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Dust control for secondary limestone roads using bentonite

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Dust control for secondary limestone roads using bentonite

by

Ahmed Mazen Wahbeh

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Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Department: Civil and Construction Engineering
Co-majors: Civil Engineering Materials
Structural Engineering

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INTRODUCTION

Statement of Problem

The majority of roads in the United States of America, approximately 55%, are unpaved. Iowa has the most extensive secondary road network in the nation. Despite the fact that these roads carry fewer than 100 vehicles per day (vpd), they are as important as high-volume roads (Handy et al., 1975). These secondary roads have helped establish Iowa as a major agricultural leader.

The low traffic volume of these secondary roads does not justify paving them. These roads are surfaced with either stream gravel or a crushed limestone aggregate. Because of this, the counties are able to provide a serviceable road at a significant cost savings.

Some major problems, however, exist when a road is surfaced with limestone. One of the most problematic is the dust created from these secondary roads. Dust creates a safety hazard to both passing and oncoming traffic. It is also a definite household nuisance in rural areas, especially in heavily populated regions surrounding larger towns.

In 1971, the Iowa Department of Environmental Quality (IDEQ) established "fugitive dust" regulations for the state of Iowa. Fugitive dust from unpaved roads may average about 75 pounds per day per vehicle mile of travel (VMT) (Hesketh & Cross, 1983) for a standard four-wheel automobile, depending on the amount of clay, moisture and vehicle speed.

Fugitive dust enters the ambient air and either becomes part of it or settles from it onto some surface. Fugitive emissions are directly related to the silt and clay content. Silt and clay are defined as the amount of material passing through a #200 sieve screen. The concentration of silt-sized particles in the air, which was indicated by volumetric air sampling, behind a car moving at 35 mph on a moderately dusty crushed-rock road, was about 100 times the pollution concentration in industrial city air (Hesketh & Cross, 1983).

Previous research sponsored by the Iowa Highway Research Board addressed the "fugitive dust" problem. This work utilized a number of different palliatives and proprietary products through laboratory screening, and demonstration test sections. A common problem encountered is that many additives are good palliatives, but not cost effective. The results of past work indicated that the bulk of "fugitive dust" that is airborne past right-of-way limits is composed of the particulates of silt, clay, and colloidal sized particulates (Hoover et al., 1981).

Since all aggregates exhibit a positively or negatively charged surface, the physical chemistry effects occurring between surfaces of fine particulates and chemical dust palliatives become highly significant. In order for a dust palliative to be effective, it is necessary that the fine particulates be flocculated, aggregated or somehow physically bonded to larger particulates in order to prevent them from becoming airborne under traffic. An effective chemical dust palliative must also provide enough stability of aggregations or binding of particulates to reduce the rate of degradation due to traffic abrasion and thus reduce the maintenance cost.

Surfaces of calcium carbonate or limestone particles are known to be positively charged. It had been postulated that introduction of material of opposite or negative charge might act to bind the small particulates together. Bentonite possesses a negative surface charge which might make it a potential candidate for reduction of dust.

OBJECTIVE

The objective of this research was to investigate the use of bentonite dust palliative for limestone-surfaced secondary roads. The project was essentially a three-phase project consisting of:

A. Laboratory screening of various percentages of bentonite to evaluate their effectiveness as soil stabilizers and dust palliatives

B. Construction of test roads, based on the results of the laboratory phase

C Observations and tests of the various sections performance and serviceability with respect to dust palliation and surface improvement.

The other objective of this research was to compare the effectiveness of the several percentages of bentonite treatment to the chloride treatment with respect to duration, performance, maintenance, and cost.

REVIEW OF LITERATURE

Dust Types and Sources

Fugitive dust particles are produced by mechanical disturbances of granular substances that are exposed to air. This disturbance can be caused by air moving at a velocity of 12 mph or more (Hesketh & Cross, 1983), or by pulverization and abrasion by some mechanical force. The main sources of dust are:

1. Unpaved roads
2. Agricultural tilling operations
3. Aggregate storage piles
4. Mining, excavating and crushing operations
5. Industrial processing and transfer operations
6. Heavy construction operations
7. Others, such as bare soil, unsealed landfills and evaporation of salt springs

Dust is generated by vehicles travelling on unpaved roads. The vehicle lifts and throws these particles into air by the rotation of the wheels. The turbulent air current under the vehicle and the eddy currents cause the fine particles to be suspended in air (Hesketh & Cross, 1983).

Environmental Effects of Dust

In addition to the direct affect of dust on human health, dust may alter the environment in many ways that can impact human health.

Fine particulates play an important role not only in air pollution, but also in long-term impacts on the acidity of fresh water bodies and soils. Dust also significantly affects light transmission characteristics (United Nations, 1979).

Location and Occurrence of Bentonite

Bentonite has been found in western Canada, Alaska, China and France. In the United States, bentonite has been reported in every state west of the Missouri River and other southern and eastern states. The western states contain much bentonite material due to the volcanic debris that has contributed material to the sedimentary beds over wide areas of these western states (Grim & Guven, 1978). Bentonite has been found in the Paleozoic and Mesozoic beds; however, it's most abundant in the Tertiary. Bentonite is also often found associated with marine beds. These marine formations may be comprised of glauconitic sand, limestone, shales or calcareous fossiliferous sands and marls. There are also some clays that can be classed as bentonite due to their composition and properties. These are found in formations ranging in age from Upper Paleozoic to Pleistocene age or possibly Recent (Slaughter & Early, 1965).

The superficial physical properties of bentonite makes it an extremely variable material. The most common colors of bentonite are pale buff, green, cream, dull green, gray, dull blue or pink. Some bentonites are open and porous, and some have a very loose feltlike texture. Others are very compact and have sharp conchoidal features. The texture of the formed bentonite is often modified by the composition of material that was carried in solution. For instance, small bread-like grains of calcium or iron carbonate are often seen, and in some deposits, calcium carbonate has completely filled the pores and produced a dense rock (Ross & Shannon, 1926).

From a study of thin sections of bentonites (Clay Minerals Society, 1968), two outstanding features were revealed:

1. Bentonite is derived from volcanic ash.
2. The characteristic mineral is crystalline.

The ash structure is preserved in a large proportion of the sections. The most abundant shapes are the flattened plates that are derived from elongated and lens-shaped bubbles. Therefore, all the types of structures that occur in glassy volcanic ash are represented in bentonite (Clay Minerals Society, 1968).

Bentonite is one of the subgroups of clay. The sodium montmorillonite - semectite (Bentonite) has the largest potential for expansion because of the extremely fine grain size and because the crystal lattice is not in the direction perpendicular to the interlayers. The other extreme subgroup is kaolinite, whose crystal lattice consists of basic unit sheet with little substitution in the lattice. Kaolinite contains bases as impurities or adsorbed material, has a reversible volume change on wetting and drying, and does not swell irreversibly. Illite has intermediate properties between montmorillonite and kaolinite. It has a higher adsorption capacity than kaolinite because it contains unit sheets suitable for replacement (Grim & Guven, 1978).

Smectites form the major mineralogical component in bentonites. Members of the montmorillonite-beidellite series are by far the common smectites in bentonites (Grim & Guven, 1978).

Microscopic examination shows that the characteristic mineral of bentonite is crystalline (Ross & Shannon, 1926). In most types of bentonite, the crystal plates stand perpendicular to the original surface of the glass fragment; the crystalline area being composed of two parallel rows of micaceous plates. The crystalline areas in bentonite show a positive and negative character of elongation.

Clay platelets, such as bentonite, form a flocculated structure, often described as a "house of cards", controlled largely by electrostatic forces. This is particularly marked in kaolinite, the platelets of which carry a negative charge on the flat surface of the crystallite but a positive charge around the edges. Therefore, edge-to-face attractions stabilize the structure. If this structure is broken down, by any pressure application, the platelets adopt a parallel arrangement of greater density whose properties are controlled by the electrostatic repulsion between parallel charged surfaces. When the positive charge on the edges decreases, the edge-to-face interactions weaken, and the "house of cards" collapses to form parallel configurations (Everett, 1988).

Based on several investigations, the data on extractable cations indicate that sodium (Na) and calcium (Ca) are the most common interlayer cations in bentonite (Grim & Guven, 1978).

Production of Limestone

Limestone is the most common sedimentary rock and is composed of calcium carbonate. Limestone rock is often one of high purity, with a calcium carbonate content of over 95%, and not uncommonly 99% (Trudgill, 1985). The initial stage of the production is the mining of the limestone. This is accomplished by either strip mining or underground mining. The stone is then transported to the crushers or screens by means of conveyor belts. The large rocks are then crushed to smaller sizes. The crushed aggregate undergoes a washing stage to reduce the amount of silt or clay in some stones. The next step is screening for suitable particle size. Finally, the stone is stockpiled for future use or transported to the road surface where it is placed (Kirby & Lowe, 1975).

Properties of Limestone

Limestone has numerous varieties of forms, types and purities. However, the principle mineral in limestone is calcite which is the stable form of calcium carbonate at ordinary temperatures.

Physical properties

Color of the pure form of calcite is white. Conventional limestone in its pure state is gray or tan; the grays being caused by carbonaceous impurities, while the presence of iron influences the tannish color. The presence of other impurities, such as pyrite, marcasite, and siderite may alter the surface color on oxidation through weathering (Boynton, 1980).

The texture of limestone is crystalline. However, the size, uniformity, and arrangement of its crystalline structure or mineral grains vary greatly, forming stone of divergent density and hardness. The bulk density of limestone ranges between about 125 and 175 pounds per cubic foot (pcf). Specific gravity of most commercial limestone has a range in values of 2.65 to 2.75. Strength of limestone varies depending on the impurities, though compressive strength generally ranges between 1200 and 28400 psi. Shear strength values range between 600 to 3000 psi. (Boynton, 1980).

Chemical properties

High calcium limestones are among the most chemically stable substances. Decomposition never occurs at ordinary temperatures. High calcium limestone dissolves in most strong acids readily, accompanied by the liberation of CO_2 gas from the stone (Boynton, 1980).

Limestone is virtually insoluble in pure distilled water and in a CO_2 free atmosphere. However, with increasing partial pressures of CO_2 solubility of limestone might be characterized as soluble. Therefore, as the percentage of CO_2 in the atmosphere increases, the solubility of calcite in water increases (Boynton, 1980).

Construction of Crushed Stone Roads

Crushed limestone aggregate has been used for many years as a successful granular surfacing material (Federal Highway Administration, 1976). A full-width placement of the stone is used when constructing limestone surfaced roads. These surfaces are excellent for those roads which do not warrant a paved bituminous or portland cement surface (McMahon, 1976).

Most crushed limestone surfaced roads are constructed using a phase construction program. Phased construction is used due to economics and to fix weak spots that may develop after the initial application (Kirby and Lowe, 1975).

The material can be applied to the surface in two ways. One way is to apply the material by using spreaders, rollers and leveling equipment. The most popular method of applying the material is using dump truck and road graders. The stone is spread over the road surface by tailgate dumping. Road graders are then used to spread and level the crushed stone over the road surface (McMahon, 1976).

The most important characteristics of the surfacing material are: the grading of the particles, and the binding properties of the material passing the #40 sieve (Spangler and Handy, 1982). The ratio of the fraction passing the #200 sieve to that passing the #40 sieve should be less than 2/3. This ratio is known as the dust ratio (Spangler and Handy, 1982).

There are some other important factors that affect the construction of unpaved roads such as the climate, the thickness of aggregate surface, aggregate density, and the subgrade density.

Maintenance and Performance for Unpaved Roads

In many regions in the United States, unpaved roads account for a major portion of the maintenance budget. The financial and operational management of this maintenance has been informal and has largely been based on historical precedent (Visser and Curtayne, 1987). In the past years, the maintenance schedule was based on experience and judgment.

In order to develop a Maintenance and Design System (MDS) program, a suite of three programs is analyzed. The first is the physical properties of the road material. Second is the traffic count of the road. Third is the analysis of the amount of deterioration (Visser & Curtayne, 1987).

The MDS method was developed to determine the blading, resurfacing, and upgrading needs of unpaved roads based on economic criteria (Visser and Curtayne, 1987). While this method may have some shortcomings, it does provide a quantifiable method of looking at the maintenance needs of crushed limestone roads.

Paige-Green and Netterberg (1987) state that an ideal unpaved road should have the following attributes.

1. be able to provide an acceptably smooth and safe ride.
2. have stability, in both wet and dry periods.
3. be able to remove excess water from the surface without excessive erosion or scouring.
4. be able to stand up to the abrasive nature of traffic.
5. be able to hold dust to minimum in dry weather.

6. have a surface that is not excessively slippery in wet weather.
7. have a surface that will not cause excessive tire wear.

Some of these factors can be achieved by selecting the proper surface material and drainage design. However, dust generated from unpaved limestone roads is a major nuisance problem to the residents that live near the road.

The concern over the dust problem that is generated from secondary roads resulted in a "fugitive dust" regulation for the state of Iowa. Many studies are in progress to address this problem.

Hoover et al. (1973) collected dust samples from stationary samplers placed at intervals along the sides of several unpaved roads. Calculations from their results indicated a production of 28 tons of dust per mile, assuming 100 vehicles per day (within the right of way). An additional 28 tons of dust per year was generated from the right of way line to points 150 feet on either side of the centerlines. Between 150 feet and 500 feet on either side of the centerlines, 44 tons were generated per year. This report stated that for every vehicle traveling one mile of unpaved road, once a day, every day of the year, one ton of dust is deposited along a 1000 foot wide corridor. The calculations from this report indicated 100 tons of road material per year per mile is lost from dust generation, assuming a traffic count of 100 vpd (Hoover et al., 1973).

Calcium chloride is the most common dust palliative used. The mechanism of palliation is based on the fact that calcium chloride absorbs the free moisture in the air. This added moisture then allows the material to be compacted into the surface crust.

Sultan (1976) conducted tests on 46 commercial chemicals for dust control. The selected chemical treatments were subjected to various environmental durability conditions, including freeze-thaw cycles, wet-dry cycles, rain-dry cycles, and various curing temperatures. This study was conducted to evaluate the degree of stabilization effected by spraying the chemicals on a compacted road surface subjected to the abrasive action of traffic. The results of this study showed that chemicals with a lignin sulfonate base provided the best performance in the traffic abrasion test (Sultan, 1976).

Another form of creating a dustless road surface is by using bitumen as a binder. Dougherty (1954) conducted a study on bitumen as a dust reducer and found that bitumen not only reduced the amount of dust generated but also improved the rideablity of the surface. Dougherty tested nine sections that were built with different surface gradations and differing binders and concluded that bitumen perform exceptionally well as a dust palliative.

Another method for dust control is watering. The proper maintenance and management of water help to control dust. The roads should be maintained in periods of wet weather so the traffic will be able to compact the surface material into crust (Roads and Streets, 1974).

Surfacing material gradation also has an influence on the amount of dust generated. The addition of fines to the gradation will allow the formation of the surface crust (Moore and Easley, 1971). The denser the crust, the less dust will be generated.

Mechanism of Dust Control

As we have seen from the previous research, the two primary applications of dust control agents are:

- surface or topically applied spray

- mixed-in-place method

The mixed-in-place method tends to have a longer durable term than the topically applied method; however, the mixed-in-place method is more expensive (Hoover, 1986).

Dust can be formed by either degradation of aggregate or a lack of stability of flocculations of silt, clay, and colloidal size particulates. The degradation of aggregate is normally generated by the travelling vehicles which cause these fine particles to become airborne. Therefore, for a dust palliative to be effective, it should provide a stable flocculation of fine particulates. For instance, water is known to provide a particulate flocculation through capillary cohesion (Hoover, 1986).

Calcium chloride and lignosulfonates use the surface tension mechanism in reducing dust. The mechanism utilizes absorbed moisture from the air which results in a change in capillary tensile force. The service life of such products are normally short. Chlorides products also tend to affect vegetation by penetrating to the groundwater (Hoover, 1986).

Some palliative agents have the tendency to concentrate in air-water interfaces which modifies the dipolar attractions of the water molecules and therefore changes the tension force of the surface, or capillary cohesion. When the surface tension is decreased, the fine particulates tend to disperse and flocculate with such an action. However, when the surface tension is increased, the fine particulates flocculate and therefore resist becoming airborne.

The mechanism of dust control for a chemical stabilizer depends on the physico—chemical properties. Since most fine grained particulates have a net negative charge, the addition of positive charges by the stabilizer agent would cause the fine particles to flocculate and bond electrostatically. This electrostatic force depends on the physico—chemical properties of both the stabilizing agent and the soil particles. This principle also is used in some salts, polymeric compounds, and emulsified asphalts (Hoover, 1986).

The spray-on application of polymeric compounds, emulsified plastics, and emulsified rubber-like compounds depends on (1) compatibility of the physico—chemical properties of both product and soil particles, and (2) the density of the surface of the application to which the product is applied. When the surface is dense, the penetration of the product will be minimal; therefore, the effect of the product will be minimal as well. However, when the surface is porous or the soil is of a single-grained structure, the product tends to penetrate and form a root-like matrix (Hoover, 1986).

In summary, airborne particles are mainly formed from silt, clay and colloidal-sized particles. These particles cause environmental hazards for health as well as traffic. Therefore, the spray-on, or mixed-in-place methods of dust control depends on the following factors:

- The relationship between time constraints and the permanency of control
- The construction and maintenance activities
- The nature of the soil densification or porous surface to which applied
- The compatibility between the soil and products in relation to physico—chemical and electrostatic properties.

The primary function of a dust control agent is to provide a stable flocculation and/or aggregation of the silt, clay and colloidal sized particles (Hoover, 1986).

Mechanism of bentonite and limestone

The mechanism of bentonite as a dust-reducing agent depends on the surface charges of both calcium carbonate (Limestone) and bentonite. From the previous literature review it was noted that platelets of bentonite have positive charges at the edges and negative charges on the flat surfaces. Similarly limestone has a positive (Ca++) surface charge in the presence of water. This make the surfaces of bentonite and limestone of opposite charges, which make them bonding together electrostatically, and therefore reducing dust. Not only does the bentonite bond to larger particles, but also the fine crushed limestone particles bond to bentonite, due to the oppositely charged surfaces; the aggolomonates thus reducing dust. One of the most important factors that determines whether a good bond will be obtained in a mix of aggregate limestone and bentonite is the nature of the surface properties of limestone and bentonite.

The bentonite plate units swell when in water and carry a net negative charge which is the result of an insufficient concentration of hydrated sodium ions in the diffuse electric double layer to neutralize counter ions adsorbed on the plate unit. Such negatively charged individual units develop Brownian movement and remain suspended in a dispersed medium (Hoiberg, 1965). On the other hand, limestones bear a positive surface charge in the presence of water. The composition of limestone would explain the surface charges. When a particle of limestone is fractured, electrostatic chemical bonds are broken, and unsatisfied chemical charges occur on the new surfaces that are formed. When the electrostatic bonds are broken, an equal number of unsatisfied electrostatic charges of calcium and carbonate ions results. The fractured aggregate forms two types of aggregates. These unsatisfied charges from the fractured aggregate become neutralized with water. The surface of one type of the fractured particle tends to adsorb carbon dioxide dissolved in water. Surface water quickly adsorbs carbon dioxide from the atmosphere. The structure Agg $Ca\text{-}Co_3H$ tends to dissociate in the presence of water in the following manner:

Agg $CaCo_3$ H = Agg Ca+ + HCO_3

As a result, the aggregate surface is elecropositive (Hoiberg, 1965). This process develops the bonding between the bentonite and limestone due to the opposite surface charges between both materials. This bond is strong in the presence of water which develops a bonded matrix. When the mixture dries the bonds remain between the surfaces. However, when the bonds are broken due to traffic it appears that these bonds may be recoverable. It can be reasoned that the water on the surfaces is not fully dried. There is a thin film of water on the particulates which needs a high temperature in order for it to dry; therefore, the surface charge for both materials remain opposite and they are capable of bonding again.

Scanning electron microscopy and X-ray dot mapping of treated materials with bentonite revealed the following (Orenn et al., 1985):

1. Fine dust particles were preferentially bonded to larger particles rather than each other.
2. Interparticle bonding was created between larger particles.

The result of this work indicated that bentonite treatment might have the potential for functioning as an effective dust palliative and stabilization agent for limestone-surfaced secondary roads (Orenn et al., 1985). Using bentonite as a soil stabilizer and dust palliative was investigated by laboratory evaluation and field trials.

PRELIMINARY LABORATORY EVALUATION

In order to investigate the possibility of using bentonite as a stabilizing agent, preliminary laboratory work considered two immediate areas of concern: (1) bentonite treatment effectiveness under mechanical degradation, and (2) strength and stability properties of the treated materials under submerged and air cured conditions.

Mechanical degradation

One of the prime problems of limestone surfaced secondary roads is the continual traffic abrasion and degradation of the larger particles. The larger particles are eventually reduced to fine materials that become airborne "fugitive dust." An effective dust palliative must be capable of cementing or bonding the fine fraction into particulate agglomerates that resist degradation.

Preliminary tests were conducted to evaluate the potential strength of the interparticle physico—chemical bonding of bentonite to limestone. Alden limestone aggregate was crushed and separated into various size fractions. Then the crushed material was recombined into a grading which met Iowa Department of Transportation gradation limits for Class A crushed stone surfacing material.

Several 5.3-pound samples of graded aggregate were treated with varying concentrations of bentonite solutions dispersed with sodium carbonate. Sodium carbonate (soda ash) is the salt of a weak acid. When sodium carbonate is added to water the following reaction happens:

$$Na_2Co_3 \quad + \quad H_2O \quad = \quad 2Na^+ \; + \quad Co_3^{--} \; + \quad H_2O$$

Sodium carbonate has the direct ability to disintegrate (or disperse) substances such as bentonite into particles of colloidal size and disperse them for a period of time (Glasstone & Lewis, 1976). The mechanism of sodium carbonate depends on the colloidal chemistry of the material. This can be easily explained with a common substance such as salt in water; the particle of solute distributed in the solvent consists essentially of single molecules or ions. On the other hand, a suspension contains particles that are large enough to be seen by the naked eye. Between these two extremes are to be found the colloidal dispersions. It is obviously impossible to distinguish between colloidal dispersions and suspensions. However, there is a gradual transition from one type to the other. The upper and lower limit of particles in the colloidal state are 0.2 *m* and 0.5 m*m*, respectively. Since bentonite particles fall in that range, sodium carbonate is considered a good dispersion agent (Orenn et al., 1985).

Samples of limestone, meeting class A gradation requirements, were prepared and tested using various concentrations of bentonite solutions with sodium carbonate. Testing of the air-dried treated and untreated samples were conducted using ceramic balls as the degradation medium. The ball mill was operated for a period of 1 hour. Figure 1 shows the results of limestone treatment using 10% solution of bentonite in water. The application rate was 1/2 pounds of solution per square yard. What is highly significant is that the minus #200 size fraction was significantly reduced from 24% to 5% of the total sample as shown in Figure 1. What is further significant is that the amount retained on each size fraction above the #200 sieve, for the treated materials, increased up through the #4 sieve. The preliminary results indicate that the physico—chemical bonding of the fine particles into agglomerates and to larger particles is a durable bond and appears capable of resisting mechanical degradation.

Strength properties

Preliminary testing of bentonite treated limestone fines was conducted to evaluate submerged and air-cured strength. The limestone fines were waste limestone screenings obtained from Iowa Limestone Company in Alden, Iowa.

One-inch square cubes were prepared and tested with and without bentonite treatment. Cubes were air-cured and tested at 7 days of age. Four tests were made at each treatment level. Figure 2 presents the results. The bentonite treated air-cured samples exhibited at least a doubling of compressive strength (unconfined compression strength test) at the 2% and 4% treatment levels. This increase may be due to the mechanism of bentonite acting to form strong physico—chemical bonding among the particles and to the larger particles. All submerged samples, treated and untreated, slaked (qualitatively determined when the sample lost its cubical configuration) within the one hour prior to testing time. It is significant to note that the bentonite treated sample, at a 4% treatment level, took 55 minutes to slake versus 10 minutes for the untreated material. This again indicates the significance of the physico—chemical bonding of particulates being imparted by the bentonite.

Recommendation

Based on laboratory test results, field trials were recommended in order to verify the function of bentonite as a dust palliative agent.

