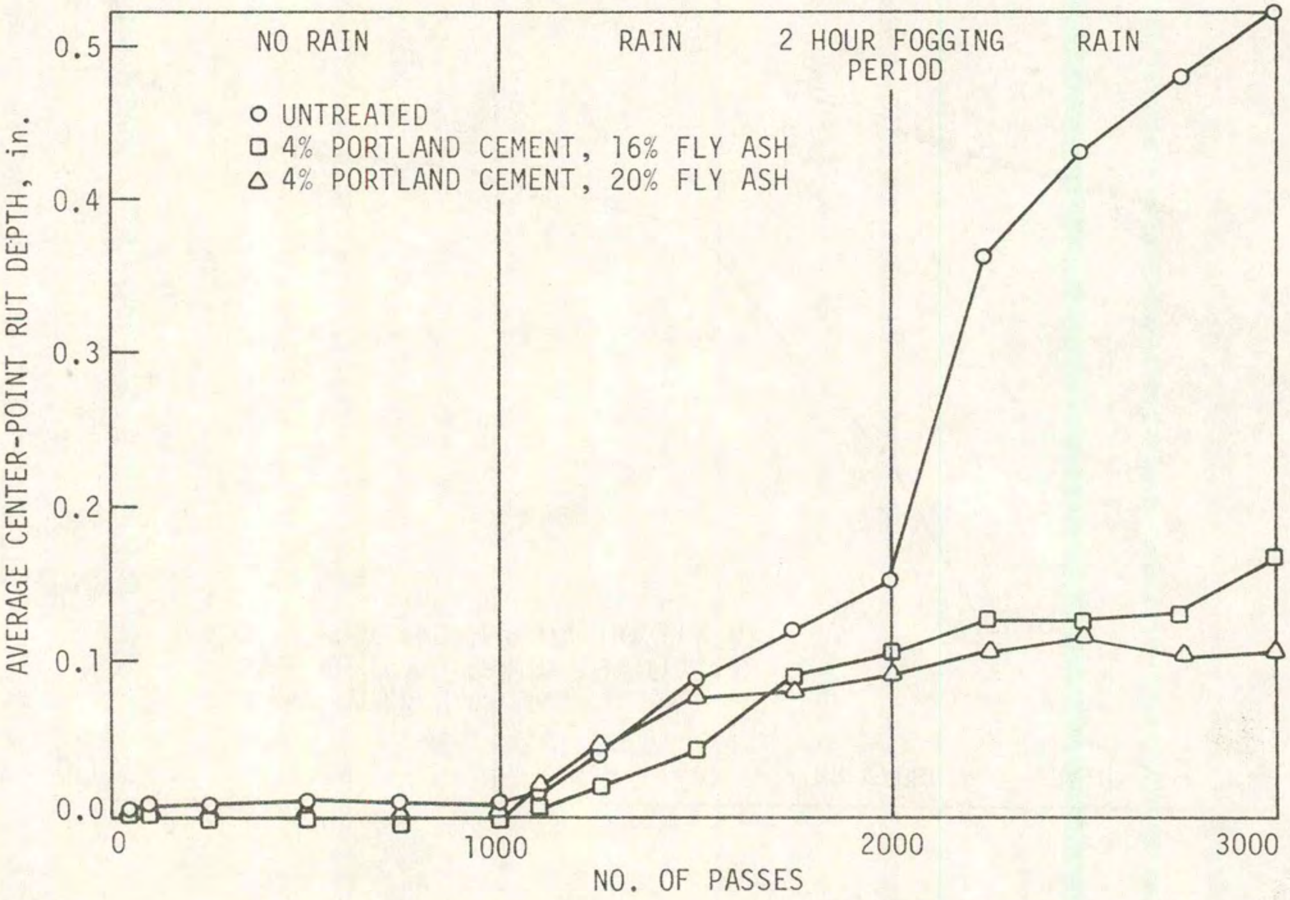

Fig. 13. Traffic simulator results, Pottawattamie County, Neola site.

more a soil heaves, the more water is imbibed during freezing, and more water during thawing lowers the thawed strength.

A modification of the Iowa freeze-thaw test developed by George and Davidson [40] was used to measure heave of both untreated and treated materials, the latter as selected from trial mix screening. The test duplicates roadway conditions of freezing from the top, while water is available at the bottom of the specimen for upward capillary moisture movement. Standard ASTM D698 (1/30 cu ft) specimens molded at optimum moisture content and density were cured, then placed in plexiglass holders which fit inside insulated Dewar (thermos) flasks filled to a predetermined depth of water for contact with the specimen base. The flasks are placed in a freezer at 20 ± 2 °F, while water in contact with the specimen base is maintained at about 35 °F. Height measurements are performed on the specimens following 16 hrs of freezing, and again after 8 hrs of thawing at room temperature. A series of 10 freeze-thaw cycles were performed on all treated and untreated specimens. Change in specimen height following freeze or thaw was expressed as a percentage elongation of the original height.

A series of specimens were molded for both freeze-thaw and Iowa K-Test at the same time and were cured under several conditions prior to testing. Upon completion of molding, six untreated specimens were wrapped, sealed, and placed in the humid room. After 7 days curing, two untreated specimens were subjected to the freeze-thaw test, while duplicate specimens were tested in the Iowa K-Test unit. The remaining pair of specimens were allowed to cure for 17 days, then utilized as control specimens in the K-Test at an age equivalent to the freeze-thaw specimens. Following freeze-thaw, each specimen was subjected to the K-Test.

Where cement and fly ash treatments were used, six specimens were prepared, cured, and tested in the same manner as described for the untreated. Duplicate specimens treated with asphalt emulsion, ammonium lignosulfonate, Coherex, or other products, were air cured for 24 hrs following molding, then wrapped, sealed, and humid cured for 6 and 16 days prior to freeze-thaw and K-Tests.

Figures 14 through 18 illustrate the effect of various treatments on the freeze-thaw elongation characteristics of several demonstration site soils. Effect of elongation may be viewed through two basic formats. Residual elongation may be described as that quantity of heaving which occurs in a material as the difference between zero elongation, and either freeze or thaw elongation, during any number of cycles, i.e., the departure of the freeze-thaw curve from the abscissa of the plot. In addition, residual elongation indicates water absorption and expansion characteristics of the material being tested, which does not dissipate through gravitational drainage during thawing. Cyclic elongation is the difference between freeze and thaw elongation during any single cycle. Large combinations of both residual and cyclic elongation represent a definite lack of freeze-thaw stability, while very low combinations of each would show a soil or soil-additive composite having little or no frost heave susceptibility.

Figures 14 and 15 illustrate the effects of residual and cyclic elongation. The untreated Honey Creek material, Figure 14, produced a definite increase of residual elongation during the first few cycles

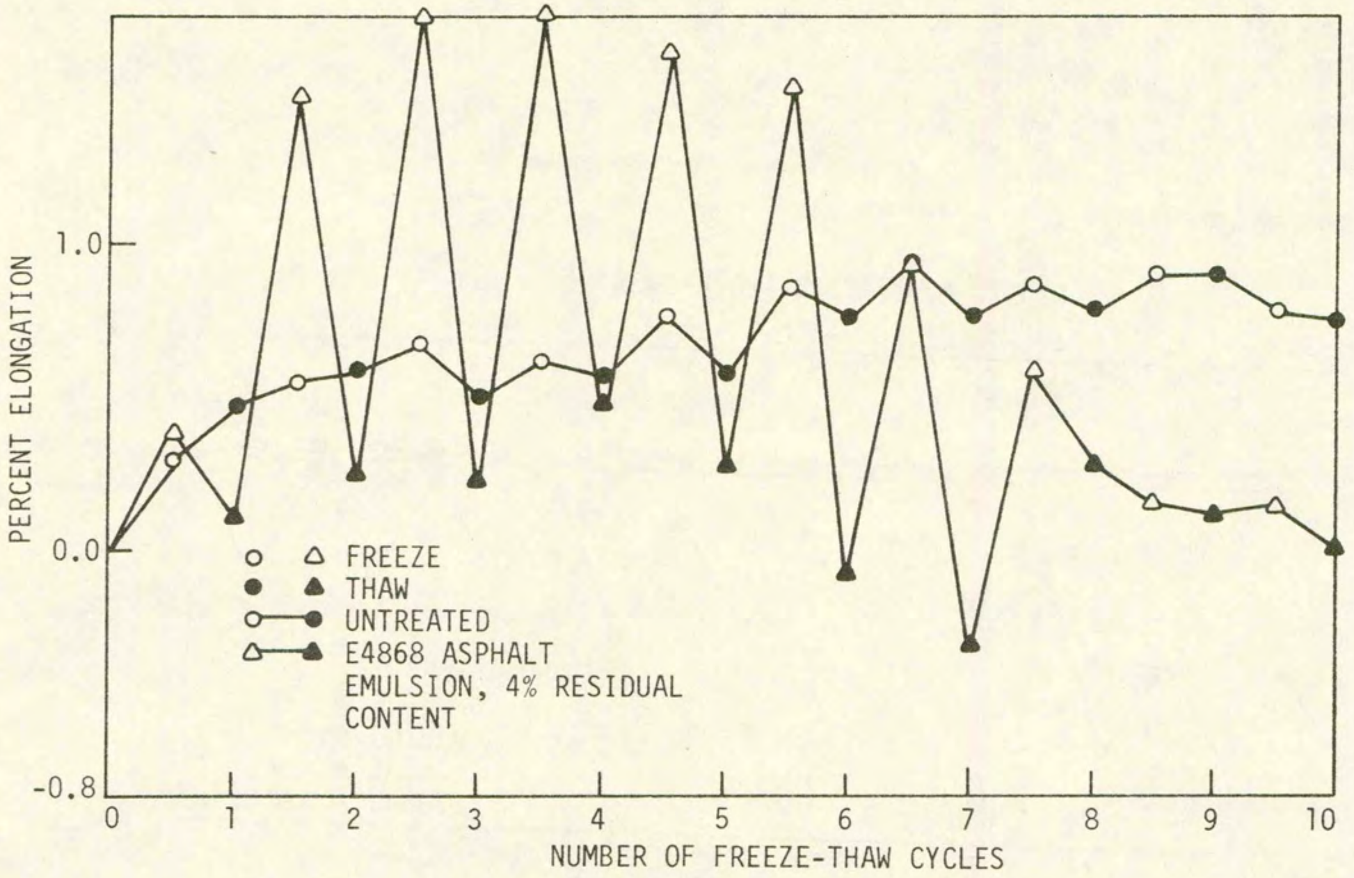

Fig. 14. Percent elongation versus number of freeze-thaw cycles, Honey Creek soil, Pottawattamie County.

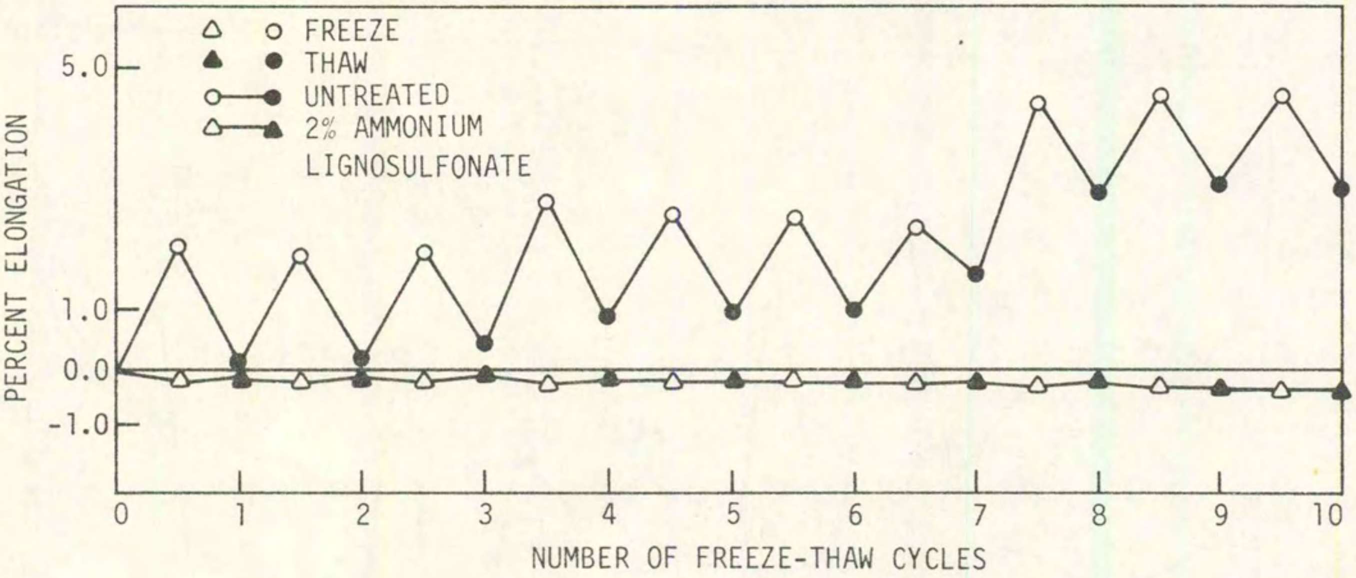

Fig. 15. Percent elongation versus number of freeze-thaw cycles, Buchanan County soil.

with a much slower rate of residual elongation increase throughout the remainder of the ten cycles. Cyclic elongation of the untreated was relatively low regardless of number of cycles. This combination would indicate the untreated soil to be moisture absorptive, but the relatively low quantity of residual elongation would indicate only a minor amount of expansive characteristics during freeze-thaw.

Asphalt emulsion E4868 treatment of the Honey Creek soil produced very significant cyclic elongations which began to decrease at about 7 cycles, the latter indicating a soil-asphalt matrix breakdown and loss of waterproofing. Further evidence of the structure breakdown was observed in a definite water softening of the upper surface of the treated specimens during the last three cycles. Use of this emulsion with the Honey Creek soil would thus provide no freeze-thaw stability.

Figure 15 shows that the use of 2% ammonium lignosulfonate with the Buchanan County soil would produce excellent freeze-thaw elongation stability, though a very minor amount of shrinkage might occur. Cyclic elongation of the untreated soil was relatively large, but remained reasonably constant throughout the ten cycles. Residual elongation occurred in approximately three steps of equal numbers of cycles indicating that while this soil had a relatively small quantity of nonplastic fines, the fines were nevertheless somewhat absorptive and expansive, and gravitational drainage was not sufficient within the thaw periods to prevent formation of ice lenses during freezing.

Use of 3% Type I Portland cement and 9% Port Neal III fly ash adequately controlled freeze-thaw elongation after an initial absorption-expansion-residual elongation of the Plymouth County soil, Figure 16.

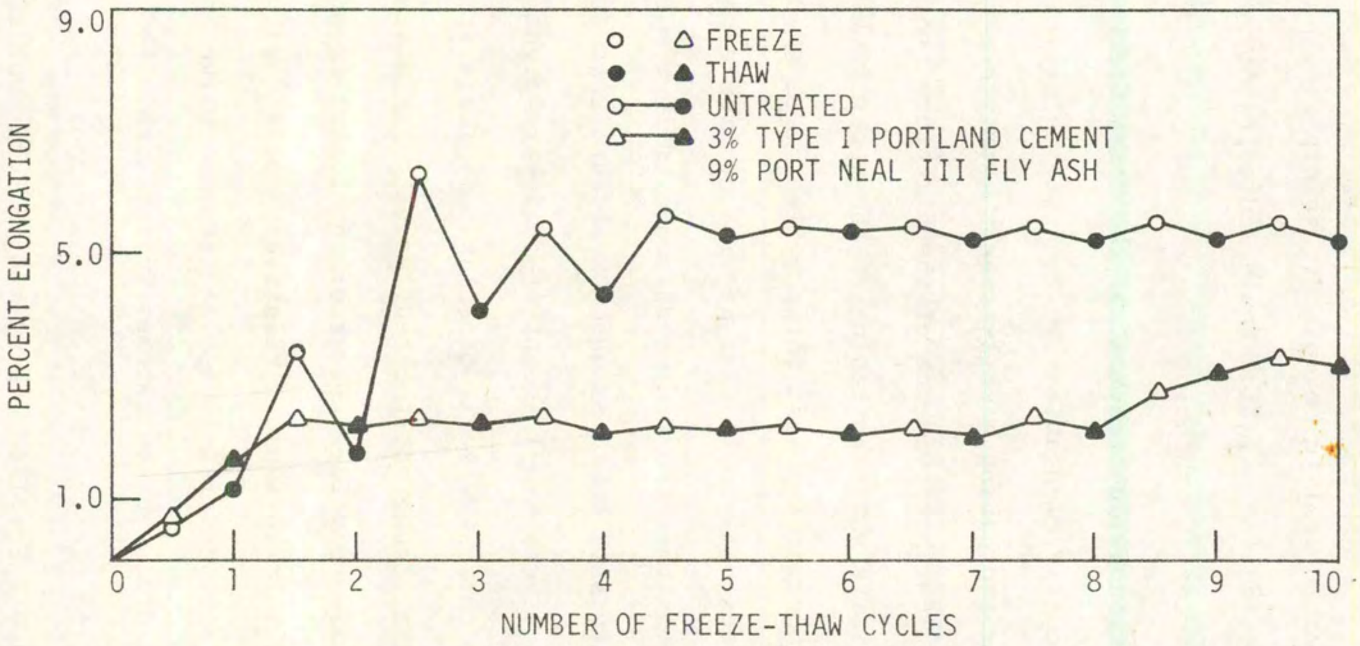

Fig. 16. Percent elongation versus number of freeze-thaw cycles, Plymouth County soil.

Little cyclic elongation appeared with the treated material indicating a definite control of additional capillary moisture to produce volumetric increases upon freezing. Magnitude of residual elongation control due to treatment was of the order of 2 to 3.

Figure 17 shows an initial rapid rate of increase in residual elongation of the untreated Neola soil, followed by an increasing rate of cyclic elongation, both indicative of the absorption-expansion characteristics of this fine-grained plastic soil. Addition of 4% Type I Portland cement and 16% Iowa Power fly ash significantly reduced these characteristics, particularly through the fourth cycle. With further freeze-thaw replications, the treated material slowly increased in both residual and cyclic elongation, exhibiting a slight potential for increased freeze-thaw susceptibility and/or possible structural breakdown.

Similar characteristics were observed with the Neola soil when treated at 4% residual asphalt content with an asphalt emulsion supplied by Hy-Way Asphalt Products, Salina, Kansas. This laboratory evaluation resulted from decisions emanating from the actual demonstration section construction presented in a succeeding section of this report. As shown in Figure 18, the treated material produced a slow, almost straight line increase in both residual and cyclic elongations during the ten cycles, indicating a small increase in freeze-thaw susceptibility and/or possible matrix breakdown. Both characteristics however, were still less than that of the untreated soil.

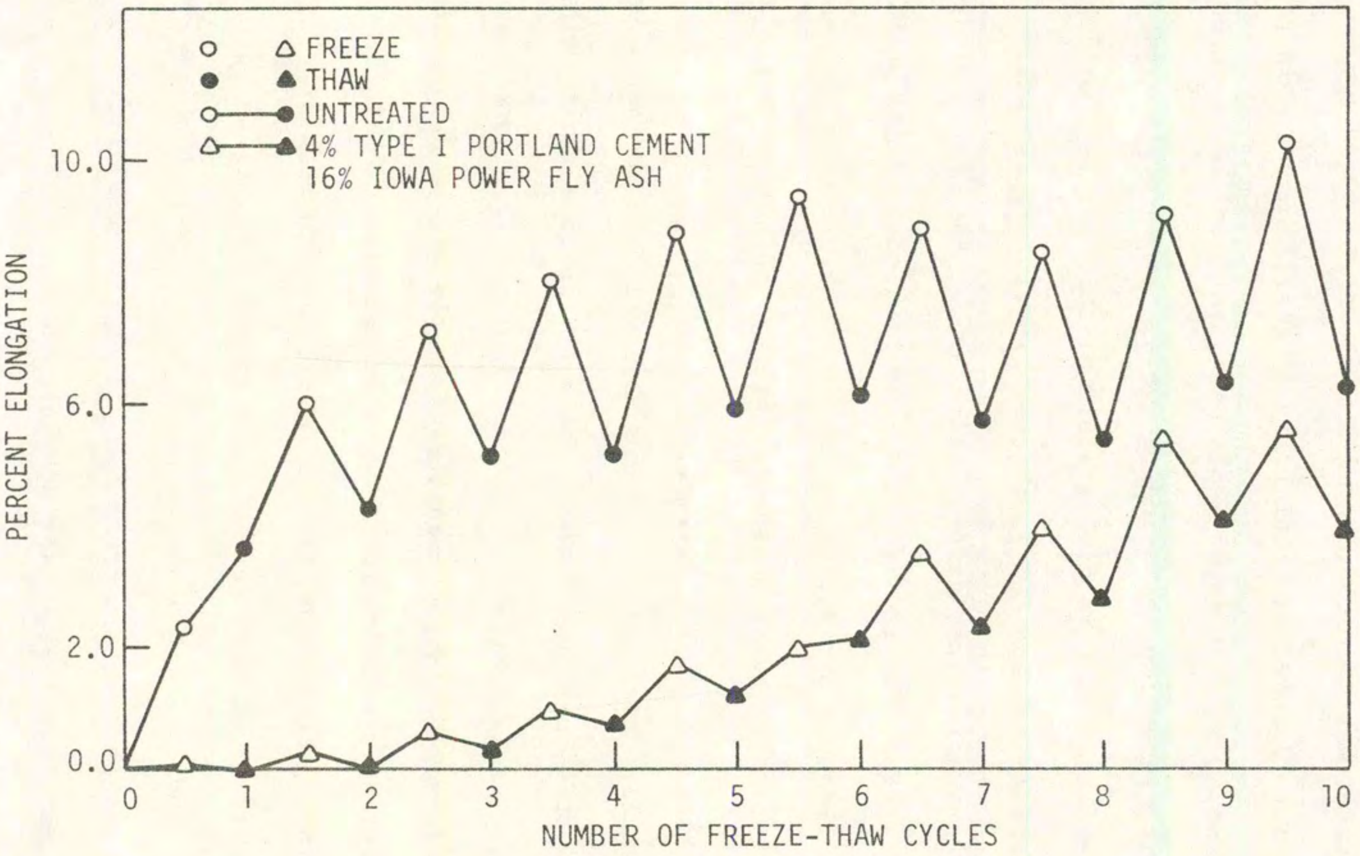

Fig. 17. Percent elongation versus number of freeze-thaw cycles, Neola soil, Pottawattamie County.

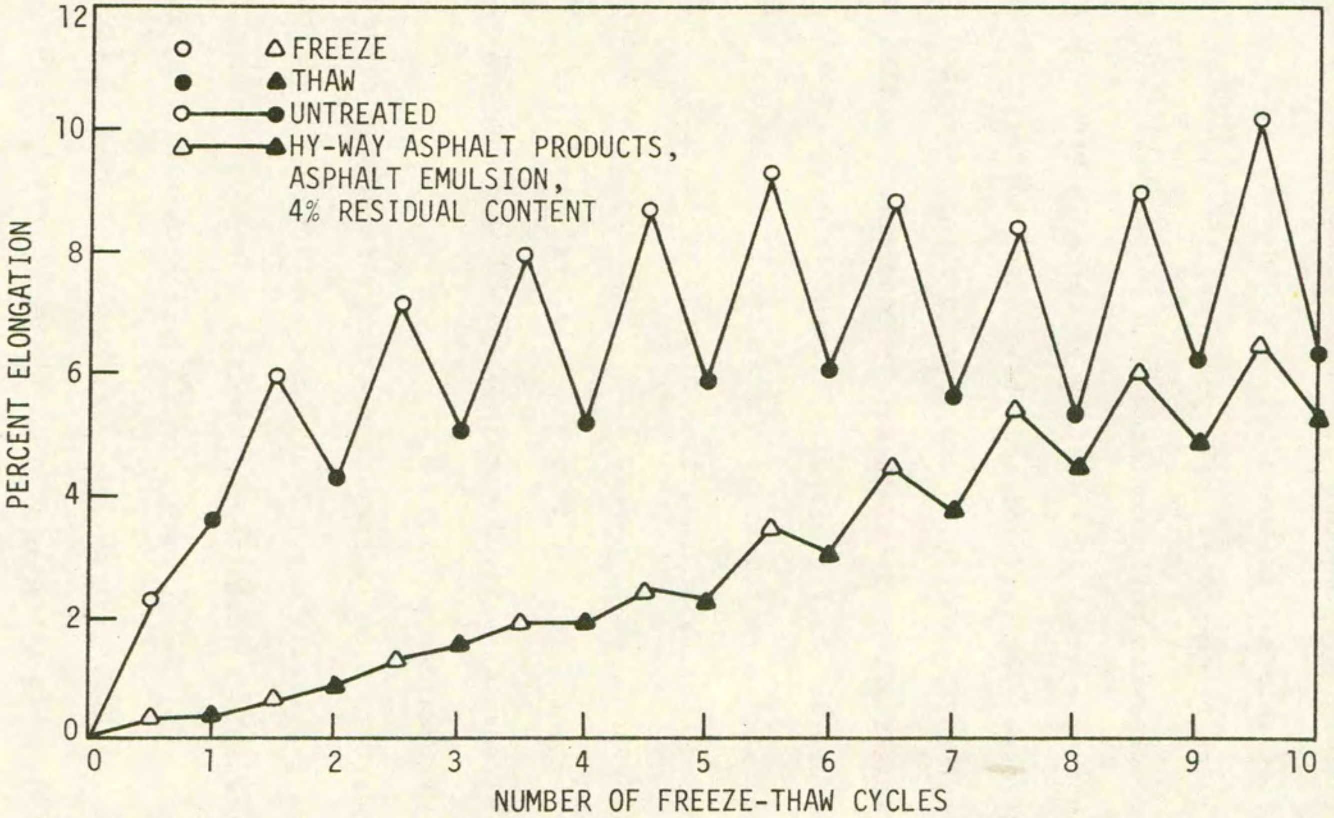

Fig. 18. Percent elongation versus number of freeze-thaw cycles, Neola soil, Pottawattamie County.

Iowa K-Test

The Iowa K-Test [12,13,22] simulates an undrained, relatively rapid field loading situation, providing quantitative values of cohesion (c), angle of internal friction (ϕ), and other strength parameters from single 1/30 cu ft compacted soil specimens. Specimens are subjected to vertical compression while confined in a split steel mold acting as a spring, in such a way that spreading of the mold provides a measure of lateral stress. The ratio of soil horizontal-to-vertical stress, K, may be continuously monitored and used to obtain strength parameters and moduli as the test progresses. The parameters c-ϕ may be used in variations of the classic Prandtl-Terzaghi bearing capacity analysis. The lateral stress ratio, K, is a measurement of lateral stability, but may be looked upon as an indicator of roadway material rutting potential. Values of K should never exceed 1.000, with smaller K values indicating less rutting potential due to greater lateral stability. The ratio of vertical stress to vertical strain obtained from the K-Test defines a vertical deformation modulus, E_v.

Standard 1/30 cu ft specimens were prepared and cured prior to the K-Test, as previously described in the section on freeze-thaw testing. Table 2 presents a summation of average K-Test parameters following (a) 7-days cure, (b) 7-days cure plus 10 freeze-thaw cycles, and (c) 17-days cure. Figures 19, 20, and 21 present the data of Table 2 in graphic form. In general, effectiveness of treatment vs non-treatment would be viewed through the K-Test parameters as increased c, ϕ and E_v coupled with decreased K, following curing. In addition, little or no change in c, ϕ, E_v or K from a 7-day cure should occur following 10 freeze-thaw cycles. These generalized effectiveness criteria will tend to vary with the stabilization mechanism of the individual additives. For example, asphalt may increase the value of c, but reduce ϕ. This does not indicate reduced effectiveness as a stabilizer, since in any variation of the Prandtl-Terzaghi bearing capacity analyses increased cohesion may more than amply offset a reduction in ϕ, thus producing increased support capacity. However, if the addition of asphalt also reduces E_v and increases K, resistance to deformation and lateral movement are reduced.

Soil-additive composites presented in Table 2 and Figures 19, 20 and 21 illustrate the preceding effectiveness criteria from the K-Test. The untreated Honey Creek soil followed the basic criteria of reduced c, ϕ, E_v, and increased K following curing and 10 freeze-thaw cycles, Figure 19. Addition of 4% residual asphalt content with the E4868 asphalt emulsion reduced ϕ and E_v, created little change in c, and increased K following curing, compared to that of the untreated soil. Specimens treated with E4868 following 10 freeze-thaw cycles were definitely softened by capillary water and could not be adequately handled for K-Testing. Use of this very low zeta potential emulsion with the Honey Creek soil would thus produce inadequate structural properties. Addition of 4% residual content of the Hy-Way asphalt emulsion produced more favorable parameters, including increased cohesion following curing. Addition of cement and Iowa Power fly ash produced a relatively rigid composite with the Honey Creek soil, 4% cement and 16% fly ash providing somewhat greater effectiveness than the 3%-13% combination.

Table 2. Summation of average moisture-density and Iowa K-Test parameters.

Soil Designation and Classification	Additive, % Dry Soil Weight	Molded Moisture Content, %	Dry Density, pcf	K-Test Parameters				Final Moisture Content, %
				K	ϕ, degrees	c, psi	E_v, psi	
Honey Creek A-6(4)	None, 7-day moist cure	9.7	123.6	0.220	37.3	9.2	4,473	10.3
	None, 7-day moist cure, 10 cycles freeze-thaw	8.6	125.4	0.353	24.5	9.4	2,043	11.6
	None, 17-day moist cure	7.6	125.4	0.212	38.7	10.1	6,152	9.5
	4% E4868, 7-day cure[a]	9.1	121.7	0.448	18.4	8.1	2,069	10.2
	4% E4868, 10 cycles freeze-thaw	10.1	120.6	-[b]	-[b]	-[b]	-[b]	11.1
	4% E4868, 17-day cure[a]	9.5	122.1	0.466	16.6	7.6	3,021	9.7
	4% Hy-Way A.E., 7-day cure[a]	10.2	114.5	0.212	31.6	25.5	3,227	6.2
	4% Hy-Way A.E., 10 cycles freeze-thaw	10.7	115.8	0.415	20.2	8.7	1,873	10.1
	4% Hy-Way A.E., 17-day cure[a]	11.0	115.2	0.243	29.9	19.7	2,831	8.2
	3% PC, 13% FA, 7-day moist cure	9.1	119.5	0.091	59.2	41.2	18,360	8.8
	3% PC, 13% FA, 10 cycles freeze-thaw	9.1	120.9	0.116	56.2	24.5	13,957	11.8
	3% PC, 13% FA, 17-day moist cure	8.7	120.2	0.095	63.1	33.9	21,816	8.6
	4% PC, 16% FA, 7-day moist cure	8.0	124.4	0.057	72.0	101.2	41,530	8.4
	4% PC, 16% FA, 10 cycles freeze-thaw	8.5	123.9	0.067	69.4	75.5	18,210	10.4
	4% PC, 16% FA, 17-day moist cure	8.3	124.0	0.053	73.0	104.7	25,217	8.2
Plymouth A-4(0)	None, 7-day moist cure	11.8	115.7	0.271	30.9	11.4	3,212	11.1
	None, 7-day moist cure, 10 cycles freeze-thaw	11.8	116.0	0.397	23.0	6.2	1,040	14.9
	None, 17-day moist cure	11.8	116.2	0.255	47.0	14.1	3,094	11.3
	2% E11, 7-day cure[a]	10.4	116.6	0.266	28.9	16.1	3,124	9.7
	2% E11, 10 cycles freeze-thaw	10.4	115.5	0.498	16.8	8.0	1,068	14.4
	2% E11, 17-day cure[a]	10.4	115.0	0.266	30.1	13.4	2,761	10.3
	4% E11, 7-day cure[a]	9.9	110.3	0.259	30.1	15.4	2,429	8.1
	4% E11, 10 cycles freeze-thaw	9.9	109.2	0.456	17.7	8.2	968	13.6
	4% E11, 17-day cure	9.9	110.4	0.251	29.3	18.4	2,778	8.4
	2% PC, 6% FA, 7-day moist cure	9.1	126.4	0.064	75.8	6.5	15,128	-

Table 2. Continued.