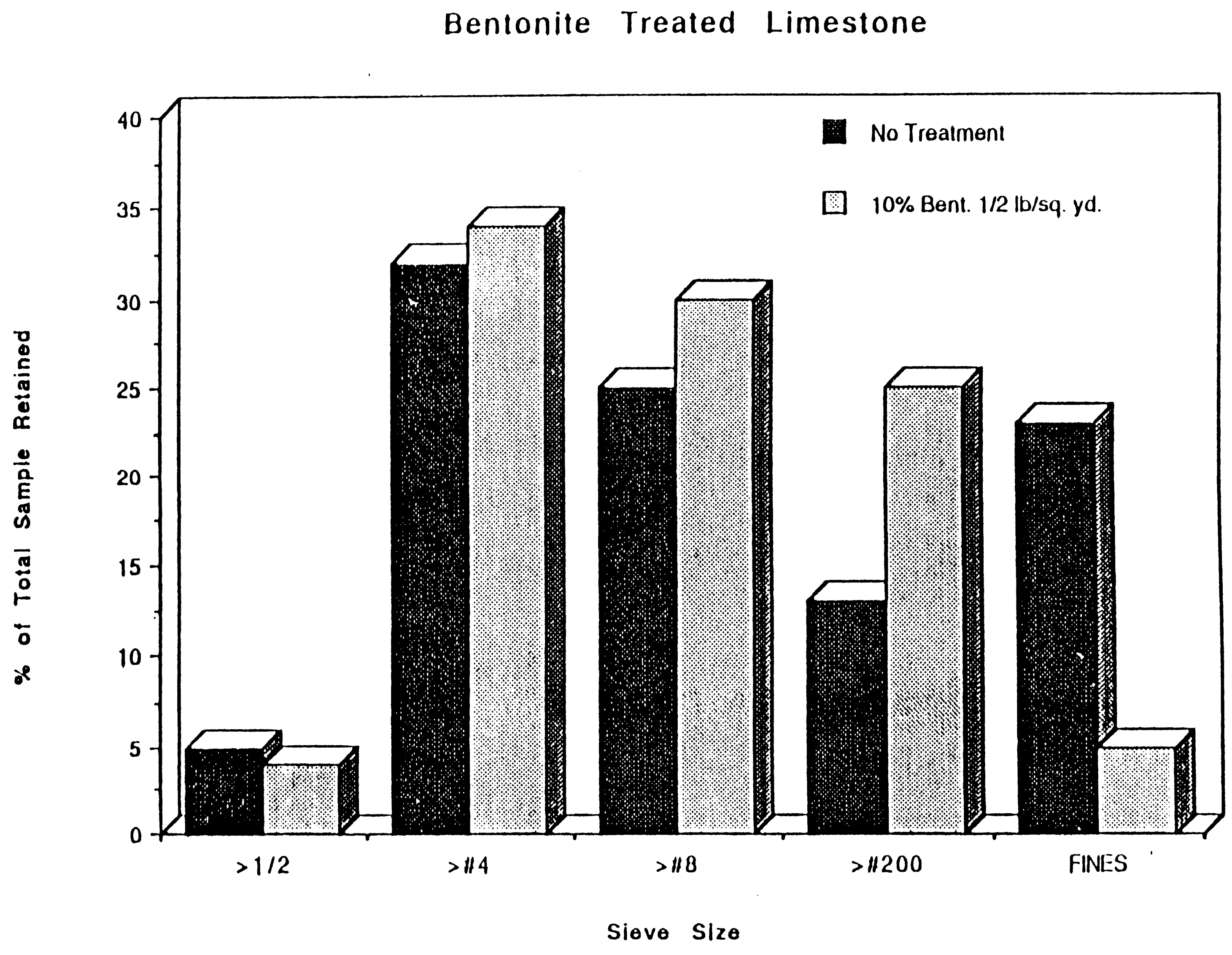


Figure 1. Sieve analysis results of treated and untreated Alden aggregate

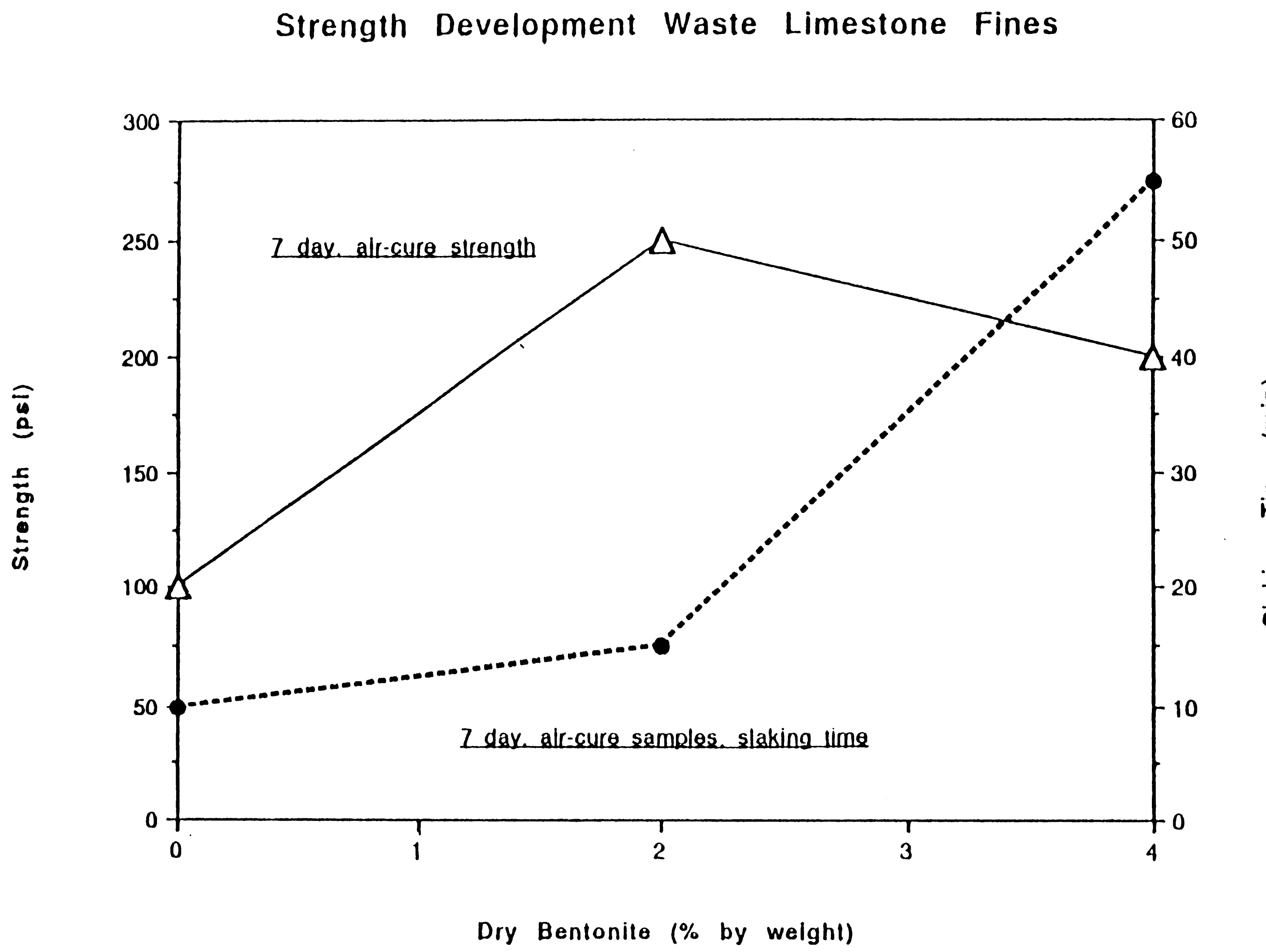


Figure 2. Compressive strength development, Bentonite treated limestone screenings

TEST ROADS SELECTION

Based on crushed limestone surfacing materials source data, and proximity to Ames, 26 counties were solicited by letter for interest in project participation. These counties are shown in Figure 3. After receiving the responses and evaluating the location, six counties were selected for field inspection based on location and proximity to Ames. These counties are:

- Tama County
- Marion County
- Poweshiek County
- Adair County
- Dallas County
- Clarke County

The locations where field inspection of test road candidates was conducted are shown in Figure 4.

Test road evaluation and selection considered the following factors.

- Road topography-Flat
- Traffic count-70 to 100 vpd
- Subgrade soil type-uniform
- Surfacing material source-Close to project
- Distance from Ames-Close to Ames
- County equipment-type and availability

Based on field observations, and discussions with the county engineers, one road was selected in Dallas County in the early stage of the project and another road in Adair County for the final stage of the project. The Dallas county road is part of secondary road R—30 running southeasterly from Woodward and intersecting Iowa Highway 141 near Granger. Figures 5 and 6 show the location and the traffic count of the test road. The Adair county road is located south of I-80 near Stuart, intersects Adair county P-28, and runs east from the intersection with P-28, parallel to I-80. Figures 7 and 8 show the location and the traffic count of the road.

Both roads were selected because they had relatively flat topography with few bordering trees that might interfere dust collection data. Both roads had a relatively uniform cross section, were well ditched, and had positive drainage. The distances are relatively short between Ames and the Dallas county road (approximately 25 miles) and the Adair County road (60 miles). Traffic counts from IDOT 1984 data for the Dallas County road, Figure 6, indicated 75 vehicles per day (vpd), while Adair County traffic counts given on IDOT 1988 Figure 10, indicate an average of 80 vpd. Both roads were surfaced with crushed limestone. Due to limited number of test roads available, it was not possible to control subgrade soil type although it can be an important factor. The equipment factor was essential because the county supplied the equipment and personnel needed to construct the roads.