Soil Designation and Classification	Additive, % Dry Soil Weight	Molded Moisture Content, %	Dry Density, pcf	K-Test Parameters				Final Moisture Content, %
				K	ϕ, degrees	c, psi	E_v, psi	
	2% PC, 6% FA, 10 cycles freeze-thaw	9.1	123.8	0.091	67.9	25.8	9,438	11.4
	2% PC, 6% FA, 17-day moist cure	9.1	124.8	0.122	57.9	10.7	7,052	8.1
	3% PC, 9% FA, 7-day moist cure	10.5	117.0	0.084	67.9	20.1	11,386	8.5
	3% PC, 9% FA, 10 cycles freeze-thaw	10.5	122.4	0.080	75.4	20.3	11,104	8.6
	3% PC, 9% FA, 17-day moist cure	10.5	119.8	0.114	60.8	12.9	9,956	9.2
	3% PC, 13% FA, 7-day moist cure	9.1	122.2	0.052	80.0	12.8	13,039	8.6
	3% PC, 13% FA, 10 cycles freeze-thaw	9.1	121.7	0.062	72.4	13.0	11,720	9.1
	3% PC, 13% FA, 17-day moist cure	9.1	121.9	0.060	79.6	2.5	10,852	8.8
Buchanan A-2-4(0)	None, 7-day moist cure	7.5	131.7	0.147	37.6	5.6	7,744	6.9
	None, 7-day moist cure, 10 cycles freeze-thaw	6.5	131.7	0.189	45.9	1.7	2,453	8.2
	None, 17-day moist cure	7.5	133.2	0.234	39.2	2.3	5,279	7.8
	2% E65, 7-day cure[a]	8.0	129.4	0.438	23.4	3.3	4,973	7.7
	2% E65, 10 cycles freeze-thaw	8.0	130.3	0.271	33.9	5.5	3,307	6.7
	2% E65, 17-day cure[a]	8.0	130.8	0.426	21.8	4.4	3,637	7.4
	4% E65, 7-day cure[a]	7.8	126.4	0.389	22.8	6.3	2,914	7.8
	4% E65, 10 cycles freeze-thaw	7.8	126.4	0.389	22.8	6.3	2,914	7.8
	4% E65, 17-day cure[a]	7.8	126.4	0.497	16.5	4.8	2,497	7.8
	0.5% Coherex, 7-day cure[a]	7.8	133.6	0.148	48.8	14.8	6,509	5.1
	0.5% Coherex, 10 cycles freeze-thaw	8.1	133.2	0.399	26.7	3.2	1,622	7.8
	0.5% Coherex, 17-day cure[a]	7.9	133.9	0.195	43.0	6.0	5,042	6.2
	2% Lignosulfonate, 7-day cure[a]	7.2	134.1	0.215	39.6	7.4	4,514	6.5
	2% Lignosulfonate, 10 cycles freeze-thaw	6.9	134.8	0.283	34.3	2.1	4,053	7.3
	2% Lignosulfonate, 17-day cure[a]	7.1	134.7	0.247	38.0	2.2	4,821	6.5

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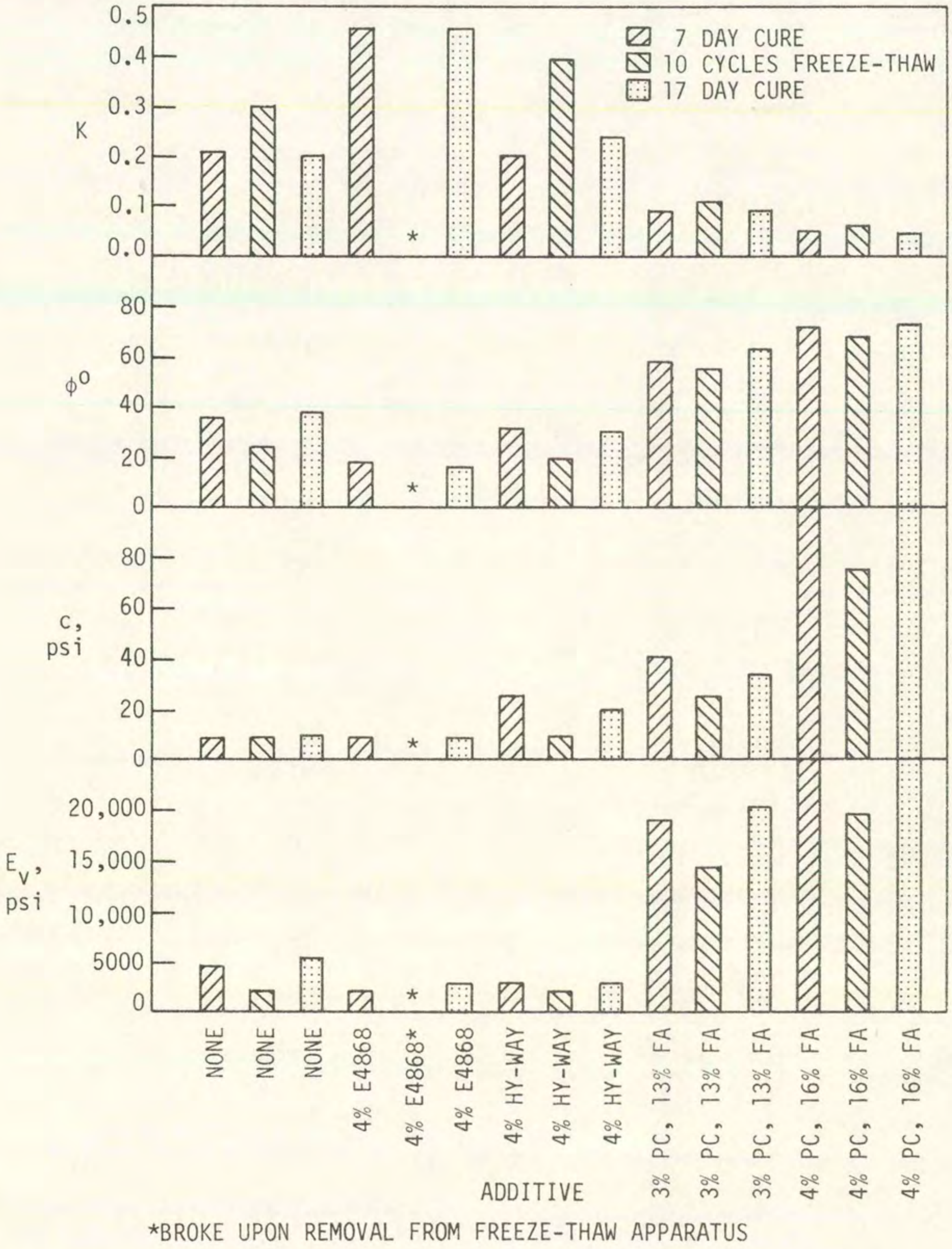
[a] Cure condition includes 1-day initial air curing, remainder moist cure.

[b] Could not be determined due to breakage upon removal from freeze-thaw apparatus.



*BROKE UPON REMOVAL FROM FREEZE-THAW APPARATUS

Fig. 19. Comparison of K-Test parameters, Honey Creek soil, Pottawattamie County.

Introduction of 2% residual asphalt content of the E11 asphalt emulsion produced parameters not unlike that of the untreated Plymouth County soil, Figure 20. Addition of 4% residual asphalt content was more effective, particularly improving cohesion not only following curing, but also after 10 freeze-thaw cycles. Combinations of the four parameters indicated soil-additive composite effectiveness with cement and Port Neal III fly ash, regardless of the contents. Each cement and fly ash combination produced significant lowering of K and increased E_v from that of the untreated. Combined c-ϕ values generally cooperated with one another in that where c was reduced, ϕ increased, and each combination exhibited considerable improvement of bearing capacity from that of the untreated Plymouth County soil.

Use of the E65 asphalt emulsion with the Buchanan County soil, Figure 21, increased cohesion effectiveness following 10 cycles of freeze-thaw by a factor of about three, a relatively significant contribution when incorporated at 4% residual asphalt content. Parameters ϕ, K, and E_v were not improved, the K values being increased considerably. With the exception of E_v and K, addition of 0.5% Coherex increased the c-ϕ parameters following curing. Following 10 cycles of freeze-thaw, Coherex reduced the effectiveness of ϕ, K, and E_v, but c was nearly double that of the untreated soil. Addition of 2% ammonium lignosulfonate generally maintained a status quo with the untreated soil following curing. After 10 cycles of freeze-thaw, the ammonium lignosulfonate, however, had basically maintained the untreated soil's lateral stability and bearing capacity and had definitely improved the vertical deformation modulus.

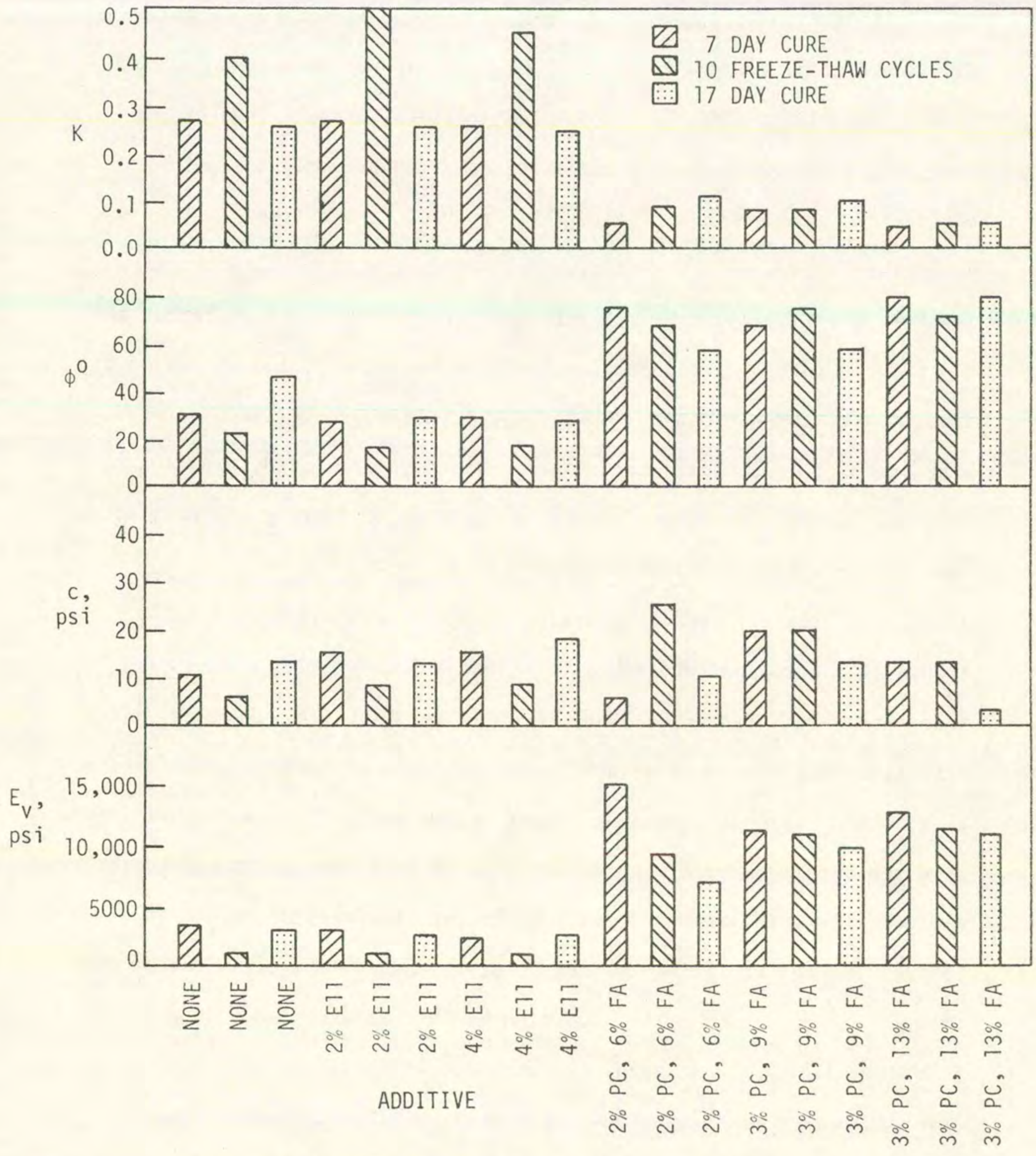


Fig. 20. Comparison of K-Test parameters, Plymouth County soil.

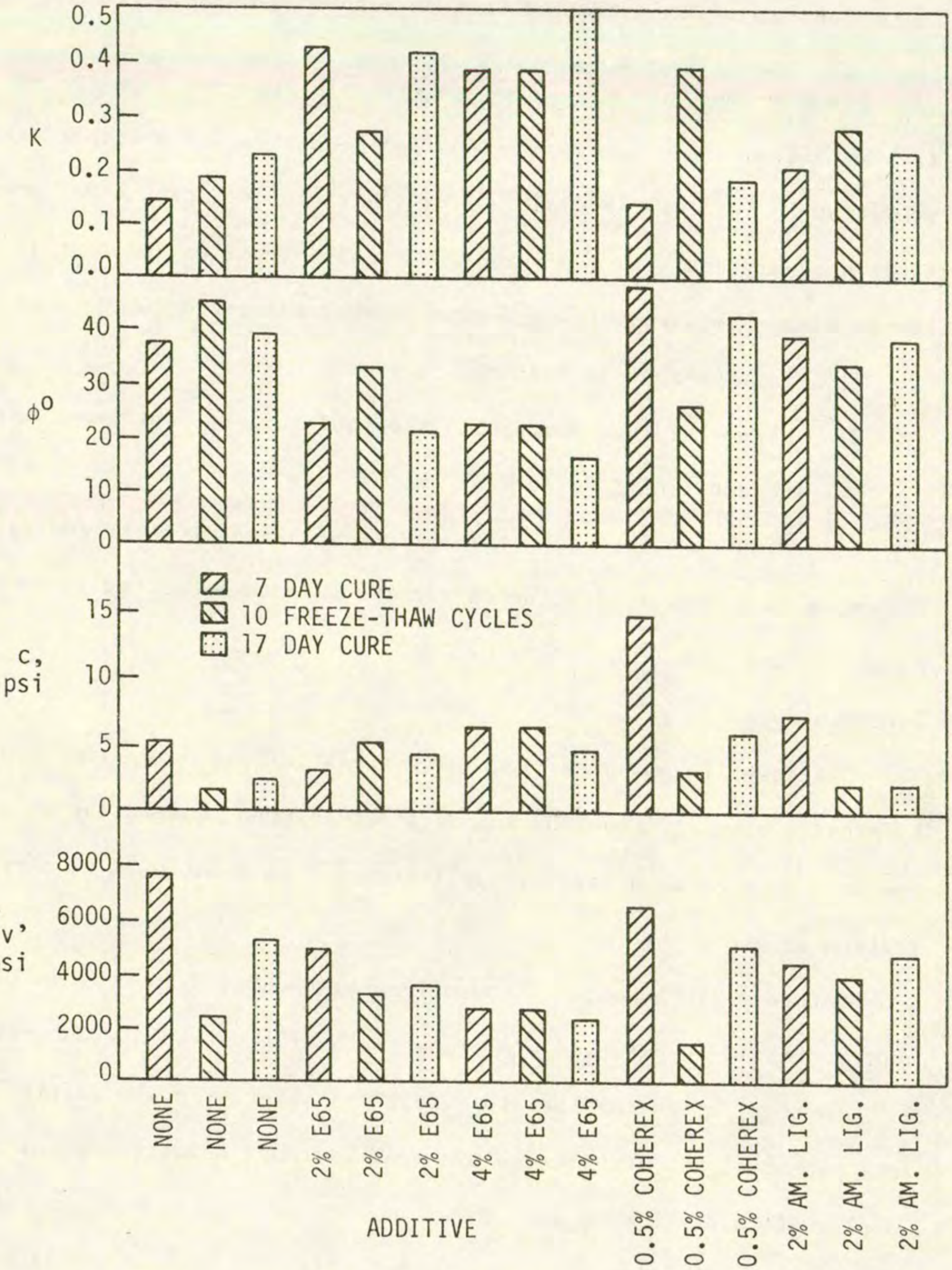


Fig. 21. Comparison of K-Test parameters, Buchanan County soil.

Demonstration Section Recommendations

Based on analysis of evaluative criteria achieved from the various test method results, recommendations for demonstration sections were submitted to each of the counties for their consideration. Recommendations were divided into the three principal categories, each utilizing the existing in-place soil/aggregate roadway material:

1) Surface-applied dust palliatives.
2) Mixed-in-place dust palliation and surface improvement products, no additional surfacing.
3) Mixed-in-place base stabilizers with seal coat surfacing.

Following is a summary listing of recommendations submitted to each participating county.

Buchanan County

Category 1) Ammonium lignosulfonate at a rate of application(s) to provide about 1.5 to 2.0% solids at an assumed penetration of about one in. Coherex at a rate of application(s) of about 0.5% at a penetration of about one in.

Category 2) Ammonium lignosulfonate, about 1.5 to 2.0% solids content, mixed-in-place to a minimum depth of about 4 in. Coherex, 0.5% content, mixed-in-place to a depth of about 4 in. A fairly low zeta potential CSS asphalt emulsion, 4% residual asphalt content mixed-in-place to a depth of 4 in.

Category 3) A fairly low zeta potential CSS asphalt emulsion, 4% residual asphalt content mixed-in-place to a minimum depth of 6 in.

Franklin County

Due to preferences stated by the County Engineer, only Category 1 recommendations were submitted.

Category 1) A low zeta potential CSS asphalt emulsion, two applications at 0.2 gal./sq yd each of 9:1 and 5:1 water dilution. Ammonium lignosulfonate at about 1% solids to an assumed depth of one in., applied at 0.23 gal./sq yd. Liquid calcium chloride applied at a rate and concentration normally used by the county. Coherex at a rate of application(s) to provide about 1.0% at an assumed penetration of about one in. Polybind Acrylic DLR 81-03 at a rate of application(s) to provide about 0.067% by dry soil weight at an assumed penetration of about one in. Amsco Res AB 1881 at a rate of application(s) to provide about 0.05% by dry soil weight at an assumed penetration of about one in.

Marion County

Category 1) A very low zeta potential CSS asphalt emulsion at a rate of application(s) to provide a minimum residual asphalt content of 2% at an assumed penetration of about one in. Coherex at a rate of application(s) to provide up to 1.0% by dry soil weight at an assumed penetration of about one in.

Category 2 and 3) A very low zeta potential CSS asphalt emulsion, 2 to 4% residual asphalt content mixed-in-place to minimum depths of 4 to 6 in.

Plymouth County

Category 1) Ammonium lignosulfonate at a rate of application(s) to provide a minimum solids content of 1.5% at an assumed penetration of about one in.

Category 2) A high zeta potential CSS asphalt emulsion, 4% residual asphalt content, mixed-in-place to about 4 in. Ammonium lignosulfonate, 1.5 to 2.0% solids content, mixed-in-place to a minimum depth of about 4 in.

Category 3) A high zeta potential CSS asphalt emulsion, 4% residual asphalt content, mixed-in-place to a minimum depth of 6 in. Combination of Type I Portland cement and Port Neal III fly ash, 3%-9%, 3%-13% and 3%-16% by dry soil weight respectively, mixed-in-place to a minimum depth of 6 in. Use of 20% fly ash only was a possibility on this site, but was not recommended due to a slight chance of swelling.

Pottawattamie County--Honey Creek

Category 1) Coherex at a rate of application(s) to provide a minimum of 0.05% by dry soil weight at an assumed penetration of about one in. A low zeta potential CSS asphalt emulsion at a rate of application(s) to provide a minimum residual asphalt content of about 4% at an assumed penetration of one in.

Category 2) A low zeta potential CSS asphalt emulsion, 4 to 6% residual asphalt content, mixed-in-place to a depth of about 4 in.

Category 3) Combination of Type I Portland cement and Iowa Power fly ash, 3%-13% and 4%-16% by dry soil weight respectively, mixed-in-place to a minimum depth of 6 in. A low zeta potential CSS asphalt emulsion, 4 to 6% residual asphalt content, mixed-in-place to a depth of 6 in.

Pottawattamie County--Mud Hollow

Due to preferences stated by the County Engineer, all testing centered on a desired usage of available fly ash.

Category 3) Fly ash only at a minimum of 35% by dry soil weight, mixed-in-place to a minimum depth of 6 in. Combination of Type I Portland cement, 3%-9% and 3%-13% by dry soil weight respectively, mixed-in-place to a minimum depth of 6 in.

Pottawattamie County--Neola

Category 1) Ammonium lignosulfonate at a rate of application(s) of 1.0 to 1.5% by dry soil weight at an assumed penetration of one in.

Category 2) A median zeta potential CSS asphalt emulsion, 4% residual asphalt content, mixed-in-place to a minimum depth of 4 in.

Category 3) Combination of Type I Portland cement and Iowa Power fly ash, 4%-16% and 4%-20% by dry soil weight respectively, mixed-in-place to a minimum depth of 6 in. A median zeta potential CSS asphalt emulsion, minimum of 4% residual asphalt content, mixed-in-place to a depth of 6 in.

Story County

Category 1) A low zeta potential CSS asphalt emulsion, two applications at 0.2 gal./sq yd each of 9:1 and 5:1 water dilutions. Coherex, to be applied in two stages for a total application of 0.5% by dry soil weight. Three-fourths of the Coherex to be incorporated to a depth of 1-1/2 to 2 in., the remaining one-fourth to be surface applied in a water solution after a minimum of two-months curing.

Category 2) Polybind Acrylic DLR 81-03, 0.1% by dry soil weight, mixed-in-place to a minimum depth of 4 in.

Category 3) Combination of 3% Type I Portland cement and 9% Ames fly ash mixed-in-place to a depth of 6 in.

Though not indicated in the above summarization, untreated control sections were recommended with each site category for comparative purposes. All recommended sections ranged in length from about 500 to 2000 ft in length. Any Category 3 stabilization was to receive a seal coat surfacing as might normally be used within each county. Therefore, no recommendations were made regarding seal coating. Estimated section costs as of late 1978 ranged from several hundred dollars to in excess of $30,000 per mile, depending on product(s) utilized and category applied within each site.

It should be clearly understood that at about the same time as the above recommendations were made to each county, all petroleum products began to rise rapidly in price, affecting every aspect of construction ranging from cost of product, to transportation, to equipment operating costs. As a consequence, all possible means of maintaining the basic program requirements and the preceding recommendations were evaluated. As will be noted in the succeeding sections however, some changes were necessary as dictated by the economic state existing in 1979 and 1980. Each county, the IHRB, and the Iowa DOT, as well as the research team, cooperated in assessing what portion, or portions, of the research objectives and construction recommendations could be sustained. As will be indicated in the succeeding section, major portions of all aspects of the program were preserved.

FIELD STUDIES

Demonstration Section Construction

Following is a description of each demonstration section construction. Selected products and construction techniques were cooperatively worked out in conjunction with each county engineer and his staff, the county supervising all construction and the research personnel providing all in-place testing prior to, during, and following construction. As previously indicated, no construction was accomplished in Buchanan County.

Pottawattamie County--Mud Hollow

This demonstration section was 1100 feet in length, and consisted of a Category 3, 6-in. compacted thickness base treatment, using 3% Type I Portland cement and 13% Iowa Power fly ash.

Construction was started August 28, 1979, by county personnel shaping the grade and scarifying the in-place road materials. After scarification, the material was thoroughly mixed using the county's tractor-towed Rex pulverizers; the process required several passes of the pulverizers to achieve a desired break up of aggregated materials to sizes generally less than 1-1/2 to 1 in.

Water was added with a spray bar equipped tank truck and the material remixed, bringing the moisture content to near optimum prior to addition of cement and fly ash. Field moisture contents were monitored by project research personnel with the use of a laboratory calibrated "Speedee" moisture meter. This preparation consumed the first day of construction and the prepared material was windrowed for the night in order to minimize moisture loss.

Portland cement and fly ash were added during the second day of construction. The cement was delivered by bulk transport and unloaded through use of the transport's pneumatic system while driving along the length of the section. Trial and error methods determined that a tank pressure of approximately 3 psi provided a uniform discharge with little release of cement dust to the atmosphere.

Fly ash was delivered to the site in tarpaulin covered county dump trucks; tarps and tailgates were sealed with duct tape to prevent loss of the fine-grained fly ash during transport. The fly ash was distributed along the length of the section through end dumping based on a precalculated spreading rate. Some "dusting" was associated with this spread process, but was considered to be of minimal impact.

Initial incorporation of the Portland cement and fly ash was accomplished by longitudinal blade mixing with a motor patrol, coupled with rotary mixing using the Rex pulverizers. Additional water was added to bring the mixture to or slightly above optimum moisture content. The mixture was bladed in a windrow along one edge of the road, then taken from the windrow and spread by motor patrol in two equal lifts. Each lift was compacted with a tractor-drawn sheepsfoot roller until the tamping feet "walked out." The top of each lift was lightly scarified to insure good bond.

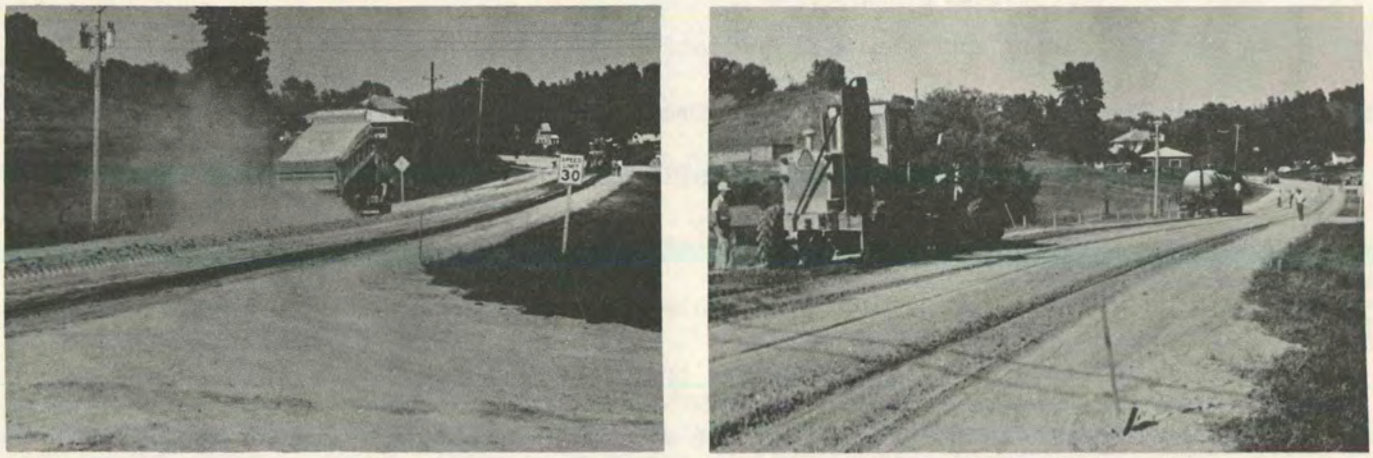
Following compaction, moisture and density over the 6-in. thick depth were determined by research project personnel with the use of a Campbell Pacific MC-10 nuclear moisture-density gauge. Final blading was performed for crown, and superrelevation in the east portion, and the surface was finished with a rubber-tired roller. Water was periodically applied as a fine spray for 24 hrs after completion, in order to provide curing and minimize hydration losses of the stabilized base.

As part of the Category 3 treatment, a seal coat wearing surface was applied after the 24-hr moist curing period. The county chose a CRS asphalt emulsion with 1/2-in. limestone chips. Though the asphalt emulsion was designed to be compatible with the chips, several problems were encountered: the emulsion had been contaminated during transport and required an inordinate amount of mixing prior to application, the chip spreader had to be adjusted several times to acquire the desired application rate, and bond of the asphalt emulsion to the cement fly ash stabilized base was inadequate. Within a few weeks following construction, the seal coat surface began to peel and was replaced in May 1980 by blading off what seal coat remained plus a fraction of the upper crust of the base, followed by a cutback asphalt seal coat wearing surface.

Figure 22 presents a series of photos during and up to 16 months following construction of the Mud Hollow section.

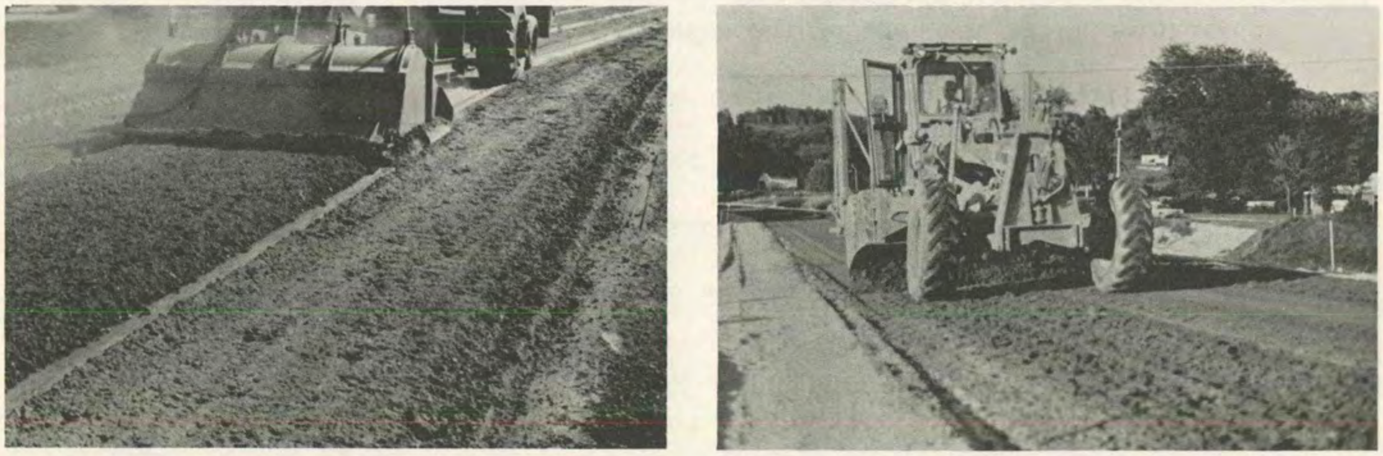
Pottawattamie County--Honey Creek

This site consisted of two sections of county road L-19. Section HC-1 began at the interchange with I-29, proceeding west about 1400 ft, where it joined section HC-2, running north about 1300 ft, ending adjacent to a KOA campground. Section HC-1 consisted of a Category 3, 6-in. compacted depth stabilization, using 4% Type I Portland cement and 16% Iowa Power fly ash. The recommended Category 3 treatment,



a. Spreading fly ash.