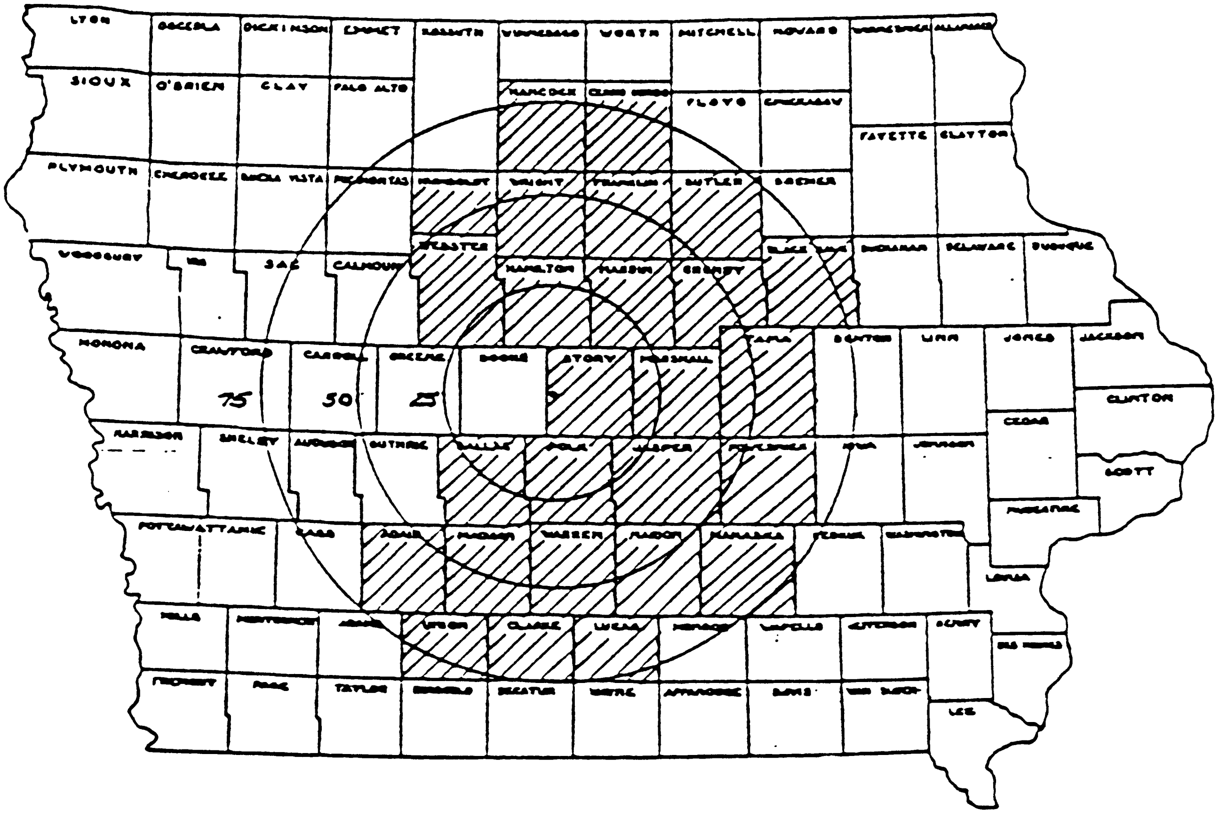


Figure 3. Counties solicited for project participation

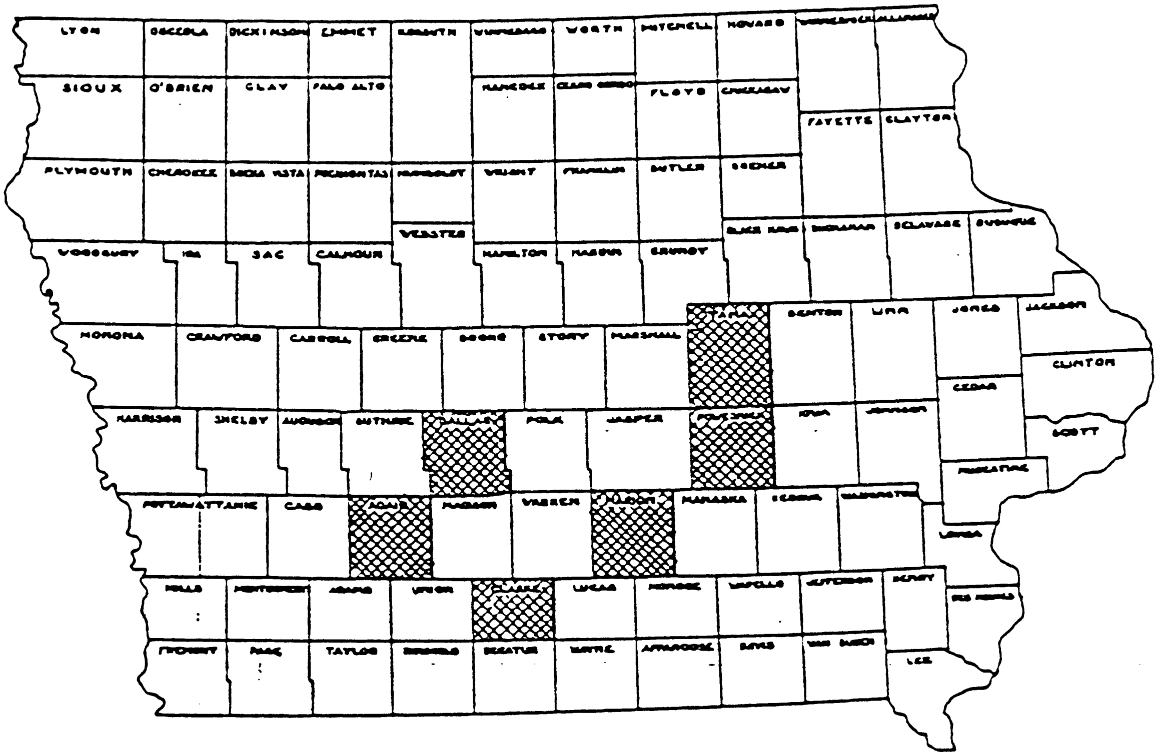


Figure 4. Counties selected for field inspection of test road candidates

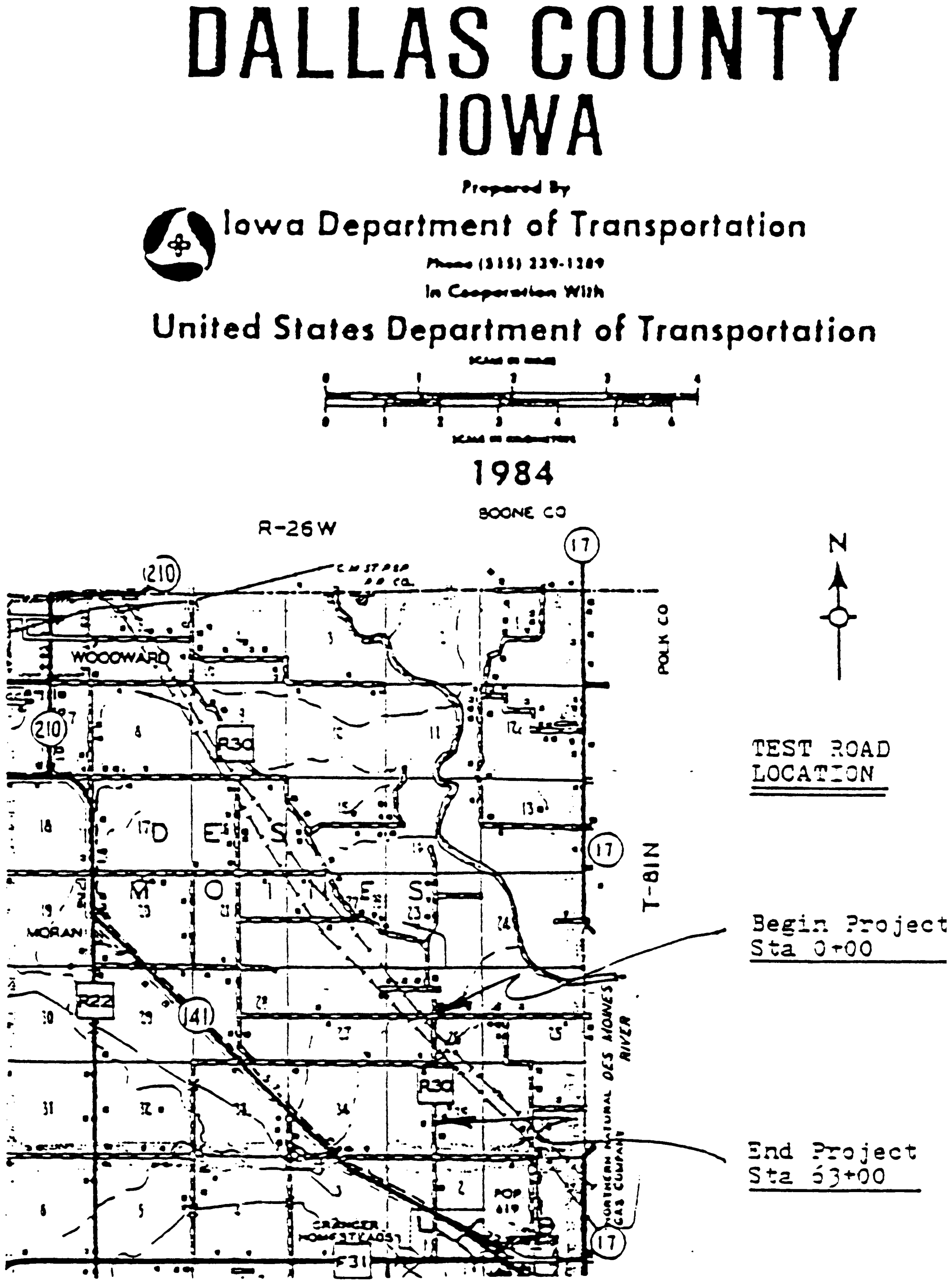


Figure 5. Dallas County test road location

DALLAS COUNTY
IOWA

Prepared By

Iowa Department of Transportation

Phone (515) 239-1289

In Cooperation With

United States Department of Transportation

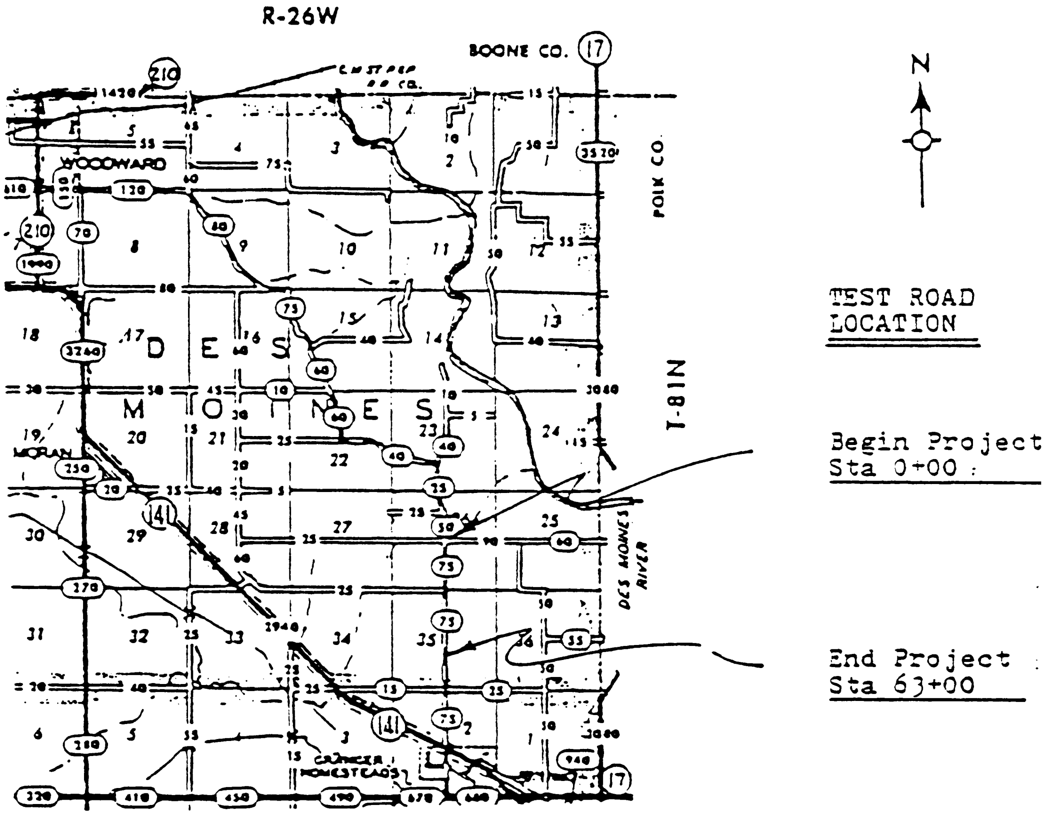
SCALE IN MILES

0 1 2 3 4

0 1 2 3 4 5 6

SCALE IN KILOMETERS

1984



TEST ROAD LOCATION

Begin Project Sta 0+00

End Project Sta 63+00

Figure 6. IDOT 1984 traffic data for Dallas County test road

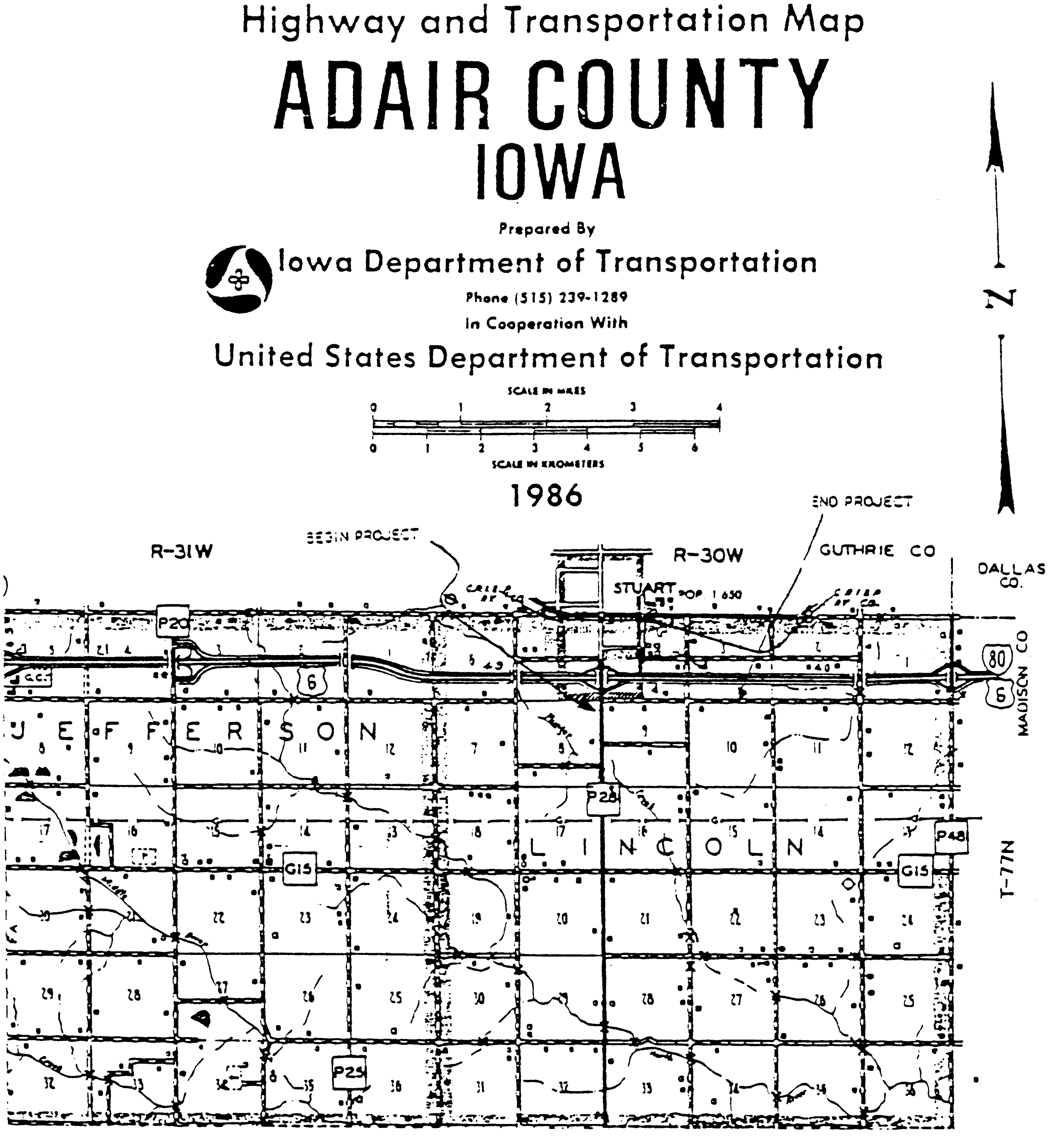


Figure 7. Adair County test road location

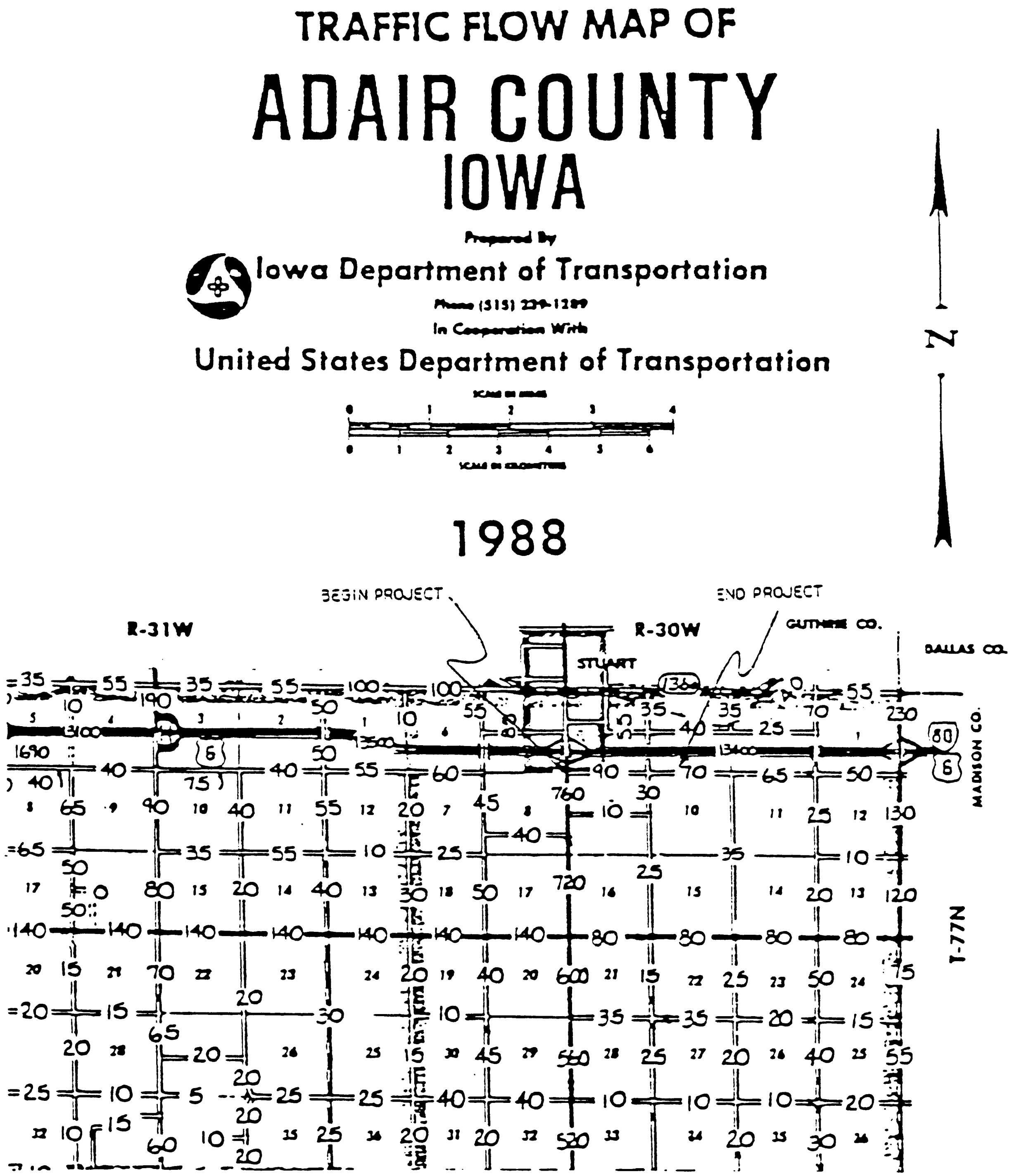


Figure 8. IDOT 1986 traffic data for Adair County test road

TEST ROAD CONSTRUCTION

Two methods were used in constructing the bentonite treated sections. These two methods were (1) mixing of a bentonite, water and soda ash slurry which was then spray applied to the loose material, and (2) the dry blade mixing of bentonite with limestone and then spray application of water and soda ash until the material was fully saturated.

Dallas County Road Construction

The construction of this road was completed in October of 1987. The test road consisted of six sections. Figure 9 shows the "as constructed" layout of the road. The untreated section was the control section against which the effectiveness of the bentonite and chloride treatments were compared.

Materials

Iowa Limestone Company of Alden, Iowa, supplied bentonite for the project. Dallas county personnel picked up the bentonite and delivered it to the project site. The sodium carbonate dispersing agent was obtained for the project from Chemserve Corporation, Detroit, Michigan. The calcium and magnesium chloride materials were delivered by Laverty Supply, Inc., to the job site.

Equipment

Two motor graders and operators, and a dump truck for the bentonite were supplied by Dallas county. Two truck-mounted spray distributors were provided by Laverty Supply. The distributors were each equipped with a 200-gal/min centrifugal circulating pump and had a capacity of 2500 gallons. The center spray bar was eight feet long and equipped with eight #65 spray nozzles. Six-foot hydraulic spray bars on each side (with six nozzles) allowed a spraying width selection of 8, 14, or 20 feet.

Chloride section construction

Both the calcium and magnesium chloride treated sections used the same construction procedures. All loose surfacing material was tight bladed into a windrow along one side of the road. This material remained there throughout the test period. The calcium and magnesium chloride solutions were then spray applied to the tight bladed surface crust in one pass using a 20-foot spray width. The magnesium chloride solution (32%) was applied at 0.76 gal/linear foot, over a 20-foot width. This yielded 800 gallons of magnesium chloride solution for the 1050-foot test section. The calcium chloride solution (39%) was also applied at 800 gallons for the 1050-foot test section. The surface penetration of both chloride treatments was very small.

Bentonite section construction

The recommended field trial of bentonite slurry spray application was a 7.5% solution by weight by Laverty Supply personnel. This percent was obtained after experimenting with various percentages ranging from 5 to 10 percent.

The first step for construction was to tight blade all the loose surfacing material and windrow it to one side. Then several cross-sectional measurements were made of the windrow to estimate the amount of aggregate to be treated. Average of this data indicated approximately 190 tons/mile of loose surfacing

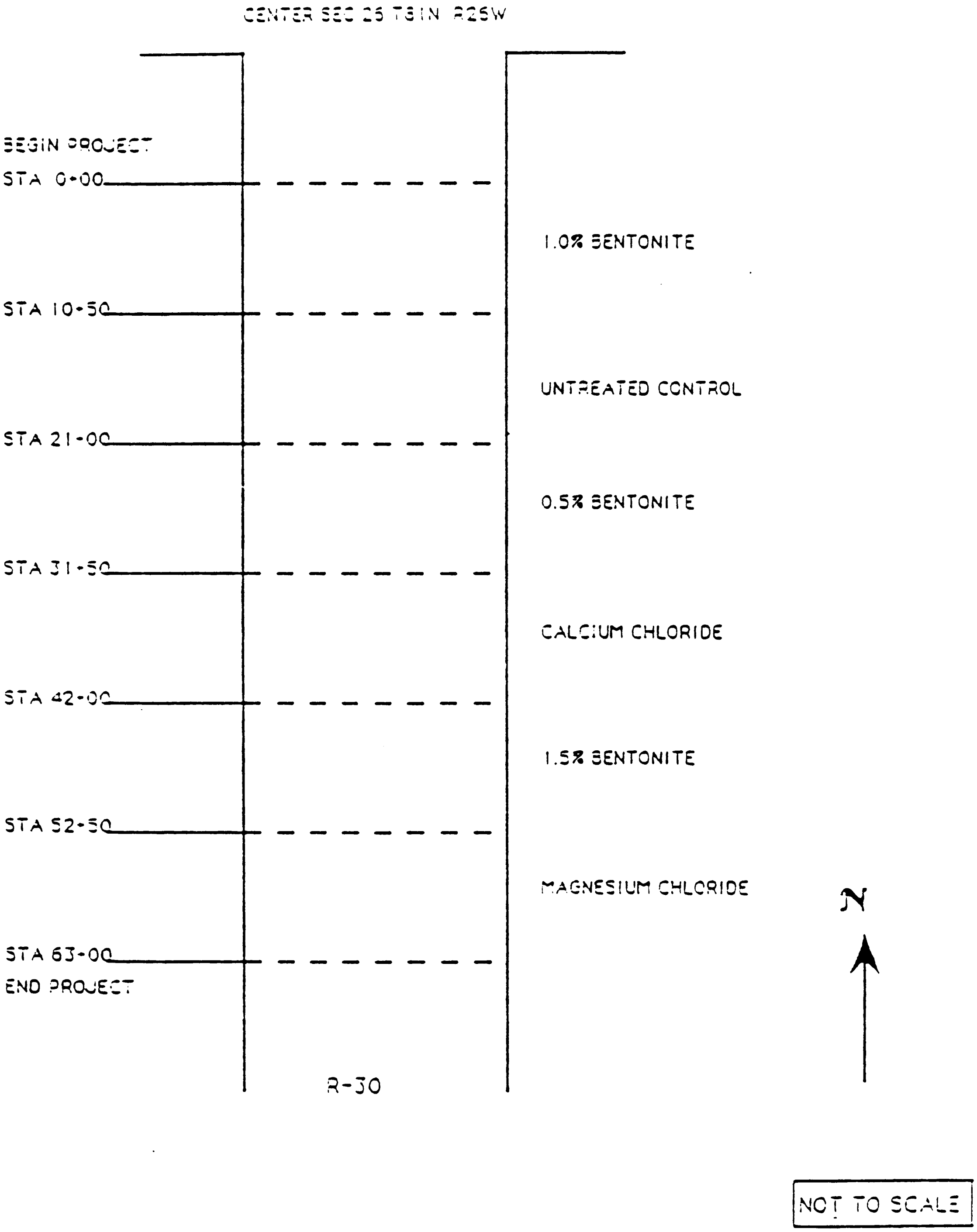


Figure 9. Dallas County test road layout, as constructed

materials. For each 1050-foot section, about 75,000 lbs. of aggregate required treatment. The next step was mixing the bentonite solution in the distributors in 1250-gallon batches at a 7.5% bentonite/soda ash solution concentration. The batch formula used 1250 gallons of water, 50 lbs. of soda ash and 750 lbs. of Bentonite. Field mixing was accomplished by connecting a 3" diameter hose to the back of the distributor which was then discharged into the top access port. The 50 lbs. of soda ash was slowly added by hand, pouring directly into the discharge stream and allowing it to circulate approximately 10 minutes. Fifty-pound bags of bentonite were then slowly added to the discharge stream until 750 lbs. had been incorporated. This was then allowed to circulate and mix for an additional 30 minutes. The next stage was spreading out the windrow to an approximate 8-foot width on half of the road. The distributor, using the center eight-foot spray bar, applied about 300 gallons (1/4 of solution) in the first pass. Immediately behind the distributor, one patrol bladed the treated aggregate to the center of the road. The second following patrol spread the windrow to an eight-foot width on the opposite side of the road. The distributor then applied another 300 gallons and the process continued until the required amount of solution had been incorporated with the surfacing. Final blade mixing was accomplished with two passes of both patrols. One final pass was made to spread the material over the surface for traffic compaction. The thickness of bentonite treatment was very close to the maximum size of the surface aggregate of 3/4 inch.

The 1.0% (by dry weight of aggregate) bentonite treated section required 2500 gallons of the 7.5% bentonite/soda ash solution. The treated material was damp to wet. In order to obtain a 3.0% applied bentonite treatment, the material would have been too wet; therefore, it was decided to apply only 0.5% and 1.5%.

Construction was completed on that basis. Test samples were collected before and during construction for laboratory testing.

Adair County Road Construction

Construction on the Adair County road started in the middle of July, 1989, after several meetings with the county engineer.

In order to obtain higher percentages of bentonite treatment, the dry mix method was used in constructing the Adair County road. Both calcium chloride treated sections were constructed by the residents living next to these sections and were incorporated into the project. Figure 10 shows the "as constructed" layout of the Adair County road.

Bentonite section construction

Prior to construction, Adair County personnel had prepared the test road by tight blading the loose surface material into a windrow along one side. Several cross-sectional measurements were taken and averaged for each section in order to calculate the amount of bentonite needed for each treatment. For the 0.5% bentonite treatment section, the total weight of loose material was calculated by taking the cross-sectional area times the length of the section and then times 132 pounds per cubic foot (pcf), the unit weight of limestone, which was determined at the laboratory prior to construction. The bentonite treatments were calculated by simply taking the total weight times the respective percentages. This was done for every section and the bentonite bags were then distributed accordingly. The next step involved distributing the dry material, by hand, next to the windrow for the entire test road. The bentonite and the loose material (limestone) were thoroughly dry mixed by the two graders and spread in a wide strips in the middle of the road. The distributor, with only water and dispersing agent (soda ash) spray applied the solution to the material and bentonite.

The field mixing process proceeded similar to that used for the Dallas County road, until the matrix had a consistency of 3 to 4 inch slump concrete. Gradation samples from each section were taken before and immediately after the construction was completed. These samples were analyzed to determine if the bentonite was influencing the gradation characteristics.

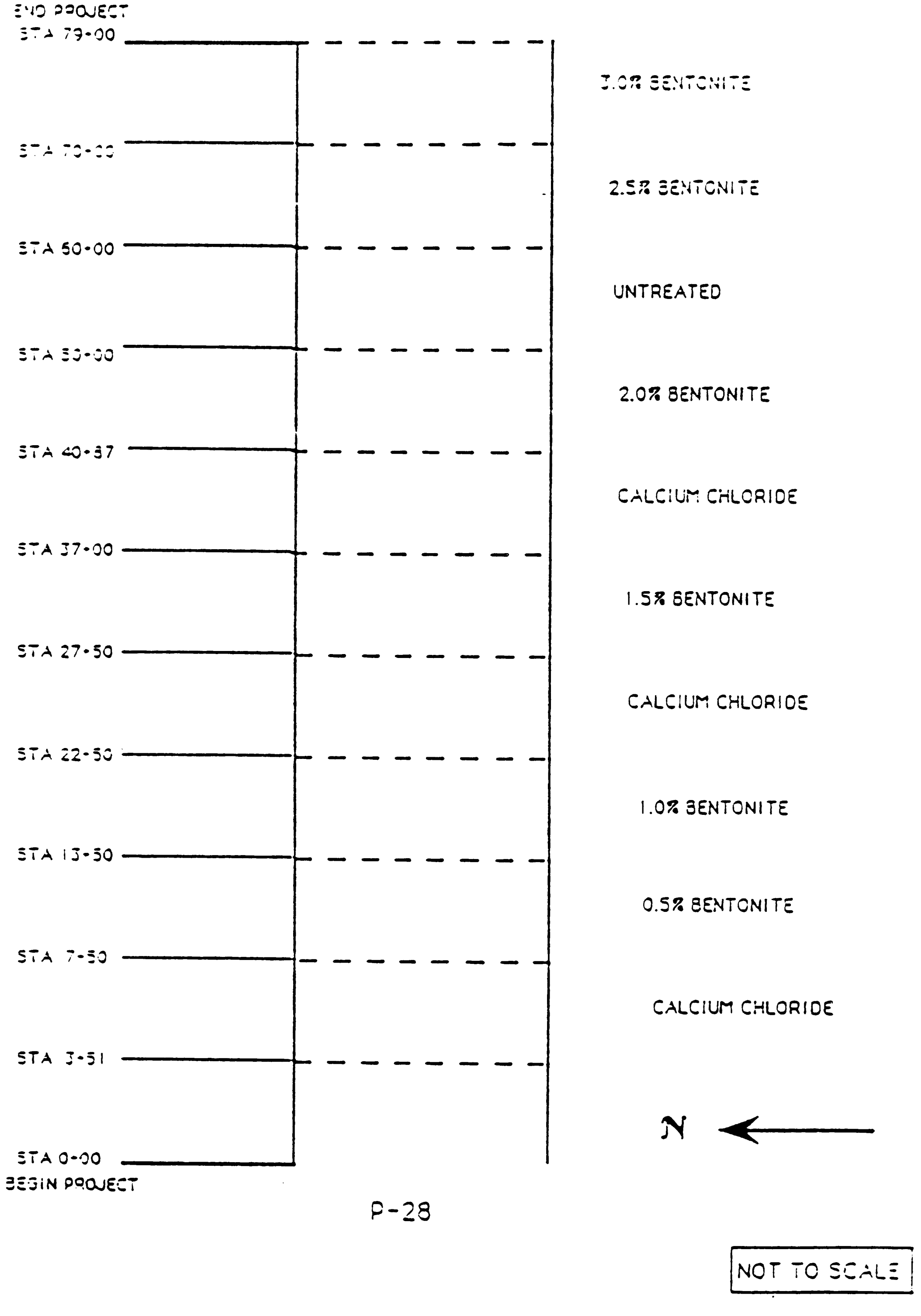


Figure 10. Adair County test road layout, as constructed

FIELD TESTING PROCEDURES AND RESULTS

Field testing of treatment effectiveness as a dust palliative consisted of the following.

1- Air tests using high volume air sampling of dust generation under traffic
2- Braking tests to evaluate the influence of treatment on braking and safety characteristics

Air Dust Samplers

Under gravitational forces, particles with a diameter smaller than a few microns rapidly reach their terminal velocity due to drag forces. Drag forces also limit the range in which the particles are projected horizontally. However, large particles of dust accelerate rapidly under gravity (Dorman, 1974).

The high volume air sampler is based on gravimetric principles and capable of sampling large volumes of air for the collection of suspended particulate matter. A glass fiber filter of known weight is used to collect the dust. Particles as small as 0.01 mm in diameter can be collected by this sampler (Hesketh & EL-Shobokshy, 1985). The accuracy of measurements depends primarily upon the uniformity of the air flow rate through the filter and the time of operating, as well as the operator skill (Hesketh & EL-Shobokshy, 1985).

The high volume sampler holder consists of three main parts, shown in Figure 11.

- •A vacuum with a filter holder attached: the filter holder involves two parts: (a) a stainless steel filter adapter with an opening at the top; (b) an open rectangular face plate of aluminum, see Figure 11.

  When the test is conducted, the filter is placed between the filter support screen and the gasket face plate.

- •A flow system: provides a continuous flow measurement.

- A flow controller: controls the flow through the sampler to ± 1 ft^3/min under variation in filter loading.

There are some other parts to the apparatus such as the roof for environmental protection and some timers (Katz, 1972).

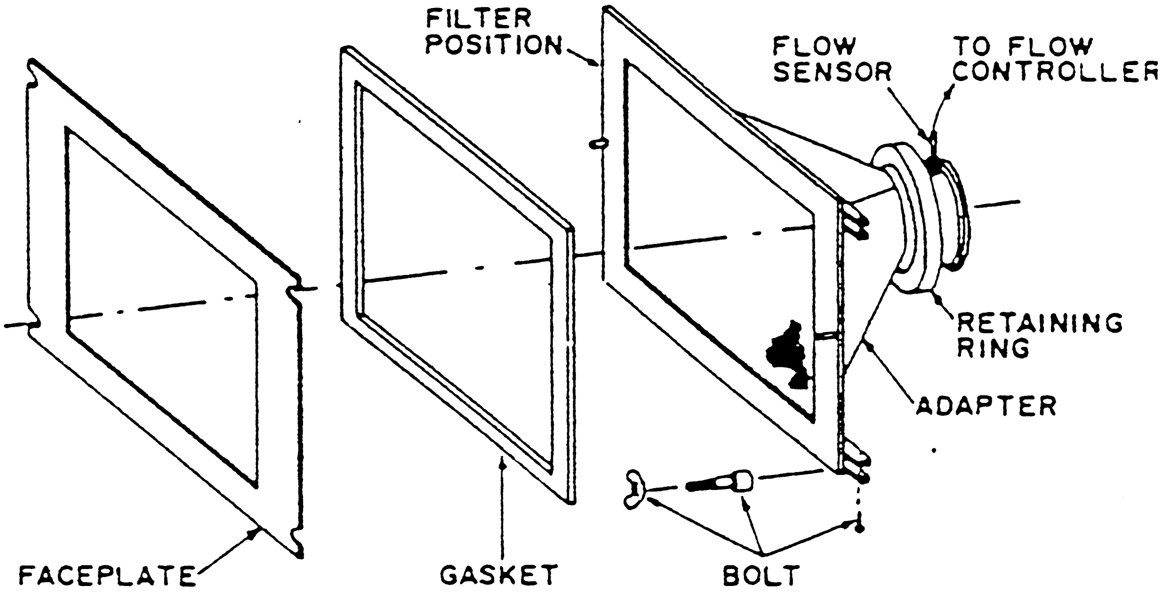


Figure 11. High-volume filter holder

The quality of the filter is very important for this kind of testing. The recommended filter media for high-volume samples is glass fiber filters with a collection efficiency of at least 99% for particles 0.30 mm in diameter (American Conference of Governmental Industrial Hygienists, 1972). These filters were purchased for this project from General Metal Works Corporation.

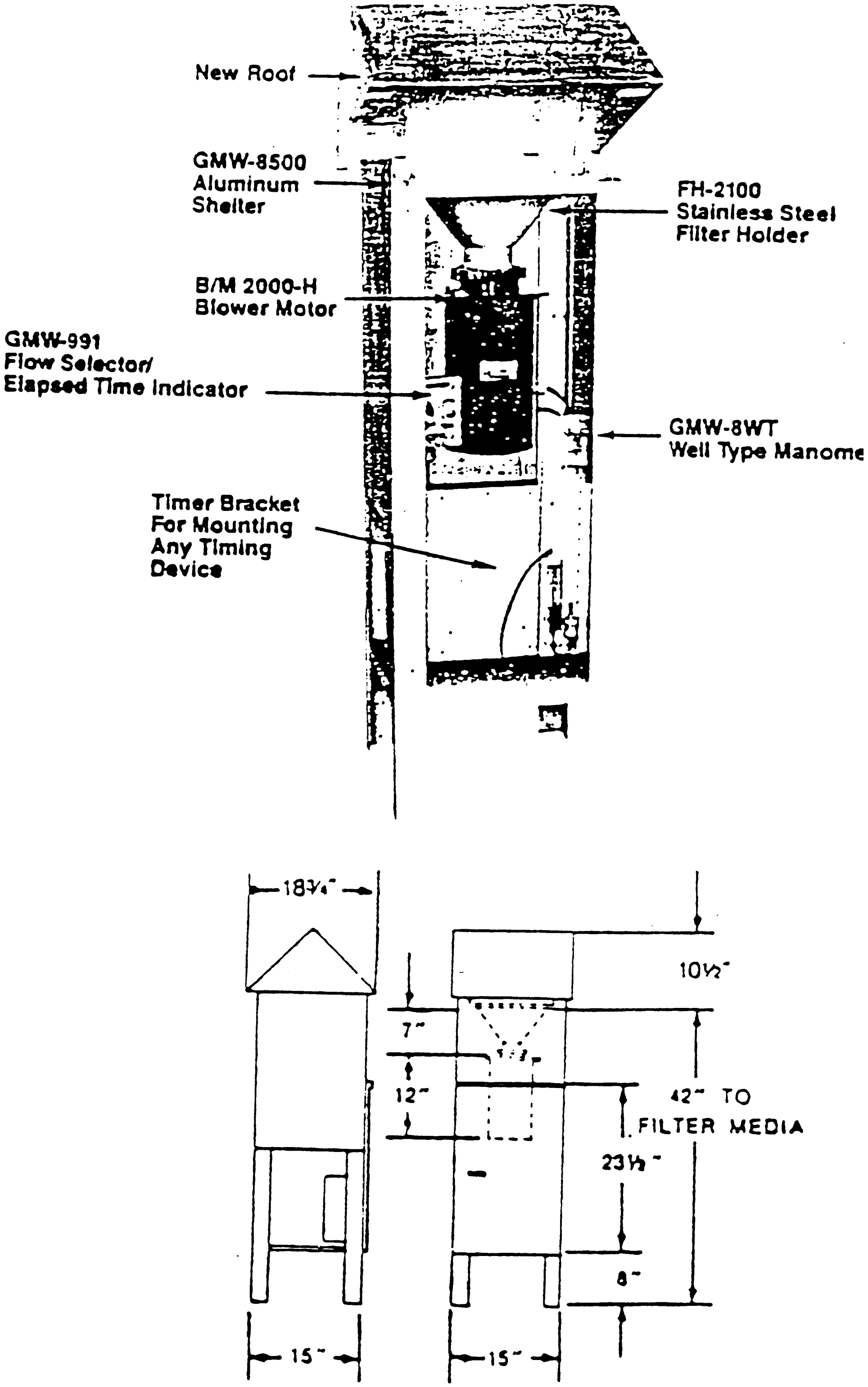


Figure 12. General Metal Works high-volume air sampler

Dust measurements were made by using two high-volume stationary air samplers manufactured by General Metal Works Corporation (Figure 12). The samplers' vacuum motors were powered by a gas generator. The samplers had a heavy duty turbine blower operating at a constant flow rate of 44 cfm volumetric suction of dusty air through glass fiber filter media. Dusting tests were conducted periodically as weather permitted. Both air samplers were placed in the longitudinal center of each test section on each side of the road at the shoulder. Dust was generated by making ten passes between the samplers with a 1/2-ton truck traveling at a speed of 40-45 mph. Testing was conducted both in and out-of-the-wheelpaths. Since the wheelpaths tend to develop a compacted crust, out-of-the-wheelpath tests were initiated to evaluate treatment effectiveness for the loose surficial material. After testing, the filter media was removed from the samplers, sealed in plastic bags in the field, and returned to the laboratory for testing. The amount of dust collected from each treated section was compared to the untreated section by normalizing the untreated section; therefore, if the amount of dust collected from the other sections was less than the amount of dust from the untreated section the result will be a negative number of reduction otherwise the result will be positive. The untreated section was the control section.

Dallas county road results

The data collected for each section of this road was plotted and compared for each treatment. The bentonite treatment comparison of the data in the wheelpath (Figures 13-18) indicates little consistent effect on dust generation up to when the new stone was applied in August 1988. From the maintenance report, it was learned that Dallas County personnel applied 300 tons per mile of class A roadstone. The variation of the data points in figures 13-22 is due to several factors such as the direction of the wind, humidity, temperature and maintenance condition of the road that might have affected the dust collection data.

Dust was significantly reduced (20 - 50%); however, in out-of-the-wheelpath tests, the 1.0% and 1.5% treatments showed the best reduction. Results obtained after the class A stone surfacing addition in August 1988 are interesting, in that the 1.5% Bentonite treatment appears to be effectively reducing dust generation in both wheelpath and out-of-the-wheelpath tests after the new surfacing application. This indicates that the fine particulate bonding capability of the bentonite is not only recoverable, but appears to be able to interact and function with newly applied material as well.

Dust data from the calcium chloride section are shown on Figures 19 and 20. These data are similar to the bentonite treated data. Also, the calcium chloride section was treated again in the beginning of summer 1989, which made some of these data look better than the bentonite treatment. The magnesium chloride section compares similarly to the bentonite sections. Both calcium and magnesium chloride sections appeared to be reducing dust out-of-the-wheelpath on the order of 10—40%. After the addition of the new stone in August 1988, the calcium section did not exhibit a consistent trend. However, after the new treatment, the road exhibited a significant dust reduction. The magnesium chloride section results, shown in Figures 21 and 22, indicated that it was acting to reduce dust generation for both test conditions. The magnesium chloride treatment generally requires about 18% more (by volume) than calcium chloride, in order to be as effective as the calcium chloride treatment (Reyier, 1972).

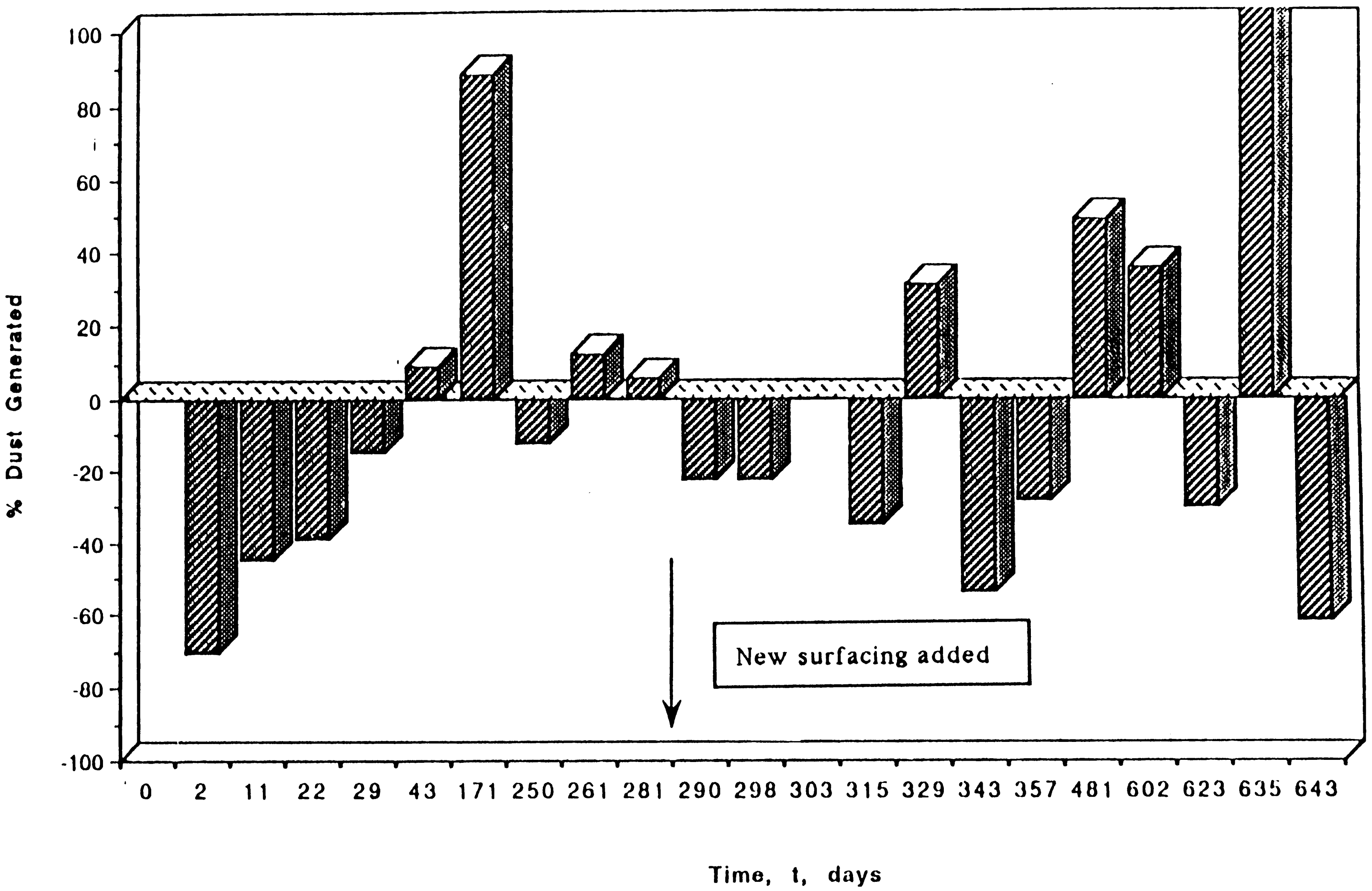


Figure 13. Dallas Co. test road dust generation for 0.5% Bentonite treatment, in Wheel Paths

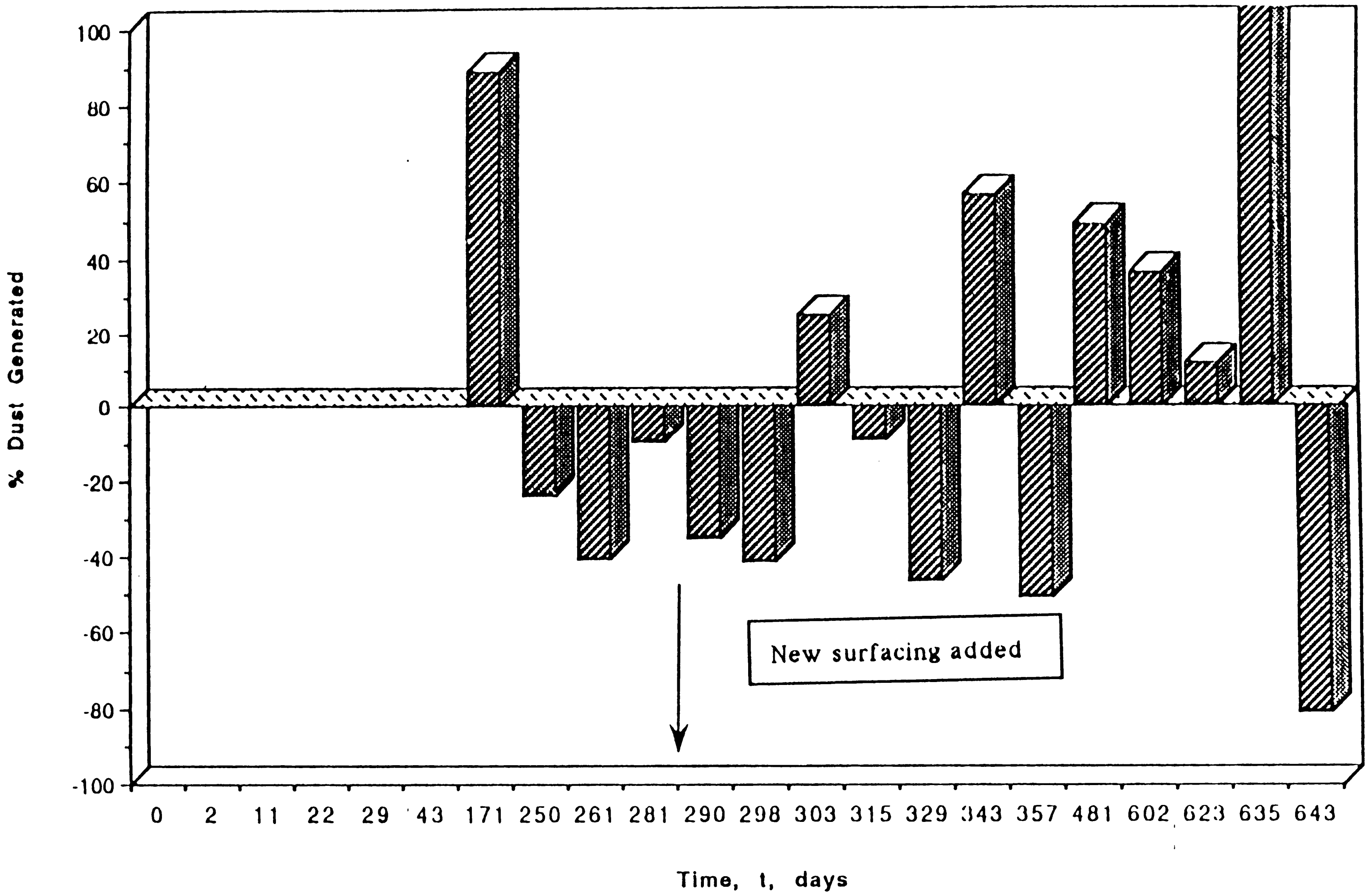


Figure 14. Dallas Co. test road dust generation for 0.5% Bentonite treatment, Out-of-Wheel Paths

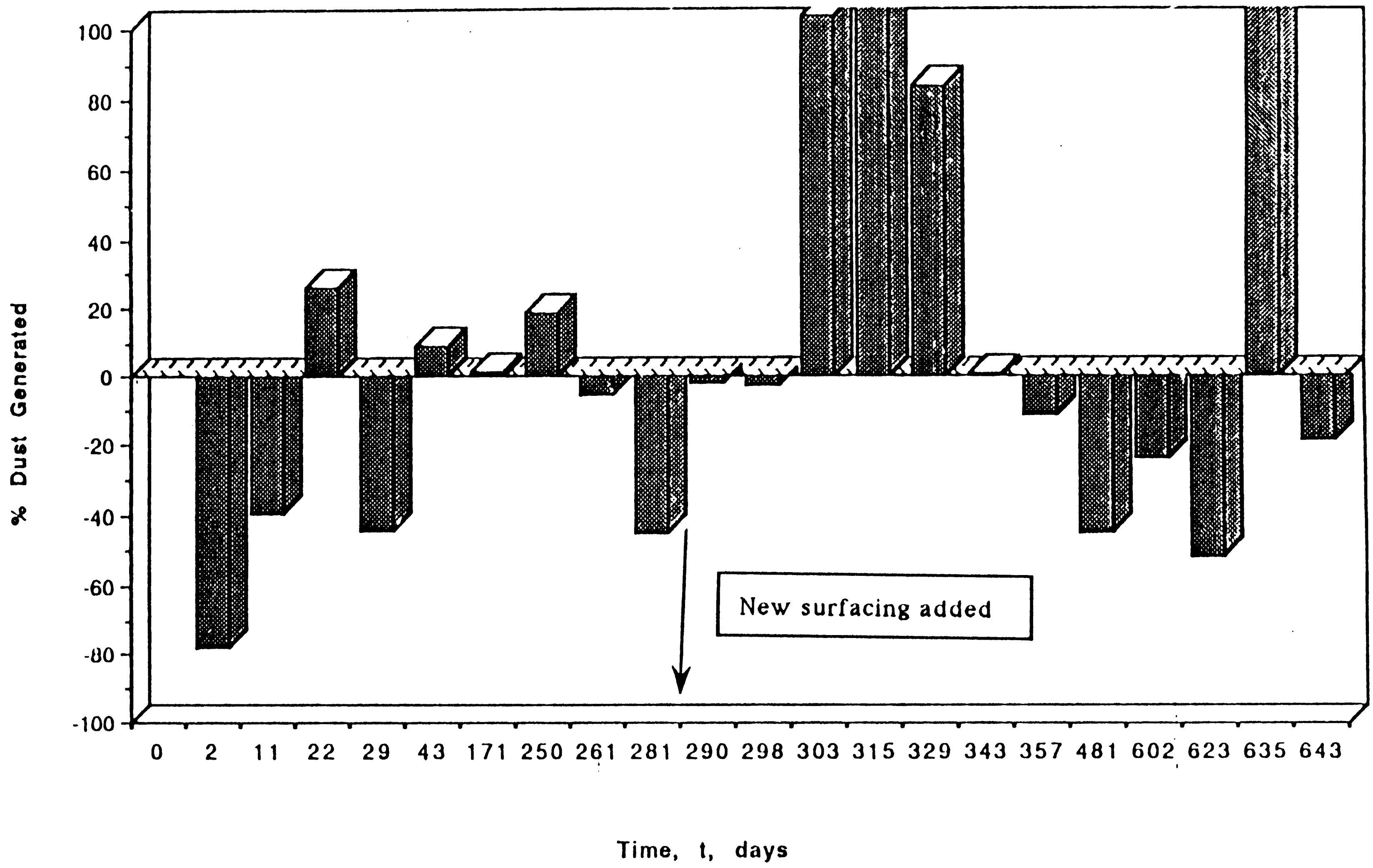


Figure 15. Dallas Co. test road dust generation for 1.0% Bentonite treatment, in Wheel Paths

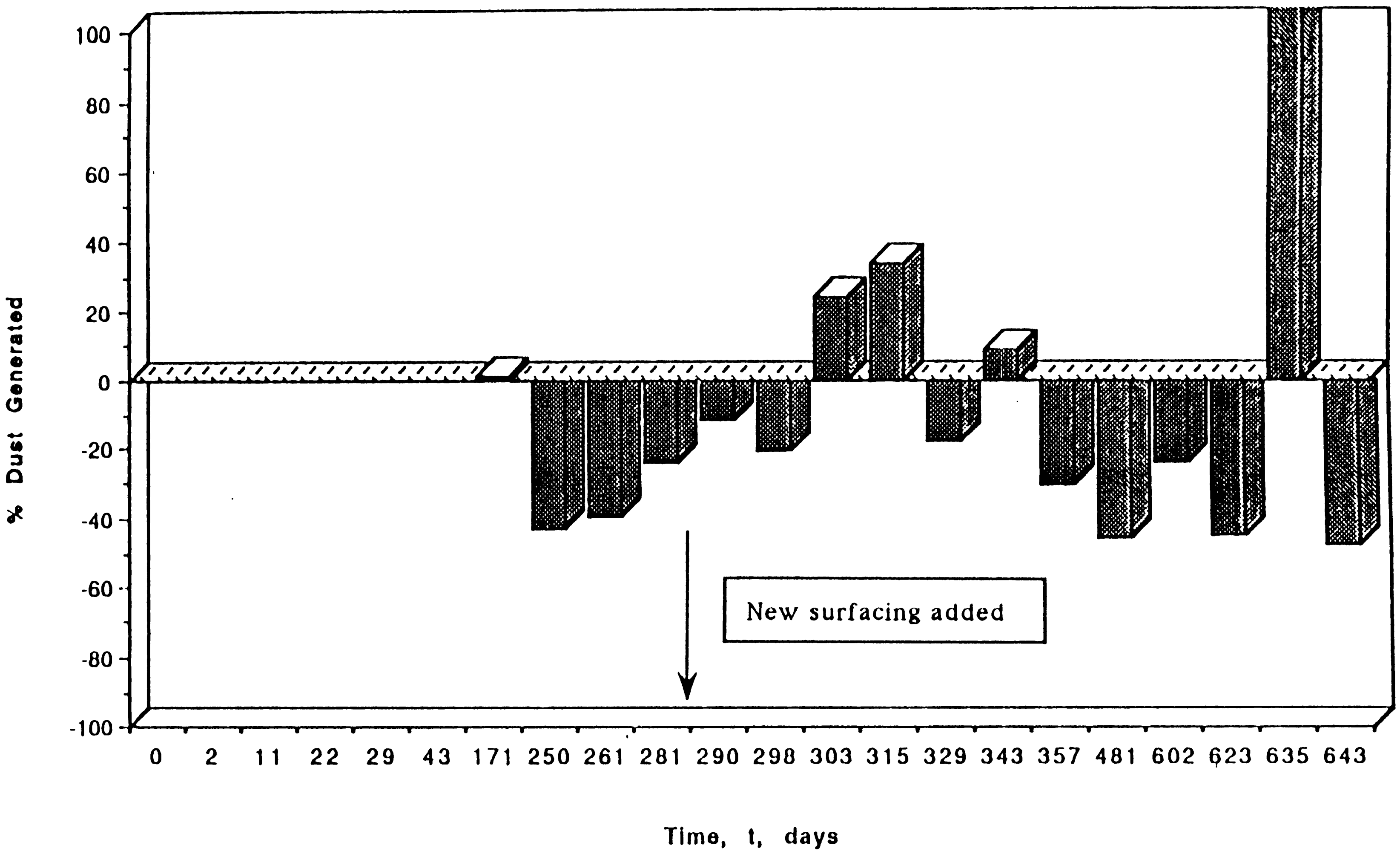


Figure 16. Dallas Co. test road dust generation for 1.0% Bentonite treatment, Out-of-Wheel Paths

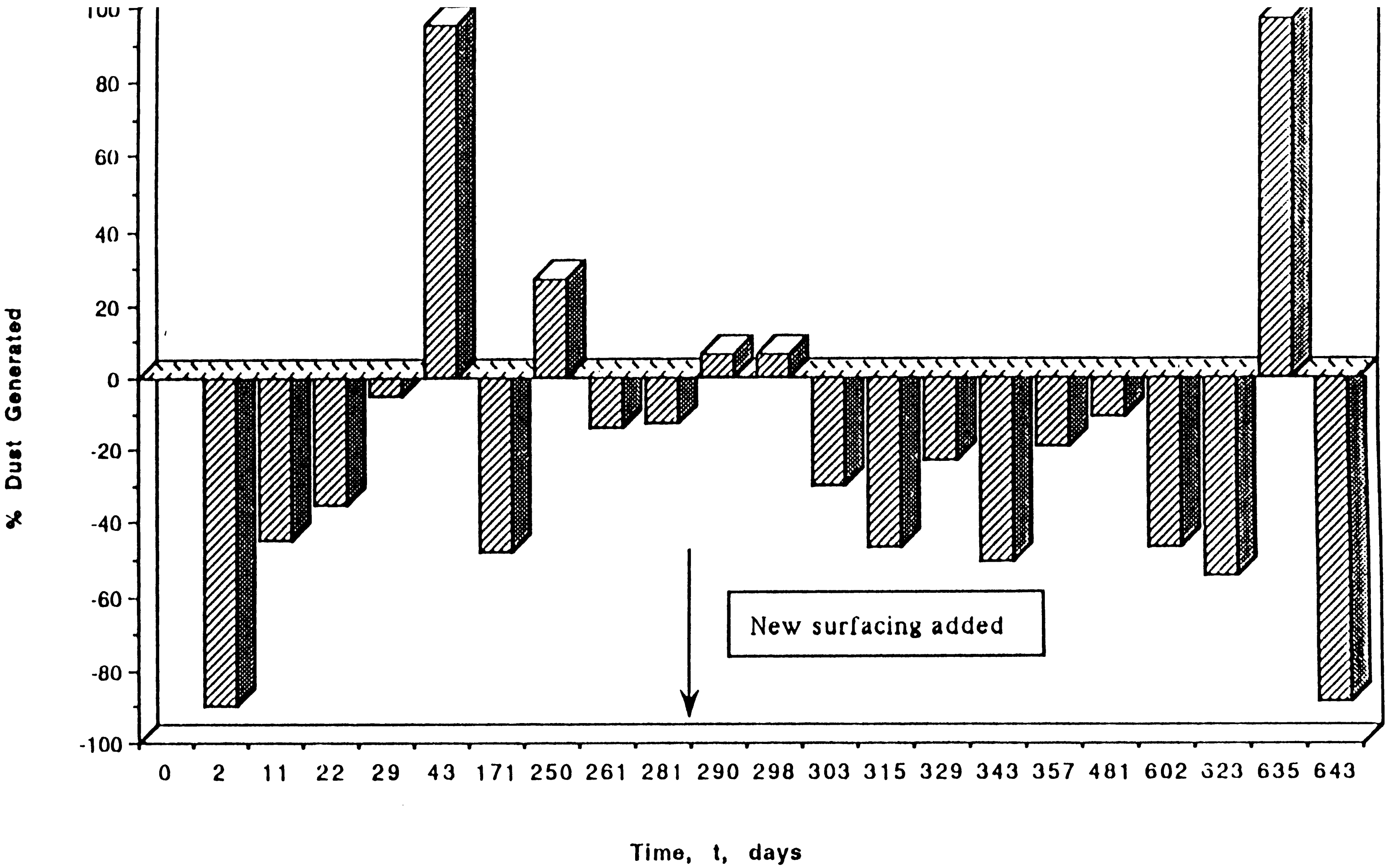


Figure 17. Dallas Co. test road dust generation for 1.5% Bentonite treatment, in Wheel Paths