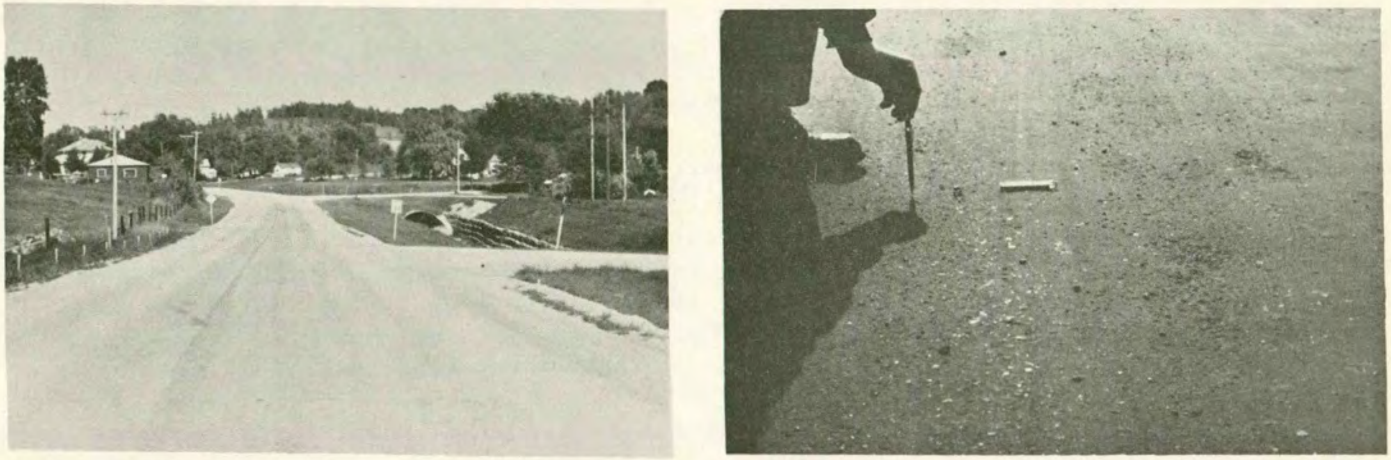
b. Addition of water (right), longitudinal mixing with blade (left).



c. In-place mixing of cement and fly ash.

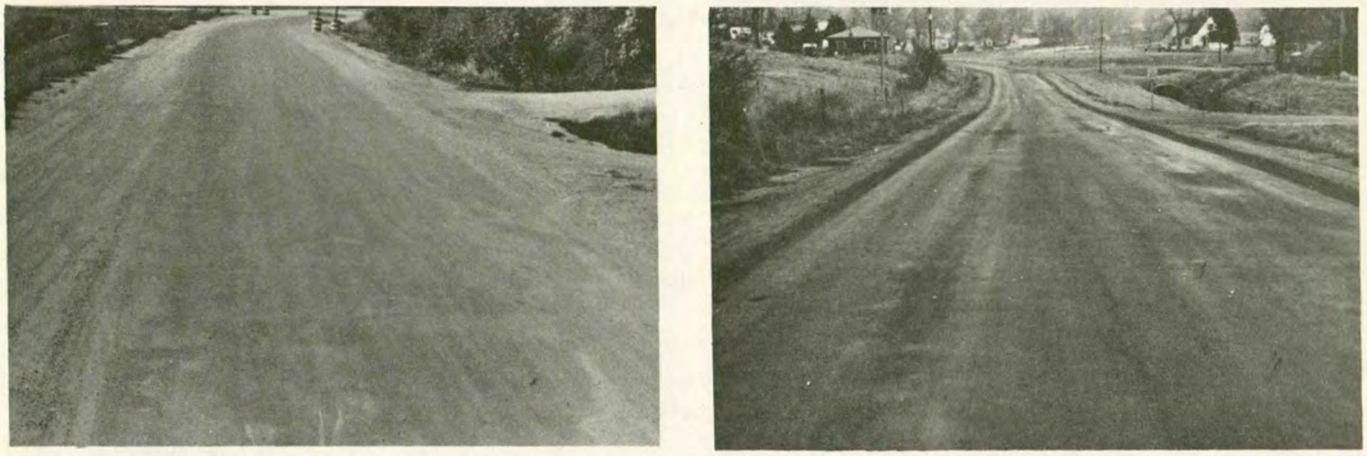
d. Final blading to known and crossection following sheepsfoot compaction.

Fig. 22. Pottawattamie County-Mud Hollow site.



e. Finished roadway, October 1979.

f. Exposed base course due to raveling of surface, February 28, 1980.



g. Finished roadway, new surface, August 26, 1980.

h. Roadway status, December 29, 1980

Fig. 22. Continued.

using 4% residual asphalt content of a low zeta potential CSS emulsion was followed for section HC-2. The emulsion was designed, prepared, and supplied by Hy-Way Asphalt Products, Inc., Salina, Kansas.

Construction of section HC-1 was completed during the week of September 10-14, 1979, by county forces. Procedures developed during construction of the Mud Hollow section were refined and applied to HC-1. Mixing of cement and fly ash, plus compaction and final finishing was conducted in one day for the full 1400-ft length, with final rolling occurring under lights. As with the Mud Hollow section, a fine spray of water was periodically applied for 24 hrs after completion, followed by the CRS asphalt emulsion seal coat surfacing.

Section HC-2 was constructed during the week of September 17-21, 1979. County crews prepared the grade by twice scarifying the untreated road material to a depth of 3 in. per pass of the motor patrol. Material from each pass was bladed into a windrow, then pulverized with the tractor-towed Rex units to break up aggregations. Water was added to near optimum moisture content and thoroughly mixed with the pulverizers. The motor patrol then moved the material into a windrow at the edge of the roadway. This process was repeated for the second scarification pass until all in-place material for a compacted 6-in. depth had been windrowed. The windrowed material was left overnight to minimize moisture loss.

The following morning, field moisture content was slightly below desired optimum for application of the emulsion without creating an early break. Therefore, approximately 1/6 of the windrowed material was spread by motor patrol. A light spray of water was applied by tank truck, which was followed by an insulated bulk transport applying the asphalt emulsion at a rate to cover the pre-moistened soil material. The blade grader folded the treated material over to provide an initial mixing, and the pulverizers made two passes over the bladed material to insure dispersion of the emulsion throughout the soil-aggregate. The treated material was then bladed to a windrow on the opposite side of the road. This process was repeated until all road material had been properly treated. The windrow was then tight bladed to minimize moisture loss, and allowed to stand overnight.

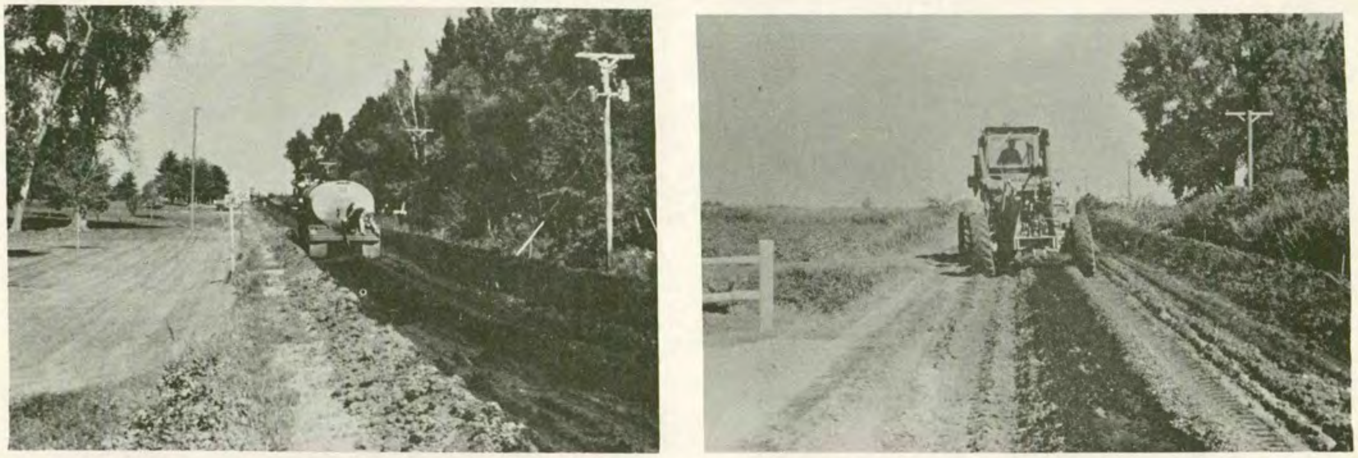
The third day included blade and pulverizer mixing to ensure dispersion of the asphalt emulsion and to facilitate loss of moisture and its accompanying break of the emulsion prior to laydown. When the moisture content of the treated mixture tested slightly below compaction optimum, laydown was initiated. The treated material was blade spread from the windrow in two equal lifts, each producing approximately 3-in. compacted depth. Each lift was compacted with a tractor-drawn sheepsfoot roller until the tamping feet walked out, the lower lift being lightly scarified to insure proper bonding. Final blading was performed for crown and surface dressing, and the surface was finished with a rubber-tired roller.

Prior to application of the CRS seal coat wearing surface, section HC-2 developed a number of soft spots, coupled with some alligatoring. Upon investigation by the County Engineer and project research personnel, spots of excessive moisture were determined to have prevented proper breaking of the emulsion and subsequent hardening of the base. Therefore, the treated material was scarified, bladed to a windrow, and remixed with the pulverizers in order to more fully aerate the material, thus releasing the excess moisture. After aeration, the treated material was replaced and compacted in the manner previously described. Moisture-density tests performed by project research personnel indicated that desired results had finally been achieved. The seal coat wearing surface was applied approximately 7 days later.

Figure 23 presents a group of photos taken during construction of section HC-2, as well as surface conditions of sections HC-1 and HC-2 up to 15 months following construction. As with the Mud Hollow cement and fly ash base, the seal coat surfacing on Honey Creek section HC-1 began to peel within a few weeks following construction. This was replaced in May 1980 by blade removal of what seal coat remained, plus a fraction of the base crust, followed by a cutback asphalt seal coat wearing surface. The initial CRS asphalt emulsion seal coat surfacing of section HC-2 was more compatible with the base and did not show signs of peeling or stripping.

Pottawattamie County--Neola

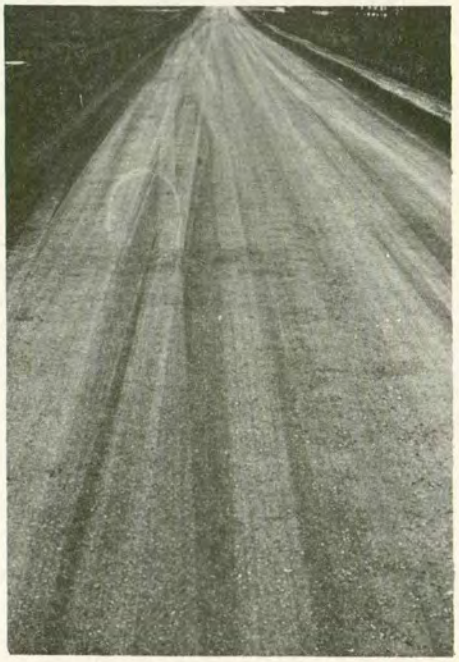
Two demonstration sections were constructed on county road L-55. Section N-1 began adjacent to the entrance of Arrowhead Park, extending 2400 ft north and west, and consisted of a Category 3, 6-in. compacted thickness base, stabilized with 4% residual asphalt content of a median zeta potential asphalt emulsion. The emulsion was designed, prepared, and supplied by Hy-Way Asphalt Products, Inc., Salina, Kansas. Section N-2 begins at the west end of section N-1, extending 1300 ft to the exit ramp from I-80, and consisted of a Category 3, 6-in. compacted



a. Asphalt emulsion application, section HC-2.

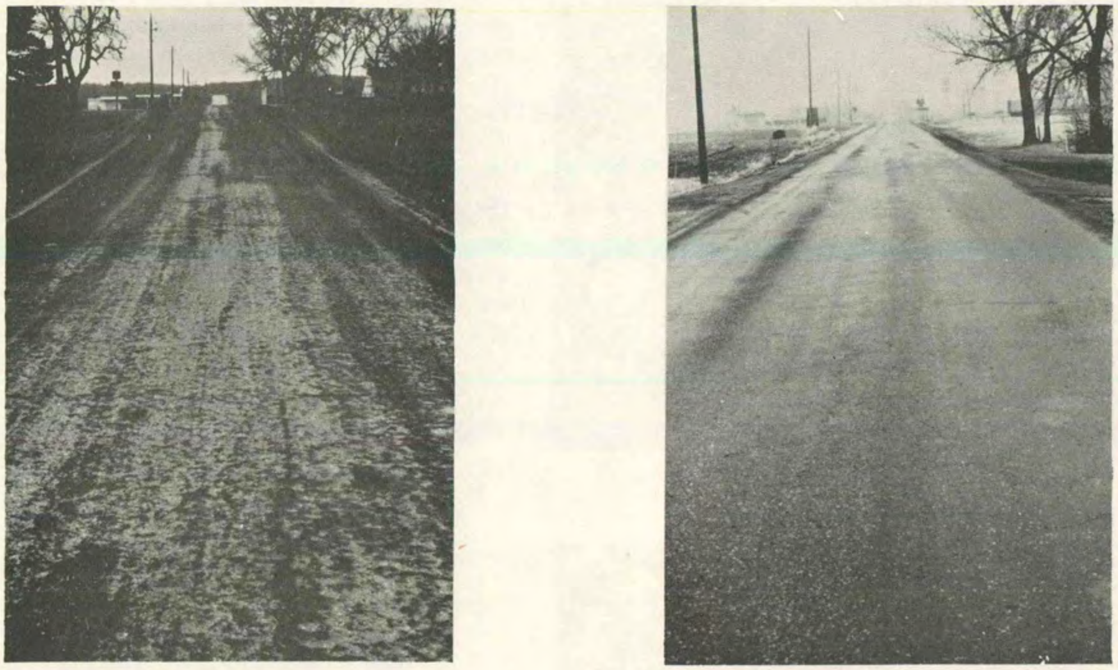
b. Initial blade grader mixing, section HC-2.

c. Rotary mixing, section HC-2.



d. Surface condition of section HC-2, February 28, 1980.

Fig. 23. Pottawattamie County-Honey Creek site.



e. Surface condition of section HC-1, February 28, 1980.

f. Surface condition of section HC-1, December 29, 1980.

Fig. 23. Continued.

thickness base, stabilized with 4% Type I Portland cement and 16% Iowa Power fly ash.

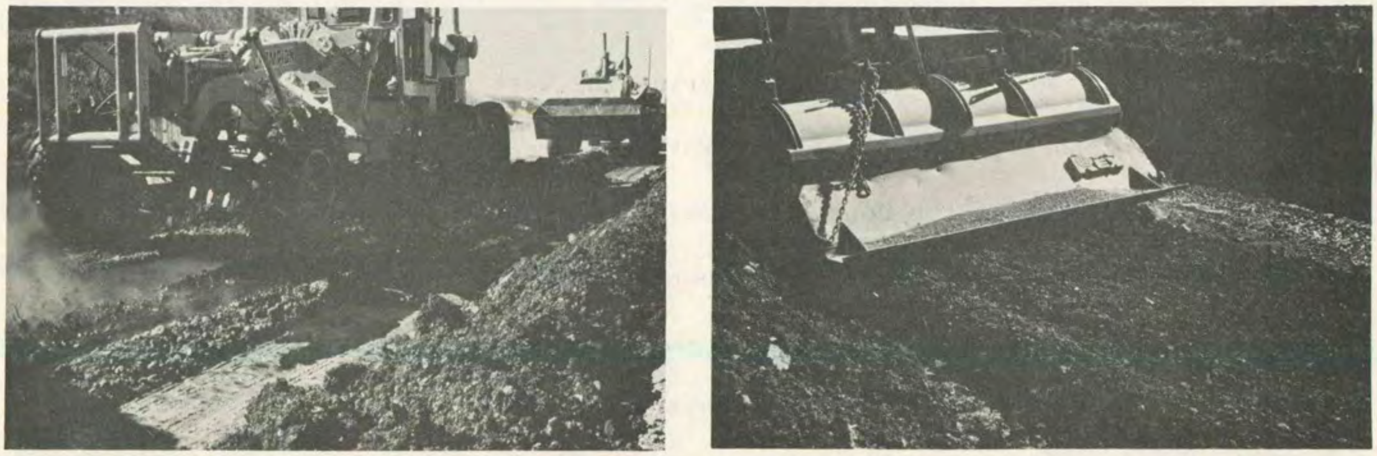
Section N-1 was constructed during the week of October 8-12, 1979, utilizing processes developed and refined during both the initial and final placement of the Honey Creek asphalt emulsion section. Familiarity with these processes enabled the county crew to increase production, allow sufficient aeration time for emulsion breakage, and complete the section in five ordinary working days.

Section N-2 was constructed during the week of October 15-19, 1979. Construction processes were identical to those developed, refined, and utilized for the Mud Hollow and Honey Creek cement-fly ash sections.

As with the preceding demonstration sections, a CRS asphalt emulsion seal coat wearing surface was applied to both Neola sections. No peeling or stripping was observed with section N-1, the CRS emulsion appearing to be compatible with the asphalt emulsion base. However, the CRS seal coat was again incompatible with the cement-fly ash stabilized base of section N-2 and was replaced in a manner identical to that followed at Mud Hollow and Honey Creek in May 1980. Figure 24 illustrates construction and surface conditions of the Neola site, the latter up to 14 months following construction.

Franklin County

Eleven test and two control sections were constructed during August 1979. Each of the six recommended products were utilized as a Category 1 dust palliative treatment. The additional test sections arose from an overlaying of strips previously treated by farmstead

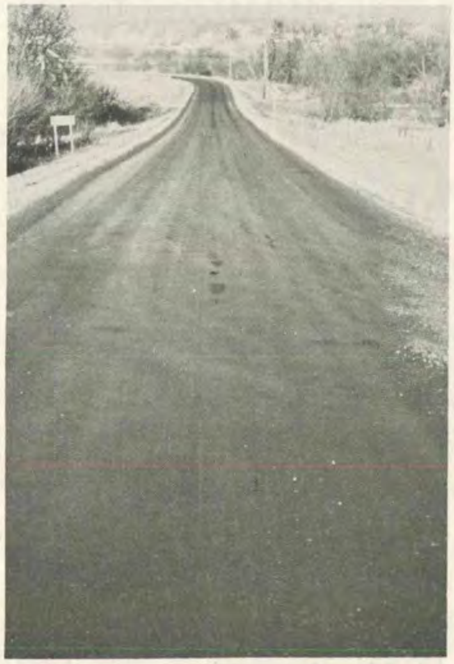


a. Asphalt emulsion application (left), initial fold over and longitudinal mixing (center), rotary mixer (rear), section N-1.

b. Rotary mixing, section N-1.

c. Mixed material windrowed (left), final mixing (right), section N-1.

d. Surface condition of section N-1, August 25, 1980.



e. Surface condition of section N-1, December 29, 1980.

Fig. 24. Pottawattamie County-Neola site.

f. Rotary mixing, section N-2.

g. Tamping foot compaction, section N-2.

i. Surface condition of section N-2, August 25, 1980.

h. Finish blading and rubber tired compaction, section N-2.

j. Surface condition of section N-2, December 29, 1980.

Fig. 24. Continued.

occupants. Figure 25 shows the test section layout. In keeping with the county engineer's desire to evaluate products which could be applied at minimal cost, all sections were tightly dressed with a blade grader, after which each product was applied as a water-diluted spray from a tanker. No additional tight blading occurred prior to a second application of product within several of the sections. Since interest in these sections was as a Category 1 treatment, analysis was primarily composed of visual observations and dust measurements; i.e., no testing was conducted during the construction process. The following summarizes application rates, surface conditions, product penetration, runoff, and a composite of visual observations made by ISU and Franklin County personnel through mid-December 1979 (about 4 months duration).

Section 1. CSSI Bitucote Products Co. Asphalt Emulsion (1320 ft)

August 13, 1979

1) Application rate--First application consisted of material diluted at a 9:1 ratio and applied at 0.2 gal./sq yd.
2) Surface condition--Damp with some puddling.
3) Penetration--Material did not appear to penetrate beneath the surface aggregate.
4) Runoff--None.
5) Appearance--Faint coloring of surface aggregate was observed. The emulsion appeared to break and coat the large aggregate. Small flakes of emulsion could be seen dispersed within the fines, but no coating was observed.

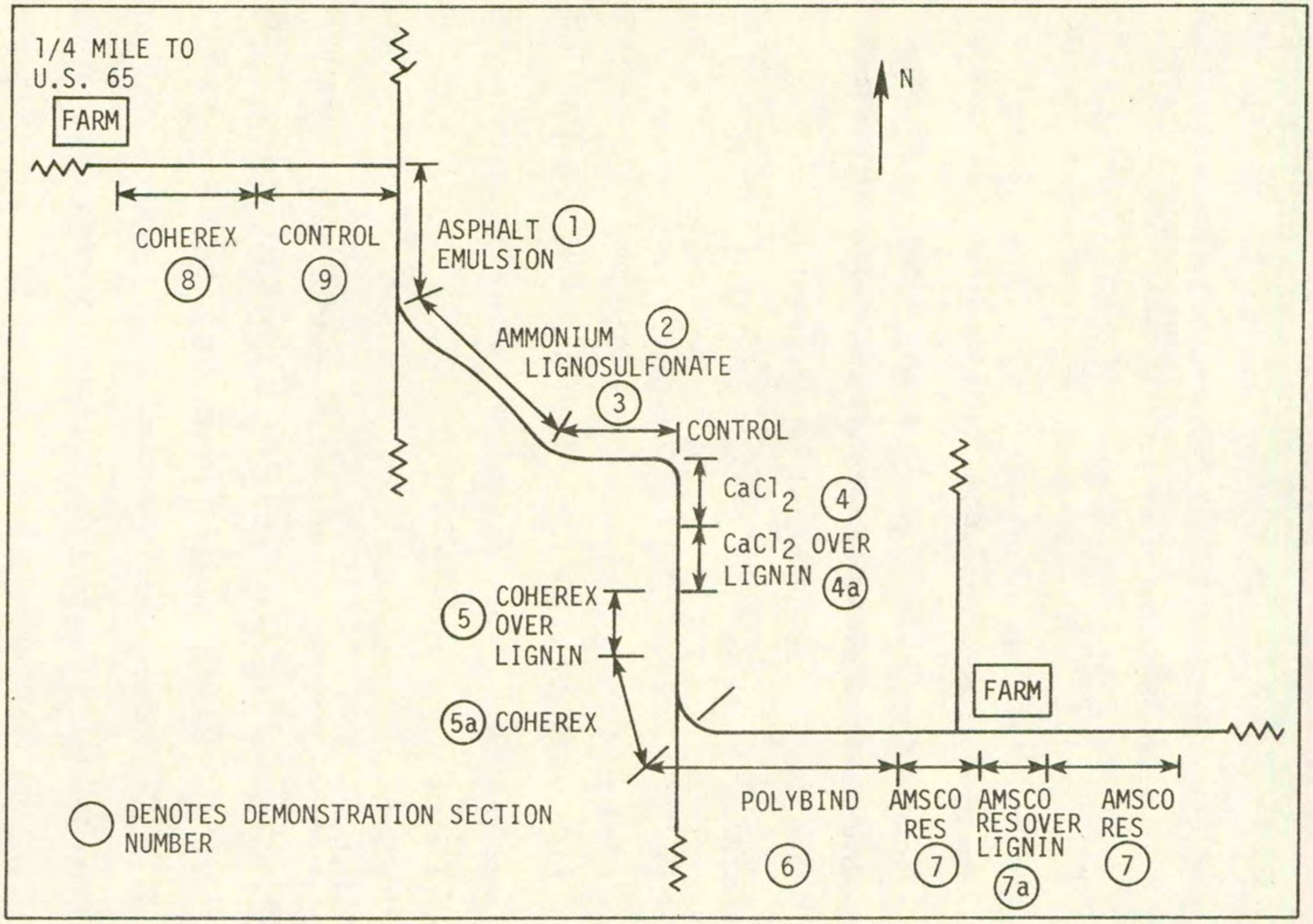


Fig. 25. Category 1 demonstration section layout, Franklin County.

August 14, 1979

1) Application rate--Second application consisted of emulsion diluted at a 5:1 ratio and applied at 0.2 gal./sq yd.
2) Surface condition--Slightly damp.
3) Penetration--Emulsion created a thin surface coating with very little penetration.
4) Runoff--Slight.
5) Appearance--The treatment was quite apparent. The emulsion appeared to break and coat the large aggregates; however, only a surface patina formed over the surface of the fines with little or no individual particle coating.

August 20, 1979

1) Surface condition--Damp.
2) Appearance--No sign of emulsion penetration could be seen and the surface had begun to ravel within the tire tracks.

October 4, 1979

1) Surface condition--Dry.
2) Appearance--Surface was badly raveled over the entire roadway; however, remnants of asphalt were quite apparent adhering to the coarse aggregate, with partial dispersion throughout the fines. The section was somewhat dusty, but not nearly as bad as the adjacent control section.

October 17, 1979

1) Surface condition--Dry.
2) Appearance--Some dust was noted, however there was still some improvement over the adjacent untreated section.

December 10, 1979

1) Surface condition--Dry.
2) Appearance--Little or no improvement over untreated section could be seen.

Section 2. Ammonium Lignosulfonate (1850 ft)

August 13, 1979

1) Application rate--Single application, diluted at 2.25:1 and applied at 0.23 gal./sq yd.
2) Surface condition--Moist.
3) Penetration--Material appeared to penetrate 1 to 1.5 in.
4) Runoff--None.

August 14, 15, 16 & 20, 1979

1) Surface condition--Damp.
2) Appearance--Dust appears to be washed from coarse aggregate. Also considerable float comprised of large aggregate was observed in parts of the section.

October 4, 17, and December 10, 1979

1) Surface condition--Dry.
2) Appearance--Section was slightly dusty in areas where considerable large aggregate float was observed. In other areas, the fines and coarse aggregate were bound in a patina to form a relatively dust-free surface. The surface was intact, without potholes.

Section 3. Control (1320 ft)

Dusty, all dates of observation, with relatively large areas of aggregate float.

Section 4. Calcium Chloride (265 ft)

August 27, 1979

1) Application rate--Single application of 38% solution applied at 0.18 gal./sq yd.
2) Surface condition--Moist.
3) Penetration--Lack of color prevented an estimate of penetration.
4) Runoff--None.

October 4, 17, and December 10, 1979

1) Surface condition--Dry.
2) Appearance--Section was relatively free of dust and chuck holes, slightly discolored as compared with adjacent control section. Some aggregate float at edges.

Section 4A. Calcium Chloride over Ammonium Lignosulfonate (430 ft)

With the exception that some runoff was observed during application, the application rates and observations for section 4 also applied to this section.

Section 5. Coherex over Ammonium Lignosulfonate (595 ft)

August 16, 1979

1) Application rate--First application consisted of material diluted at a 6:1 ratio and applied at 0.37 gal./sq yd.
2) Surface condition--Moist.
3) Penetration--Penetration of 1/2 to 3/4 in. was observed.
4) Runoff--Some, appeared to be caused by a somewhat impervious surface created by a previous lignin treatment.
5) Appearance--The treatment was made obvious by the yellow-green color of the product.

August 20, 1979

1) Application rate--Second application consisted of the product diluted at a 4:1 ratio and applied at 0.29 gal./sq yd.
2) Surface condition--Moist.
3) Penetration--None observed.
4) Runoff--A considerable amount was observed. The second application may not have been beneficial.
5) Appearance--Coherex puddled on the surface.

August 27, 1979

1) Surface condition--Moist.
2) Appearance--Surface exceptionally tight and hard with very little loose aggregate or float.

October 4, 17, and December 10, 1979

1) Surface condition--Dry.
2) Appearance--No dust was observed. Surface was tight and free from chuckholes.

Section 5A. Coherex (475 ft)

Application dates, rates, and surface conditions at time of application were identical to those for Section 5. The Coherex penetrated to a depth of about 1 in. Some second application runoff was observed but not to the extent of that which occurred in Section 5. This section was dust free at the last inspection, December 10, 1979; however, limited spalling and potholing began to develop after two month's service.

Section 6. Polybind Acrylic DLR 81-03 (1970 ft)

August 14, 1979

1) Application rate--For the first application, this product was diluted at 40:1 and applied at 0.17 gal./sq yd.
2) Surface condition--Moist.
3) Penetration--Material soaked in, but depth could not be determined.
4) Runoff--None.
5) Appearance--Soil particles appeared sticky.

August 15, 1979

A second application was made at the same rates and surface conditions prevalent on August 14, 1979.

August 20, 1979

1) Surface condition--Moist.
2) Appearance--Surface was fairly tight; however, a small amount of dust prone float was noticeable.

October 4, 1979

1) Surface condition--Dry.
2) Appearance--Some dusting was noticeable, but the section was still an improvement over the untreated control. It appeared that some agglomeration of the fines had occurred, and the dust which formed was of a particle size large enough to prevent wind transport by settling back on the roadway.

October 14, and December 10, 1979

1) Surface condition--Dry.

2) Appearance--The treatment was still slightly apparent, but not very effective as dusting was occurring.

Section 7. Amsco Res AB 1881 (1720 ft)

August 20, 1979

1) Application rate--Product was diluted at a 17:1 ratio and applied at 0.12 gal./sq yd.

2) Surface condition--Moist.

3) Penetration--Material soaked in, but penetration depth could not be determined.

4) Runoff--None.

5) Appearance--Soil particles were sticky.

October 4, 10, and December 10, 1979

1) Surface condition--Dry.

2) Appearance--Treatment was not visibly apparent, and road surface was dusty.

Section 7A. Amsco Res AB 1881 over Ammonium Lignosulfonate (600 ft)

The application rates and surface conditions at time of treatment were identical to those for Section 7. The section was dust free as of the last inspection, December 10, 1979; however, some potholes had developed.

Section 8. Coherex (1250 ft)

The construction dates, application rates, and surface conditions at the time of construction were the same as those for Section 5A. This section was relatively dust free as of the last inspection, December 10, 1979. In general, this section performed better than its equivalent (Section 5A), and may be due at least in part to the fact that it was not subjected to heavy trucks negotiating the relatively steep grade at Section 5A.[*] Other observations regarding the use of the Coherex were the washing of fines from the coarse aggregate upon application, and the development of a hard, black colored, surface patina, after a few days of traffic. These phenomena were probably due to the curing of surfactants and asphalt contained in the Coherex.

Section 9. Control (1250 ft)

Dusty, all dates of observation, with relatively large areas of aggregate float.

Discussion

Figure 26 illustrates surface conditions of the sections on October 4, 1979, nearly two months after construction. Of the products applied, ammonium lignosulfonate, calcium chloride, and Coherex appeared to have produced the most visually effective dust abatement. At least in terms of the visual subjective analysis, the Polybind, Amsco Res, and asphalt emulsion did not appear as effective as the other products.

A consideration which may have influenced performance of each of the products was the less than ideal climatic conditions during, and/or shortly after placement. The road surface was moist for all treatments, and rains followed construction application. Such conditions may have affected penetration depths and caused at least a partial loss of the more water soluble products prior to proper curing.