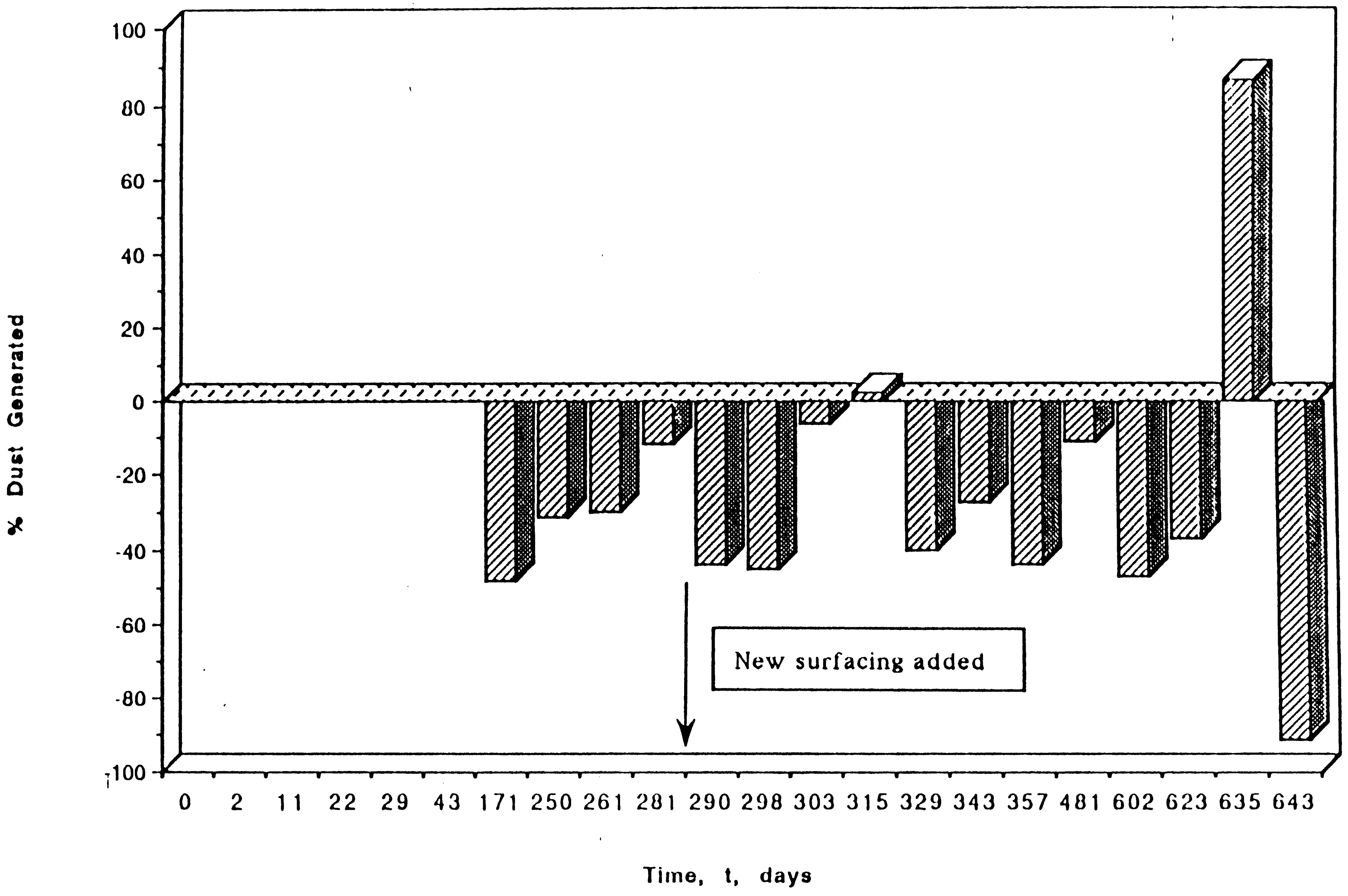


Figure 18. Dallas Co. test road dust generation for 1.5% Bentonite treatment, Out-of-Wheel Paths

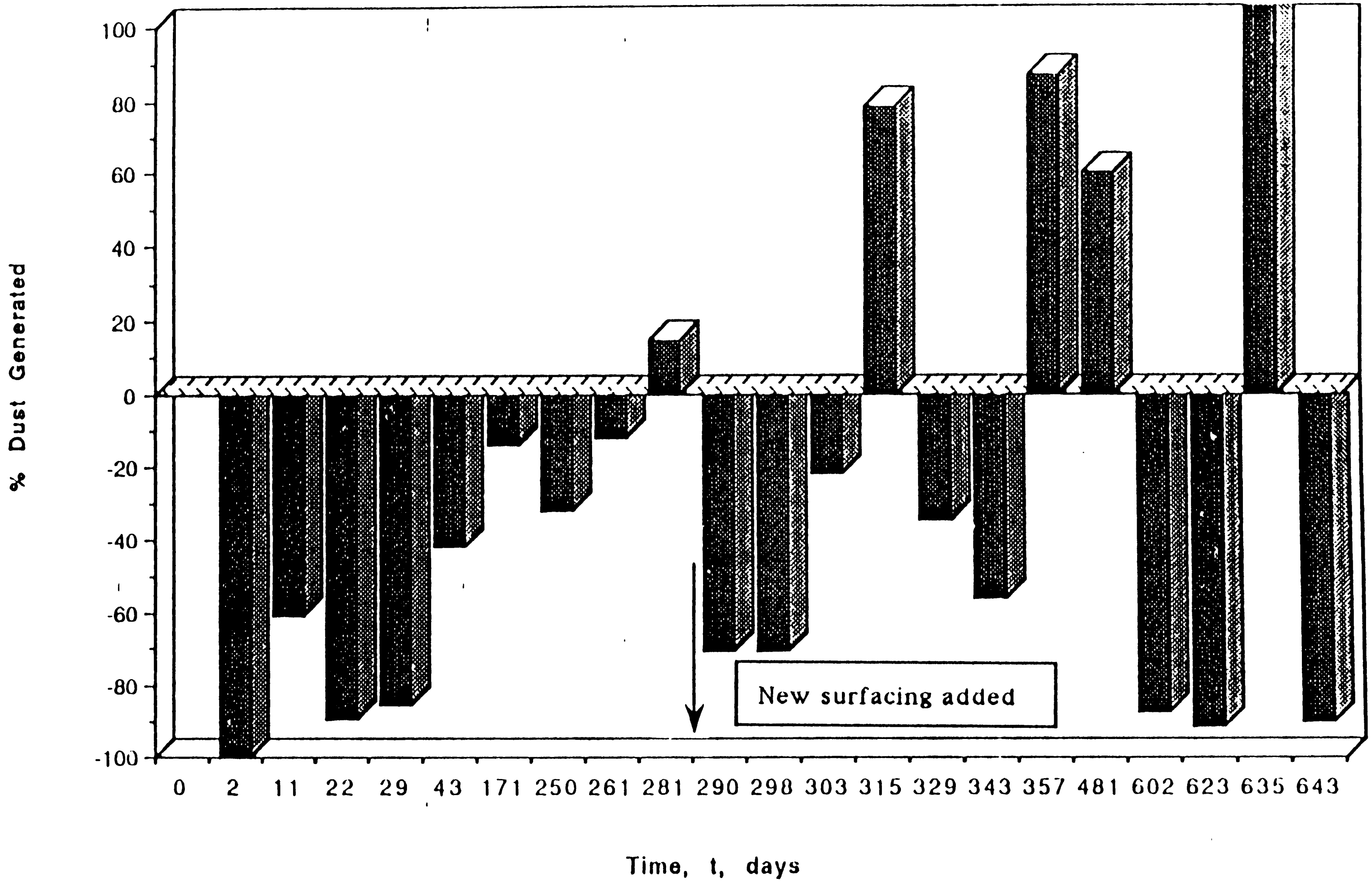


Figure 19. Dallas Co. test road dust generation for calcium chloride treatment, in Wheel Paths

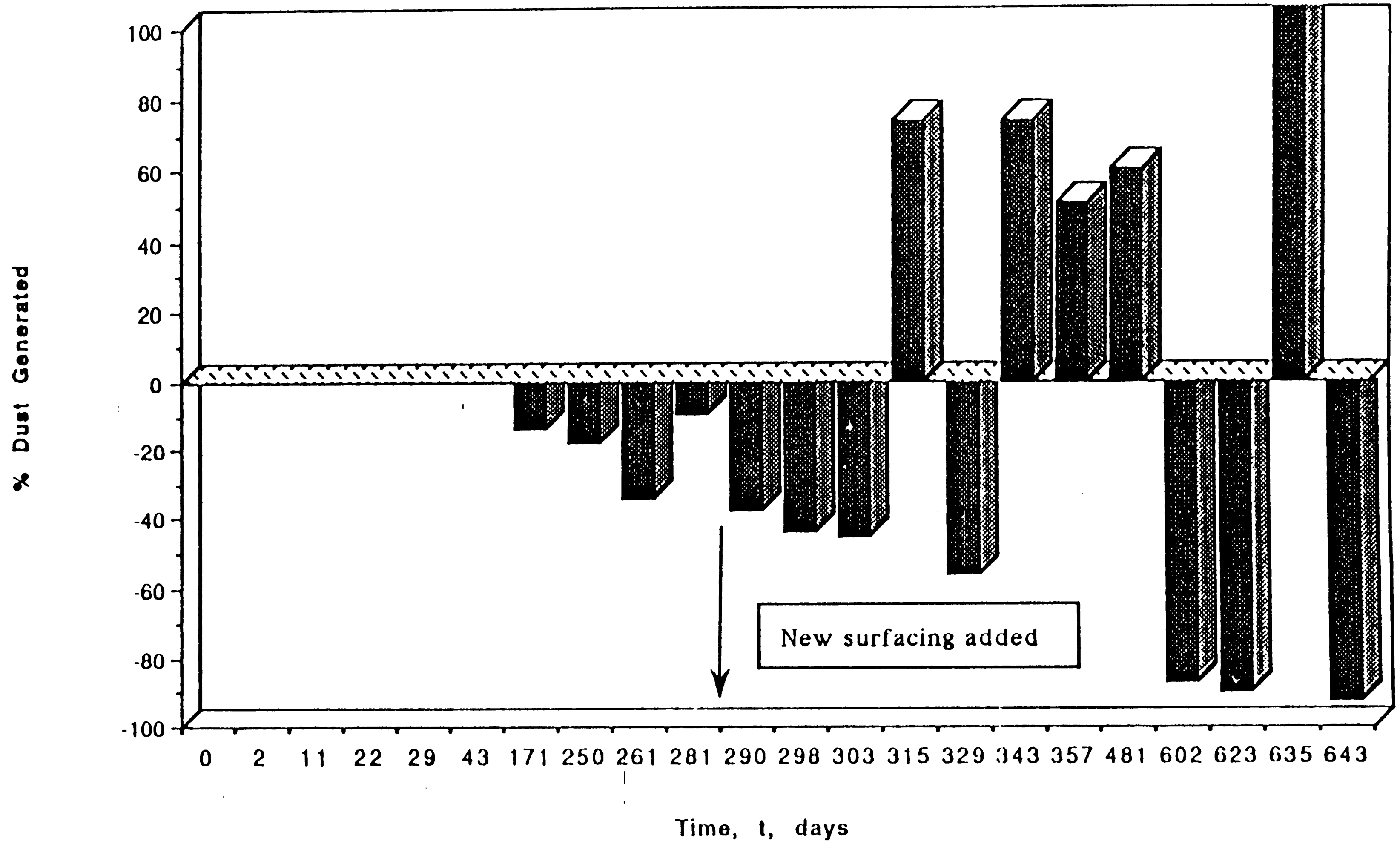


Figure 20. Dallas Co. test road dust generation for calcium chloride treatment, Out-of-Wheel Paths

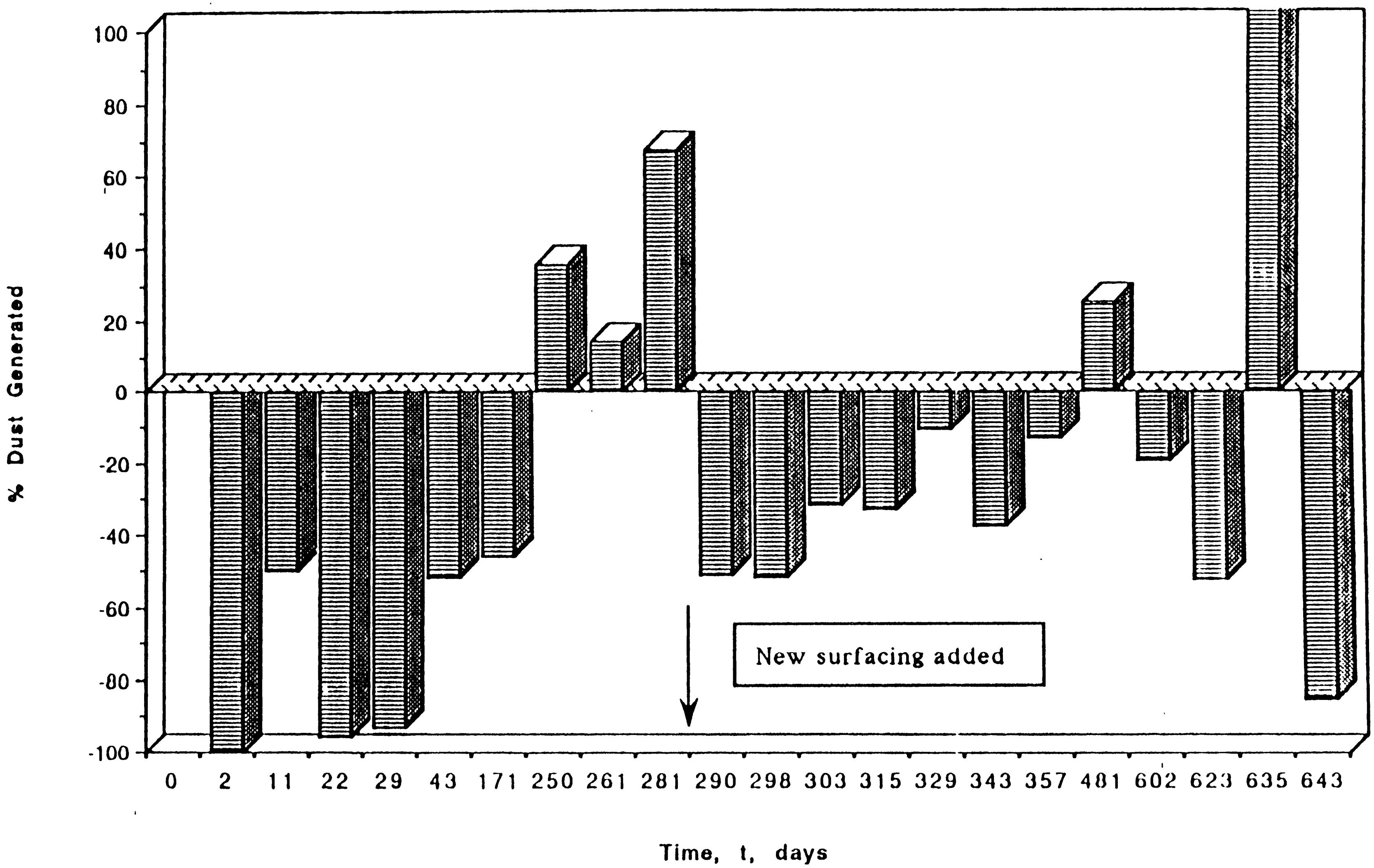


Figure 21. Dallas Co. test road dust generation for magnesium chloride treatment, in Wheel Path

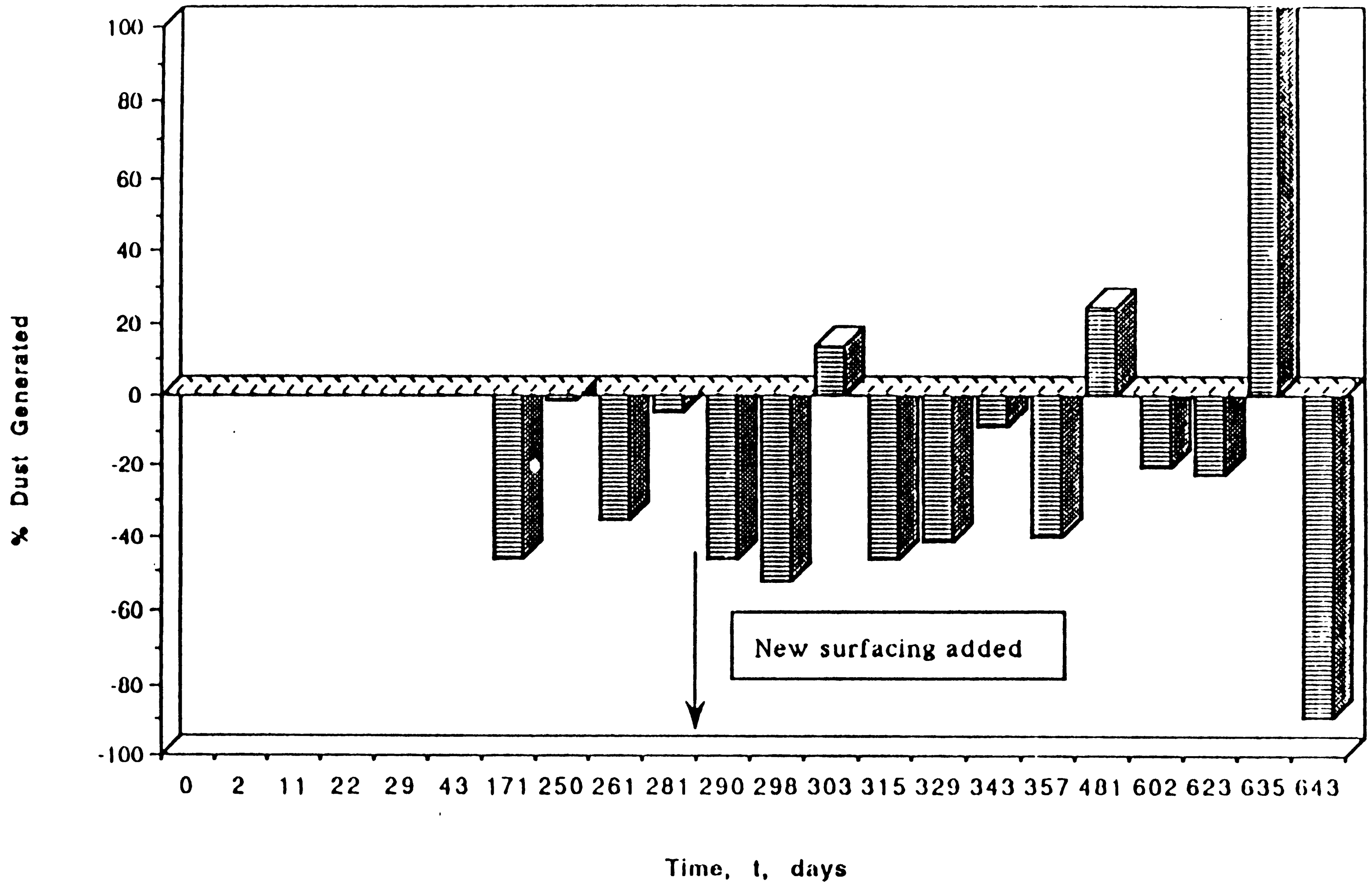


Figure 22. Dallas Co. test road dust generation for magnesium chloride treatment, Out-of-Wheel Path

The results of the chlorides were similar to the 1.5% bentonite treatment. Table 1 presents rough averages of wheelpath dust reduction, by treatment type, from October 1987 through January 1988. Due to the data variability and limited number of tests, these data can not be statistically compared and should be viewed qualitatively rather than quantitavely. The averages shown are rough estimates. The test was conducted five times for this period. These data show that both the calcium chloride and magnesium chloride have a high percentage of reduction; however, the bentonite treatments were much less than the chloride treatments. This indicates that chloride treatments are very effective for the period tested.

Table 1. Dust Reduction Averages from October 1987 — January 1988 - Dallas County test road

TREATMENT	% DUST REDUCTION/WHEELPATH
0.5% Bentonite	32
1.0% Bentonite	26
1.5% Bentonite	16
Calcium Chloride	76
Magnesium Chloride	80

Table 2 presents the averages of 1988 test results for the period up to the new stone application in August. The total number of tests was six for this specific period. From this table we see that bentonite treatments appear to be almost as effective as the chloride treatment. This is due to the short duration of effectiveness of the chloride treatments. In this table the out-of-wheelpath data were included. The chloride treatments have high averages in the wheelpath because as mentioned earlier the loose material was bladed to one side of the road and remained there for the project period; however, the bentonite treatment areas were maintained normally by the county therefore the wheelpath data were sometimes the same as the out-of-wheelpath.

Table 2. Dust Reduction Averages for January 1988 - August 1988

TREATMENT	% DUST REDUCTION WHEELPATH	% DUST REDUCTION OUT-OF-WHEELPATH
0.5% Bentonite	+8	14
1.0% Bentonite	6	25
1.5% Bentonite	7	38
Calcium Chloride	30	27
Magnesium Chloride	3	31

Table 3 shows data reduction for the ten tests conducted after the new stone application. From this table we see that the bentonite treatment appears to be as effective as the chloride treatment in the out-of-wheelpath tests. The reason for low averages in the wheel-path is that the addition of new material reduced the concentration of bentonite in the surfacing material. In out-of-wheelpath tests the averages are higher which indicates the mechanism of bentonite in bonding the particles together in the loose material was minimal due to the compacted crust developed. This table also shows the effect of the calcium chloride treatment which was applied again at the beginning of summer 1989.

Table 3. Dust reduction averages for August 1988 through September 1989

TREATMENT	% DUST REDUCTION WHEELPATH	% DUST REDUCTION OUT-OF-WHEELPATH
0.5% Bentonite	8	11
1.0% Bentonite	5	4
1.5% Bentonite	28	24
Calcium Chloride [a]	+12	+2
Magnesium Chloride	14	11

[a] This section had been treated again in the beginning of summer 1989.

Table 4 shows the average for the entire period of testing over the two years. This table presents the average of the twenty-one tests. The overall averages of the entire test period which was almost two years shows that the bentonite treatment is still effective over that time period even with the addition of new surfacing material. Again the averages for the wheelpath are lower than the averages for out of the out-of-wheelpath.

Table 4. Dust reduction averages from October 1987 through October 1989

TREATMENT	% DUST REDUCTION WHEELPATH	% DUST REDUCTION OUT-OF-WHEELPATH
0.5% Bentonite	2	6
1.0% Bentonite	6	15
1.5% Bentonite	20	27
Calcium Chloride	20	6
Magnesium Chloride	22	16

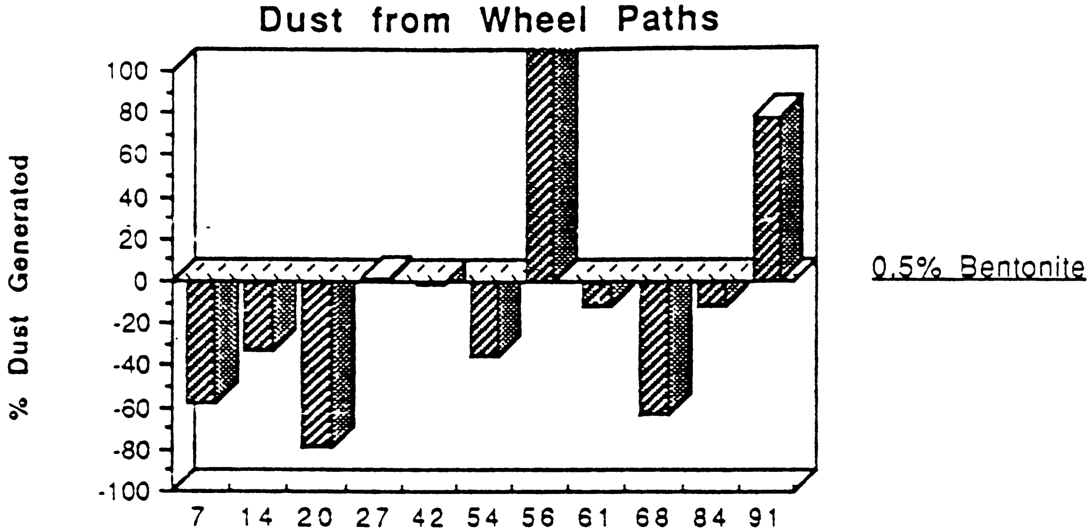
In analyzing these data over the entire project period, we can come to the conclusion that the 1.5% Bentonite treatment has a potential long-term reduction of dust in the range of 20% to 30%. The results from Table 1 indicated that the 0.5% treatment was the most effective of the bentonite treated sections in the short term. However, the data from Table 3 indicated that the 1.5% treatment (or higher) may be more effective from a long-term standpoint.

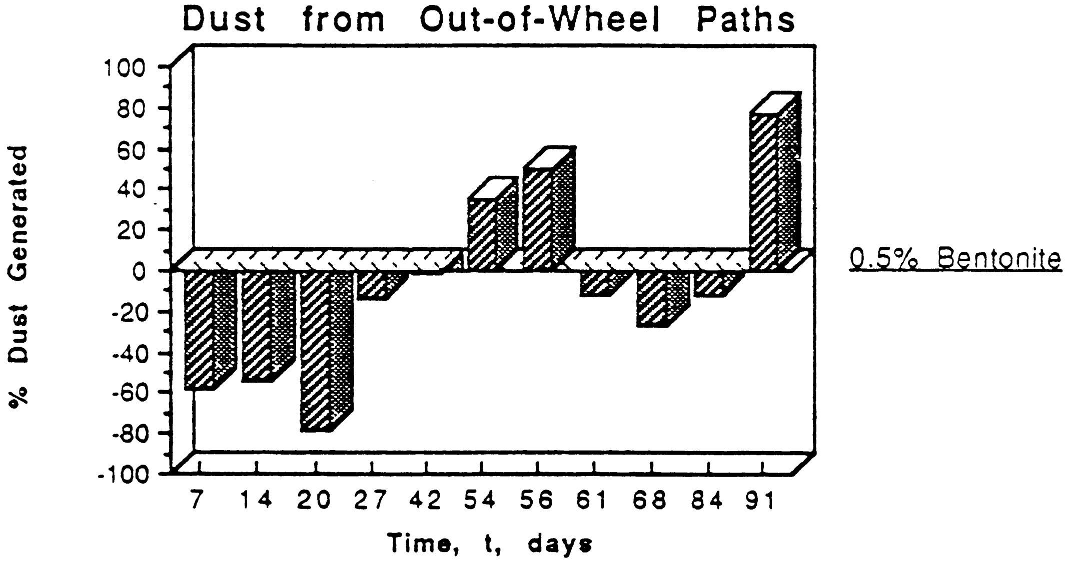
Adair county road results

Based on the results from Dallas County, higher percentages of bentonite treatments were incorporated in the test road in Adair County. Dust data collected from this test road showed an increase in dust reduction at the higher percentages of bentonite. Figures 23-30 show the percentage of dust reduction for each section. Rough averages for the eleven tests of dust reduction over the test period by treatment type are as follows:

Table 5. Dust reduction averages from August 1989 through November 1989

TREATMENT	% DUST REDUCTION WHEELPATH	% DUST REDUCTION OUT-OF-WHEELPATH
0.5% Bentonite	8	9
1.0% Bentonite	11	11
1.5% Bentonite	17	12
2.0% Bentonite	5	14
2.5% Bentonite	10	19
3.0% Bentonite	42	33
Calcium Chloride (both sections)	30	48





gure 23. Adair County test road dust generation for 0.5% Bentonite treatment

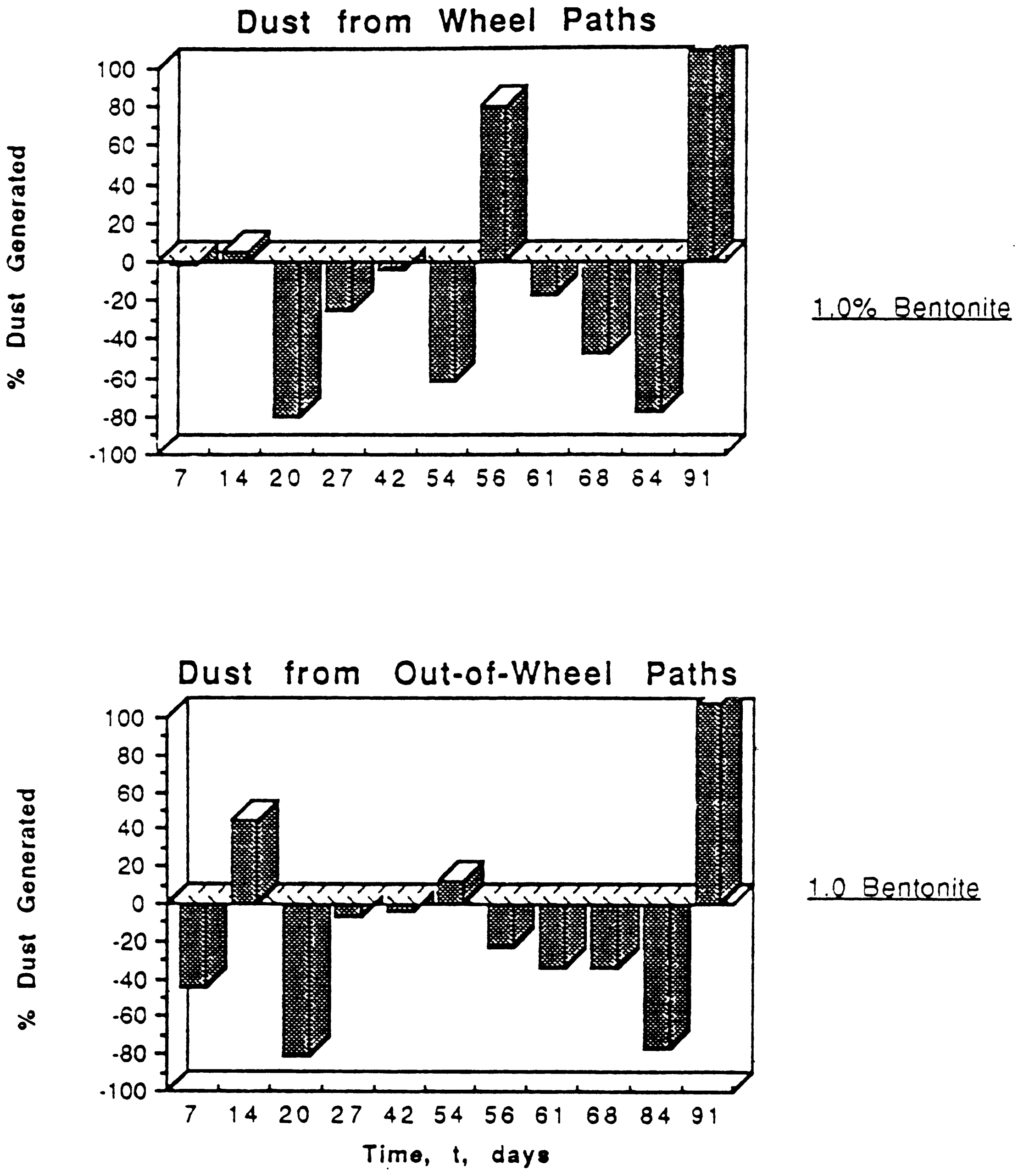
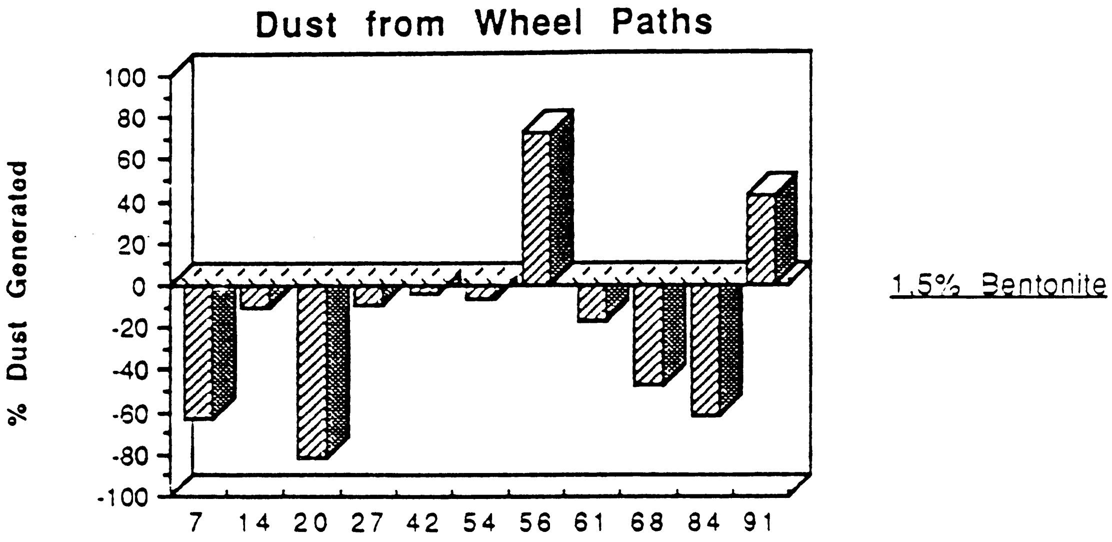


Figure 24. Adair County test road dust generation for 1.0% Bentonite treatment



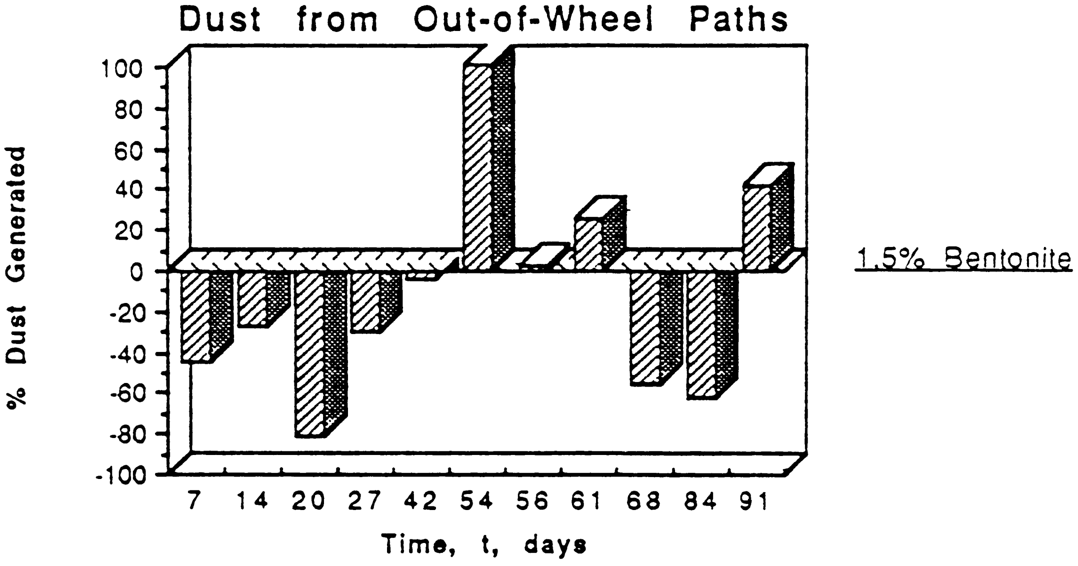
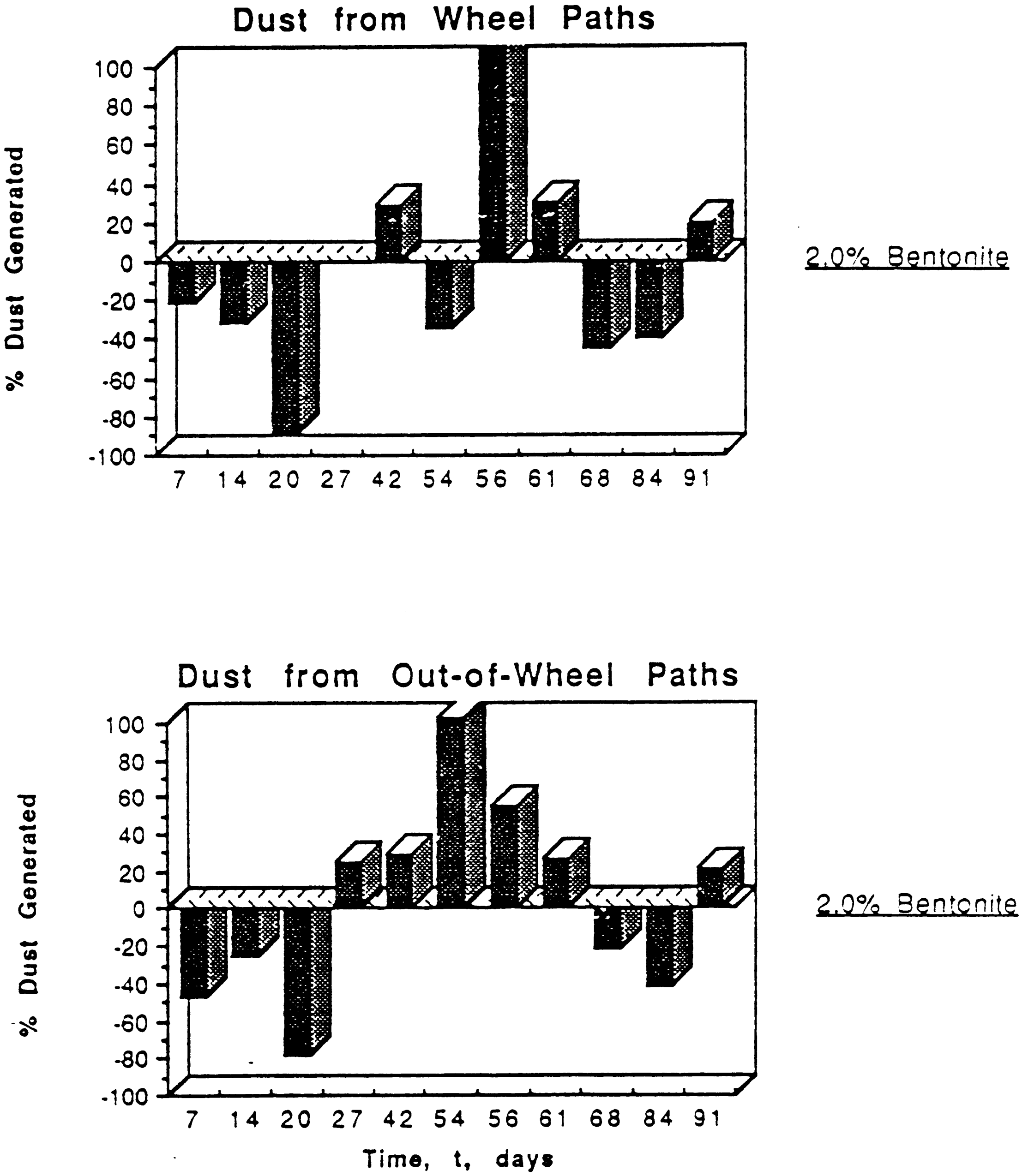


Figure 25. Adair County test road dust generation for 1.5% Bentonite treatment



gure 26. Adair County test road dust generation for 2.0% Bentonite treatment

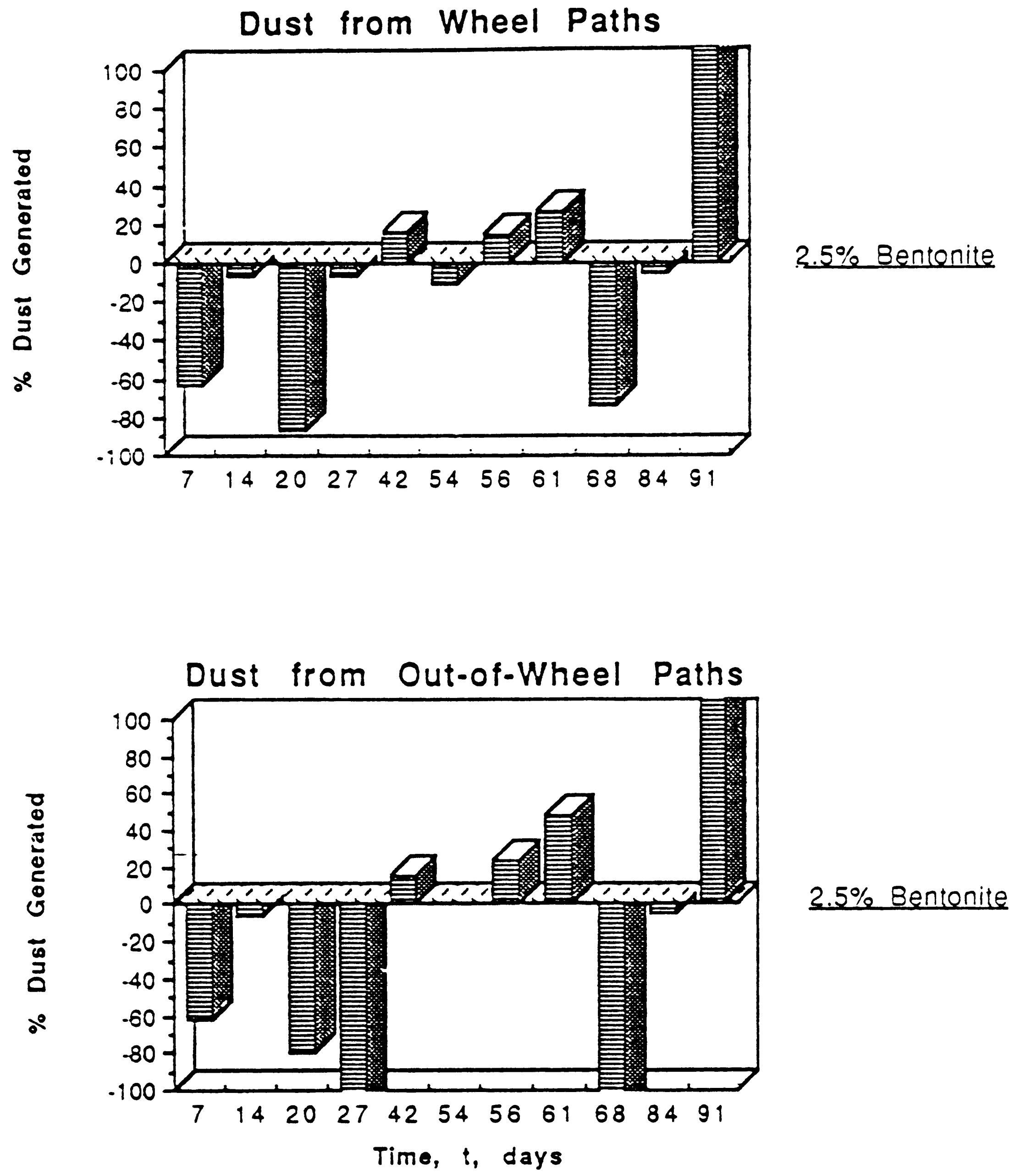
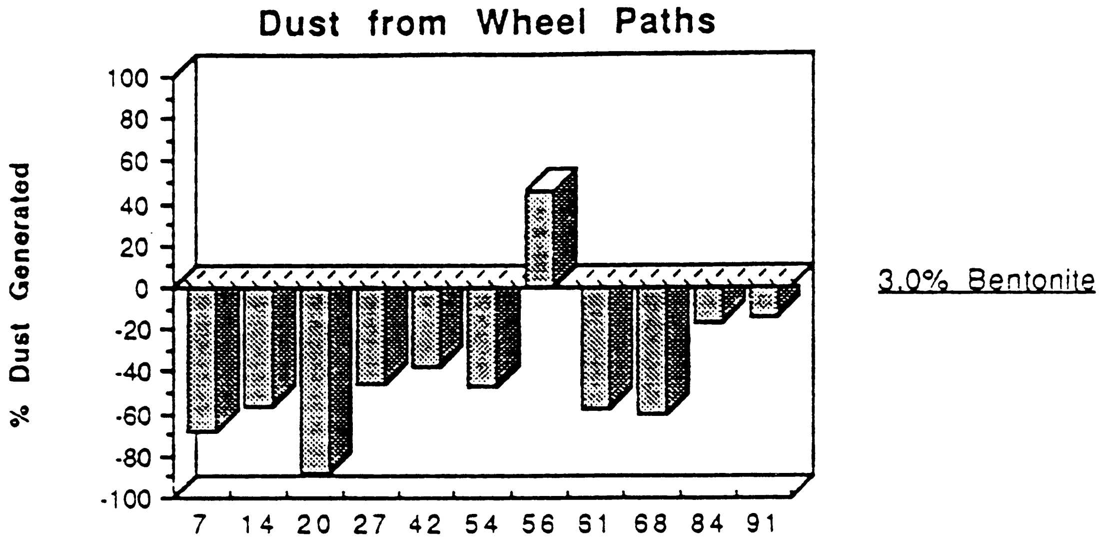


Figure 27. Adair County test road dust generation for 2.5% Bentonite treatment



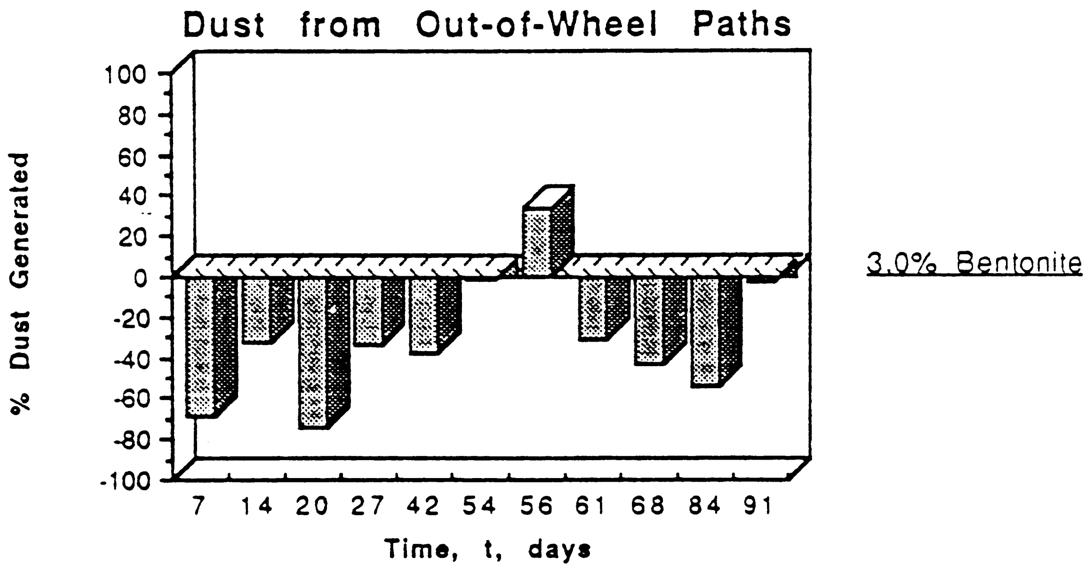


Figure 28. Adair County test road dust generation for 3.0% Bentonite treatment

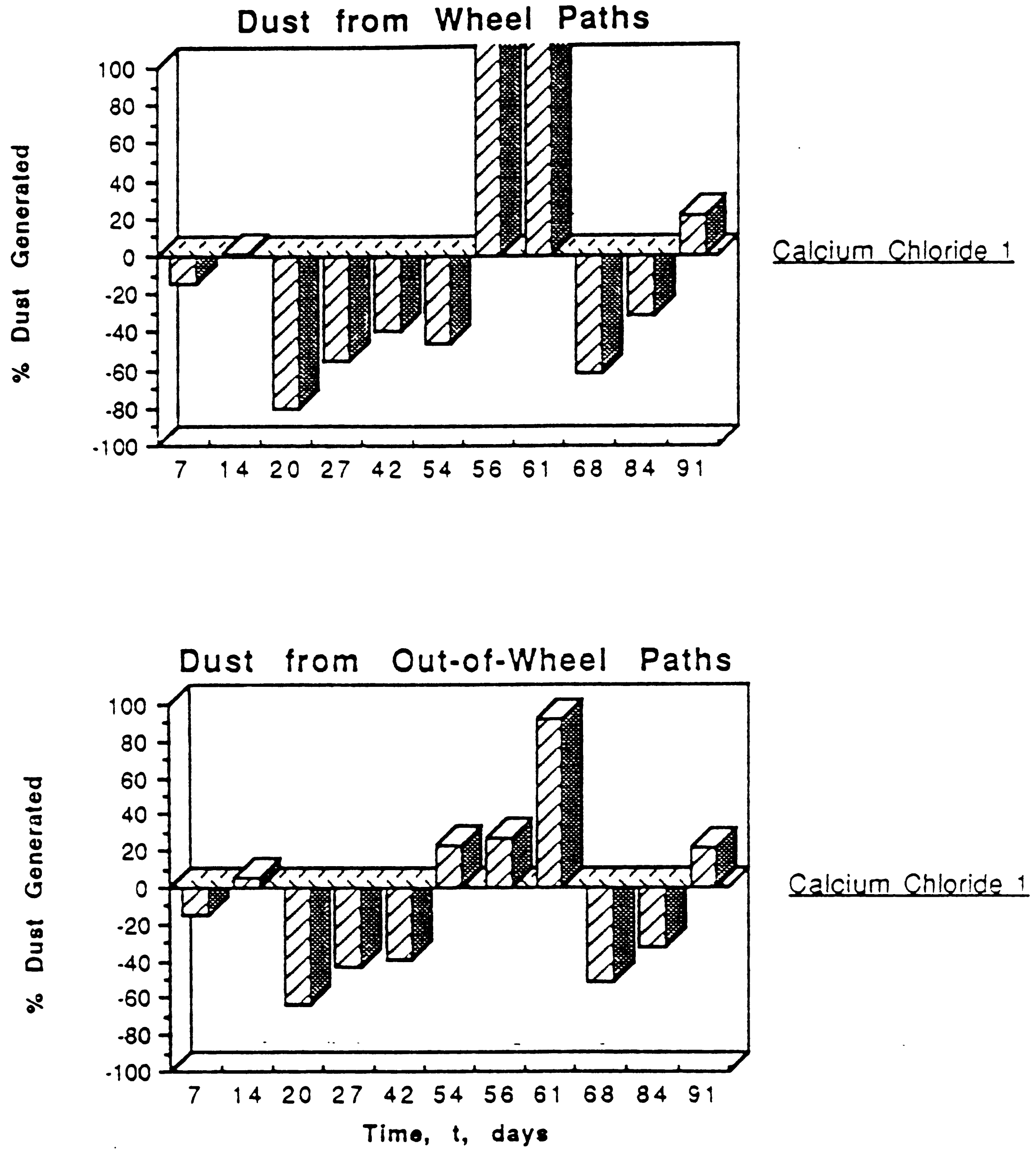
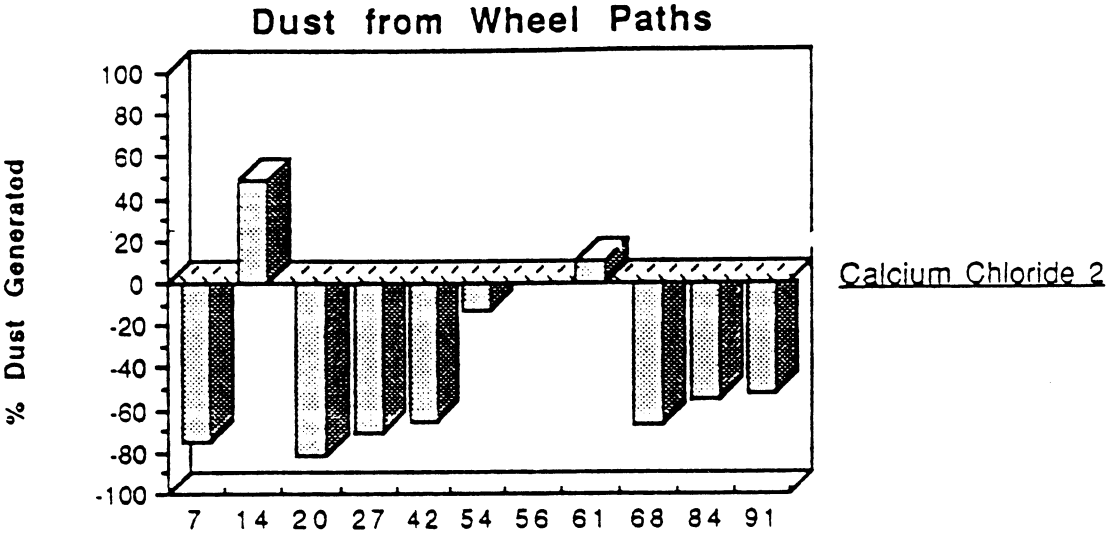