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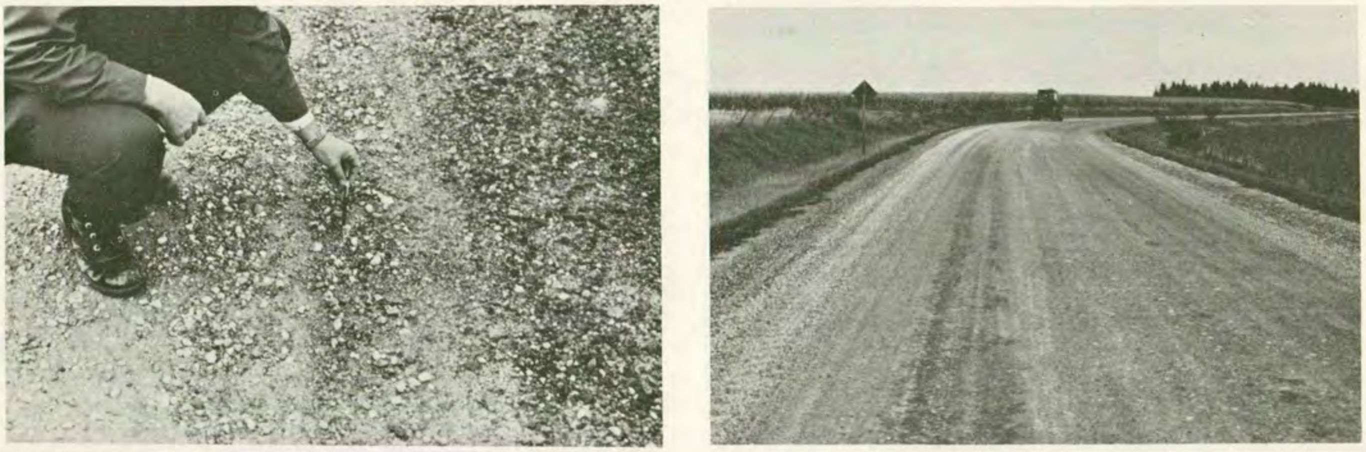
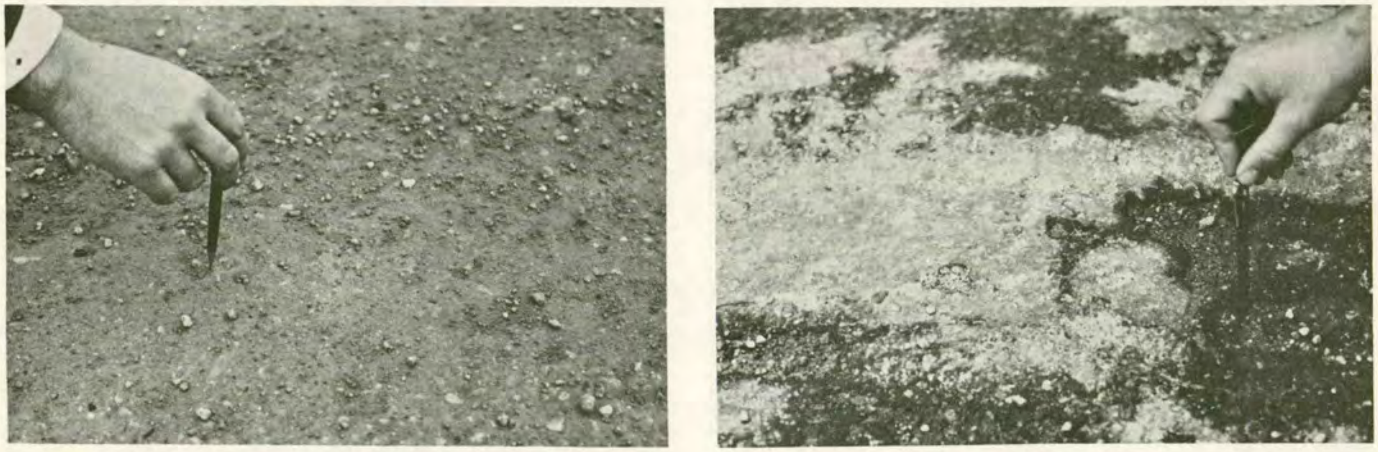
[*] About one mile east of Section 7 is a commercial quarry/pit operation. Though the percentage ADT associated with truck traffic is unknown, the volume of such traffic is considerable, and all test sections have been subjected to same.



a. Section 1, CSSI asphalt emulsion.

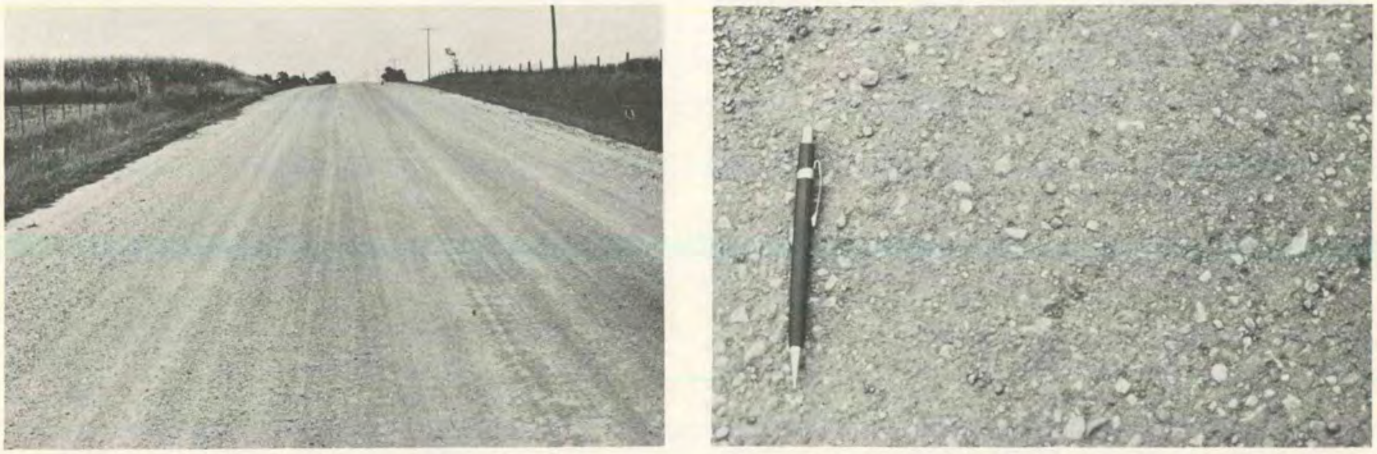
b. Section 2, ammonium lignosulfonate.



c. Section 4, calcium chloride.

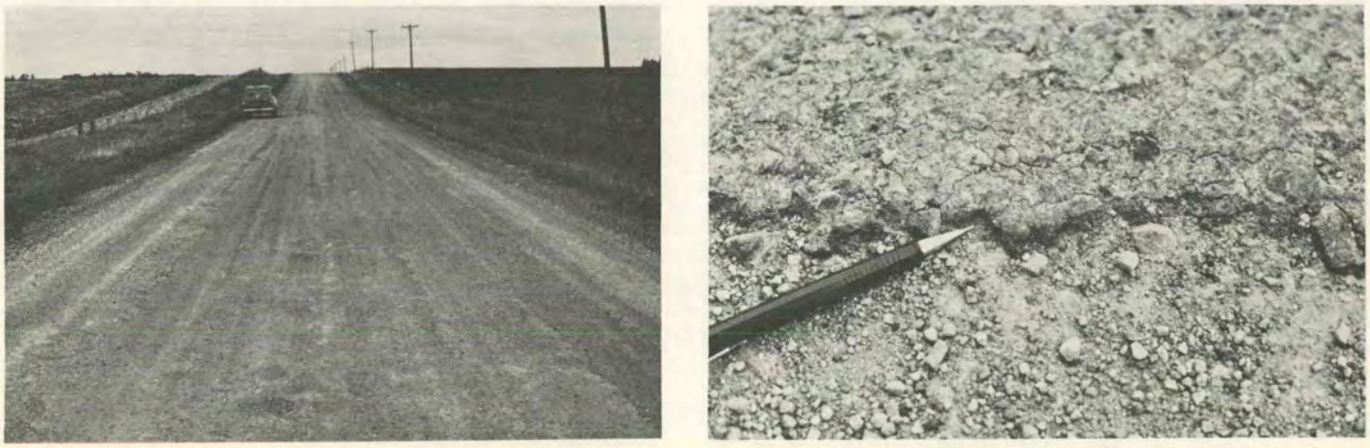
d. Section 5, coherex over previously applied lignosulfonate.

Fig. 26. Surface conditions of Franklin County sections, October 4, 1979.



e. Section 6, Polybind Acrylic DLR 81-03.

f. Section 7, Amsco Res AB 1881.



g. Section 8, Coherex

h. Section 8, Coherex, closeup at roadway edge.

Fig. 26. Continued.

A factor of concern to all county engineers is the ability to maintain a palliative-treated roadway surface. With the exception of the Coherex, all sections could have been repaired for potholing, washboarding, and aggregate pullout, by regrading. Where Coherex was used, a rather hard durable, surface patina was developed (Figures 26d, g and h), which led to limited spalling and development of minor chuckholes under traffic.

In retrospect, portions of the above problems could potentially be reduced through a modification of the Category 1 construction, more closely approximating that of the mixed-in-place Category 2. Such placement conditions will later be noted with the Story County site.

Plymouth County

Costs limited demonstration section construction to Category 3 using cement and fly ash. While the county was interested in Category 3 construction using a high zeta potential asphalt emulsion, this possibility was postponed for at least one year. Consequently, only a portion of the two-mile length site was utilized.

Iowa Public Service Port Neal III fly ash was used in all laboratory testing for this site, but was unavailable at time of construction and would have to be replaced with the more reactive, higher oxide content, Port Neal IV ash. Modifications were therefore made in the recommended percentage combinations of cement and fly ash. Beginning at a T-intersection about 1-1/4 miles north of Iowa Highway 3, three 6-in. compacted thickness test sections were consecutively constructed from north to south: section PL-1 containing 3% Type I Portland cement and 13% fly ash, 1378 ft in length; section PL-2 containing 3% cement and 9% fly ash, 1387 ft length; and section PL-3 containing 2% cement and 6% fly ash, 2070 ft length. Following application of the required quantity of fly ash within section PL-3, a portion of a tanker of ash remained. In addition, about 250 ft of untreated roadway existed between the south end of section PL-3 and a railroad track that crossed the site. It was therefore elected to incorporate the remaining ash to a compacted depth of 6 in. into this short section without Portland cement. The quantity of ash was sufficient to produce this trial section at a content of about 7% by dry soil weight.

Construction of the stabilized base sections was begun July 29, completed July 30, and seal-coat surfaced July 31, 1980. Each section was scarified to required depth. Portland cement and fly ash were delivered to the site by bulk transport, and consecutively unloaded through use of the transports' pneumatic system while driving the length of the scarified section. Some dusting was associated with this spread process, Figure 27a. In order to prevent additional dust problems, initial mixing and pulverization of the cement, fly ash, and soil was accomplished with a tractor drawn disc, Figure 27b. This was followed with longitudinal blade mixing, as well as leveling and shaping by blade grader. A self-propelled rotary mixer with attached water tanker was then introduced for final pulverization, completion of mixing, and introduction of water for required optimum moisture content, Figure 27c. Since the material was relatively friable, aggregations were reduced to a maximum size of 1-1/2 to 1 in. or less. Initial compaction was accomplished with a tamping foot roller, Figure 27d. Following final blading to crown, cross section and profile, Figure 27e, finish rolling

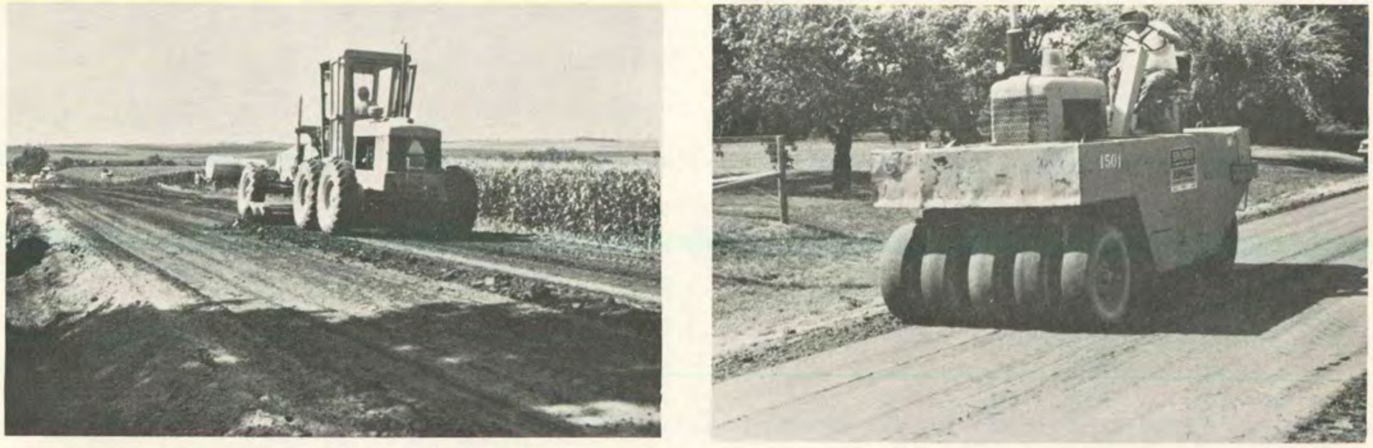
a. Cement spread.

b. Initial mixing and pulverization of cement, fly ash and soil.

c. Final mixing, with water tanker direct feed to rotary mixer.

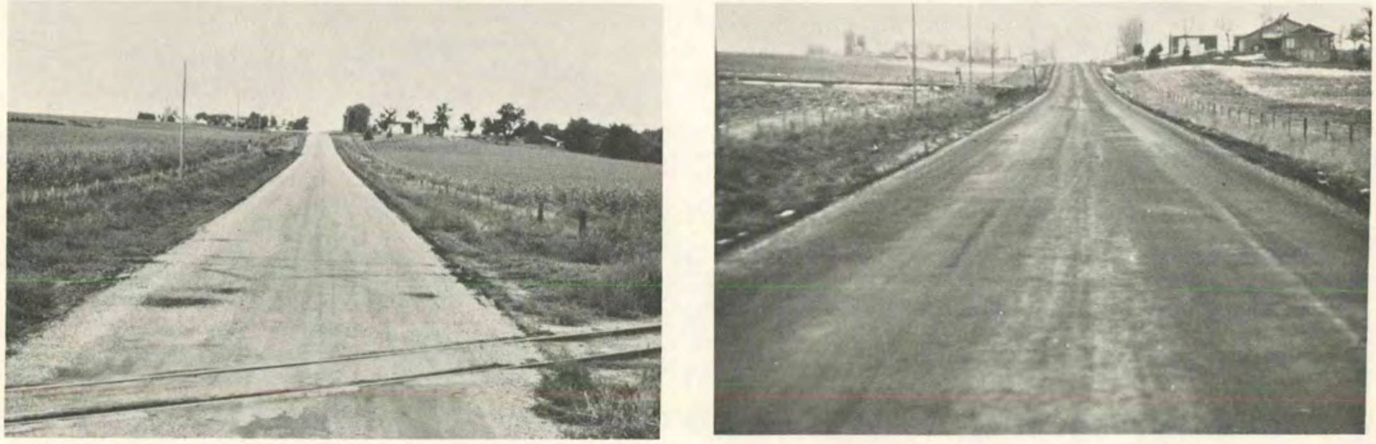
d. Tamping foot compaction.

Figure 27. Plymouth County.



e. Final blading to crown, cross-section, and profile.

f. Finish rolling.



g. Surface condition, August 27, 1980.

h. Surface condition, December 28, 1980.

Fig. 27. Continued.

was done with a self-propelled rubber-tired compactor, Figure 27f. Until application of the seal coat surfacing, each section surface was lightly sprayed with water for moist curing, as well as loss prevention of cementation effects.

Figures 27g and h illustrate existing surface conditions of the Plymouth County site about one and five months, respectively, following construction.

Story County

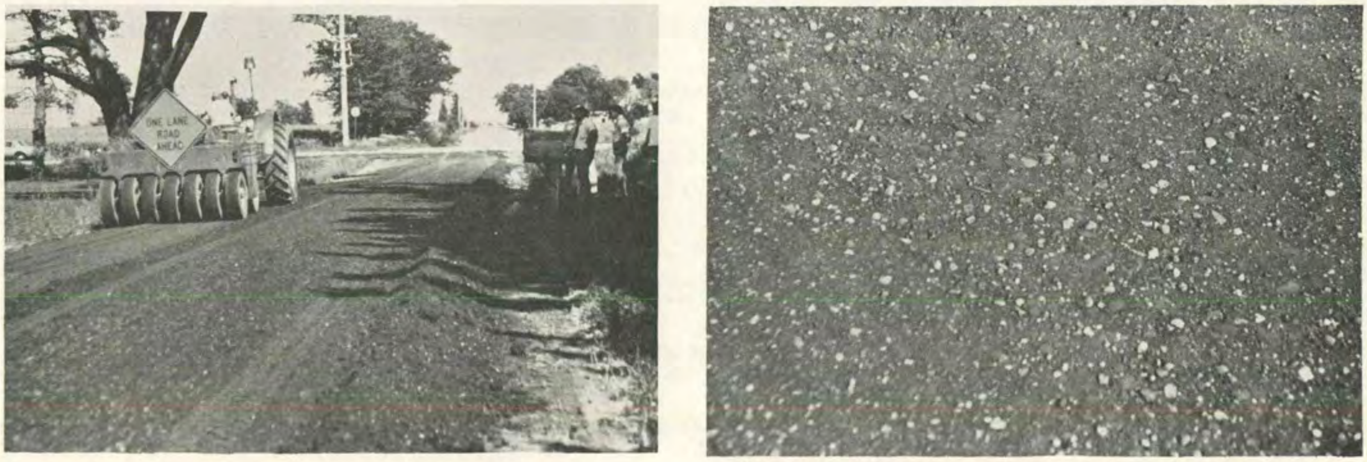
The several recommendations envisaged for the Story County site were eventually narrowed to a single Category 1 construction, due primarily to costs, as well as a potential variability and supply of the Ames Municipal fly ash. Coherex was utilized in a two stage modification of Category 1 construction, at a total application of 0.5% by dry soil weight, over an 800 ft length at the east end of the site.

On August 18, 1980, the section was tight bladed for profile and cross-section smoothness. The in-place material was then scarified to a depth of about 2 in.; this was accomplished with markings applied to the scarifier teeth of the blade grader. The scarified material was bladed into a windrow in the roadway center, after which the windrow was notched.

In order to provide a total of 0.5% to the 800-ft length and 2-in. depth of this section, four 55-gal. drums of Coherex were required. Three of the drums were individually diluted with water in a 250-gal. trailer mounted tank and distributed by gravity within the notched windrow, Figure 28a. A blade followed, laying over the soil material as indicated in Figure 28b. This process was continued until the three

a. First stage application of Coherex to notched windrow.

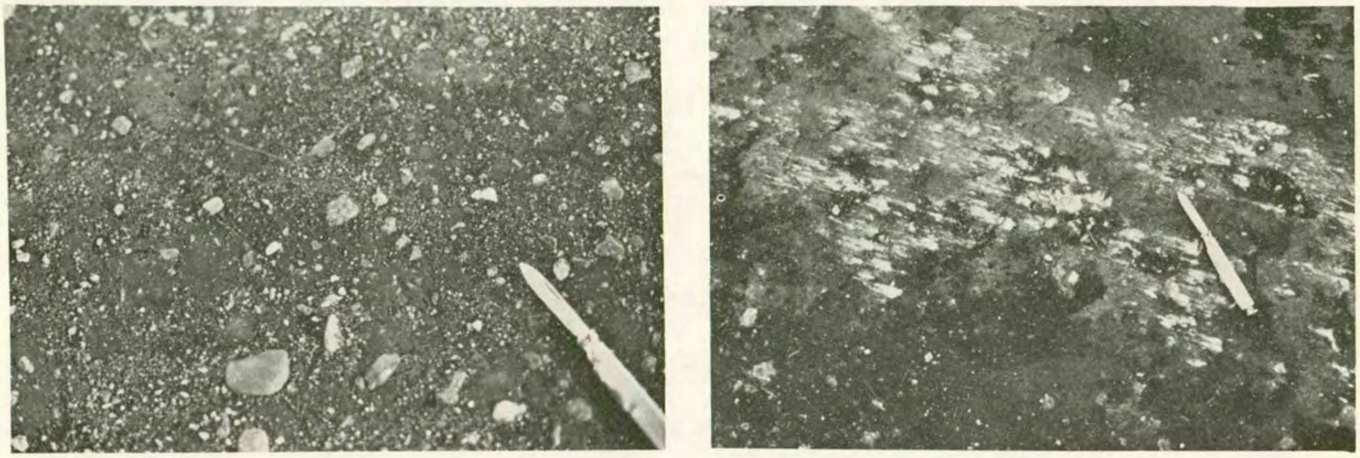
b. Initial mixing.



c. Rubber tired compaction.

d. Surface condition, completion of construction, August 18, 1980.

Fig. 28. Story County.



e. Surface condition, October 10, 1980.

f. Surface condition following tight blading, October 16, 1980.

g. Second stage application of Coherex, October 16, 1980.

h. Surface condition, December 30, 1980.

Fig. 28. Continued.

drums had been distributed. Blade mixing was continued, coupled with a light spray of water for optimum moisture content for compaction, until the mixture was of uniform color and texture. The mixture was then bladed to roadway crown, cross-section, and profile and compacted with a tractor drawn rubber-tired roller, Figure 28c. Figure 28d shows the surface texture upon completion of final blading and rolling. Processing of this first stage required about five hours.

No maintenance was performed on this section until the second stage of construction, October 16, 1980. Initially during this two month period, the section showed a slight amount of wheel track rutting. However, a slow darkening and hardening occurred, and a few potholes had developed by about the first of October. Figure 28e is a view of the surface texture as of October 10, 1980, illustrating the tightly bound surface matrix.

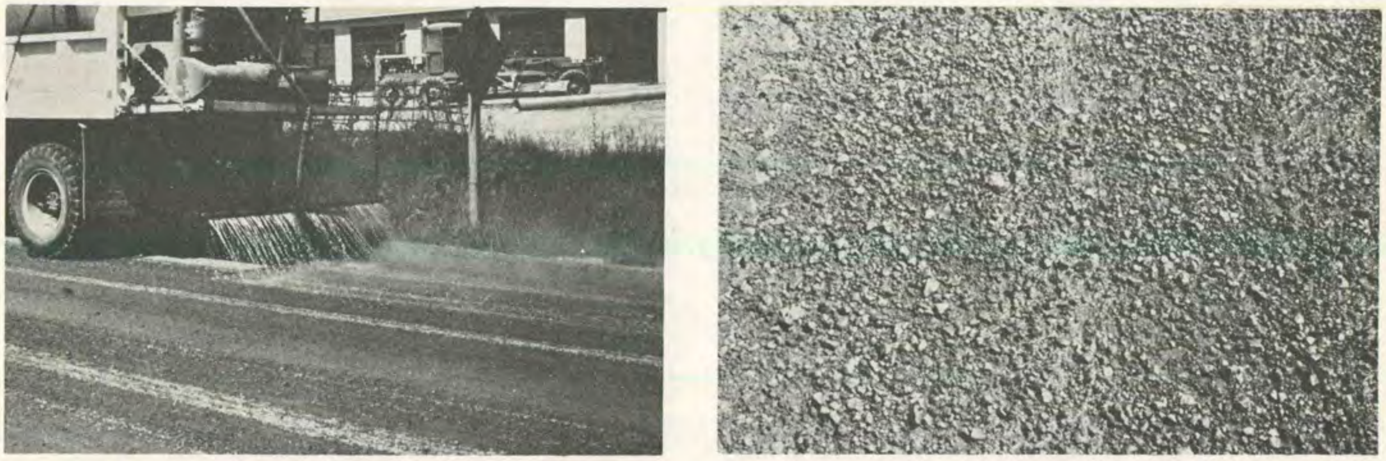
On October 16, 1980, the section was tight bladed for removal of any rutting, and filling of potholes. The surface was found to be quite dense and durable with stone particles within the matrix being fractured during blading, Figure 28f. Following blading, the surface was compacted with the rubber tired roller and the remainder of the Coherex was spray applied, Figure 28g.

Figure 28h shows the section's surface condition on December 30, 1980. Between the time of the second (surface) application and late March 1981, the section developed limited dimpling and potholing, with a slight amount of surface aggregate being thrown to the edges. Examination indicated the bulk of these effects to be with materials which had been bladed into surface depressions during stage two and had not apparently bonded to the first stage surface. From August 1980 through March, 1981, visual observations indicated little traffic-created dusting.

Marion County

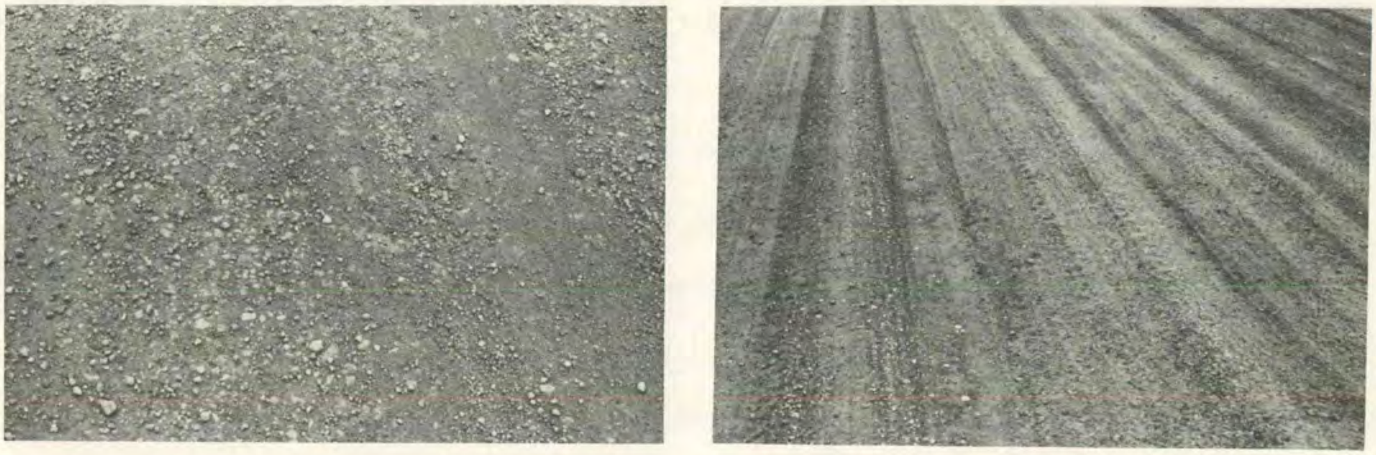
Due to costs, coupled with a breakdown of the county's asphalt distributor, only Category 1 demonstration sections were constructed with Coherex. The on-site crushed stone aggregate surface was quite dense and tight, which the County Engineer elected not to disturb, other than with a light surface blading. Consequently, the Coherex was applied as a surface palliative in two stages, seven days apart, on two 500-ft length sections. Section 1 received a total application of about 0.2% Coherex and section 2 about 0.7%, each assuming a penetration of one inch. One-half of the respective quantities of Coherex was diluted in about 400 gals. of water and surface sprayed August 21, 1980, Figure 29a. The remaining half was diluted in about 400 gals. of water and surface sprayed August 28, 1980. Respective dilution and application rates per section per date were about 20:1 and 0.27 gal./sq yd for section 1, and 6.5:1 and 0.30 gal./sq yd for section 2.

Figures 29b, c, and d present section 2 surface conditions immediately after the first application and just prior to and immediately following the second application, respectively. No runoff was observed on either section during application. The surface following each application was moist, with penetration of about 3/4 in., but the moist appearance dissipated relatively quickly leaving a surface color and texture which was not unlike that of the untreated control. No surface darkening, hardening, or matrix development was observed as had occurred



a. First surface spray application, section 2, August 21, 1980.

b. Surface condition immediately after spraying, August 21, 1980.



c. Surface condition before second spray application, August 28, 1980.

d. Surface condition immediately after spraying, August 28, 1980.

Figure 29. Marion County.

with both the Franklin and Story County sections. During the seven days prior to the second application, visual dusting was evident. Within 7 to 14 days following the second application, dusting was also apparent. Examination of the in-situ aggregate surface materials indicated only traces of the Coherex. It appeared that the Coherex had been absorbed into the crushed stone particles thus producing no surface coating for a binder matrix. It was felt that had the subgrade and surface materials been intermixed, as in the laboratory testing, a better matrix would probably have been formed. It could be concluded on the basis of visual observations, however, that surface application of Coherex to an absorptive crushed stone would not produce cost-beneficial control of dusting.

Dust Measurements

A major effort of this project was devoted to collection and quantification of dust associated with untreated and treated soil-aggregate surfaced roads. Previous studies by Hoover et al. [6] and Becker [28], provided limited field data on the nature of dust generation and distribution. Upon county agreement of proposed demonstration sites, dust collection was initiated, and data was obtained primarily during the spring through fall months of 1978 through 1980.

Beginning at the top of the foreslopes, collectors were installed at varying distances transverse to the roadway centerline. Each bucket collector approximated those provided in ASTM designation D-1739 for collection and analysis of dustfall. The collectors consisted of 6-in.

diameter by 7-in. high semi-rigid plastic containers, clamped to the upper portion of a steel support stake 4 ft long. Each collector was positioned approximately 3 ft above ground surface, and half-filled with distilled water. Approximately every two weeks during the collection period, each collector was examined for water level maintenance. Collection periods varied, due primarily to climatic conditions and/or start or end of demonstration section construction, but for the most part ranged from about 30 to 60 days. Following collection, each bucket was sealed and transported to the laboratory for quantification and particle size analysis.

Dustfall data collection was not without problems. A number of collectors were used for public target practice. Several were destroyed by farm animals. Several collectors and support stakes disappeared, while a few (particularly at the Story County site adjacent to ISU land) were destroyed by farming equipment. In most instances, the collectors were reinstalled and appropriate adjustments were made in the time rate of depositional data. While the majority of collectors were undisturbed during sampling, a number of valuable observations were lost due to circumstances beyond the control of either county (who assisted in surveillance) or research project personnel.

In the laboratory, collectors were first placed in low temperature ovens for evaporation of excess water. The contents were then transferred to tared beakers; seeds, chaff, insects, and other organic contaminants were removed; and the beakers were reweighed to the nearest 0.0001 gm.

Dust Quantification

Quantity of dust particulates was calculated as pounds/acre/day/ 100 vehicles of average daily traffic (ADT). Though ADT's of the sites varied over a considerable range, all data were adjusted to the common datum of 100 vehicles per day for purposes of comparison among locations. Such data can be retransformed by multiplying the data presented herein by the factor ADT ÷ 100.

Initial comparisons were made by plotting quantity of depositional dust versus distance from centerline of roadway on linear scales for each location. The resulting curves were somewhat difficult to analyze. Handy et al. [7] showed limited dust collection data described by a semi-logarithmic regression having a break occurring near the ROW. Kettleman [41] and Eaton [42] concluded that deposition of volcanic ash from its source could be described with logarithmic functions. Lutenegger [43] described a mechanism for deposition of loess that varied logarithmically with distance from the source. Thus, previous research provided strong evidence that roadway particulate deposition might best be described in terms of logarithmic functions.