Figure 29. Adair County test road dust generation for Calcium Chloride 1 treatment


Dust from Wheel Paths

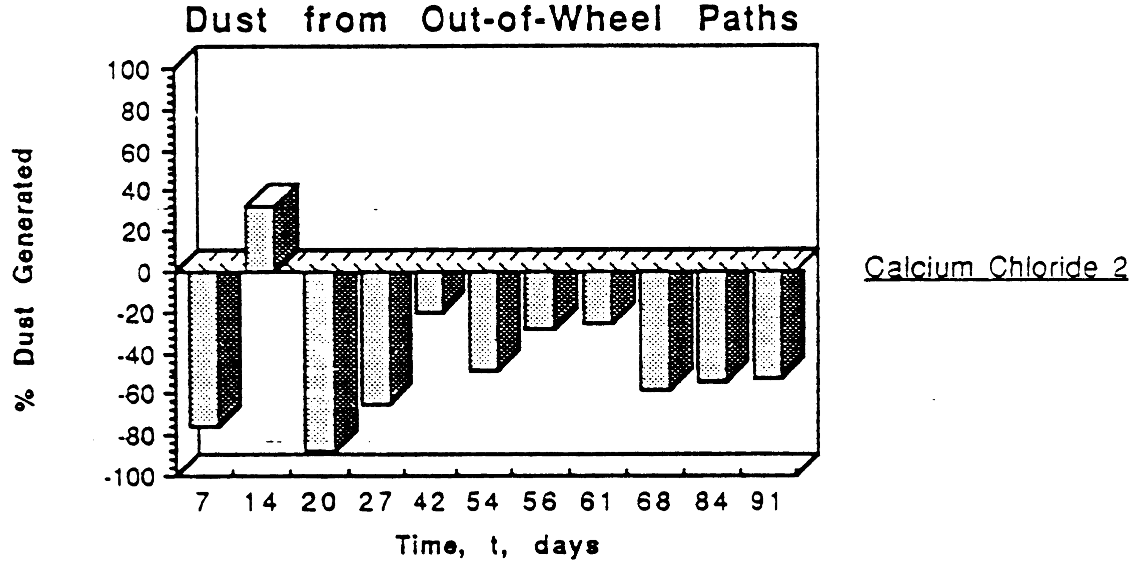

Dust from Out-of-Wheel Paths

Figure 30. Adair County test road dust generation for Calcium Chloride 2 treatment

Comparison of the data for the bentonite treated sections in both wheelpath and out-of-wheelpath indicate that the 2.5% and 3.0% treatments appear to have a significant effect on reducing dust.

The results from Table 5 indicates that the higher percentage treatments may be as effective as the calcium chloride treatment. Also, the bonding action appears recoverable from weather and traffic abrasion.

Braking Characteristics

This test was initiated to determine the effect on the stopping distance compared to the untreated section. The braking test was accomplished using a 1/2-ton pickup. The test vehicle was brought to a speed of 25 mph. As the operator passed by a set mark, the brakes were locked. The braking distance was measured from the start of the skid mark to the center of the front wheels of the truck.

Figures 31 and 32 show the data collected for the Dallas county road. The test was conducted for both dry and wet surface conditions. Ten tests were conducted under dry conditions; however, only four tests were conducted under wet conditions. The reason for the fewer number is that the test under wet conditions could be conducted only when the surface material was fully saturated with water. Although there are not enough data to be statistically significant, several trends are evident.

Data for Dallas County road for both wet and dry conditions show the same trends. There are not any significant differences in braking distance between

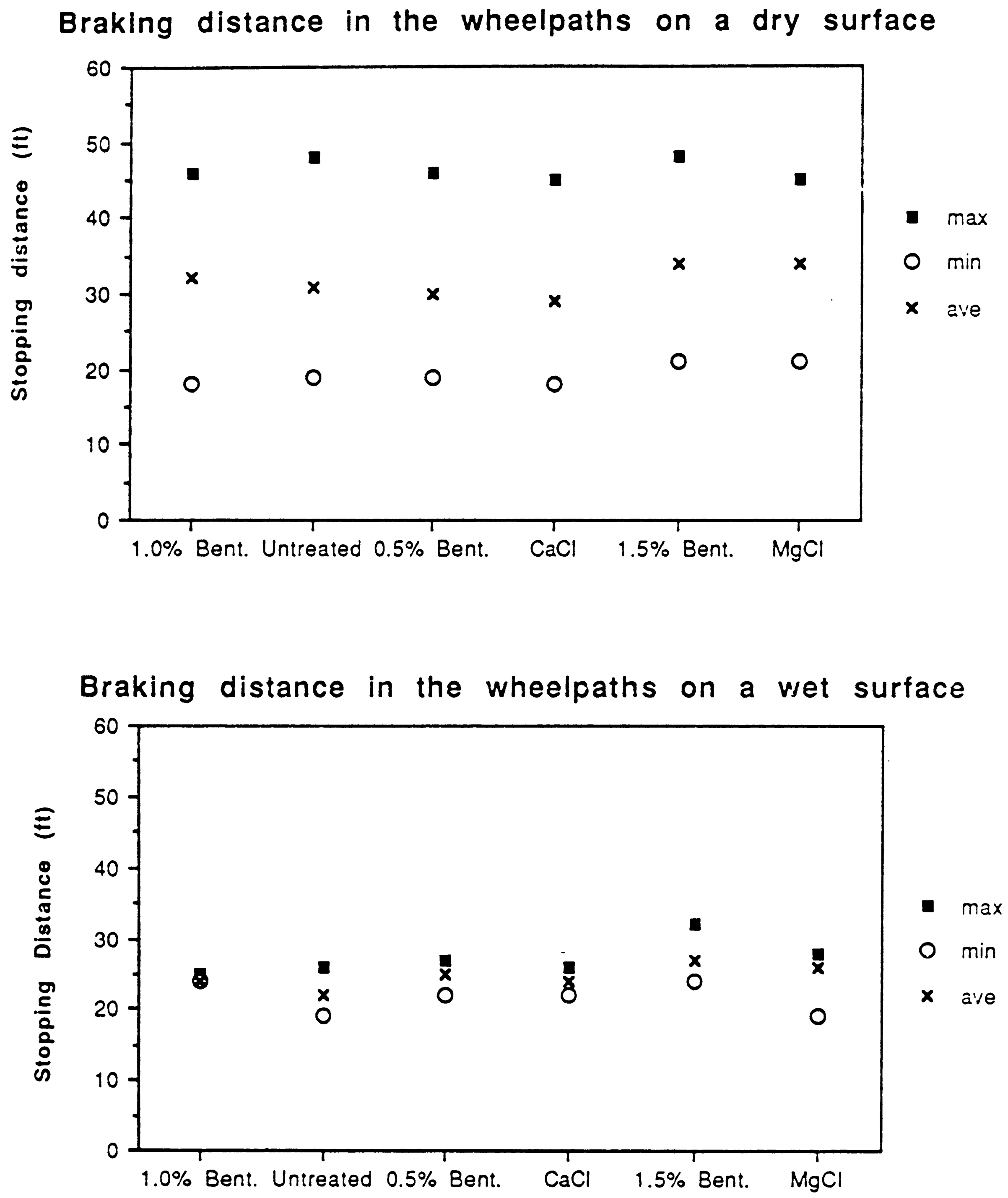
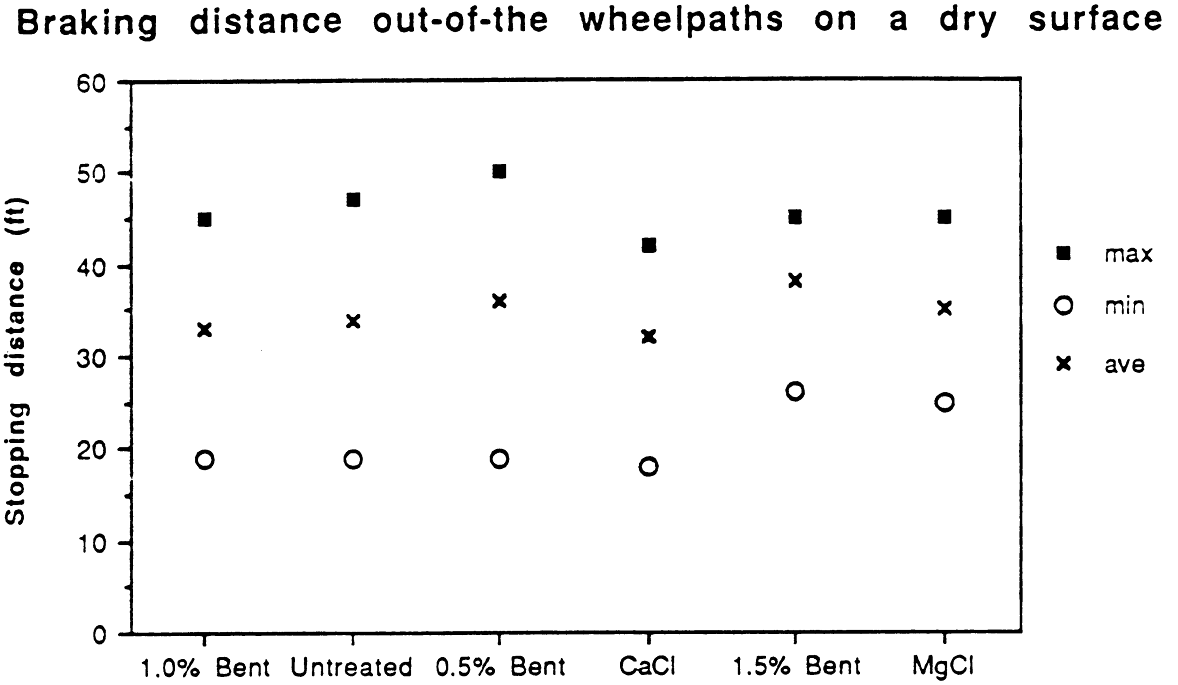


Figure 31. Wheelpath braking distance results for Dallas County test road



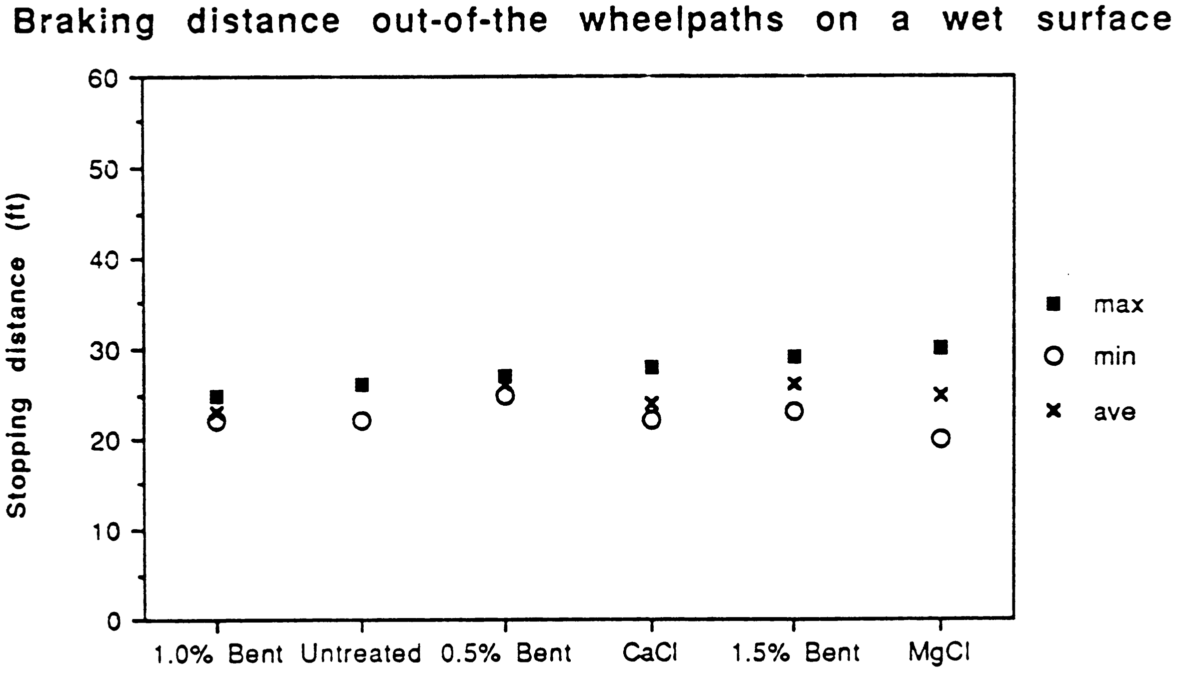
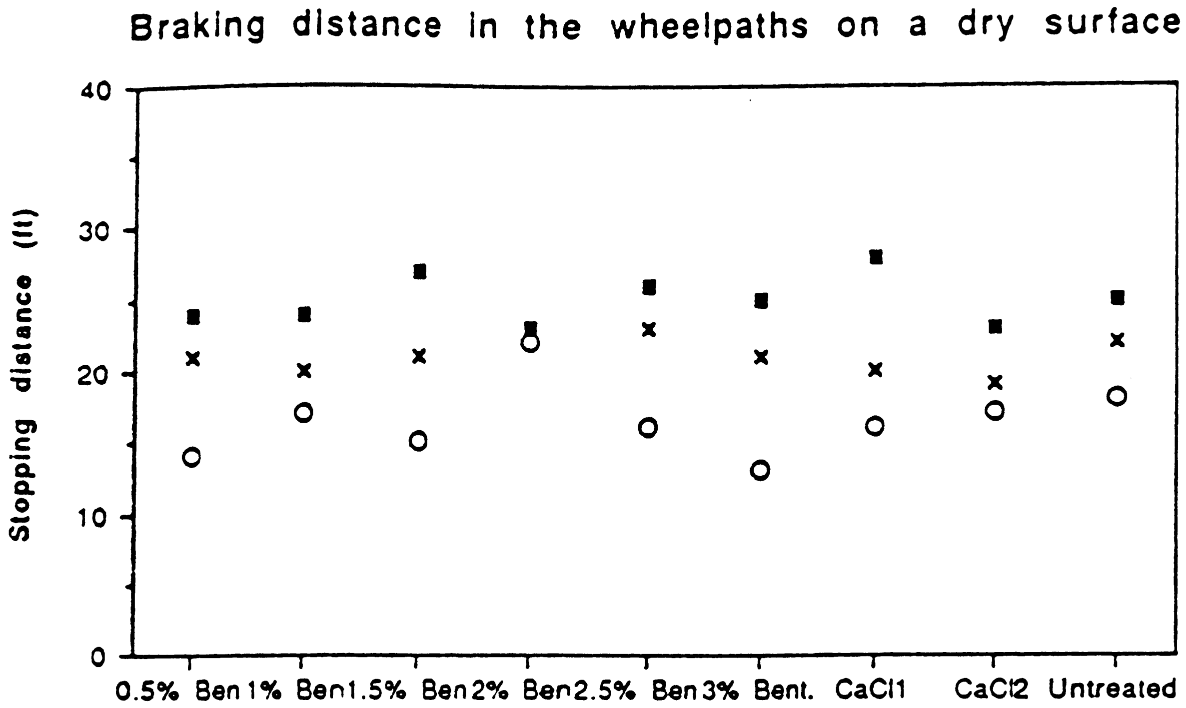


Figure 32. Out-of-Wheelpath braking distance results for Dallas County test road

the sections. The out-of-wheelpath tests also show the same trends as the wheelpath tests for all bentonite treatment sections. The average braking distances for the wet surface seemed less than the dry surface. The reason may be that the wet particles have a clean surface which makes more friction contacts with tires than for dry dusty aggregate surfaces.

Figure 33 presents the results for the ten dry wheelpath tests of Adair County road. From that figure, we observe that the higher percentage of bentonite treatment appear to have almost the same braking distance as the calcium chloride sections and untreated sections.

Figure 34 shows the results for the four out-of-wheelpath tests for Adair County road. Again, the same observations can be made. Although the number of test data are not statistically significant, these results indicate no adverse effect on braking characteristics for the various treatments of bentonite.


Braking distance in the wheelpaths on a dry surface

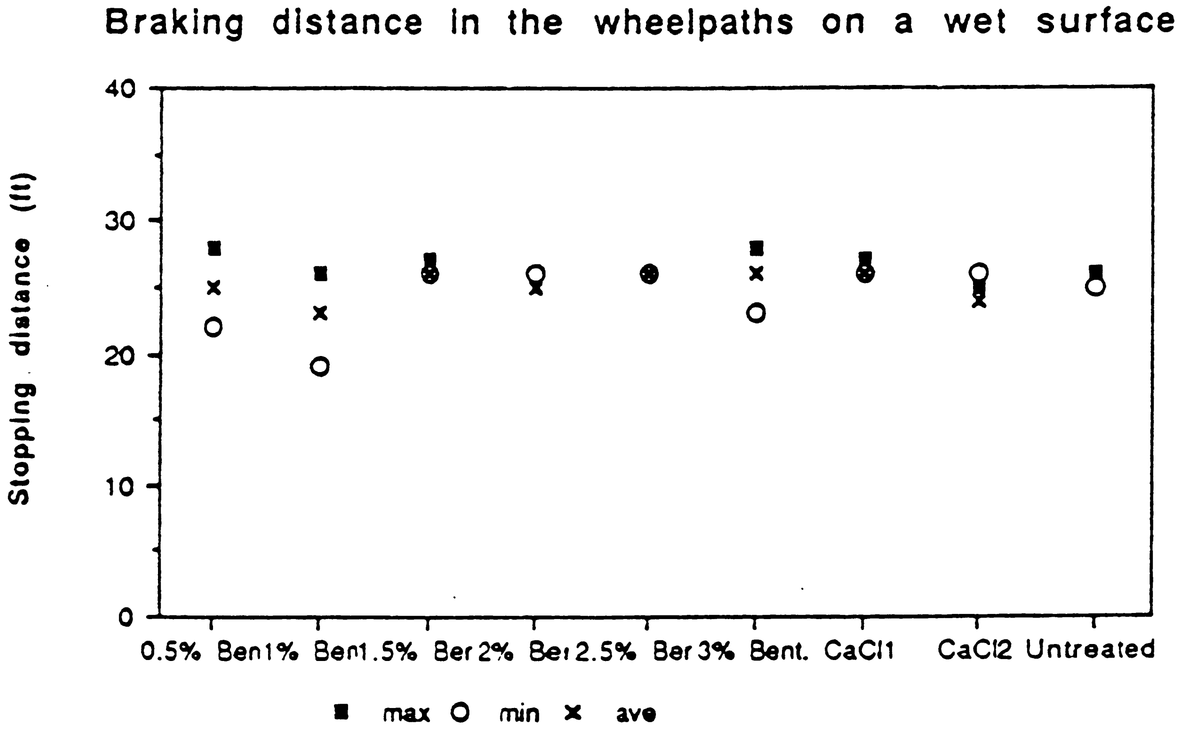
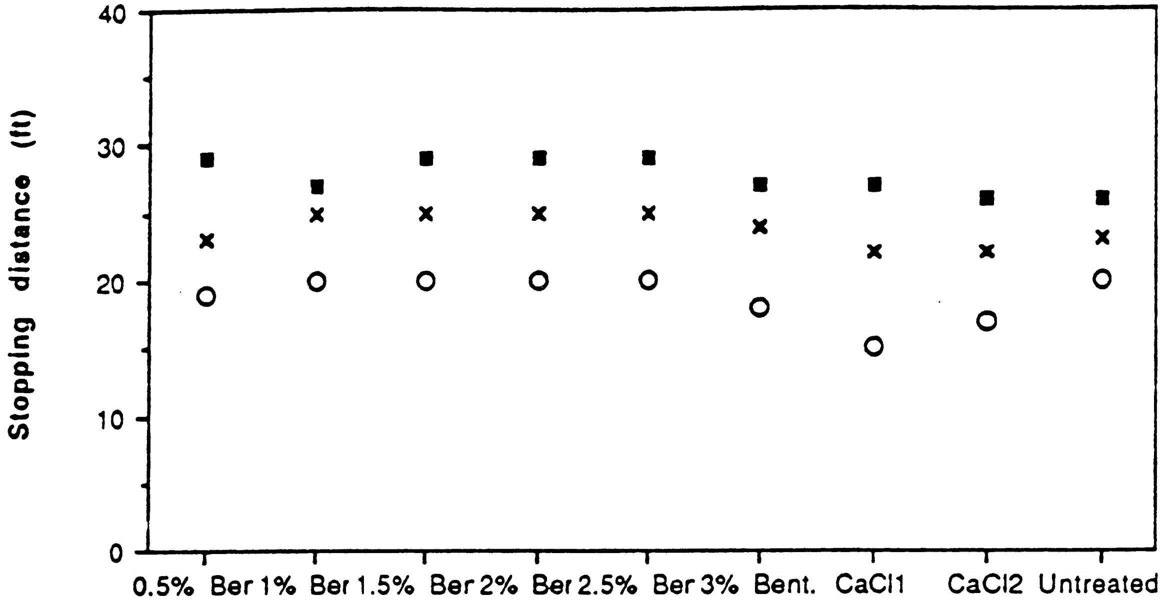

Braking distance in the wheelpaths on a wet surface

Figure 33. Wheelpath braking distance results for Adair County test road

Braking distance out-of-the wheelpaths on a dry surface



Braking distance out-of-the wheelpaths on a wet surface

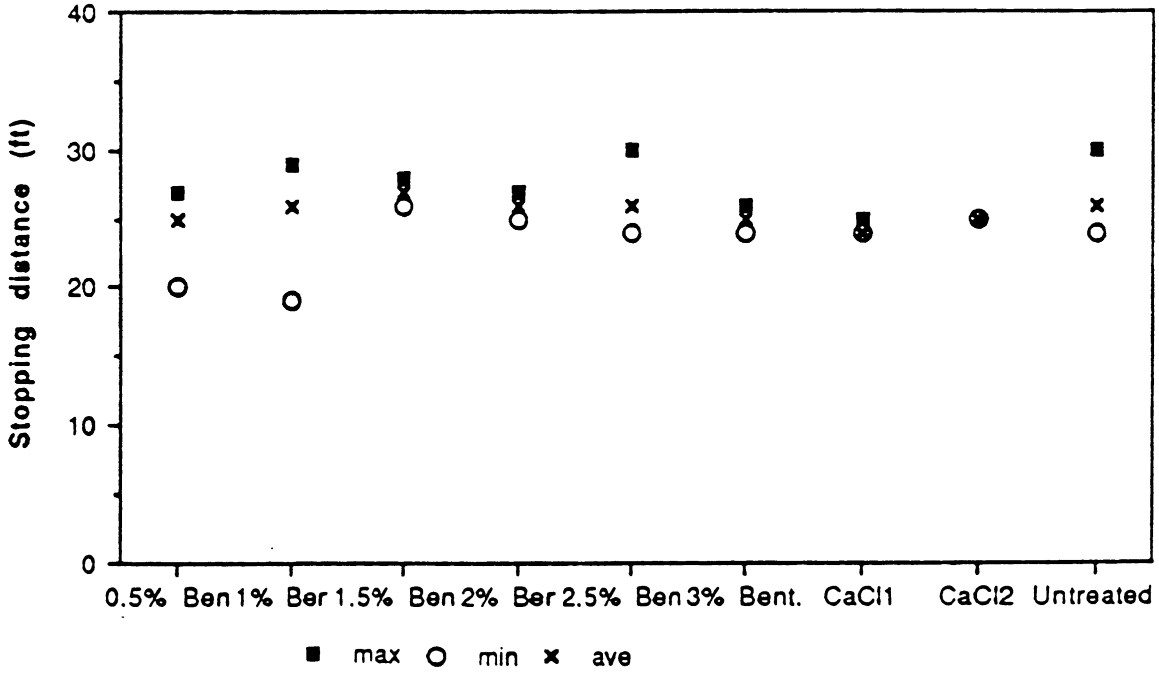


Figure 34. Out-of-Wheelpath braking distance results for Adair County test road

LABORATORY TESTING

Before and during the time of construction, several bag samples of untreated and treated aggregates were obtained from all test sections. Other samples were collected during the entire project period. These samples were returned to the laboratory and tested for gradation. Selected samples were prepared for scanning electron microscopy analysis.