About 200 sets of dust quantity versus distance from centerline data were accumulated prior to as well as following construction of the previously described demonstration sections. All data sets were regressed to find the most highly correlated mathematical relationship existing between the two variables. This involved linear, exponential, logarithmic and power functions. Each function has a relationship to a log-log plot of the two pieces of data. For example, a power function takes the form $y = bx^m$, where y would be the quantity of depositional dust in lbs/acre/day/100 vehicles, x the distance from centerline in feet, b the y intercept, and m the slope. This function would become a straight line on a log-log plot. Linear, exponential, and logarithmic functions would, however, be seen as curves on a log-log plot. High values of b would indicate considerable dust at the centerline source of the roadway. A number of tests for equality of intercept values indicated that overall dustfall levels varied for each site. For each regression analysis, the coefficient of determination, r^2, was obtained. This value is the square of the correlation coefficient and varies in value from 0 to 1, the closer the value of this measurement of strength of relationship to 1, the better the fit between the model and the data. For example, if $r^2 = 0.69$, the regression explained 69 percent of the variation in dustfall, increasing in significance with increasing number of data sets.

Table 3 presents a summation of pre-construction dust data sets for each year of observation. No correlative attempts were made between each year's data. Instead, the data was regressed for (a) all sites combined, (b) all buckets to the east, west, north, and south of roadway centerline, and (c) whether or not the sites were open or closed. The latter was defined in regard to demonstration site sheltering, such as topography, trees, foliage, and buildings. For example, the Mud Hollow roadway parallels a deep creek within the loess hills of Pottawattamie County and was thus regarded as a closed site, whereas the Buchanan site was relatively flat with no surrounding trees, foliage, or hills to hinder a wind.

Table 3. Summary of pre-construction dustfall observations.

Year	Location	Direction from Roadway Centerline	Shelter	Distance from Centerline, ft	Quantity of Dust, lbs/acre/day/ 100 vehicles
78	Buchanan	North	Open	18	34.70
78	Buchanan	North		33	20.27
78	Buchanan	North		50	10.74
78	Buchanan	North		72	7.53
78	Buchanan	South		17	40.06
78	Buchanan	South		32	19.79
78	Buchanan	South		50	8.32
78	Buchanan	South		71	6.83
78	Marion	North	Open	17	61.29
78	Marion	North		26	52.14
78	Marion	North		40	7.62
78	Marion	North		74	7.29
78	Marion	North		115	5.98
78	Marion	South	Closed	17	19.08
78	Marion	South		29	9.74
78	Marion	South		43	5.89
78	Plymouth	East	Open	33	196.19
78	Plymouth	East		83	143.87
78	Plymouth	West		13	84.87
78	Plymouth	West		24	224.63
78	Plymouth	West		35	6.45

Table 3. Continued.

Year	Location	Direction from Roadway Centerline	Shelter	Distance from Centerline, ft	Quantity of Dust, lbs/acre/day/ 100 vehicles
78	Honey Creek	East	Closed	14	13.28
78	Honey Creek	East		20	5.30
78	Honey Creek	East		33	2.32
78	Honey Creek	East		83	1.01
78	Honey Creek	East		133	1.18
78	Honey Creek	West	Closed	13	17.04
78	Honey Creek	West		18	7.22
78	Honey Creek	West		35	2.97
78	Honey Creek	West		85	1.16
78	Mud Hollow	North	Closed	16	8.68
78	Mud Hollow	North		31	9.00
78	Mud Hollow	North		39	6.48
78	Mud Hollow	North		89	2.79
78	Mud Hollow	South		16	29.65
78	Mud Hollow	South		30	3.27
78	Mud Hollow	South		43	2.35
78	Mud Hollow	South		93	1.16
78	Mud Hollow	South		143	1.13
78	Neola	North	Open	14	61.85
78	Neola	North		26	10.75
78	Neola	North		34	3.98

Table 3. Continued.

Year	Location	Direction from Roadway Centerline	Shelter	Distance from Centerline, ft	Quantity of Dust, lbs/acre/day/ 100 vehicles
78	Neola	North		84	1.36
78	Neola	South		16	34.47
78	Neola	South		22	24.60
78	Neola	South		36	5.08
78	Neola	South		61	2.77
79	Buchanan	North	Open	18	44.47
79	Buchanan	North		27	6.64
79	Buchanan	North		42	10.59
79	Buchanan	North		59	6.64
79	Buchanan	South		18	41.00
79	Buchanan	South		29	13.89
79	Buchanan	South		48	0.92
79	Buchanan	South		61	3.00
79	Franklin	North	Open	13	231.37
79	Franklin	North		30	60.63
79	Franklin	North		44	30.76
79	Franklin	North		69	20.37
79	Franklin	North		93	16.44
79	Franklin	North		129	28.89
79	Franklin	South		19	27.05
79	Franklin	South		31	7.76

Table 3. Continued.

Year	Location	Direction from Roadway Centerline	Shelter	Distance from Centerline, ft	Quantity of Dust, lbs/acre/day/ 100 vehicles
79	Franklin	South		41	26.95
79	Franklin	South		58	22.01
79	Franklin	South		77	13.50
79	Marion	North	Open	17	82.37
79	Marion	North		26	59.50
79	Marion	North		66	7.32
79	Marion	North		118	4.62
79	Marion	South	Closed	20	19.79
79	Marion	South		46	2.31
79	Plymouth	East	Open	13	79.27
79	Plymouth	East		22	67.54
79	Plymouth	East		34	251.52
79	Plymouth	East		48	15.45
79	Plymouth	West		24	124.29
79	Plymouth	West		32	64.82
79	Honey Creek	North	Closed	16	15.80
79	Honey Creek	North		28	9.57
79	Honey Creek	North		42	3.47
79	Honey Creek	North		58	3.85
79	Honey Creek	South	Closed	16	13.23
79	Honey Creek	South		28	4.58

Table 3. Continued.

Year	Location	Direction from Roadway Centerline	Shelter	Distance from Centerline, ft	Quantity of Dust, lbs/acre/day/ 100 vehicles
79	Honey Creek	South		41	2.70
79	Honey Creek	South		62	2.28
79	Mud Hollow	North		19	13.64
79	Mud Hollow	North		30	9.45
79	Mud Hollow	South		33	0.95
79	Mud Hollow	South		42	0.51
79	Neola	East	Closed	17	20.83
79	Neola	East		25	15.80
79	Neola	East		32	2.16
79	Neola	East		43	3.97
79	Neola	West		26	19.64
79	Neola	West		36	2.76
79	Neola	West		47	0.43
79	Story	North	Open	25	69.15
79	Story	North		33	17.62
79	Story	North		49	1.96
79	Story	North		74	1.04
79	Story	South		31	11.36
79	Story	South		44	8.26
79	Story	South		58	1.50
80	Marion	North	Open	16	110.35

Table 3. Continued.

Year	Location	Direction from Roadway Centerline	Shelter	Distance from Centerline, ft	Quantity of Dust, lbs/acre/day/ 100 vehicles
80	Marion	North		37	17.04
80	Marion	North		67	7.99
80	Marion	North		114	3.39
80	Marion	South	Closed	19	27.68
80	Marion	South		34	16.10
80	Marion	South		47	5.21
80	Story	North	Open	15	67.14
80	Story	North		26	51.54
80	Story	North		38	14.82
80	Story	South		16	40.95
80	Story	South		25	22.75
80	Story	South		37	6.64
80	Franklin	North	Open	15	89.47
80	Franklin	North		30	55.71
80	Franklin	South		16	63.00
80	Franklin	South		25	73.13
80	Franklin	South		32	48.88
80	Franklin	North		16	70.00
80	Franklin	North		26	49.93
80	Franklin	North		33	28.47
80	Franklin	South		16	73.26

Table 3. Continued.

Year	Location	Direction from Roadway Centerline	Shelter	Distance from Centerline, ft	Quantity of Dust, lbs/acre/day/ 100 vehicles
80	Franklin	South		23	64.06
80	Franklin	South		32	25.31
80	Marion	North	Open	16	51.15
80	Marion	North		37	9.91
80	Marion	North		67	6.15
80	Marion	North		114	3.79
80	Marion	South	Closed	19	13.42
80	Marion	South		34	3.58
80	Marion	South		47	3.48

Figure 30 illustrates a log-log plot of the data of Table 3 plus several of the regressions performed thereon. In addition, Figure 30 shows collector positioning relative to direction from roadway centerline. Table 4 presents a summation of the pre-construction regression analyses of the various sites.

As may be seen from Figure 30, dustfall in any direction does not follow a perfect relationship. Dust quantities during any period of measurement are affected by wind velocity and direction, topography, trees, grasses and other plant growth, moisture content of the roadway surface, type of roadway surfacing, humidity of the air and other factors. However, the regression plots of Figure 30 illustrate the

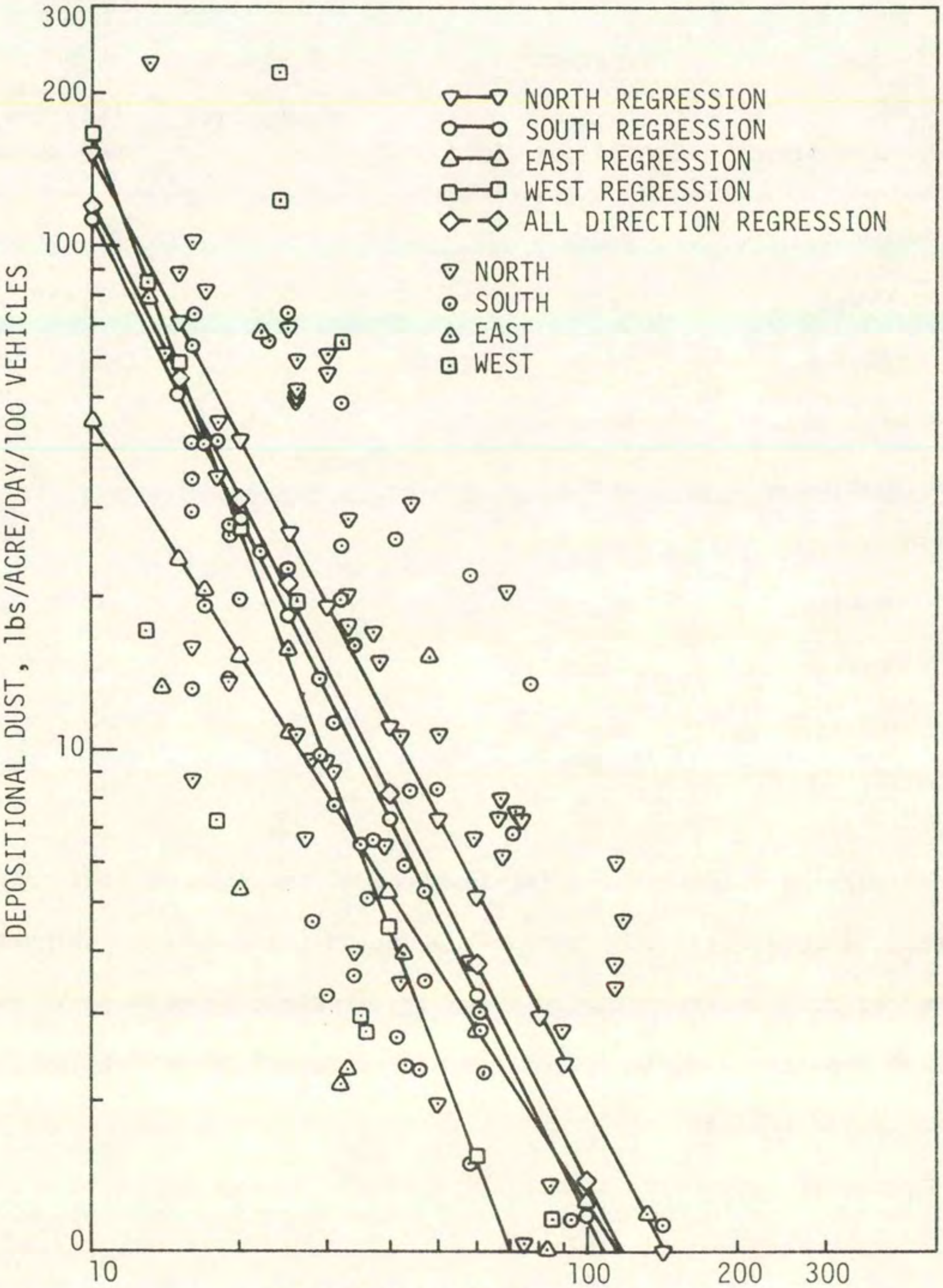


Fig. 30. Pre-construction depositional dust versus distance from centerline, all sites.

effect of wind direction. The "north regression" shows the greatest dust quantities occurring on the north side of any roadway. The period of measurement within this study was spring through fall, when the dominant wind source is from the south; therefore, the greater quantity of dustfall occurs to the north. Figure 30 illustrates also a greater distance of dustfall occurring north, south, and east of centerline and again illustrates the primary directions of wind within the state.

Smith et al. [30] determined an ambient dust level of 1.5 lbs/acre/day as an average from several locations across the U.S. In an effort to suggest an ambient level for Iowa, five bucket collectors were established in northern Polk County in 1980, in a relatively open region of pasture isolated from soil-aggregate surfaced roadways. An average ambient quantity of dust was found to be 0.92 lbs/acre/day, i.e., not dissimilar to that determined by Smith et al. [30]. Both of these ambient levels of dust were introduced into all regression analyses in order to anticipate a distance from roadway centerline at which such levels might occur due only to road dustfall/100 vehicles of ADT.

As previously noted, a portion of this investigation was to determine the quantity of dustfall at the ROW. Within all regressions, calculations were thus made to anticipate the quantity of dust at the ROW, assumed to be 33 ft from centerline.

Table 4 presents the pre-construction depositional dust regressions for all sites from Table 3, as well as the preceding predictions of dust quantity at the ROW, and distance from centerline at which ambient levels might be anticipated. The influence of wind direction may again be seen in Table 4 with all north side oriented collectors predicting

Table 4. Pre-construction depositional dust regression, all sites.

Direction from Centerline	No. of Data Sets	Function	Equation*	r^2	Ambient Dust Prediction Distance, ft		Dust Prediction at 33 ft, lbs/acre/day/100 Vehicles
					1.5 lbs/acre	0.92 lbs/acre	
All sites	111	Power	$y = 10{,}463.33x^{-1.94}$	0.5743	96.0	123.6	12.6
All--closed	40	Power	$y = 663.51x^{-1.39}$	0.5697	79.9	113.6	5.2
All--open	72	Power	$y = 16{,}693.96x^{-1.96}$	0.6002	116.2	149.2	17.8
West--all	10	Power	$y = 70{,}282.17x^{-2.62}$	0.5020	60.8	73.2	7.5
West--closed	6	Power	$y = 2072.86x^{-1.83}$	0.5196	52.2	68.2	3.1
West--open	4	Exponential	$y = 453.79e^{-0.09x}$	0.4223	64.8	70.3	23.1
East--all	12	Power	$y = 1612.41x^{-1.55}$	0.5605	89.2	122.2	7.0
East--closed	9	Power	$y = 407.95x^{-1.29}$	0.7152	77.4	113.11	4.5
East--open	3	Linear	$y = 105.65 - 1.86x$	0.9941	55.9	56.2	40.4
South--all	42	Power	$y = 10{,}789.51x^{-1.98}$	0.6900	88.7	113.6	10.6
South--closed	15	Power	$y = 2258.46x^{-1.65}$	0.8191	85.1	114.6	7.1
South--open	23	Power	$y = 12{,}407.19x^{-1.96}$	0.7555	99.7	128.0	13.1
North--all	46	Power	$y = 12{,}127.59x^{-1.90}$	0.6406	114.4	148.0	16.0
North--closed	9	Power	$y = 355.95x^{-1.11}$	0.9014	138.5	215.2	7.4
North--open	32	Power	$y = 12{,}073.17x^{-1.81}$	0.7431	143.4	187.9	21.7

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*y = quantity of depositional dust, lbs/acre/day/100 vehicles, and x = distance from centerline, ft.

greater distances before ambient levels were reached. Quantity of dust at the ROW appeared most severely affected by whether the sites were regarded as open or closed. Regardless of wind direction, open sites produced greater quantities of dust than did those sites considered closed. Ambient levels were predicted at from less than two to greater than six times the ROW distance from roadway centerline.

Air quality regulatory agencies have adopted allowable particulate levels, expressed in terms of concentration of particulates per volume of air and quantified as micrograms per cubic meter. A supplemental study, therefore, utilized both volumetric and depositional devices at the same distance from centerline, height above ground level, same location, and under identical environmental conditions. The intake of a Gelman Model 15003 portable sampler was mounted through a hole in the bottom of a bucket collector in order that adjacent depositional and volumetric cross-sectional areas were the same. The Gelman sampler was operated at its full capacity of 0.5 cu ft per minute. Distances from roadway centerline of the adjacent units were varied. Actual traffic counts of 100 vehicles were recorded as well as the time interval of such occurrence. Twelve such tests were conducted at the demonstration sites in Story, Plymouth, and Franklin Counties, each considered an open site.

Figure 31 presents the correlative linear regression of the volumetric versus depositional dust study. All attempts at fitting the model through the origin resulted in significant lowering of the coefficients; i.e., a linear regression produced the most significant model. As noted in Figure 31, the model intercept of 2626 $\mu g/m^3$ might

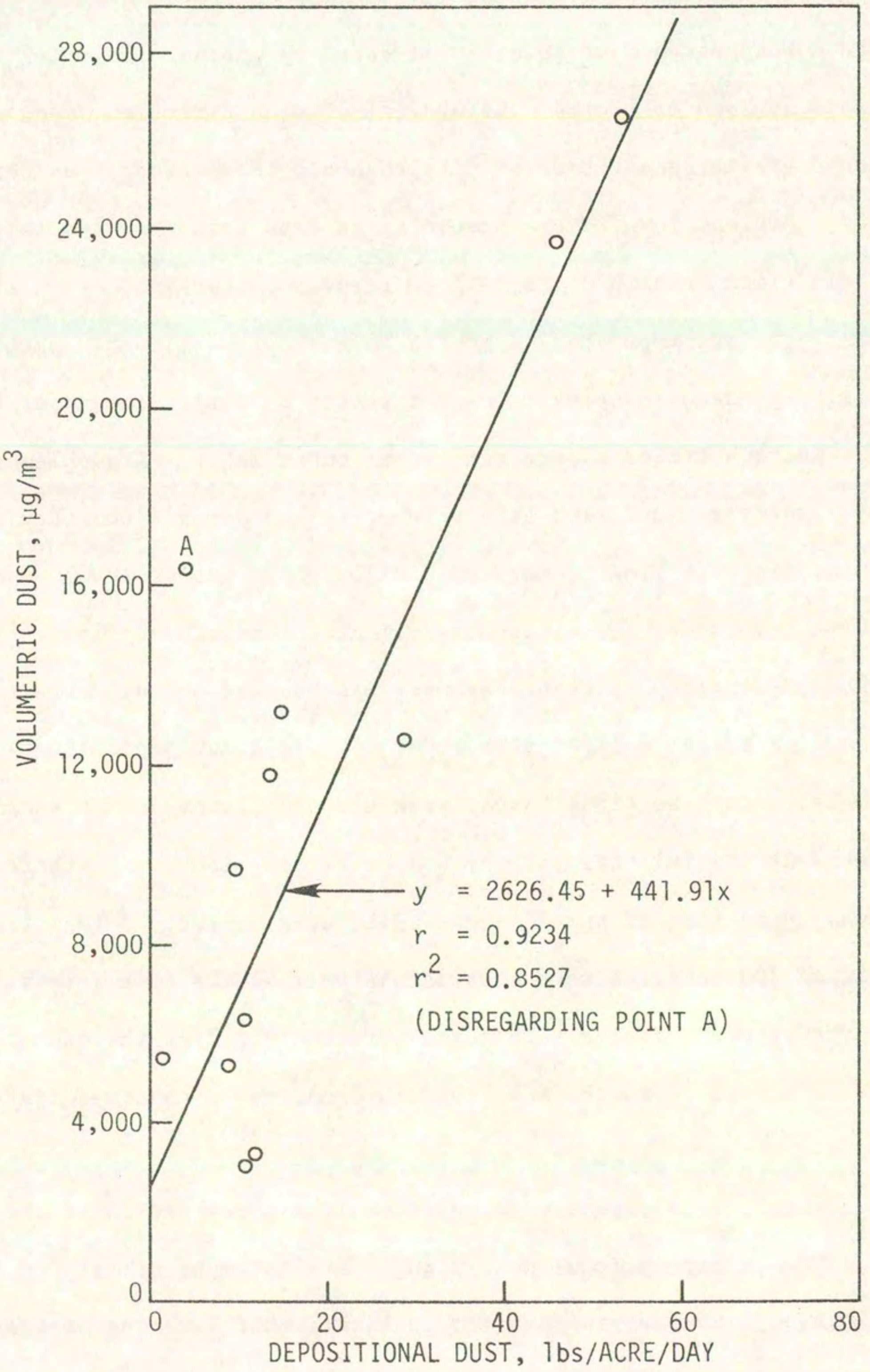

Fig. 31. Volumetric versus depositional dust.

be assumed as an ambient level. From Table 4 it may be noted that ROW quantities for all sites, open and closed, were respectively 12.6, 17.8, and 5.2 lbs/acre/day. Correlations for all east-west and north-south sites indicated ROW levels of 7.9 and 13.1 lbs/acre/day, respectively. Averaging these values produces about 11 lbs/acre/day. ROW levels within the depositional versus volumetric study were of the order of 10 lbs/acre/day. If it is thus assumed that 10 lbs/acre/day occurs at the ROW, the volumetric versus depositional regression of Figure 31 would thus produce about 7000 $\mu g/m^3$ of volumetric dust, or about 2.7 times the assumed ambient level.

The regression noted within Figure 31 provided a partial comparison of dustfall by depositional methods versus regulatory air standards. Ambient air quality standards for particulates are divided into a primary level corresponding to human health (75 $\mu g/m^3$) and a secondary level applicable to plants and animals (60 $\mu g/m^3$) [44]. It should be understood that such levels are obtained by techniques different from those within this study, but could be looked upon as equivalent to the intercept ambient level of Figure 31. Application of the regression model of Figure 31 to the data of Table 3 indicated only eight data sets would tend to approach the possible ambient level, each occurring at least 33 ft from the roadway centerline. Application of the regression model to Table 4 predictions of dustfall at 33 ft indicated no compliance with ambient level at the ROW.

All Category 3 construction of demonstration site sections provided relatively dust free surfaces. No Category 2 construction was demonstrated. Consequently, only Category 1 treatments of the Franklin and

Marion County sections, plus the modified Category 1 treatment of the Story County section, were monitored for dust control. Collectors were established either side of centerline immediately following treatment application. Dustfall measurements versus distance from centerline were regressed to find the most highly correlated mathematical relationship existing between the two variables.

Table 5 presents the depositional dust regression equations, ambient dustfall distance predictions, and estimates of dustfall quantities at the ROW for the Marion County demonstration sections. Figure 32 illustrates the regression plots from the data of Table 5. The pre-construction data again illustrate the effect of wind direction, since the slope as well as quantity at 33 ft were greatest to the north of centerline. Little effect on predicted ambient level distances or quantity of dust at the ROW were obtained after seven days following the first application of Coherex regardless of quantity. Forty-three days after the second application, a slight reduction in ambient level distances was noted with the low content section 1, but was coupled with a slight increase in dust quantity at 33 ft. A small additional reduction in ambient level distances was observed with the higher content section 2 at 43 days after the second application, but this was accompanied with an increase in dust quantity at 33 ft when compared with both the control and section 1. Based on the regression data, plus the previously noted visual observations during and following application, it was concluded that surface application(s) of Coherex were ineffective for control of dusting with the absorptive crushed stone of this site.

Table 5. Depositional dust regressions, Marion County.

Condition	No. of Data Sets	Function	Equation*	r^2	Ambient Dust Prediction Distance, ft		Dust Prediction at 33 ft, lbs/acre/day/ 100 vehicles
					1.5 lbs/acre	0.92 lbs/acre	
Pre-construction No. & So.	25	Power	$y = 2855.73x^{-1.53}$	0.6028	141.3	194.7	13.7
Pre-construction North	14	Power	$y = 8097.77x^{-1.68}$	0.8901	166.3	222.5	22.7
Pre-construction South	11	Exponential	$y = 57.28e^{-0.059x}$	0.7322	62.1	70.4	7.8
Control, 7 days after 1st application	7	Power	$y = 4227.59x^{-1.55}$	0.8396	165.9	227.2	18.4
Sect. 1, 7 days after 1st application	4	Power	$y = 4260.83x^{-1.57}$	0.6929	157.6	215.1	17.3
Sect. 2, 7 days after 1st application	5	Power	$y = 11{,}321.47x^{-1.82}$	0.7279	136.2	178.2	19.0
Control, 43 days after 2nd application	6	Exponential	$y = 14.30e^{-0.017x}$	0.9465	132.9	161.7	8.2
Sect. 1, 43 days after 2nd application	6	Power	$y = 2878.51x^{-1.62}$	0.8969	105.1	142.0	9.6
Sect. 2, 43 days after 2nd application	4	Power	$y = 28{,}474.84x^{-2.23}$	0.8311	83.4	103.8	11.5

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[*] y = quantity of depositional dust, lbs/acre/day/100 vehicles, and x = distance from centerline, ft.

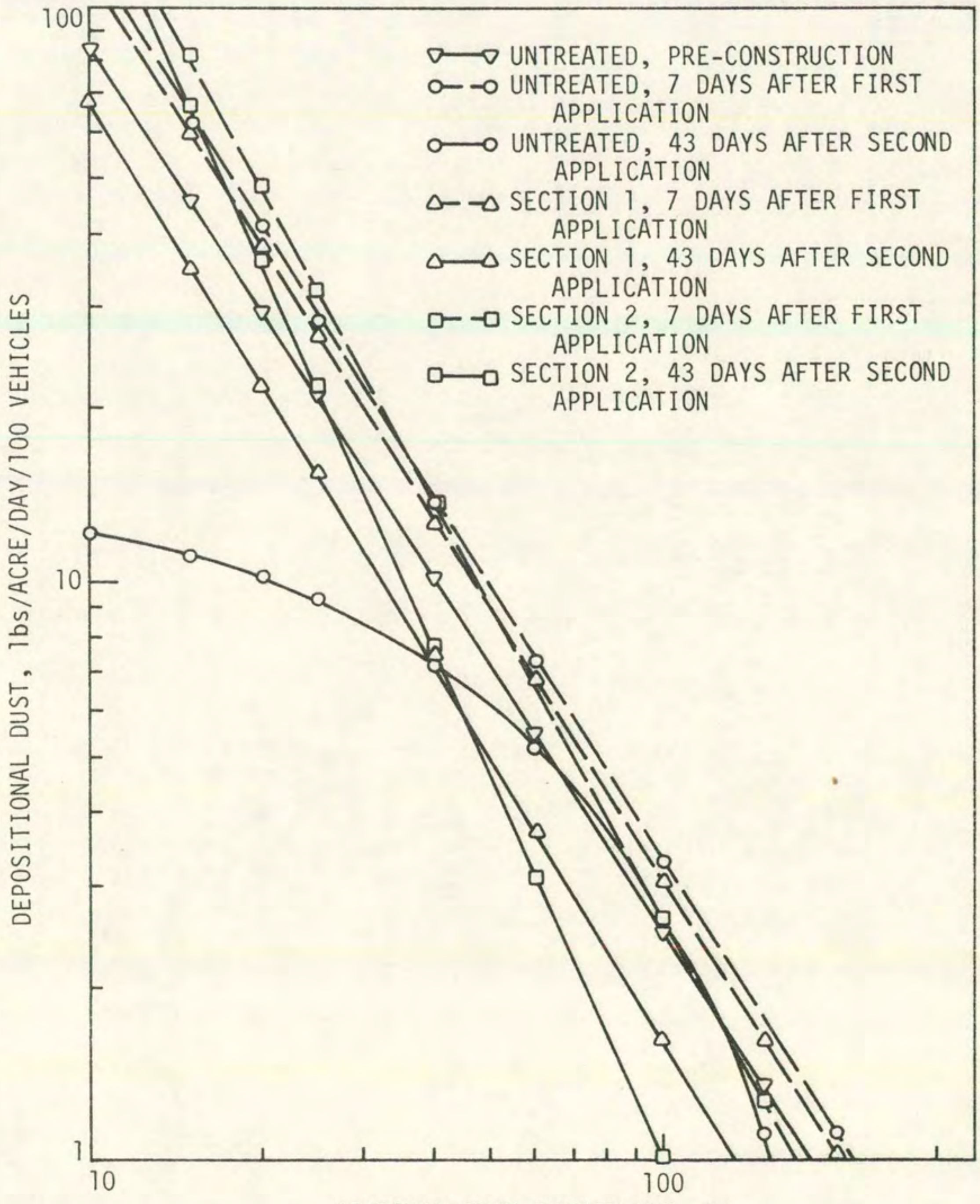

Fig. 32. Regressions of depositional dust versus distance from centerline, Marion County.

Table 6 and Figure 33 present regression analyses for the Story County Coherex demonstration section 47 days after initial incorporation. No basic changes were noted in ambient level distances or dust quantity at 33 ft between pre-construction and the control section at 47 days following Coherex incorporation in the treated section. However, 47 days after incorporation, the Coherex section had produced a reduction in both ambient level distances and quantity at 33 ft. Unfortunately, no collectors could be established following the second or surface spray application of Coherex in mid-October 1980, due to the onset of nightly freezing temperatures creating ice in the collectors. Therefore, only visual observations of effectiveness could be made during the nearly 5-1/2 months from the second application to late March 1981, as presented in a preceding section. Based on these observations as well as the data of Table 6, it was concluded that the Coherex was an effective dust control agent with this site material. In addition, it was concluded that the modified Category 1 method of construction was probably more effective than just a surface-applied spray technique. One criticism of the treated section, however, is that the Coherex mix may be much too durable for any spring blade maintenance. A lower application rate might rectify this condition.

Tables 7 and 8 present depositional dust regressions for data accumulated from the Franklin County demonstration sections after approximately 3 and 11 months. Figure 34 is a graphic presentation of the regression data of Table 8.

In Table 7, no data are presented on control section 3, section 4A, or section 6. In addition, sections 7 and 7A are combined. Each

Table 6. Depositional dust regressions, Story County.

Condition	No. of Data Sets	Function	Equation*	r^2	Ambient Dust Prediction Distance, ft		Dust Prediction at 33 ft, lbs/acre/day/100 vehicles
					1.5 lbs/acre	0.92 lbs/acre	
Pre-construction No. & So.	7	Power	$y = 9{,}791{,}278.05x^{-3.815}$	0.9124	61.1	69.5	15.8
Control, 47 days after 1st application	6	Exponential	$y = 186.83e^{-0.075x}$	0.7300	64.2	70.7	15.6
Treated, 47 days after 1st application	7†	Logarithmic	$y = 180.15 - 47.78\ln x$	0.7672	42.0	42.6	13.1

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[*] y = quantity of depositional dust, lbs/acre/day/100 vehicles, and x = distance from centerline, ft.

[†] Does not include 5 data sets whose buckets were twice replaced and twice destroyed by personnel of adjacent ISU experimental farm.

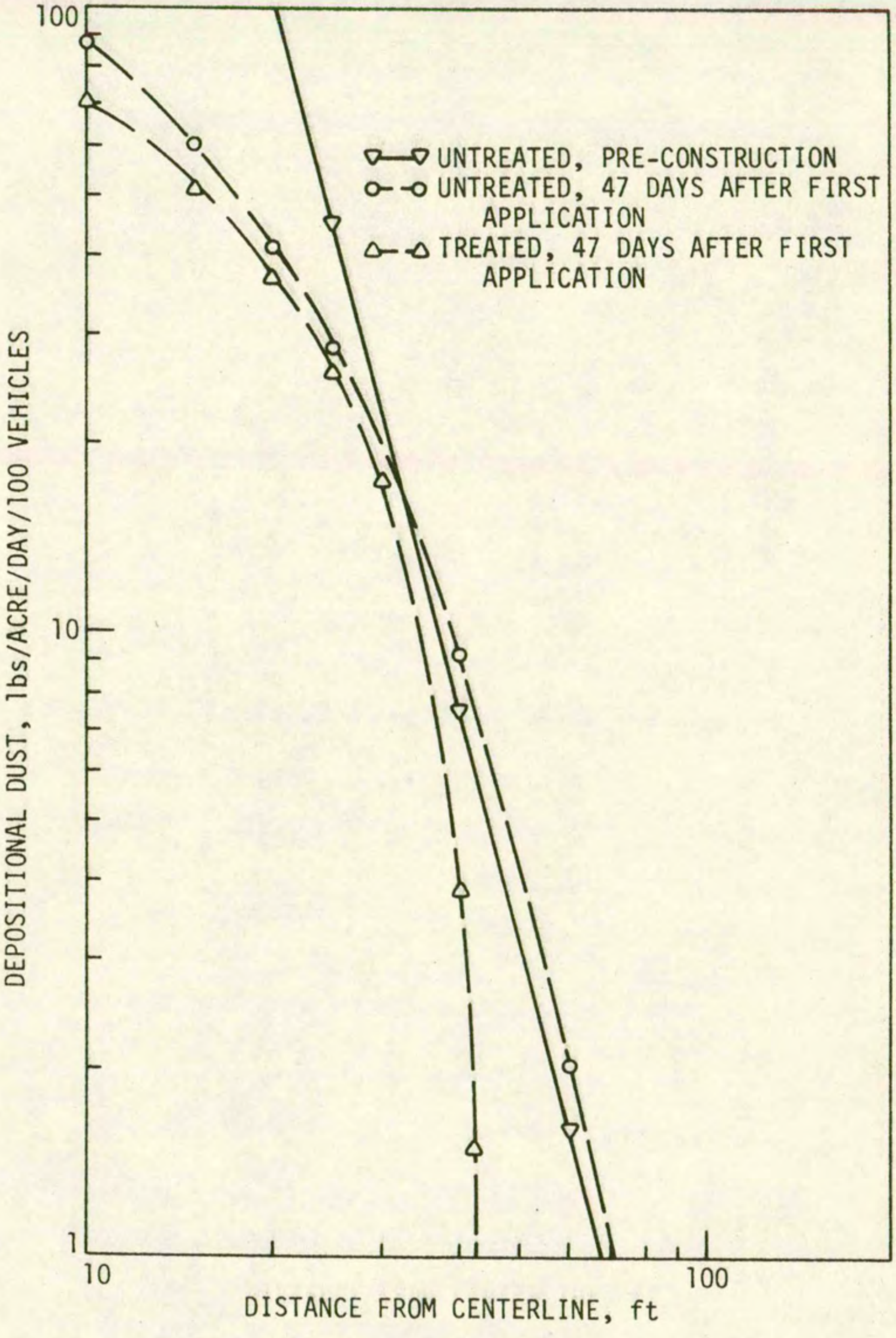

Fig. 33. Regressions of depositional dust versus distance from centerline, Story County.

Table 7. Depositional dust regressions, Franklin County, approximately 3 months after application.

Condition	No. of Data Sets	Function	Equation*	r^2	Ambient Dust Prediction Distance, ft 1.5 lbs/acre	 0.92 lbs/acre	Dust Prediction at 33 ft lbs/acre/day/ 100 vehicles
Pre-construction	8	Power	$y = 7363.38x^{-1.42}$	0.9485	399.9	564.4	51.6
Post-construction							
Control Section 9	3	Power	$y = 474{,}206.68x^{-2.76}$	0.9928	97.8	116.8	30.2
Section 1	5	Power	$y = 12{,}076{,}189.79x^{-3.64}$	0.9691	79.1	90.4	36.0
Section 2	5	Power	$y = 344{,}915.42x^{-2.87}$	0.8240	74.1	87.9	15.3
Section 4	6	Power	$y = 49{,}912.04x^{-2.37}$	0.8803	80.9	99.4	12.6
Section 5	3	Power	$y = 16{,}247.66x^{-2.50}$	0.9741	41.1	49.9	2.6
Section 5A	3	Power	$y = 1438.75x^{-1.55}$	0.9980	84.7	116.2	6.5
Sections 7 & 7A	5	Power	$y = 1{,}330{,}075.30x^{-3.12}$	0.5919	80.2	93.8	24.0
Section 8	4	Power	$y = 72{,}623{,}452.86x^{-4.62}$	0.9242	45.9	51.1	7.0

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*y = quantity of depositional dust, lbs/acre/day/100 vehicles, and x = distance from centerline, ft.

Table 8. Depositional dust regressions, Franklin County, approximately 11 months after application.

Condition	No. of Data Sets	Function	Equation*	r^2	Ambient Dust Prediction Distance, ft 1.5 lbs/acre	Ambient Dust Prediction Distance, ft 0.92 lbs/acre	Dust Prediction at 33 ft, lbs/acre/day/ 100 vehicles
Pre-construction	8	Power	$y = 7363.38x^{-1.42}$	0.9485	399.9	564.4	51.6
Post-construction							
Control Sections 3 and 9	9	Exponential	$y = 106.82e^{-0.023x}$	0.5949	185.0	206.2	49.9
Section 1	5	Exponential	$y = 249.61e^{-0.035x}$	0.8246	145.1	158.9	78.0
Section 2	4	Power	$y = 19{,}225.38x^{-1.73}$	0.9338	235.9	312.8	45.2
Section 4	4	Power	$y = 5161.25x^{-1.49}$	0.9482	238.1	330.7	28.4
Section 4A	5	Power	$y = 32{,}949.52x^{-2.00}$	0.8709	148.3	189.4	30.3
Section 5	4	Power	$y = 3908.59x^{-1.55}$	0.9400	158.4	217.1	17.1
Section 5A	5	Exponential	$y = 98.22e^{-0.040x}$	0.9877	104.7	117.0	26.3
Section 8	4	Exponential	$y = 316.75e^{-0.065x}$	0.8471	82.7	90.3	37.4

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*y = quantity of depositional dust, lbs/acre/day/100 vehicles, and x = distance from centerline, ft.

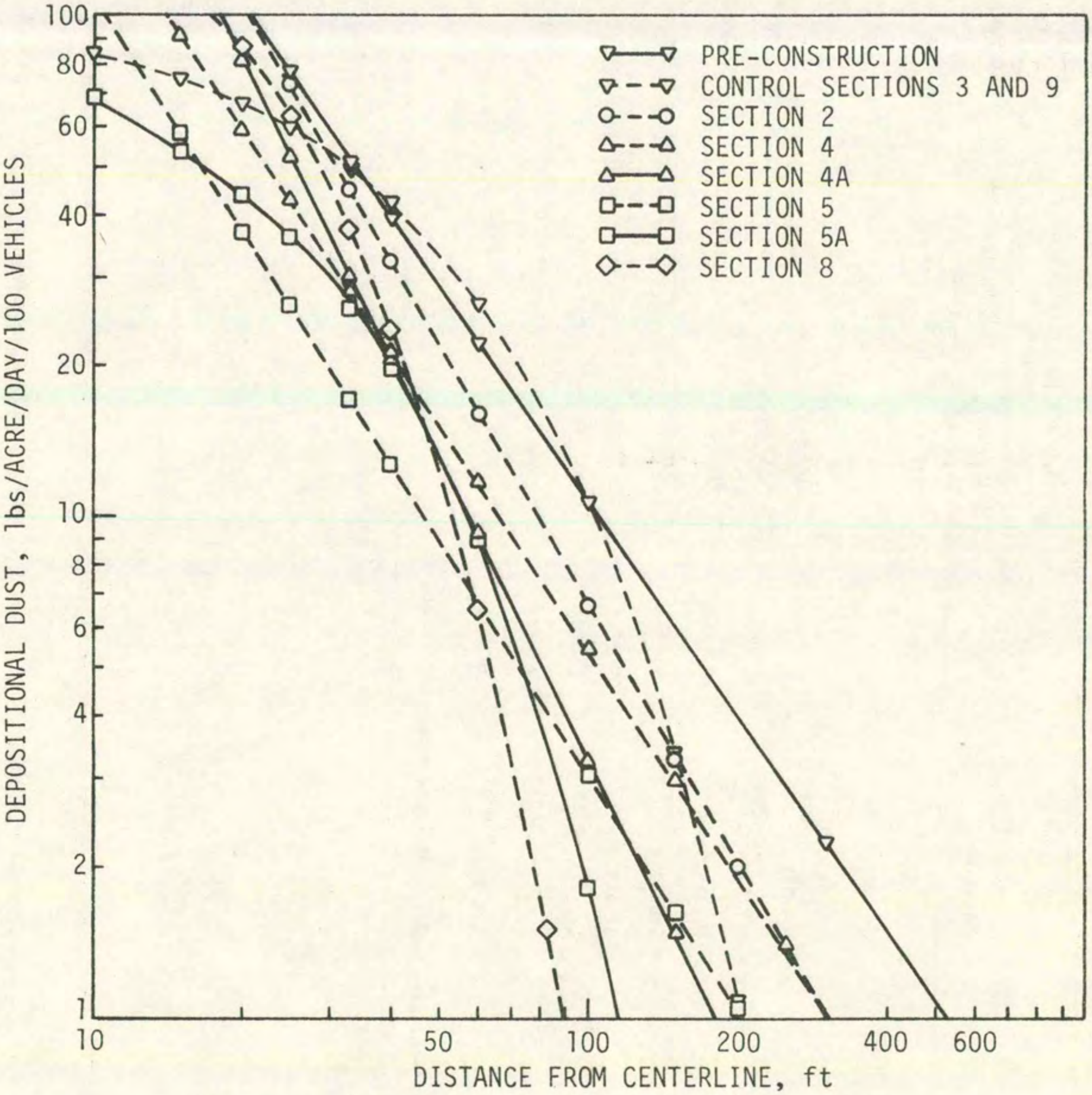

Fig. 34. Regressions of depositional dust versus distance from centerline, Franklin County, approximately 11 months after application.

of the foregoing were due to vandalism, or in one instance, a cattle herd. However, the data are still adequate to indicate areas of treatment effectiveness. Pre-construction data indicated considerable quantities of dust from this site, as was also visibly noticeable. Nearly three months after treatment, section 1 (asphalt emulsion) showed a very high quantity of dust as evidenced with the intercept of the regression equation, as well as the quantity at 33 ft. This combination, and in particular the regression intercept, would tend to indicate, however, that the very fine particulates may have absorbed the emulsion, producing a slightly larger aggregation which was then deposited within a shorter distance of centerline. The latter is evident in the ambient distance predictions when compared with the untreated control. Section 2 (ammonium lignosulfonate) produced a relatively large quantity of dust as evidenced by the regression intercept. The aggregated fine particulates, however, dropped much closer to the centerline as shown by a further reduction in ambient distance predictions and a 50% reduction in quantity at 33 ft when compared to the untreated control. Lesser quantities of dust were produced from section 4 (calcium chloride), but ambient level predictions indicated the dust moved slightly further from centerline, as well as produced somewhat less dustfall at 33 ft than did the lignosulfonate. Application of Coherex over a previously applied lignin, section 5, produced significant changes in dust quantity, ambient distances, and predicted quantity at 33 ft when compared to the untreated control. Section 5A (Coherex only) produced a relatively low regression intercept indicative of reduced dust. Ambient level distances were similar to the control; however, predicted quantity at 33 ft was nearly five times less. After nearly three months, sections 7 and 7A (respectively Amsco Res AB 1881 only, and Amsco Res AB 1881 over a previously applied ammonium lignosulfonate) were somewhat more effective than the control, but considerably less effective than sections 2, 4, 5, 5A, and 8. Section 8 produced a significant quantity of dust but the particulates were apparently well aggregated and dropped within a short distance of centerline.

Following the winter of 1979-80, collectors were re-established for selected sections at the Franklin County site. Selection was based primarily on the visual observations previously presented, as well as observations during the winter and early spring of 1980. As a consequence, sections 6, 7, and 7A were concluded as ineffective, and no collectors were re-established thereon.

Table 8 presents depositional dust regressions of the re-established buckets, as collected approximately 11 months following the respective Category 1 treatments. Section 1 (asphalt emulsion) still showed a larger quantity of dustfall at 33 ft, coupled with somewhat reduced ambient level distances, when compared to the untreated control sections. Section 2 (ammonium lignosulfonate) indicated reduced effectiveness from about eight months earlier, but still showed a slight reduction in quantity at 33 ft when compared to the control. Section 4 (calcium chloride) also indicated reduced effectiveness, but still showed a distinct reduction in predicted 33-ft dustfall quantity. Section 4A (calcium chloride over a previously applied lignin) indicated a degree of particulate aggregation retention when compared to the control, through both ambient distances and dust quantity at 33 ft. Effectiveness of section 5 (Coherex over a previously applied lignin) was still quite evident after about 11 months, as shown by reduced ambient distance, and quantity at 33 ft. Section 5A (Coherex) was still reasonably effective, showing definite reductions in ambient distances and 33-ft quantity. Section 8 (Coherex) still showed significant reductions in ambient distances but was not as effective in reducing predicted dustfall quantity at 33 ft.

In general, it could be concluded that a Category 1 treatment using Coherex at the Franklin County site produced the greater overall effectiveness both in terms of dust quantity at the ROW and reduction of dustfall distances to achieve ambient levels of particulates. The ammonium lignosulfonate and calcium chloride were still somewhat effective after nearly 11 months of usage. The CSSI asphalt emulsion, Polybind Acrylic DLR 81-03, and Amsco Res AB 1881 were concluded as ineffective. Laboratory trafficability tests projected similar conclusions.

Particle size analysis was performed through a combination of two methods on many of the dust samples collected during the course of the research project. First, each sample was dry sieved through a nest of sieves including the number 200 U.S. standard mesh (0.074 mm). The percent passing each sieve size was then graphed.

Where greater than 1.85 gms of minus 200 mesh material were obtained from each sample, a Sedigraph 5000 Particle Size Analyzer could be used for continuation of the particle size distribution curve from 0.074 to 0.001 mm diameter. This unit uses collimated Tungsten X-rays for measurement of concentration of particles in accordance with Stokes Law

[45]. Precision of the Sedigraph 5000 has been found to be reproducible within ± 1.0% [45,46]. Size distributions obtained from the Sedigraph were corrected to percentage of total sample and plotted in conjunction with the sieve analysis for a complete particle size distribution.

Typical examples of pre-construction grain size distribution curves for several depositional dust samples are presented in Figures 35 through 38. Figures 35 and 36 indicate a trend of increasing percentage of 0.005 mm size particles with increasing distance from roadway centerline. Figures 37 and 38 indicate both increased silt and clay size fractions versus distance from centerline.

Calculation of the median and one standard deviation of each particle size classification percentage from 42 pre-construction dust samples between centerline and 20 ft, 21 to 33 ft, and beyond 33 ft, indicates a generalized trend that silt size particles are predominant.

Distance from Centerline	Gravel 76.2 to 2.0 mm	Sand 2.0 to 0.074 mm	Silt 0.074 to 0.005 mm	Clay < 0.005 mm	0.010 mm
0-20 ft	7	41 ± 22	49 ± 24	10 ± 8	15 ± 10
21-33 ft	5	32 ± 17	59 ± 18	8 ± 5	13 ± 6
> 33 ft	0	37 ± 17	55 ± 29	12 ± 11	20 ± 11
Beyond 33 ft	-	-	-	-	-

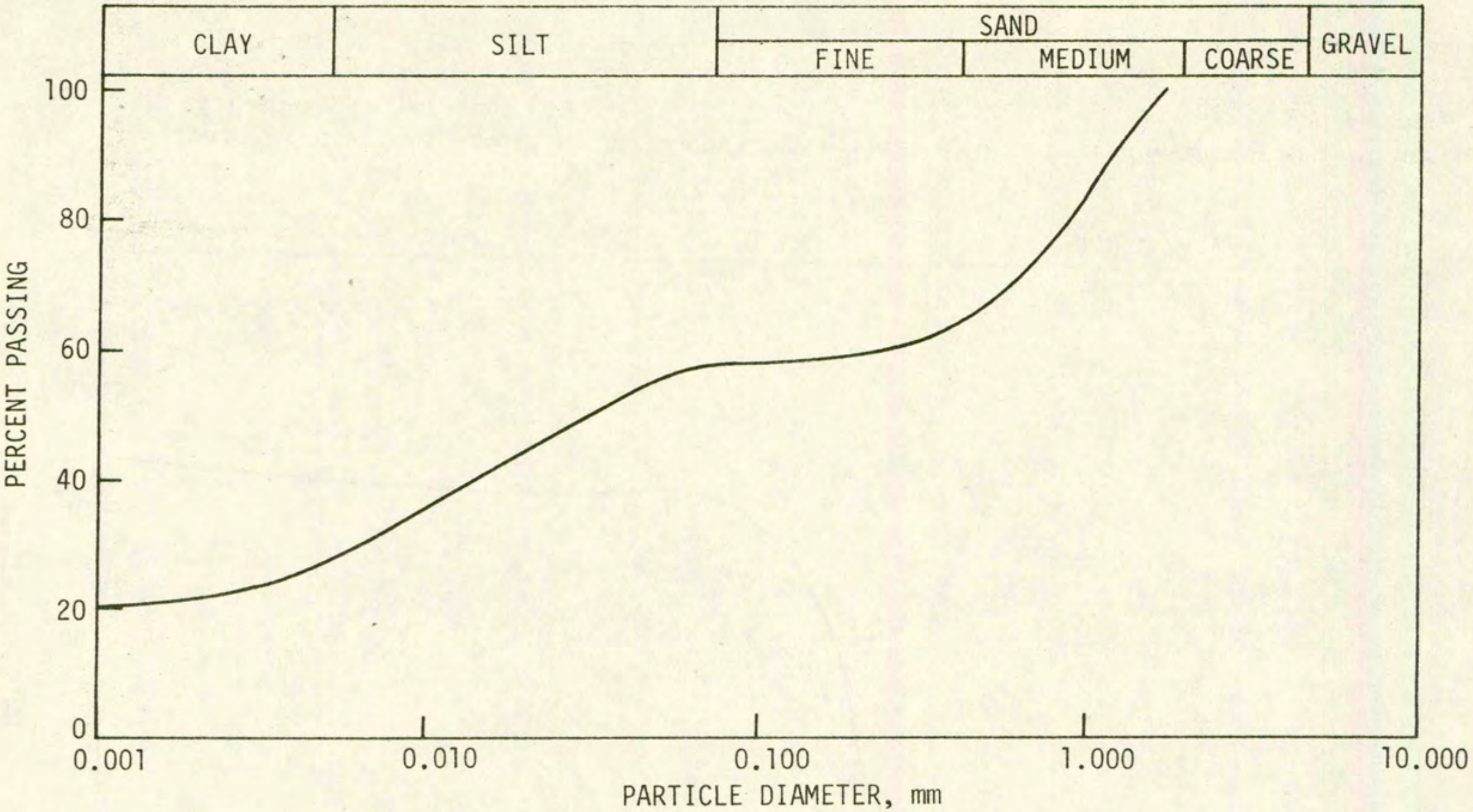

Fig. 35. Particle size distribution, Buchanan County site, 1978. Dust collector 18 feet north of roadway centerline.

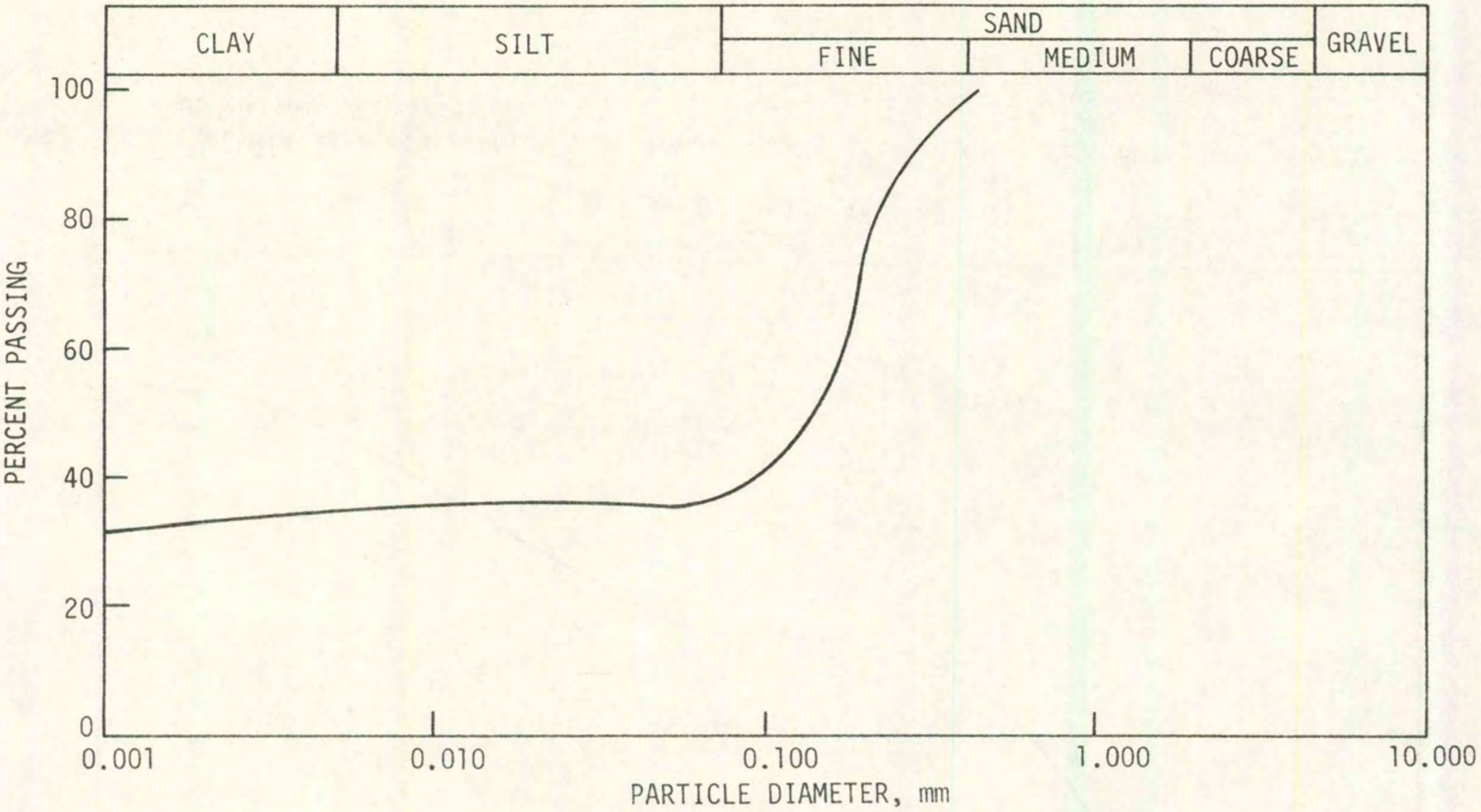

Fig. 36. Particle size distribution, Buchanan County site, 1978. Dust collector 50 feet north of roadway centerline.

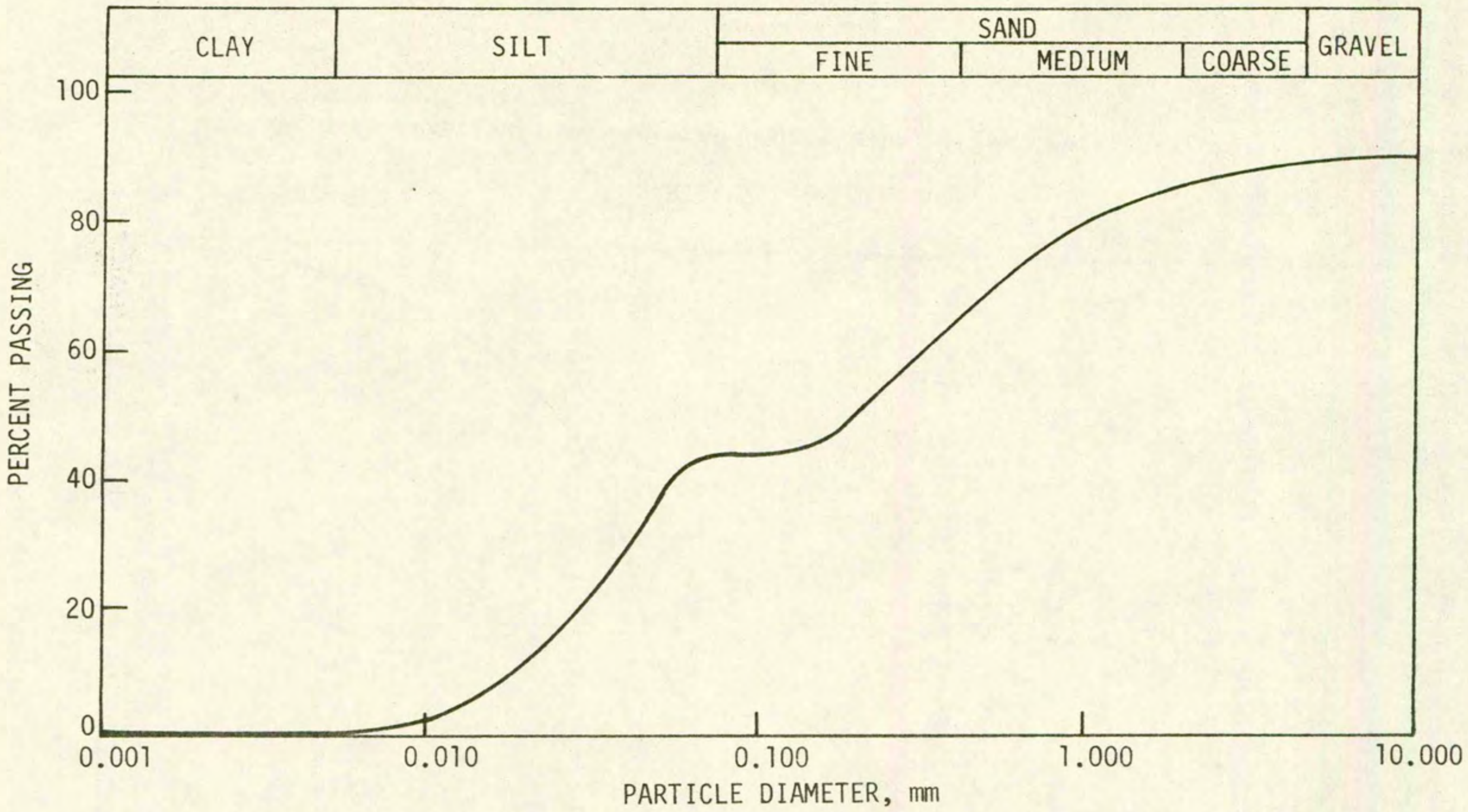

Fig. 37. Particle size distribution, Buchanan County site, 1979. Dust collector 18 feet south of roadway centerline.

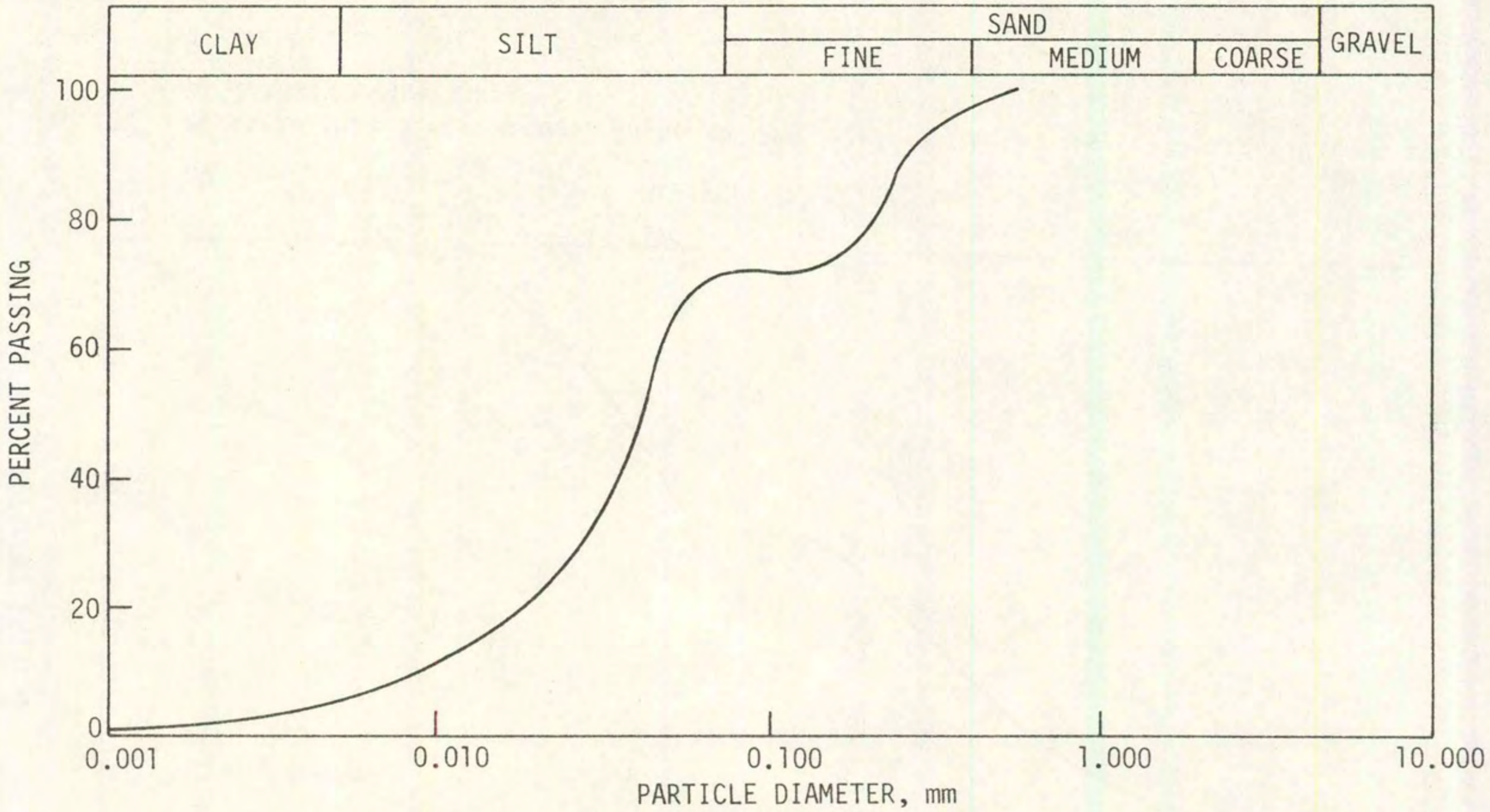

Fig. 38. Particle size distribution, Buchanan County site, 1979. Dust collector 29 feet south of roadway centerline.

Beyond 33 ft all particle size classification percentages may certainly tend to dissipate with distance due to particulate weight and dispersion characteristics. But as may be seen in the above table, silt and clay size percentages generally become predominant with distance. Thus, the primary mechanism of a Category 1 dust palliative must be such that particulates less than 0.074 mm diameter are bound together, at least as a climatically stable flocculated aggregation of 74 micron or larger in diameter, in order to disperse and/or drop within the ROW. Products which provide this flocculated mechanism must therefore be compatible with the surface chemistry and physico-chemical properties of the particulates.

A prominent feature of all dust sample particle size curves was the presence of a distinct plateau occurring between the 100-mesh (150 microns) and 200-mesh (74 microns) sieve sizes, Figures 35 through 38. This phenomenon suggests a bimodal material and was found to be reflective of gradations of in-situ roadway materials at all sites. Considering the construction sequence of most secondary roads (embankment built of local soil materials, then topped with crushed or other granular material), occurrence of bimodal particle size distributions might be expected.

Processes involved in dust transportation provide another explanation for bimodal particle size distributions for dust samples. Saltation induced by vehicle traffic, which includes the fraction above the 200-mesh (74 micron) sieve, would be a distinct mechanism for transportation of larger particles. Suspension of particles in air would be confined to particles smaller than the 200-mesh sieve and subject to settling characteristics described by Stoke's law.

Kittleman [41] concluded that volcanic ash particles transported by suspension in air exhibited decreasing median particle size with increasing distance from the source. Table 9 presents median particle size data for that fraction of 42 pre-construction dust collector samples passing the 200-mesh sieve as determined with the Sedigraph.

Table 9. Dustfall sample median particle size of that fraction of the soil passing the No. 200 U.S. Standard sieve.

Year	Location	Side	Distance from Centerline, ft	Untreated Median Particle Diameter, microns
78	Buchanan	North	18	10
78	Buchanan	North	50	6
78	Buchanan	South	17	20
78	Buchanan	South	32	2
79	Buchanan	North	18	28
79	Buchanan	South	18	34
79	Buchanan	South	29	32
79	Franklin	North	13	18
79	Franklin	North	30	18
78	Marion	North	17	20
78	Marion	North	26	29
78	Marion	South	17	27
79	Marion	North	17	39
79	Marion	North	26	33
79	Marion	North	66	25
79	Marion	South	20	31
78	Plymouth	East	23	18
78	Plymouth	East	83	21
78	Plymouth	West	24	12

Table 9. Continued.

Year	Location	Side	Distance from Centerline, ft	Untreated Median Particle Diameter, microns
79	Plymouth	East	13	32
79	Plymouth	East	22	34
79	Plymouth	West	24	36
79	Plymouth	West	32	30
78	Honey Creek	West	13	18
78	Honey Creek	West	18	9
78	Mud Hollow	South	16	16
78	Neola	North	14	31
78	Neola	North	34	50
78	Neola	South	16	27
78	Neola	South	22	29
79	Honey Creek	North	16	31
79	Honey Creek	North	28	29
79	Honey Creek	South	16	29
79	Mud Hollow	North	19	30
79	Mud Hollow	North	30	31
79	Neola	East	17	36
79	Neola	East	25	36
79	Neola	West	26	26
79	Story	North	25	37
79	Story	North	49	24
79	Story	South	31	22
79	Story	South	44	24

Median particle diameter of the suspension fraction of dust samples from the Buchanan County site decreased with increased distance from roadway centerline. Similar data from the Franklin County site showed no change in median particle size with distance. The Marion County site exhibited a larger median particle size with increased distance for the 1978 season north-oriented collectors. The 1979 season north-oriented data exhibited a steady decline in median particle diameter with increasing distance from roadway centerline. No trend was ascertained for south-oriented Marion County collectors in either 1978 or 1979 due to lack of appropriate sample size.

Plymouth County data exhibited mixed trends for median particle size with distance. As shown in Table 9, data from both 1978 and 1979 east side collectors showed larger median diameter with increasing distance. Due to problems encountered with sampling, only one sample from 1978 west side collectors was available and no trend was realized. Data from 1979 west side collectors indicated a decrease in median diameter with increased distance from centerline.

Particle size analysis of the Honey Creek site dust samples indicated a decrease in median size with increased distance from the source. As seen in Table 9, median size decreased 9 microns in 1978 west side collectors spaced 5 feet apart. Data from 1979 north side collectors showed a decrease of 2 microns over a distance of 12 feet.

Data from Mud Hollow site for 1978 were incomplete; therefore, no trend was established. The 1979 data for north-side collectors exhibited a decrease of 1-micron median size over a distance of 11 feet and was not considered significant.

Dust collected at the Neola site in 1978 exhibited increasing median size with distance. North side data showed an increase of 19 microns over 20 ft, a significant change, while data from south side samples exhibited an increase of 2 microns over 6 ft change in distance. Data for 1979 east-oriented collectors indicated a constant median size of 36 microns for a change in distance of 8 ft.

The Story County site showed a decrease in median size of 13 microns over 24 ft for 1979 north side samples, but 1979 south side samples exhibited a reverse in this trend, with an increase of 2 microns in a distance of 13 ft.

In general, it was thus seen that a trend of decreasing median particle size with increasing distance from a roadway source was not common to all sites and varied with orientation within some sites. Variation in sheltering or openness of the site, orientation, and environmental conditions may thus bear heavily on the grain size distribution of dust samples from unpaved roads, and therefore on median particle size versus distance. This premise was also substantiated from median particle diameters of whole samples from a number of Category 1 treated sections, Table 10.

Particle size analysis of Category 1 post-construction dust samples is illustrated in Table 10 for the Franklin County sections, at approximately three months after construction. The agglomeration of clay and silt size particles produced increased percentages of sand and gravel size particles, as well as increased the median particle diameter. For example, comparison of the combined sand-gravel and silt-clay sizes of those sections and products previously noted as effective dust palliatives, with similar untreated control section data, indicates increased sand-gravel percentages due to treatment. In addition, median particle diameter increased with treatment, indicating a shift of the particle

Table 10. Particle size of Franklin County dust samples.

Condition	Direction from Centerline	Distance from Centerline, ft	Particle Size Classifications, %				Percentage 0.010 mm	Median Particle Diameter, microns
			Gravel, 76.2 to 2.00 mm	Sand, 2.00 to 0.074 mm	Silt, 0.074 to 0.005 mm	Clay, < 0.005 mm		
Pre-construction	North	13	0	78	7	15	16	460
	North	30	0	19	74	7	13	25
	North	44	0	20	80*		ND	ND
	North	69	0	45	55		ND	ND
	North	93	0	32	68		ND	ND
	North	129	0	76	24		ND	ND
	South	19	0	59	41		ND	ND
	South	31	0	58	42		ND	ND
	South	41	0	33	67		ND	ND
	South	58	0	66	34		ND	ND
Section 1 (asphalt emulsion)	East	17.5	8	44	46	2	3	163
	East	23	0	33	57	10	14	44
	East	30	0	26	72	2	4	37
	West	16	6	40	49	5	7	55
	West	24	9	53	34	4	5	196
	West	32	0	43	54	3	5	54
Section 2 (ammonium lignosulfonate)	East	15.5	0	51	47	2	2	155
	East	22.0	0	39	56	5	8	53
	East	30	0	20	80		ND	ND
	West	17	0	62	33	5	6	225
	West	24	10	40	41	9	11	74
	West	30	0	24	76		ND	ND
Section 4 (calcium chloride)	East	16	0	34	63	3	5	50
	East	22	0	45	53	2	3	61
	East	30.5	0	21	79		ND	ND
	West	16	0	26	63	11	15	39
	West	23.5	0	36	61	3	6	59
	West	33	0	46	54		ND	ND

Table 10. Continued.

Condition	Direction from Centerline	Distance from Centerline, ft	Particle Size Classifications, %				Percentage 0.010 mm	Median Particle Diameter, microns
			Gravel, 76.2 to 2.00 mm	Sand, 2.00 to 0.074 mm	Silt, 0.074 to 0.005 mm	Clay, < 0.005 mm		
Section 5 (Coherex over lignin)	East	15	16	39	45		ND	ND
	East	26	0	54	46		ND	ND
	West	16	0	61	39		ND	ND
	West	25	0	31	69		ND	ND
Section 5A (Coherex)	East	17	0	47	53		ND	ND
	East	25	0	43	57		ND	ND
	East	33	0	30	70		ND	ND
	West	16	0	58	42		ND	ND
Section 7 (Amsco Res AB 1881)	South	23.5	51	30	18	1	1	5100
	South	31	0	46	54		ND	ND
Section 7A (Amsco Res AB 1881 over lignin)	South	16	0	34	64	2	4	46
	South	24	2	49	46	3	5	170
	South	30	0	42	55	3	6	53
Section 8 (Coherex)	North	18	0	38	60	2	3	52
	North	32	0	9	91		ND	ND
	South	22	0	48	51	1	2	65
	South	33	0	41	59		ND	ND
Section 9 (Control)	North	18	0	37	62	1	2	53
	North	32	0	21	69	10	17	26
	South	22	0	35	63	2	5	44
	South	33	0	38	62		ND	ND

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*Represents combined silt-clay fraction due to inadequate weight of sample passing No. 200 sieve for use in Sedigraph.

size distribution towards the larger sizes and classifications. In most instances, this trend is noted for samples closer to the roadway centerline, substantiating the dustfall regression hypothesis that dust quantities close to centerline may have been high, but the effect of aggregation caused particles to settle out closer to the source. Particle size classifications close to the ROW limits were quite limited in number due to sample quantity, but generally indicate some reduction in quantity of clay size particulates.

While the treatments in Sections 1, 7, and 7A were generally concluded as ineffective for relatively long-term dust palliation, several of the preceding positive effects on particle size distribution and classification may be noted for these sections in Table 10, at approximately three months after construction.

One objective of this project was to identify a minimal level of dusting within the ROW, which would lower exterior ROW emissions to acceptable levels. It may be ascertained from the preceding discussions that this objective was not easily identifiable nor quantifiable. The objective of identifying products and Category 1 techniques which possess potential for achieving acceptable levels of dust reduction or abatement was reasonably attained. Dust measurement techniques utilized within this study are relatively simple, may be performed by most technical personnel, and provide identifiable quantities. However, the variables affecting identification of acceptable mineral levels of dusting from an unpaved road surface, either within the ROW corridor or at the boundary of the ROW, are numerous, lending themselves to a subjective analysis only.

Safety, operational, and vehicle maintenance considerations are the prime objectives of dust reduction within the ROW corridor. Freedom of envelopment for plants, animals, and humans is the prime objective for dust reduction beyond the ROW. From the data accumulated in this study, it appears that Category 1 surface-applied palliatives may at least partially achieve both of these objectives. However, the full realization of one may be accomplished with only a partial realization of the other. For example, the data appears to show that palliative treatments may flocculate many particulates, allowing the aggregations to drop within the ROW, but quantities of such aggregations may still be quite high within the ROW corridor and ambient level distances only partially reduced. Thus, a full realization of both objectives can only be accomplished through paving--an economic impossibility.

Utilizing the measurement techniques described in this study, the data thus suggest two subjectively ascertained, minimal-level quantities. First, an ambient level should be achieved within a distance of 100 to 150 ft, or less, of an unpaved roadway centerline. Second, a dust quantity of 15 lbs/acre/day/100 vehicles, or less, be achieved at the ROW. Utilization of a palliative product, or products, which provide long-term maintenance of such ambient distance criteria is probably more cost-effective than products requiring two or more annual applications. Based on the data within this study, such subjective criteria would probably necessitate refinement with time, but (1) could be met with presently available products, (2) would not require palliative treatment (nor paving) of all soil-aggregate surfaced roads in the state, and (3) would eliminate the necessity for short length palliation adjoining many farm units or other physical facilities. From the standpoint of safety only, these criteria would of necessity have to be reduced.

Demonstration Section Evaluation, Pottawattamie and Plymouth Counties

Presented herein is a summation of in-situ evaluations of Category 3 demonstration sections constructed in Pottawattamie and Plymouth Counties. Pre-construction testing of each section consisted predominantly of Benkelman beam, plate-bearing, and in-situ moisture-density tests. During construction, in-situ testing primarily involved monitoring of moisture and density. Representative samples of the mixed-in-place roadway materials were removed full depth from each section just prior to initial compaction, and a series of 1/30 cu ft specimens were field-molded under standard AASHTO compaction at field moisture content. All specimens were wrapped, sealed, and returned to the laboratory for curing in the humid room. Periodically, a series of specimens were tested using the Iowa K-Test. Post-construction testing was predominantly a repetition of in-situ pre-construction tests, but also included limited evaluations of Shelby tube specimens removed from the stabilized bases. Visual monitoring of each section was conducted periodically, in order to identify any patterns of cracking, rutting, surface peeling, or potholing.

Pottawattamie County--Mud Hollow

Comparison of average laboratory and field moisture-density test data is tabulated below:

	γ_d,pcf	M.C., %
Laboratory AASHTO T-99, untreated road material	117.8	13.0
In-situ untreated road material (prior to construction)	125.5	3.9
Field molded AASHTO T-99 treated material	117.8	10.8
In-situ treated material (24 hr after construction)	114.1	10.4
In-situ treated material (30 days after construction)	110.4	9.5

As noted above, addition of Portland cement and fly ash decreased the optimum moisture content with little change in maximum dry density of standard T-99 laboratory specimens. Past experience has shown that this is to be expected from a construction viewpoint. Average in-situ values prior to construction indicated the material was above standard maximum laboratory density. This may be attributed to the amount of compactive effort due to traffic over a long time period. In-situ values of the treated material 24 hrs after construction demonstrate that 96% of standard T-99 density was obtained in the field. In-situ T-99 values for the treated material 30 days after construction were within one standard deviation of the 24 hr values, and therefore were not significantly different.

As previously presented, the Iowa K-Test provides discrete evaluations of cohesion, angle of internal friction, lateral stress ratio, and vertical deformation modulus. Average results of Iowa K-Tests performed on the Mud Hollow site materials are presented in Table 11. Significant improvements may be noted in each of the parameters and moduli due to inclusion of 3% Type I Portland cement and 13% Iowa Power fly ash. Increased c, ϕ, and E_v values, as compared to the untreated material, indicate improved shearing resistance and vertical stress-strain characteristics. When compared to the untreated material, a decrease in K indicates improvement. A soil in which K approaches 1.000 would be highly deformable under the slightest vertical loading and in a pavement system would result in considerable rutting and shoving. Conversely, as K approaches zero, the soil is stiffer, more rigid, and will produce less lateral movement and/or deformation under a vertical loading. In each case illustrated in Table 11, the cement and fly ash stabilized base significantly reduced K.

Cohesion and angle of internal friction parameters may be used in conjunction with various forms of the basic Terzaghi equation for ultimate bearing capacity [39]. For purposes of comparative strength of the various stabilized base materials within this study, the following format for a circular loaded area was utilized:

$$q_o = \frac{\gamma B}{2} N_\gamma + 1.3\ cN_c + \gamma DN_q$$

where q_o = ultimate bearing capacity; N_γ, N_c, and N_q are bearing capacity factors dependent on ϕ; γ = unit weight (density) of the soil; B = diameter of the loaded area; c = cohesion; and D = surcharge depth. Since only a seal coat surface was used on each base, the surcharge was considered negligible and the third term was dropped. One foot was assumed for B

Table 11. Average results of Iowa K-Tests, Pottawattamie County--Mud Hollow site.

Condition	Cohesion c, psi	Angle of Internal Friction ϕ, degrees	Lateral Stress Ratio, K	Vertical Deformation Modulus E_v,psi	Dry Density, pcf	Moisture Content, %	Ultimate Bearing Capacity, psi
Laboratory AASHTO T-99, untreated road material (7-day moist cure)	6.2	34.3	0.260	3,815	120.1	12.7	453
Laboratory AASHTO T-99, treated road material (7-day moist cure)	ID*	ID*	0.009	51,930	116.4	10.5	ID*
Field molded AASHTO T-99, treated road material (30 days after construction)	27.3	53.5	0.127	8,355	105.1	16.2	22,614
Field molded AASHTO T-99, treated road material (90 days after construction)	19.4	46.2	0.157	7,684	114.0	13.1	5,216
In-situ Shelby tube treated road material, removed at 24 hrs (tested 30 days after construction)†	9.9	43.9	0.183	3,870	109.9	12.9	2,043

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*ID = Indeterminate; i.e., greater than equipment, computer, and theoretical capacities.

†Specimens extremely disturbed during sampling and extrusion from Shelby tube.

since (1) it approximates the diameter of an equivalent circular loaded area for many dual truck tires, and (2) was equal to the plate diameter used in the plate-bearing test. The last column of Table 11 presents the average ultimate bearing capacities for the Mud Hollow site materials as computed from K-Test c-ϕ parameters obtained from untreated and treated laboratory specimens, as well as field molded and Shelby tube treated specimens. In all cases, the ultimate bearing capacity of the treated base material was of a ratio of 4 or greater than the untreated soil.

Although the plate-bearing test is somewhat cumbersome, it has the advantages of (1) being the basis of evaluative procedures used in several pavement design methods, (2) providing a subsurface influence configuration roughly equivalent to that of prototype tire loads, and (3) being readily associated with the modulus of deformation of elastic theory, a basic material parameter which can be back-computed. For design purposes, the modulus of subgrade reaction, K, is normally defined as $K = P/\Delta$, where P = plate stress at 10 psi and Δ = the corresponding stable deformation value [47]. Values of K presented in Table 12 however, were determined at P = 75 psi since: (1) for all practical purposes the tests were run on the surface of the bases, not on the subgrades; and (2) potential for correlation with Benkelman beam deflections was obtained at 75 psi air pressure in the load truck tires.

Deformation moduli were computed using the relation

$$E = \frac{\pi p D\ (1 - v^2)}{4W}$$

where E = deformation modulus, p = plate stress, D = plate diameter, ν = Poisson's ratio, and W = plate settlement. For comparative purposes, ν was assumed as 0.33, a value commonly used for unsaturated soils. The expression was developed by Burmister [48] for a rigid plate on a homogeneous material. In a strict sense, the equation may not apply to the internal response of the stabilized base only, but may be a valid indicator of net response of the composite surface, base, and subgrade system when obtained from plate and Benkelman beam deformations at 75 psi.

A third parameter which may be derived from a plate-bearing test is the permanent deformation occurring after unloading. Values represent the intersection of the unloading curve with the abscissa of the plate stress versus deformation plot. Magnitude of permanent deformation is an important factor in evaluation of a Category 3 secondary road test section, since economics tend to dictate the use of in-place soil-aggregate materials, which in themselves, or over a period of time following stabilization, may undergo permanent or plastic deformation. Although the question of acceptable permanent deformation magnitude has not been universally resolved, experience suggests 1/2 in. or less of permanent set as an upper limit.

Table 12 presents a comparison of average in-situ plate bearing and Benkelman beam test results of the Mud Hollow site. From pre- to post-construction, the K modulus was increased through use of cement and fly ash treatment. Composite plate deformation of the treated base section decreased from pre- to post-construction, and the deformation modulus E increased. Permanent deformation had decreased to only 0.001

Table 12. Comparison of average plate-bearing and Benkelman beam tests, Pottawattamie County--Mud Hollow site.

	Plate-Bearing				Benkelman Beam	
Section	Modulus of Subgrade Reaction, K, pci	Deformation at 75 psi, in.	Deformation Modulus, E, psi	Permanent Deformation, in.	Deformation at 75 psi, in.	Deformation Modulus, E, psi
Control, pre-construction	--	--	--	--	0.038	16,576
Control, about 9 months after construction	3000	0.050	12,600	N.D.	0.026	24,226
Control, about 12 months after construction	3125	0.024	26,232	0.004	0.030	20,985
Control, about 14 months after construction	--	--	--	--	0.046	13,686
Cement and fly ash treated, pre-construction	1380	0.058	11,592	0.014	0.036	17,497
Cement and fly ash treated, about 9 months after construction	1856	0.041	15,625	0.011	0.037	18,073
Cement and fly ash treated, about 12 months after construction	2500	0.030	20,985	0.001	0.040	15,739
Cement and fly ash treated, about 14 months after construction	--	--	--	--	0.037	18,073

in. about 12 months after construction. Basically the above increases or decreases in such values represent formation of a rigid base condition. Fluctuations in such values with time may represent changes in (1) environmental conditions within the composite system, such as moisture content, and (2) structural changes of the composite system, such as shear and/or fatigue, or (3) both. During the relatively short duration of time over which this section could be evaluated, fluctuation of deformations and moduli obtained from both the plate-bearing and Benkelman beam tests were quite small.

As of December 29, 1980, this section was in good condition. Some spots of slight surface cupping were observed, but appeared associated with some of the spalling which occurred during the early spring of 1980 due to lack of seal coat surfacing. Some transverse cracking was noted, but little longitudinal cracking was observed. No spalling or vertical displacement could be ascertained across any cracking. Probing of surface cracking indicated hard base material below the seal coat. No rutting or shoving of profile, cross-section, or seal coat surface was observable. The surface seal coat also appeared tightly bonded to the base.

Pottawattamie County--Honey Creek

Comparison of average laboratory and field moisture-density test data is tabulated below:

	γ_d, pcf	M.C., %
Laboratory AASHTO T-99, untreated material	124.8	10.0
In-situ untreated material (prior to construction)	125.9	3.0
Section HC-1		
Laboratory AASHTO T-99, treated material	124.0	9.2
In-situ treated material (24 hrs after construction	114.2	6.6
In-situ treated material (21 days after construction)	114.2	8.2
Section HC-2		
Laboratory AASHTO T-99, treated material	119.1	11.5
In-situ treated material (24 hrs after construction)	118.4	13.3
In-situ treated material (10 days after initial construction, 24 hrs after final construction)	114.1	8.7

In-situ values of the cement and fly ash section HC-1, 24 hrs after construction indicated that field compaction had achieved 92% of laboratory maximum density for the treated material. Density was unchanged after 21 days, though an increase of 1.6% moisture content was noted and may be attributed to heavy precipitation in the area during this time period.

Moisture-density tests of the asphalt emulsion section HC-2 indicated that county crews had achieved 99% of maximum laboratory density for the treated material, although at an average moisture content 1.8%

higher than optimum, a definite indication that inadequate breaking had occurred. Results of in-situ M-D tests, performed following the previously described remedial construction for correction of excessive moisture, indicated 95.8% of laboratory maximum density was achieved in the field after lowering the moisture content to 8.7%. This is indicative of the workability of asphalt emulsion mixes before the "breaking" process has taken place.

Average results of Iowa K-Tests performed at various times on the Honey Creek site materials are presented in Tables 13 and 14. All Shelby tube specimens from the cement and fly ash section HC-1 were highly disturbed and could not be tested. Diamond-bit core samples were also disturbed and could not be tested, since no portion of the core was of adequate length to be used in the 4.56-in.-high K-Test unit. K-Tests performed on the treated laboratory, field molded, and cured specimens indicated significant increases in c, ϕ, E_v, and ultimate bearing capacity when compared to the untreated material, Table 13. Lateral stress ratio K was reduced by a factor of 2 to 4.

When compared to the untreated soil, Table 14, addition of asphalt emulsion resulted in a lowering of c, ϕ, E_v, and ultimate bearing capacity while the lateral stress ratio was increased. The effect of molding moisture content on these parameters is quite evident, particularly on field molded specimens prepared at the time of initial construction; i.e., about 1.6 to 3.4% greater moisture than laboratory optimum. However, as noted from the Shelby tube specimens, after the section was reconstructed and the emulsion had properly broken, the moisture content was reduced, and each parameter was considerably improved--the

Table 13. Average results of Iowa K-Tests, Pottawattamie County--Honey Creek section HC-1, cement and fly ash.

Condition	Cohesion c, psi	Angle of Internal Friction ϕ, degrees	Lateral Stress Ratio, K	Vertical Deformation Modulus E_v, psi	Dry Density, pcf	Moisture Content, %	Ultimate Bearing Capacity, psi
Laboratory AASHTO T-99, untreated road material (7-day moist cure)	9.2	37.3	0.220	4,473	123.6	10.3	904
Laboratory AASHTO T-99, treated road material (7-day moist cure)	101.2	72.0	0.057	41,530	124.4	8.4	> 50,000
Field molded AASHTO T-99, treated road material (14 days after construction)	43.3	54.7	0.102	12,682	120.9	7.2	44,394
Field molded AASHTO T-99, treated road material (90 days after construction)	ID*	ID*	0.087	17,153	119.5	8.2	ID*
Field molded AASHTO T-99, treated road material (about 18 months after construction)†	21.9	52.6	0.129	9,065	114.0	8.9	15,156

Note: In-situ Shelby tube treated road material specimens were extremely disturbed during sampling and extrusion and could not be K-tested.

*ID = Indeterminate; i.e., greater than equipment, computer, and theoretical capacities.

†Single specimen.

Table 14. Average results of Iowa K-Tests, Pottawattamie County--Honey Creek Section HC-2, asphalt emulsion.

Condition	Cohesion c, psi	Angle of Internal Friction ϕ, degrees	Lateral Stress Ratio, K	Vertical Deformation Modulus E_v, psi	Dry Density, pcf	Moisture Content, %	Ultimate Bearing Capacity, psi
Laboratory AASHTO T-99, untreated road material (7-day moist cure)	9.2	37.3	0.220	4473	123.6	10.3	904
Laboratory AASHTO T-99, treated road material (7-day moist cure)	8.1	18.4	0.448	2069	121.7	10.2	169
Field molded AASHTO T-99, treated road material (75 days after construction)	7.9	13.4	0.512	1668	110.3	11.8	121
In-situ Shelby tube treated road material (75 days after construction)	7.3	33.2	0.270	2086	112.1	7.4	479
Field molded AASHTO T-99, treated road material (about 18 months after construction)	4.6	9.9	0.604	2094	110.3	13.6	195

bearing capacity by a factor of four. The Shelby tube parameters of Table 14 are not unlike those of Table 2 following 10 cycles of freeze-thaw and would generally indicate maintenance of effectiveness under adverse weather conditions into the early winter of 1979-80.

Maintenance of the HC-2 section effectiveness is also noted from the plate-bearing and Benkelman beam test results of Table 15. Beam deflections were relatively constant from time of pre-construction testing (several days prior to construction) to about 13 months following construction. The plate-bearing data showed no basic change in permanent deformation, K, E, or deformation at 75 psi, over a period of several months.

Table 15 illustrates stress-strain improvement for section HC-1. Increases in K and E, coupled with decreasing deformation at 75 psi as well as a reduction in permanent deformation, are noted from the plate tests. While beam deflections of the cement and fly ash section were reduced by about one-half from that of pre-construction, they remained relatively constant during the last four months of testing.

As of December 29, 1980, both Honey Creek sections were in good condition. The emulsion section had a relatively smooth profile and cross-section with no observed cracking, rutting, or shoving. A number of cupped dimples were noticeable in section HC-2 but were the result of improper backfilling and compaction from Shelby tube sampling early the previous winter.

Section HC-1 showed limited transverse cracking, generally in the neighborhood of 10-ft spacing, coupled with limited longitudinal cracking about 3 ft from shoulders, with scattered light longitudinal cracking

Table 15. Comparison of average plate-bearing and Benkelman beam tests, Pottawattamie County--Honey Creek site.

	Plate-Bearing				Benkelman Beam	
Section	Modulus of Subgrade Reaction, K, pci	Deformation at 75 psi, in.	Deformation Modulus, E, psi	Permanent Deformation, in.	Deformation at 75 psi, in.	Deformation Modulus E, psi
Control, about 9 months after construction	758	0.099	6,359	0.034	0.100	6,296
Control, about 11 months after construction	872	0.086	7,320	0.015	0.103	6,112
Control, about 13 months after construction	--	--	--	--	0.085	7,407
HC-1, cement and fly ash pre-construction	1415	0.053	11,879	0.016	0.066	9,539
HC-1, cement and fly ash about 9 months after construction	1744	0.043	14,641	0.012	0.037	17,015
HC-1, cement and fly ash about 11 months after construction	2679	0.028	22,484	0.002	0.033	19,078
HC-1, cement and fly ash about 13 months after construction	--	--	--	--	0.038	16,567
HC-2, asphalt emulsion, pre-construction	806	0.093	6,769	0.033	0.088	7,154
HC-2, asphalt emulsion, about 9 months after construction	457	0.164	3,839	0.090	0.096	6,558
HC-2, asphalt emulsion, about 11 months after construction	466	0.161	3,910	0.088	0.091	6,918
HC-2, asphalt emulsion, about 13 months after construction	--	--	--	--	0.079	7,969

near the centerline. Unlike the Mud Hollow site, the Honey Creek site had very narrow shoulders, thus providing little or no lateral restraint at the edges of the stabilized base. However, no spalling or vertical displacement was observed across any cracking, and as at Mud Hollow, probing of a number of the cracks indicated hard base below the seal coat surfacing. No potholing was apparent, but some cup depressions were observable, probably resulting from base spalling early the previous spring when little of the original seal coat surfacing remained. No rutting or shoving was noted, and the seal coat surface appeared tightly bonded. A slight spalling was occurring on the south 1 to 2 ft of surface and base adjacent to the entrance of Nickerson Farms Restaurant, probably due to relatively heavy traffic-turning movement at this location immediately off the I-29 ramp.

Pottawattamie County--Neola

The following table presents a comparison of average laboratory and field moisture-density test data:

	γ_d, pcf	M.C., %
Laboratory AASHTO T-99, untreated road material	113.5	15.0
In-situ untreated road material (prior to construction)	120.5	7.4
<u>Section N-1</u>		
Laboratory AASHTO T-99, treated road material	102.8	19.0
In-situ treated material (3 days after construction)	119.5	10.5
<u>Section N-2</u>		
Laboratory AASHTO T-99, treated road material	115.7	13.0
In-situ treated material (24 hrs after construction)	116.3	7.9

Moisture-density tests for section N-1 indicate some of the usual difficulties encountered in working with an asphalt emulsion-treated, fine-grained soil material, AASHTO classification A-7-5(12). The laboratory treated material exhibited a decrease in maximum density of 10.7 pcf with an increase of 4% in optimum moisture, while the in-situ density of the treated material was 16.7 pcf greater than that of the laboratory treated soil. While this latter difference in density is greater than one standard deviation in testing, it is also indicative of allowances in aeration of moisture content (needed for proper dispersion of the emulsion) following breaking and prior to compaction of the mixture.

Addition of Portland cement and fly ash in Section N-2 laboratory materials increased maximum density by 2.2 pcf but decreased optimum moisture content by 2.0%. Field compaction achieved slightly greater than 100% of laboratory maximum density. The difference in densities is within one standard deviation of the testing mean.

Results of average parameters obtained from Iowa K-Tests performed on the Neola site materials are presented in Tables 16 and 17. The effect of moisture content on ultimate bearing capacity, c, ϕ, and K is again evident, Table 16. However, the vertical deformation modulus, E_V, achieved with all emulsion-treated section N-1 specimens, appeared to resist the effect of moisture content. This apparent resistance was due to less vertical strain at failure for the treated specimens as compared to the laboratory untreated specimens. For example, vertical strain at failure of the in-situ Shelby tube specimens was about 5%, as compared to in excess of 10% for the untreated laboratory specimens.

Table 17 also shows the effect of moisture content on section N-2 field molded specimens after about 17 months in the moist curing room, where unfortunately the wrappings had been torn and the specimens subjected to a fine water mist for an unknown number of months. Even under such adverse water conditions, these specimens still showed considerable improvement in each parameter as well as ultimate bearing capacity when compared to the average untreated material. Due to difficulties encountered with Shelby tube samples from the Mud Hollow and Honey Creek cement and fly ash sections, no attempt was made to remove such specimens at Neola. Several diamond-bit core samples were

Table 16. Average results of Iowa K-Tests, Pottawattamie County--Neola section N-1, asphalt emulsion.

Condition	Cohesion c, psi	Angle of Internal Friction ϕ, degrees	Lateral Stress Ratio, K	Vertical Deformation Modulus E_v, psi	Dry Density, pcf	Moisture Content, %	Ultimate Bearing Capacity, psi
Laboratory AASHTO T-99, untreated road material (7-day moist cure)	14.4	33.1	0.235	1848	104.3	10.6	922
Laboratory AASHTO T-99, treated road material (7-day moist cure)	13.5	29.0	0.280	2090	102.3	10.6	608
Field molded AASHTO T-99, treated road material (52 days after construction)	4.9	4.8	0.724	2689	103.8	18.5	47
In-situ Shelby tube treated road material, removed at 24 hours (tested 52 days after construction)	7.7	23.9	0.371	3657	116.8	12.2	236

Table 17. Average results of Iowa K-Tests, Pottawattamie County--Neola section N-2, cement and fly ash.

Condition	Cohesion c, psi	Angle of Internal Friction ϕ, degrees	Lateral Stress Ratio, K	Vertical Deformation Modulus E_v, psi	Dry Density, pcf	Moisture Content, %	Ultimate Bearing Capacity, psi
Laboratory AASHTO T-99, untreated road material (7-day moist cure)	14.4	33.1	0.235	1,848	104.3	10.6	922
Laboratory AASHTO T-99, treated road material (7-day moist cure)	25.0	50.7	0.122	12,362	104.5	13.3	13,077
Field molded AASHTO T-99, treated road material (49 days after construction)	63.3	48.1	0.096	18,049	119.0	12.5	21,923
Field molded AASHTO T-99, treated road material (about 17 months after construction)	20.0	37.5	0.197	9,095	108.2	18.4	1,943

removed from the N-2 section, but no portion thereof was of sufficient length for usage in the K-Test unit.

Table 18 presents average plate-bearing and Benkelman beam data for Neola sections N-1 and N-2. When related to pre-construction or the control sections, the N-1 section plate-bearing data indicate a lowering of both K and E, coupled with increased deformation at 75 psi and increased permanent deformation. Conversely, the Benkelman beam data showed a distinct lowering of deformation from pre-construction to treatment versus time, coupled with a doubling of deformation modulus about 12 months after construction.

Each average deformation and moduli obtained with section N-2 showed definite improvement when compared with either the pre-construction or the control sections, Table 18.

Visual inspection December 30, 1980, indicated both Neola sections to be in good condition. Though no rutting, shoving, or potholing was observed in section N-1, a few slight surface depressions of limited area were noted throughout the length of the section. Examination of these depressions showed no structural defects such as alligatoring. A few light transverse cracks were noted in the outer 3 to 4 ft (north side) portion of the curve near a culvert.

Transverse cracking similar to that observed with both the Mud Hollow and Honey Creek cement and fly ash sections was observed in section N-2. Very little longitudinal cracking was noted as the section had somewhat wider shoulders than at Honey Creek, thereby probably adding to lateral stability. No rutting, shoving, or potholing was observed. The seal coat surfacing appeared tightly bonded to the

Table 18. Comparison of average plate-bearing and Benkelman beam tests, Pottawattamie County--Neola site.

Section	Plate-Bearing				Benkelman Beam	
	Modulus of Subgrade Reaction, K, pci	Deformation at 75 psi, in.	Deformation Modulus, E, psi	Permanent Deformation, in.	Deformation at 75 psi, in.	Deformation Modulus, E, psi
Control:						
About 8 months after construction	1210	0.062	10,210	--	0.048	13,123
About 10 months after construction	1210	0.062	10,154	0.017	0.057	11,045
About 12 months after construction	--	--	--	--	0.065	9,686
N-1, asphalt emulsion:						
Pre-construction	490	0.153	4,115	0.101	0.139	4,529
About 8 months after construction	329	0.228	2,761	0.223	0.083	7,585
About 10 months after construction	252	0.298	2,113	0.192	0.074	8,508
About 12 months after construction	--	--	--	--	0.068	9,258
N-2, cement and fly ash:						
Pre-construction	586	0.128	4,918	0.055	0.081	7,772
About 8 months after construction	1316	0.057	11,045	0.019	0.049	12,848
About 10 months after construction	1786	0.042	14,990	0.004	0.040	15,739
About 12 months after construction	--	--	--	--	0.041	15,355

stabilized base throughout the section length. Beginning near the north-side T-intersection and extending westerly about 100 to 150 ft was a region of large random block surface cracking the full width of roadway. Each block was at least 4- to 5-ft minimum length in all directions. No surface spalling was apparent within each block or across the cracking between each block. Probing of the cracking indicated no penetration of base as the base appeared quite hard at either edge of the crack. While no vertical displacement of crack edges was observed within this short area, each block appeared to have some very slight warping with the low point of the block adjacent to the cracking. No discernible cause of the block cracking could be ascertained, but this region needs periodic inspection in order to determine its cause as well as any maintenance which may ultimately be needed.

Plymouth County

Average field and laboratory moisture-density test data for each Plymouth County section are summarized in the following table:

	γ_d, pcf	M.S., %
Laboratory AASHTO T-99 untreated road material	125.2	9.9
In-situ untreated road material one week prior to construction	128.4	7.8
<u>Section PL-1</u>		
Laboratory AASHTO T-99 treated road material*	130.0	8.4
In-situ treated material immediately after construction†	108.0	10.8
In-situ treated material 24 hrs after construction†	118.1	9.4
<u>Section PL-2</u>		
Laboratory AASHTO T-99, treated road material*	129.4	9.2
In-situ treated road material immediately after construction†	113.0	12.6
In-situ treated road material 24 hrs after construction†	115.0	10.6
<u>Section PL-3</u>		
Laboratory AASHTO T-99 treated road material*	129.6	9.4
In-situ treated road material 24 hrs after construction†	119.0	9.0
<u>0% P.C.--7% F.A.</u>		
In-situ treated road material 24 hrs after construction	117.1	12.4

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*Laboratory tests conducted with Port Neal III fly ash.

†Test section constructed with Port Neal IV fly ash.

Sections PL-1 through PL-3 were those considered as primary demonstration sections. The section containing 0% cement and 7% fly ash only was previously noted as an add-on during construction. To a very large extent, each section was without benefit of either screening or other laboratory tests due to the change of fly ash source shortly before construction. Differences in laboratory versus in-situ density data reflect the variation in fly ashes. Changes in average moisture content of sections PL-1 and PL-2 within 24 hrs after construction tend to reflect the cementitious properties of the mix.

Based on experiences with Shelby tube and diamond-bit core samples in Pottawattamie County, no attempt was made to obtain either type of sample for K-Testing from the Plymouth County sections. Table 19 presents a comparison of the average laboratory and field molded K-Test results. Regardless of variation in fly ashes, stabilized mixtures produced considerable improvement in each parameter and ultimate bearing capacity from that achieved with the untreated road material. Though some variations in average c, ϕ, K, and E_v may be noted for each of the field molded mixtures nine months after construction, only a relatively small variation in ultimate bearing capacity occurred. A portion of this lack of variation may be attributed to the higher moisture content of the 3%-13% field mix, since some increase in average bearing capacity was attained with the 3%-9% as compared with the 2%-6% mix, both at similar average moisture contents.

In an effort to discern immediate improvements in stability, Benkelman beam tests were conducted beginning one day after construction. Average beam deflections of the stabilized bases at age one day were

Table 19. Average results of Iowa K-Tests, Plymouth County sections.

Condition	Cohesion c, psi	Angle of Internal Friction, ϕ, Degrees	Lateral Stress Ratio K	Vertical Deformation Modulus E_v, psi	Dry Density, pcf	Moisture Content, %	Ultimate Bearing Capacity, psi
Laboratory AASHTO T-99, untreated road material (7-day moist cure)	11.4	30.9	0.271	3,212	115.7	11.8	603
Laboratory AASHTO T-99, 2% PC, 6% FA (7-day moist cure)*	6.5	75.8	0.064	15,128	126.4	9.1	> 50,000
Field molded AASHTO T-99, 2% PC, 6% FA (about 9 months after construction)†	26.2	48.9	0.136	9,585	109.7	15.3	5,427
Laboratory AASHTO T-99, 3% PC, 9% FA (7 day moist cure)*	20.1	67.9	0.084	11,386	117.0	10.5	> 50,000
Field molded AASHTO T-99, 3% PC, 9% FA (about 9 months after construction)†	45.1	42.0	0.128	12,150	109.2	16.0	7,291
Laboratory AASHTO T-99, 3% PC, 13% FA (7-day moist cure)*	12.8	80.0	0.052	13,039	122.2	9.1	> 50,000
Field molded AASHTO T-99, 3% PC, 13% FA (about 9 months after construction)†	31.6	43.4	0.141	10,990	105.0	21.4	5,941

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[*] Laboratory tests conducted with Port Neal III fly ash.

[†] Test section constructed with Port Neal IV fly ash.

similar to or slightly greater than the pre-construction values, Table 20. Two days following construction, beam deflections were reduced within sections PL-1 and PL-2. Further reductions in average deflections occurred at both one and three months following construction in each of the three demonstration sections, resulting in distinct improvements in the calculated deformation moduli, E. Benkelman beam deflections of the 0% cement and 7% fly ash section basically remained constant from one day through about three months following construction, indicating the possibility that maximum strength and stability of this section had been achieved within the first day.

Plate-bearing tests after construction followed a pattern very similar to that of the Benkelman beam, resulting in improved K, E, deformation at 75 psi, and permanent deformation, Table 20.

During inspection of the Plymouth County site December 28, 1980, each section appeared in good condition. Section PL-1 (3% cement and 13% fly ash) showed no visible cracking, potholing, rutting, or shoving. About a half-dozen, 3- to 4-in.-width strips of surfacing were missing along the centerline of section and appeared to be caused by a lack of overlap during seal coating. In an area of the center east lane, north of the Puetz farm, about 3-ft wide by 12-ft long, the seal coat had developed several bubbles about 6-in. in diameter. Each bubble had an appearance similar to that which may be observed with a flat asphalt roof under which water has accumulated. Probing of the bubbles did not produce water, however, and the base felt hard.

Section PL-2 (3% cement and 9% fly ash) had one visible transverse crack. No vertical movement was observed across the crack and the base

Table 20. Comparison of average plate-bearing and Benkelman beam tests, Plymouth County sections.

	Plate-Bearing				Benkelman Beam	
Section	Modulus of Subgrade Reaction K, pci	Deformation at 75 psi, in.	Deformation Modulus, E, psi	Permanent Deformation, in.	Deformation at 75 psi, in.	Deformation Modulus, E, psi
Control:						
Pre-construction	781	0.096	6,558	0.030	0.091	6,918
About 1 month after construction	543	0.138	4,562	0.050	0.075	8,394
About 3 months after construction	--	--	--	--	0.085	7,407
PL-1, 3% PC-13% FA:						
Pre-construction	798	0.094	6,697	0.025	0.103	6,112
One day after construction	789	0.095	6,627	0.034	0.101	6,233
Two days after construction	--	--	--	--	0.082	7,678
About 1 month after construction	1293	0.058	10,855	0.011	0.069	9,124
About 3 months after construction	--	--	--	--	0.067	9,396
PL-2, 3% PC-9% FA:						
Pre-construction	714	0.105	5,996	0.029	0.081	7,772
One day after construction	--	--	--	--	0.107	5,884
Two days after construction	--	--	--	--	0.074	8,508
About 1 month after construction	1042	0.072	8,744	0.015	0.048	13,116
About 3 months after construction	--	--	--	--	0.051	12,344
PL-3, 2% PC-6% FA:						
Pre-construction	399	0.118	3,349	0.037	0.088	7,154
One day after construction	--	--	--	--	0.077	8,176
About 1 month after construction	1087	0.069	9,124	0.016	0.062	10,154
About 3 months after construction	--	--	--	--	0.054	11,659
0% PC-7% FA:						
One day after construction	--	--	--	--	0.066	9,539
About 1 month after construction	586[*]	0.128[*]	4,918[*]	0.034[*]	0.065	9,686
About 3 months after construction	--	--	--	--	0.070	8,994

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[*] Only one plate bearing test.

appeared hard on either side. Several narrow centerline strips were lacking seal coat and appeared due to little or no overlap during surfacing. No observable rutting, shoving, or potholing was identifiable.

Section PL-3 (2% cement and 7% fly ash) indicated slight evidence of rutting. Three transverse cracks were evident in this section, but no vertical displacement was noticeable, and the base was hard either side of the crack.

Section PL-3 produced some problems during mixing due to a localized region of large gravel and rock within the subgrade. Immediately adjacent to this section is an abandoned gravel pit. Initial sampling of this site had not indicated this localized condition. During construction, the rock broke several mixer teeth and created some difficulties during compaction and blade finishing. Many of the stones had to be removed by hand. Several pothole type surface depressions were noted in this region during the December inspection and were probably due to lack of backfilling and compaction created by the rock removal. Just south of this region, a soft spot about 2-ft wide by 8-ft long appeared to be developing in the center of the west lane. The seal coat surfacing was slightly alligatored and a sharp probe could be inserted to a depth of about 1 to 1-1/2 in. before striking hard material. The softened base material was moist and had the feel and appearance of a lack of cement and fly ash.

The transition from section PL-3 to the 0% cement and 7% fly ash section contained several transverse cracks spaced from 3 to 6 ft apart. No alligatoring, potholes, rutting, shoving, or transverse cracking was observed within the body of the 0%-7% section.

Throughout the Plymouth sections, random spots of bleeding asphalt were evident. The seal coat surfacing appeared firm and tightly bonded within each tire path, but sounded hollow to punky when struck with a blunt instrument between wheel paths.

As with all the project Category 3 demonstration sections, and the Plymouth County sections in particular, continued in-situ testing and visual evaluation is needed. The Plymouth County site provides an exceptional opportunity for evaluative investigation of stabilized bases containing a range of cement and highly reactive fly ash contents; the latter, a product whose usage must be considered for continued economic development in highway design and construction.

Benkelman Beam and Plate-Bearing Deformation Correlation

Tables 12, 15, 18, and 20 identify average plate-bearing and Benkelman beam test deformations at 75 psi vertical stress for the Category 3 demonstration sections. Comparison of the quantity of average deformation for each test indicates a considerable degree of similarity. A few exceptions may be noted: for example, the N-1 section at Neola, where plate deformations were considerably higher than those observed from the Benkelman beam. These exceptions are indicative of two conditions: (1) the manner in which each in-situ test is conducted, and (2) whether the material may be broadly termed elastic or plastic. During any incrementally applied plate-bearing loading, each load is maintained until such time as an equilibrium deformation is attained. A maximum deformation/ deflection is obtained during the Benkelman beam test with a near instantaneous loading of a moving set of dual truck tires. If a material is relatively elastic, maximum plate-bearing deformation per increment of loading is attained relatively fast; if plastic, deformation continues for a period of time. The Neola N-1 section example illustrates a more plastic, deformable material condition. For those materials which are more elastic, the quantity of deformation from either test should be similar.

Figure 39 presents the regression correlation of Benkelman beam versus plate-bearing deformations for the more elastic materials, each at 75 psi stress, as determined from the Pottawattamie and Plymouth County demonstration sections. The regression indicates a relatively high coefficient of determination r^2 and correlation coefficient r. The ordinate intercept tends to indicate the quantity of deformation which occurs during the seat loading of the plate; i.e., deformation under a small initial plate loading utilized to ensure contact of component parts of the test equipment.

This correlation is presented herein in view of the following purpose. If any consideration is given to continuance of in-situ deformation evaluation of the Pottawattamie and Plymouth County demonstration sections, the regression of Figure 39 may be of assistance in calculating or predicting values of the respective modulus of subgrade reaction K, or deformation modulus E; i.e., a continuance of the bulk of the average data of Tables 12, 15, 18, and 20.

Demonstration Section Costs

An objective of this project was to examine the costs and economic feasibility of each type of demonstration section. Each cost listed

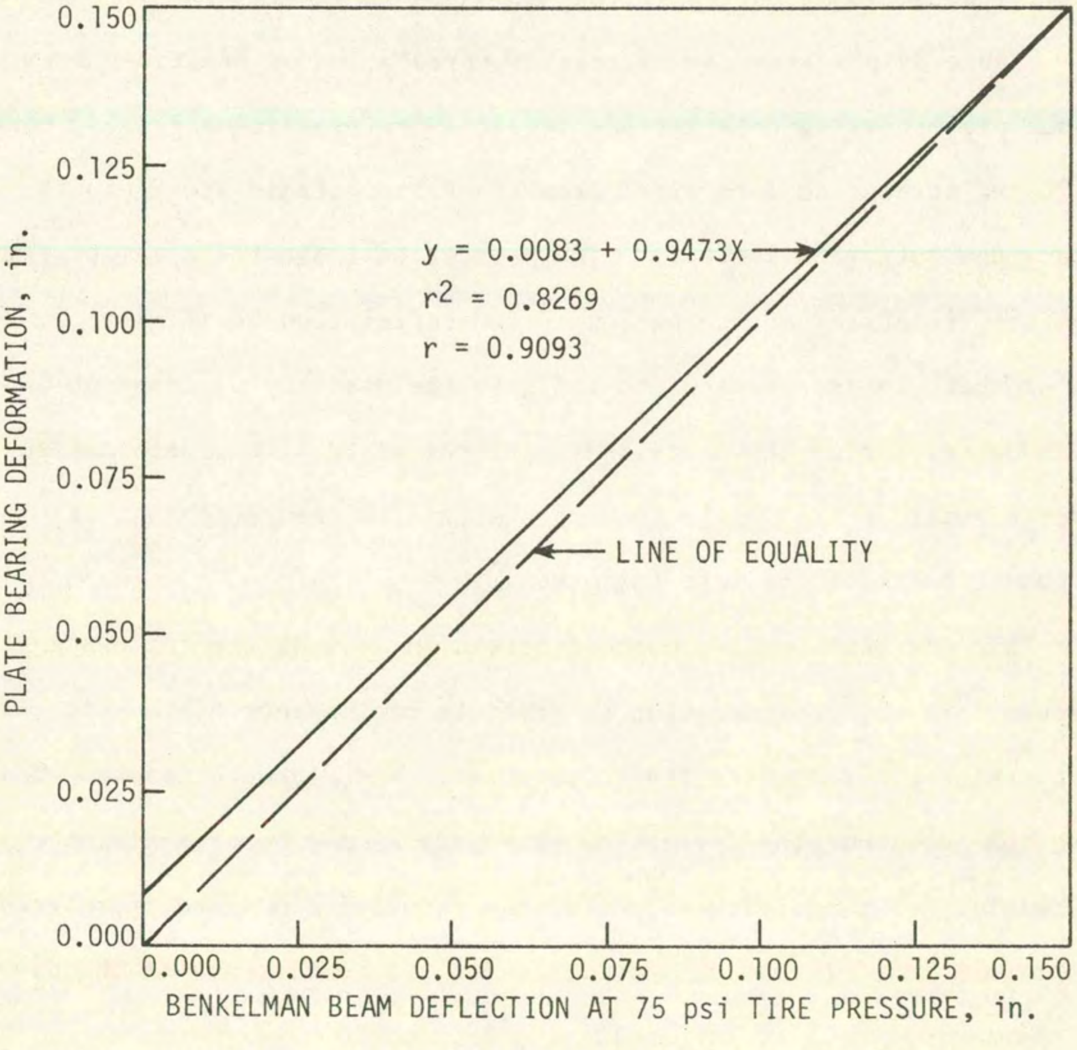

Fig. 39. Correlation of Benkelman beam deflection versus plate bearing deformation at 75 psi.

below was supplied by the respective county or estimated by project research personnel. Each has been projected to cost per mile for the sake of comparison. It should be understood that each item presented is based on costs at time of construction only, and that most equipment, labor, and materials costs have changed since the first sections were constructed in 1979.

Costs of the Pottawattamie County--Mud Hollow cement and fly ash Category 3 section was $35,480/mile. Of this figure, $12,278 represents equipment, $12,575 was labor, and $10,627 was materials. The Pottawattamie County--Honey Creek cement and fly ash Category 3 section HC-1 was $27,295/mile, with equipment costing $4710, labor $8736, and materials $13,849. Honey Creek asphalt emulsion Category 3 section HC-2 was constructed for $62,389/mile which included the remedial construction operation due to moisture content and lack of break of the asphalt emulsion. The cost of section HC-2 without the remedial processing was $55,743/mile. Of the $62,389/mile, equipment was $12,494, labor was $12,061, and materials were $37,834. The Neola Category 3 asphalt emulsion section N-1 was projected to a per mile cost of $50,194, consisting of $6990 equipment, $6028 labor, and $37,176 materials. Neola cement and fly ash Category 3 section N-2 was projected at $32,008/mile, including $10,847 for equipment, $9608 for labor, and $11,553 for materials.

Each Pottawattamie County section was constructed with county equipment utilizing county personnel, with the exception of cement and asphalt emulsion tankers and operators. Mud Hollow was the first cement and fly ash section, while Honey Creek HC-2 was the first emulsified asphalt section to be constructed. As may be noted in the preceding paragraph, after personnel were familiarized with procedures for each process in each of these first sections, equipment and labor costs dropped substantially for the remaining sections.

Construction of the Plymouth County sections was accomplished with a combination of rented equipment and personnel from Brower Const. Co., as well as support services from the county, the latter including such items as a water pump, tanker and operator. Data supplied by the Plymouth County Engineer's office indicated a total cost of about $19,438 for the 5080-ft total length of project. This figure includes about $2000 for county personnel and equipment, the remainder for materials, rented equipment, and personnel. Stabilization materials were $3414, stabilization equipment and operator rental was $5679, and seal coat surfacing including equipment, labor, and materials was $8345.

The stabilization material costs were quite low due to the generous cooperation of suppliers. Thus, a cost estimate between the individual Plymouth County sections becomes difficult. However, if it is assumed that the previously described construction operations were constant for each individual section, an approximation of combined stabilization equipment and operator rental, seal coating, and county equipment and personnel would account for about $16,700/mile/section, not including the cement and fly ash additives. Assuming cement at $60/ton and fly ash at $10/ton, an approximation of additive costs/section/mile would be $11,800 for section PL-1, $10,300 for section PL-2, $6800 for section PL-3, and $2700 for the 0% Portland cement-7% fly ash section. The relative total costs per section might thus be projected as $28,500/mile at 3% PC-13% FA, $27,000/mile at 3% PC-9% FA, $23,500/mile at 2% PC-6% FA, and $19,400/mile at 0% PC-7% FA. Though each of the above are approximations, the 3% PC-13% FA section does not appear too far removed from similar Pottawattamie County sections.

The preceding Category 3 stabilization cost estimates might be viewed in perspective by comparison with a higher type pavement constructed in Linn County in early 1980. This consisted of 5.99 miles of Portland cement concrete 6-in. thick and 24-ft wide. Effective cost per mile was $102,926 including incidentals for finish grading of the subgrade.

The Category 1 Coherex-treated Marion county sections were previously described as being ineffective due to absorptive aggregate. At the time of construction, Coherex was quoted by the supplier at $1.40/gal. Transportation in 55 gal. drums added about $1.20/gal., for an estimated cost of $2.60/gal. at the Marion County site. Cost of Coherex only for this site was thus estimated at about $1100/mile for section 1, and $4940/mile for section 2. Therefore, from only a cost of product versus dust palliation benefit standpoint, Coherex cannot be recommended for further usage with the type of aggregate available in this region.

At the Story County site, cost of Coherex only was estimated at about $3775/mile. Manipulation costs of the modified two-stage Category 1 application was about $4240/mile including both labor and equipment, or a projected total cost of about $8015/mile.

Due to the generous cooperation of several of the product suppliers, costs of the various Franklin County sections can only be estimated.

Projections shown below are thus based on supplier quoted 1979 product prices, quantity of material, dilution and application rates utilized per section, plus estimates of transportation and application charges per product and section. Total costs of the section 1 asphalt emulsion were estimated at about \$850/mile. Ammonium lignosulfonate section 2 would cost about \$2440/mile. Sections 4 and 4A received identical applications of calcium chloride at a cost of about \$1120/mile. Sections 5, 5A, and 8 received identical applications of Coherex at a projected cost per mile of \$5230. The Polybind Acrylic DLR 81-03 section 6 was estimated at about \$1550/mile. Sections 7 and 7A received identical applications of Amsco Res AB 1881 at a projected cost per mile of about \$700.

Cost-benefits of the Category 3 Pottawattamie and Plymouth County demonstration sections cannot be effectively ascertained except with time. Subjectively, these sections should have a service life of at least five or more years before requiring major maintenance. If the five-year value is assumed, costs of this type of construction prorated to an annual basis would range from about \$12,500/mile to less than \$4000/mile/ year. These values might be further reduced if the potential annual aggregate replacement as well as possible dust palliative costs were subtracted therefrom.

In general, the Category 3 cement and fly ash type of construction appears more cost effective than does the use of asphalt emulsion, particularly if consideration is given to the use of Category 3 as an intermediate form of construction, ultimately to be paved with a higher type surface. In addition, each Category 3 section may be considered relatively dust free.

From the standpoint of dust palliative effectiveness, a Category 1 (or modified Category 1 as used in Story County) application of Coherex appears superior to any of the other palliative products utilized in this study, so long as it is not used with absorptive aggregates. However, the present cost of Coherex in Iowa tends to limit its potential usage.

Costs of asphalt emulsions, Polybind Acrylic DLR 81-03 and Amsco Res AB 1881, appear quite satisfactory on a per mile basis for Category 1 palliative usage. However, their effectiveness as dust control agents appears limited, if not questionable.

From a subjective cost-benefit standpoint, the calcium chloride and ammonium lignosulfonate appear favorable. Based on prior research presented within the literature review in a preceding section of this report, however, it appears that further effectiveness of these two products might be obtained if they were initially incorporated with applied surface aggregate or mixed with the in-situ soil-aggregate surfacing.

SUMMARY AND CONCLUSIONS

The study documented herein was implemented as a mission-oriented project designed to quantify and evaluate dust control and surface improvement processes for unpaved roads. In order to accomplish this mission, three levels of processing and treatment were established for comparison with untreated soil aggregate-surfaced roads utilizing only the existing in-place roadway materials: Category 1, surface applied dust palliation; Category 2, mixed-in-place dust palliation and surface improvement, without additional surfacing; and Category 3, mixed-in-place base stabilization with seal coat surfacing.

Demonstration sections were developed in several representative geographic/geologic regions of the state including Plymouth, Pottawattamie, Story, Franklin, and Marion counties. Samples from these, as well as other possible sites, were subjected to laboratory tests including unconfined compression, freeze-thaw durability, Iowa K-Test, and trafficability testing, in both the untreated and treated conditions, as well as under varying forms of curing. The purpose of the laboratory testing was for evaluation of the subject material for potential use in one or more of the three categories of dust control and/or surface improvement processing.

Field studies were initiated in each potential demonstration site for measurement of dustfall within, as well as to the exterior of the ROW. Such measurements were continued following Category 1 applications of selected palliation treatments. In-situ pre- and post-construction tests were conducted within each Category 3 demonstration section, including periodic plate-bearing, Benkelman beam, and moisture-density tests. During Category 3 construction, assistance was provided each county in construction coordination and moisture-density control. Specimens were field molded from each Category 3 mix prior to field compaction and returned to the laboratory for periodic testing of moisture-density and K-Test parameters.

Dustfall testing included both quantity and particle-size distribution versus distance from roadway centerline. Through regression analyses of dustfall data, predictions were developed for quantity of dust at the ROW, as well as distance from roadway centerline at which ambient levels of dusting might be anticipated. Through such analyses, two potential control criteria for dustfall were developed.

Based on comparison of pre- and post-Category 1 treatment applications, dust reduction effectiveness of several palliatives was evaluated. Such evaluations were coupled with estimated costs of each treatment as an approach to respective cost-benefits.

Based on comparison of laboratory tests, pre- and post-construction in-situ tests, and visual examinations, each Category 3 stabilized base demonstration section was evaluated for structural integrity.

The following generalized conclusions are thus founded on the various tests, investigations, and analyses presented within this report:

1) Unconfined compression tests of 2-in. by 2-in. cylindrical specimens can provide an initial method of trial mix suitability of various products for possible use as dust palliatives

and/or surface improvement agents. Such trial mix testing should be followed by more refined testing on selected mixes.

2) Stability of various product and soil mixtures can be evaluated with freeze-thaw durability, trafficability, and the Iowa K-Test. Freeze-thaw elongation provides an indication of climatic stability as well as susceptibility to capillary moisture increases and heave potential. Trafficability tests provide a quantitative measure of waterproofing and resistance to an adverse traffic loading and environmental condition. The Iowa K-Test provides a quick measure of the undrained shear parameters: cohesion c and angle of internal friction ϕ. In addition, the K-Test provides a qualitative measure of rutting potential of a mixture through the lateral stress ratio K and a measure of stress-strain relations through the vertical deformation modulus E_v.

3) Of the products evaluated through the various laboratory tests, only the combined Portland cement and fly ash appeared effective as a Category 3 stabilization process with most soil-aggregate classifications, though optimum quantities of the two products varied with each material. Variation of CSS asphalt emulsion zeta potential exhibited pronounced effects on mixture compatibility and required asphalt content, regardless of consideration of categorical usage. In a similar manner, the laboratory tests indicated categorical usage of ammonium lignosulfonate, Coherex, Polybind Acrylic DLR 81-03,

and Amsco Res AB 1881 varied from negative to potentially effective depending on soil-aggregate type.

4) All demonstration sections, regardless of category level of processing, were constructed with conventional equipment.

5) Utilizing the measurement and analytical techniques described in this study, two recommendations of minimal roadway dustfall criteria were subjectively quantified. First, an ambient level should be achieved within a distance of 100 to 150 ft or less of an unpaved roadway centerline. Second, a quantity of 15 lbs/acre/day/100 vehicles, or less, should be achieved at the ROW. Such criteria should be considered as a reasonable starting point, with possible refinement with time.

6) Effective dust abatement as well as structural improvement may be obtained through Category 3 construction processing of an unpaved road using cement and fly ash or emulsified asphalt.

7) Only limited Category 1 dust palliation and cost effectiveness were obtained with Amsco Res AB 1881, Polybind Acrylic DLR 81-03, and cationic asphalt emulsion. Coherex appeared very effective as a dust palliative so long as it was not used with an absorptive aggregate. However, the cost of Coherex would limit its usage in Iowa. Calcium chloride and ammonium lignosulfonate appeared comparatively cost-effective as dust palliatives. Effectiveness of both the chloride and lignosulfonates might be enhanced if incorporated with a soil-aggregate surface using methods and/or specifications cited in preceding sections of this report.

RECOMMENDATIONS

No Category 2 process was accepted for demonstration section construction. It is recommended that consideration be given to one or more Category 2 trials using the techniques and evaluative procedures described in this report.

As noted in the section on costs, effective cost-benefits of the Category 3 Pottawattamie and Plymouth County demonstration sections can only be determined with time. Each of the nine sections in these counties are recommended for continued in-situ testing and visual evaluation for a period of three to five years from time of construction.

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