Gradation Analysis

Two methods of gradation analysis were conducted on each sample, (1) extended dry sieve analysis (10 minutes on a Gilson) followed by (2) wet sieve analysis of each sample. Figure 35 presents the average sieve analysis results for all untreated aggregate samples for the Dallas County road. From that figure we can see the material is finer than IDOT specifications for crushed stone surfacing. Assuming the material originally met the specifications, this implies degradation had reduced the material to a finer gradation and/or the subgrade had pumped. From Figure 36, it is noted that for the #30, #50 and #200 material, the washed results are slightly higher than the dry sieve results. Figures 36 and 37 show the gradation results for 1.5% and 0.5% at the construction time for Adair and Dallas County roads, respectively. The samples were allowed to air dry prior to analysis. There is a wide difference noted between dry and wet sieve analysis values on the #30, #50 and #200 sieve. This indicates strong dry bonding and aggregation of fines to the particles retained on these sieves. Figures 38 and 39 present the results from samples obtained from the same sections after 60 days following construction. Again, the dry bonding and aggregation is evident from the #30, #50 and #200 sieve results. These test results appear to confirm the fact that the soda ash dispersed bentonite was acting to aggregate the fine particles.

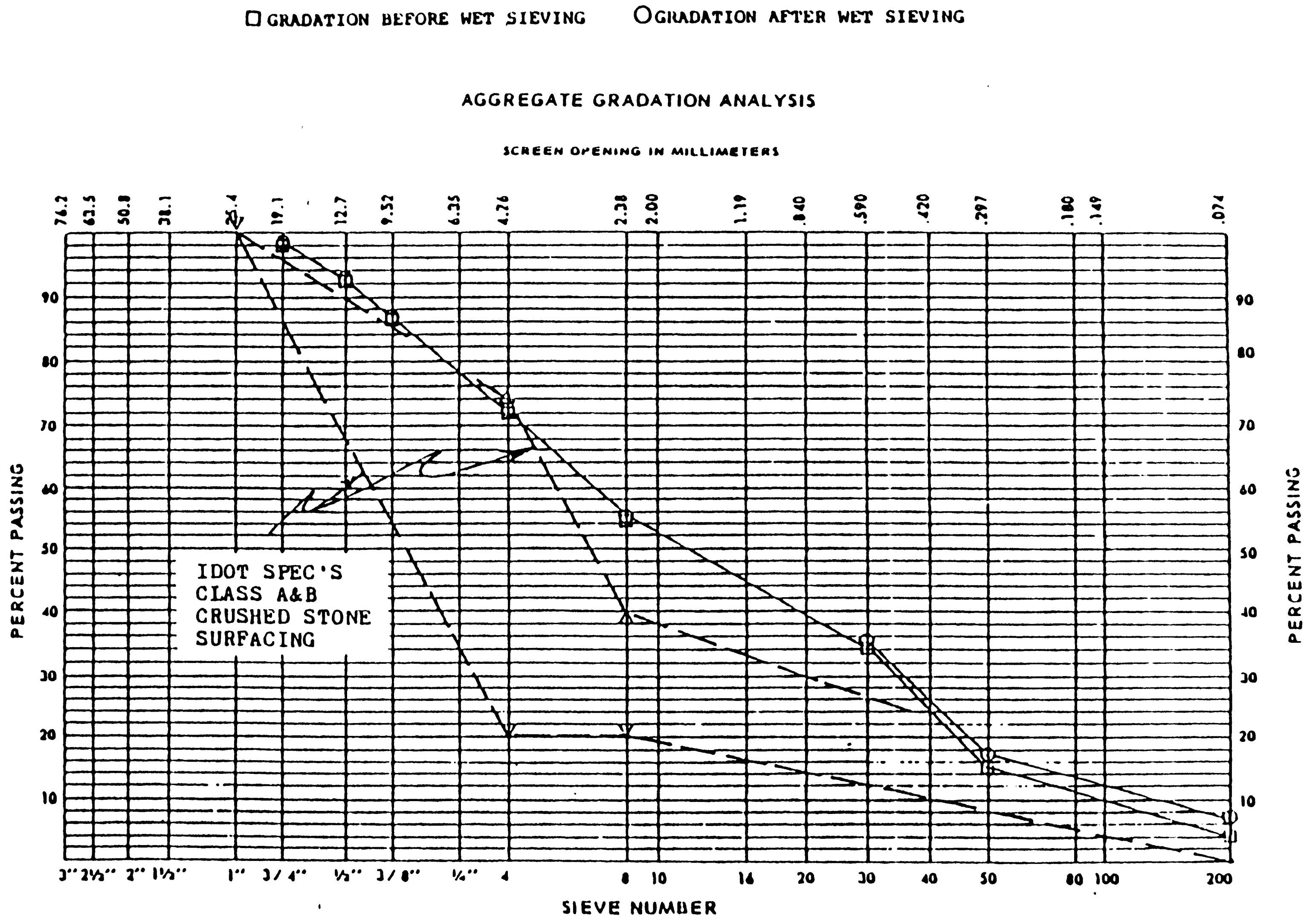


Figure 35. Average gradation test results for all untreated aggregate samples, Dallas Co.

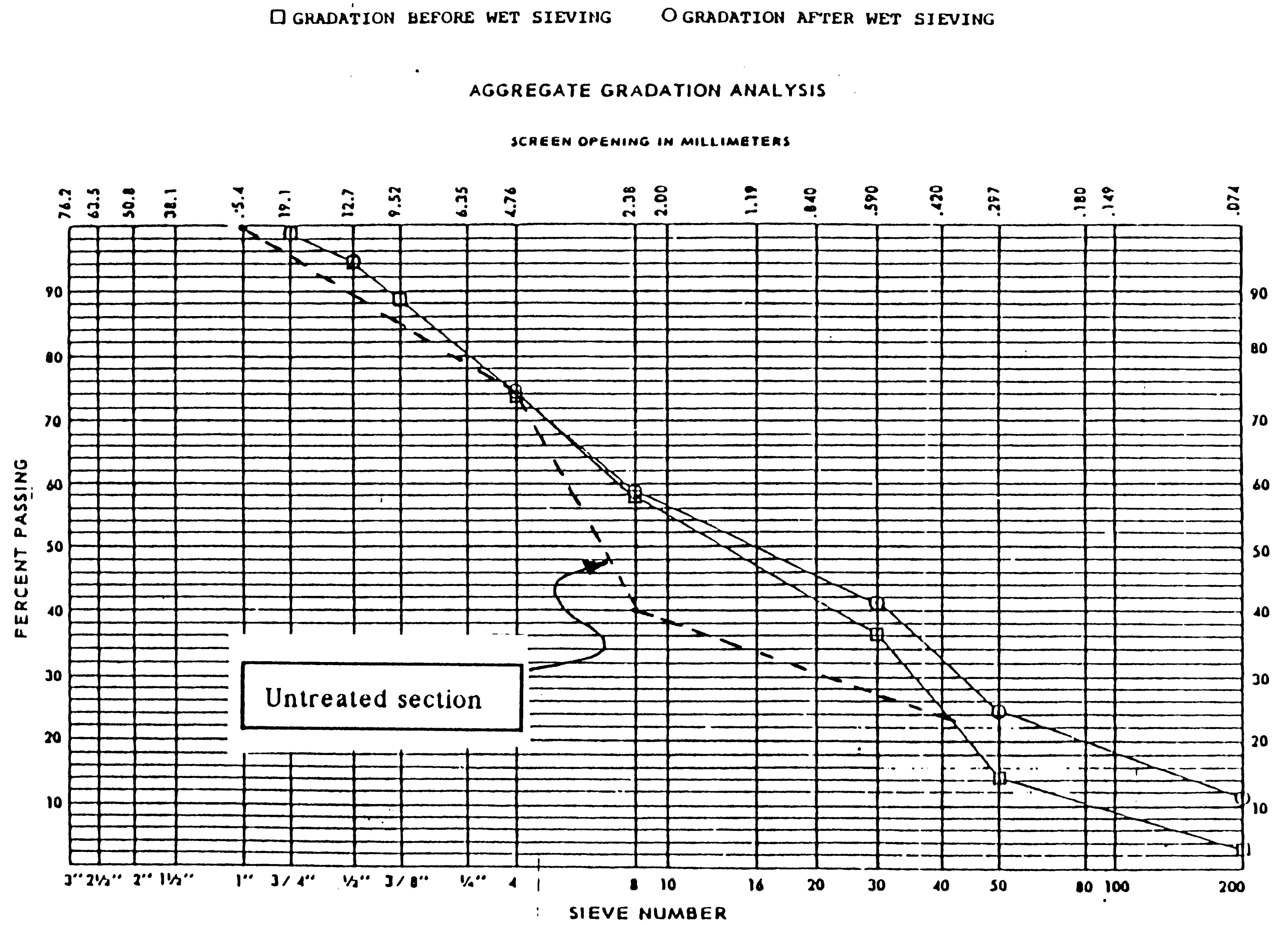


Figure 36. Gradation test results for 0.5% Bentonite treatment at construction time, Dallas County

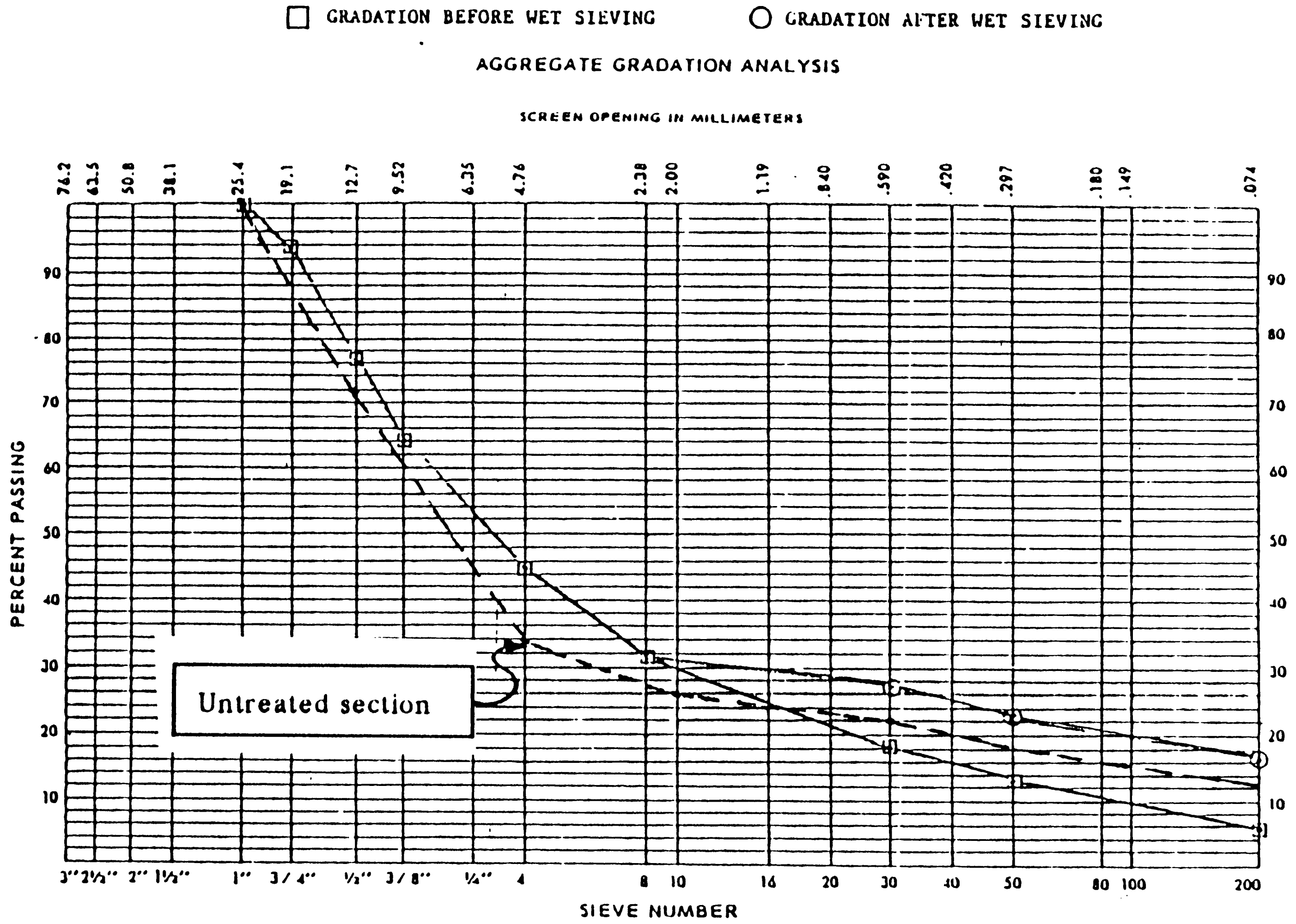


Figure 37. Gradation test results for 1.5% Bentonite treatment at construction time, Adair County

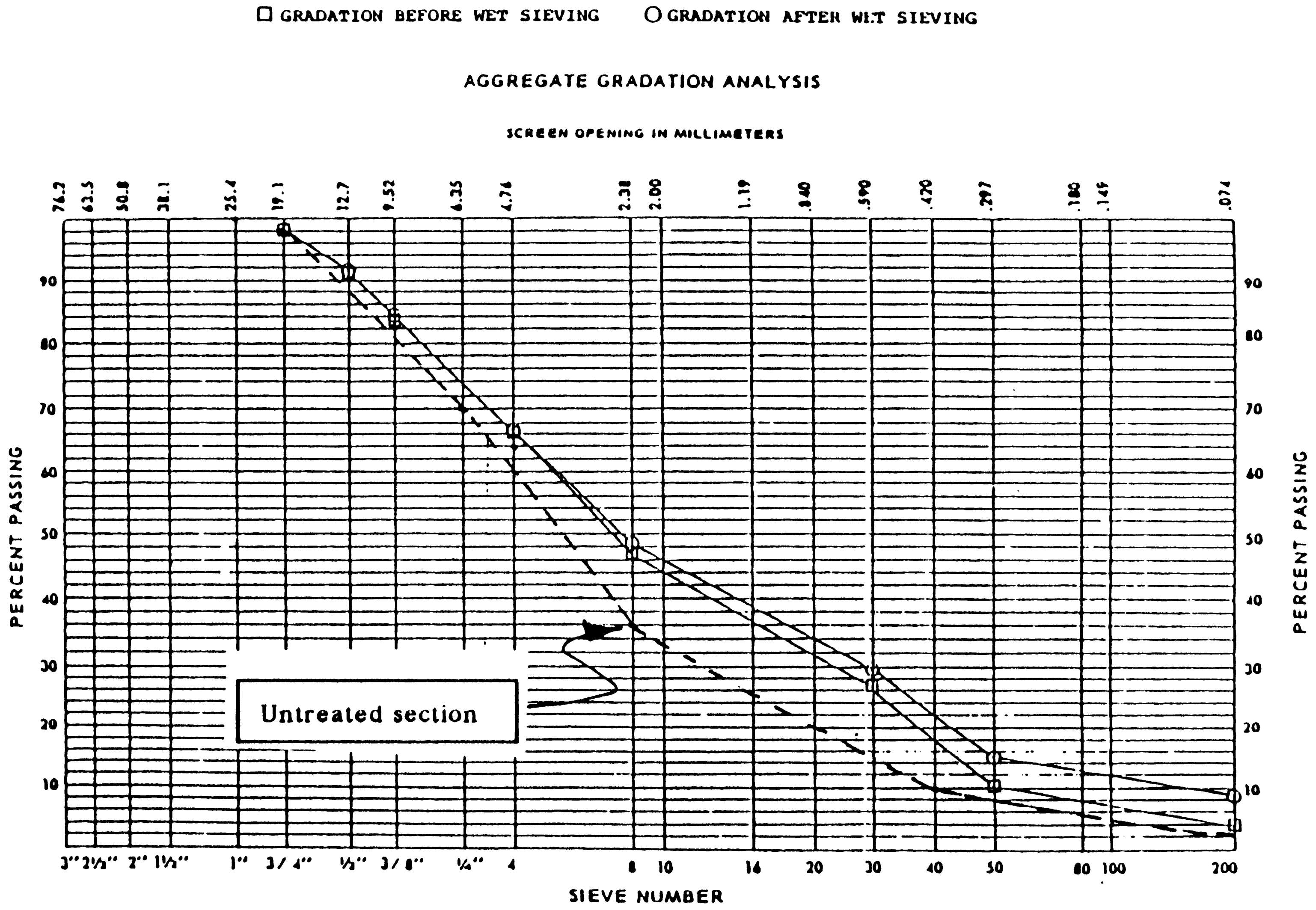


Figure 38. Gradation test results for 0.5% Bentonite treatment after 60 days following construction, Dallas County

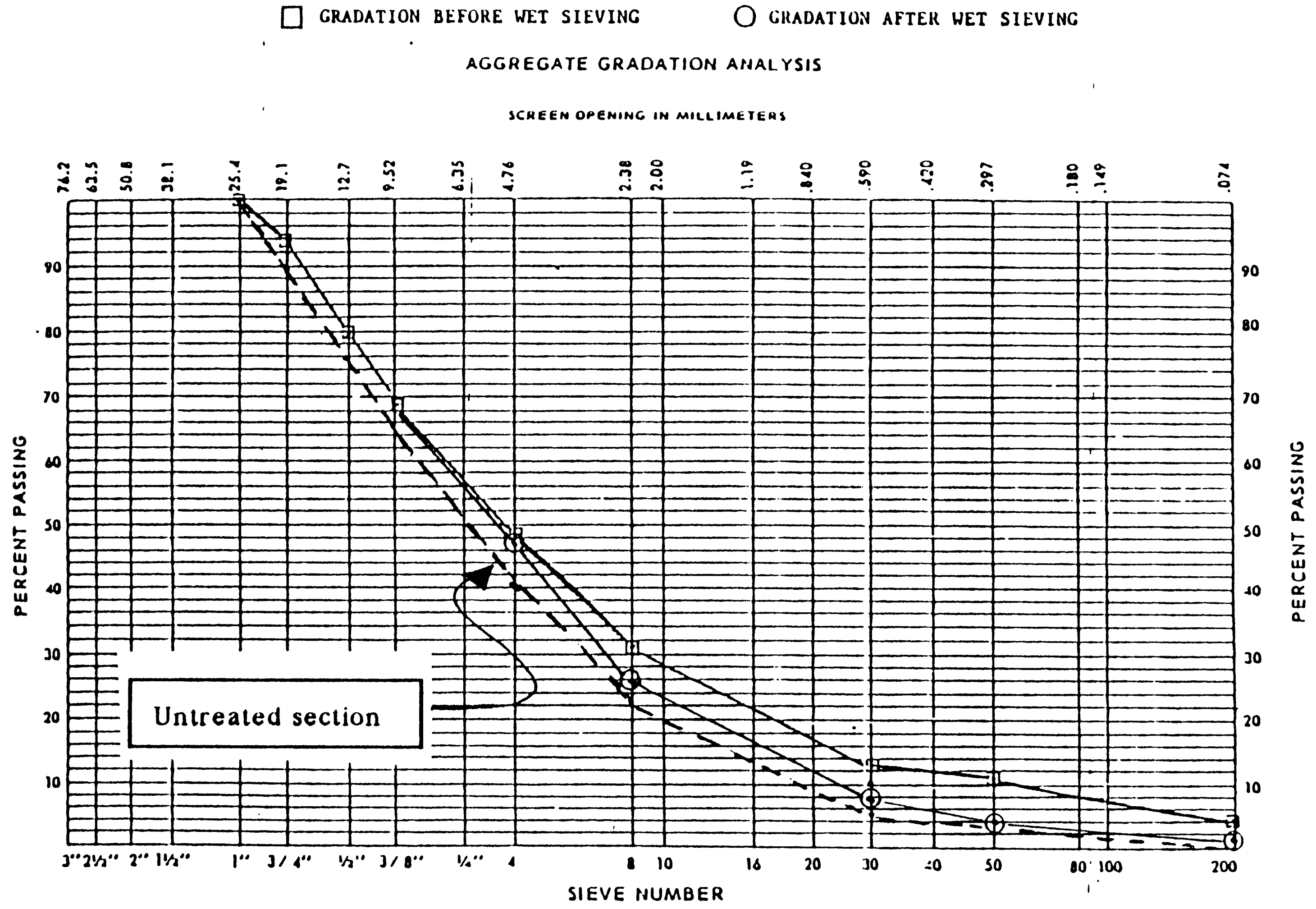


Figure 39. Gradation test results for 1.5% Bentonite treatment after 60 days following construction, Adair County

Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) is mainly used for imaging and elemental analysis. Therefore, in order to verify that particle-to-particle bonding was taking place with bentonite treatment, samples of the material retained on the #30, #50, #100 and #200 sieves from all sections of bentonite treatments were mounted for scanning SEM analysis.

The previous study on bentonite by Grim indicated that bentonite has positive charges on the surface and negative charges on the edges. The limestone has a positive charge on the surface, which makes it electrically attracted to bentonite. Thus, the particles bond together causing a reduction in dust.

After studying the bentonite material, it was concluded that the main elements in the bentonite were:

• Aluminum	Al	• Lithium	Li
• Silicon	Si	• Oxygen	O_2
• Iron	Fe	• Sodium	Na
• Potassium	K	• Calcium	Ca

Because limestone contains mainly calcium, it was decided to conduct dot-mapping on the elements that were found only in bentonite.

SEM sample preparations

A thin film of the treated material was placed on small carbon studs. After all the samples were prepared, they were sputter coated with gold. Samples were selected from each section from last year's testing from both test roads.

Dot-Mapping analysis

Dot-mapping is a very useful graphic technique. In this technique, the brightness of the SEM CRT beam at each point on the display is modulated by the x-ray output from the element of interest. The other convenient feature is the ability to remove background counts from a dot-map. The emission of continuum x-rays is essentially random with respect to time, producing a random, low density spatial distribution of events on the dot-map. X-ray counts are then output only when they are received at the mapping module with a frequency above the specified level.

In order to use the dot-mapping technique, we chose elements that were found only in bentonite, such as aluminum. Calcium was used to verify the limestone. The test was conducted on several samples from both Dallas and Adair county roads for all the applied percentages. The result from these samples were almost the same for all samples of all various percentage of treatments. Bentonite was spread over the limestone particles which indicates the function of soda ash as a dispersing agent. Also the fine dust particles were bonded to larger particles instead of to each other. The other important result was that bentonite was found between the large particles of limestone. In comparison, some samples from the untreated control sections were analyzed and no significant bonding was found. The result from these tests appear to verify particle-to-particle bonding.

Typical results are shown on the SEM photos on Figures 40, 41, and 42. These results are typical of numerous SEM observation and study from #50, #200, and minus #200 sieve dry fractions obtained throughout the project.

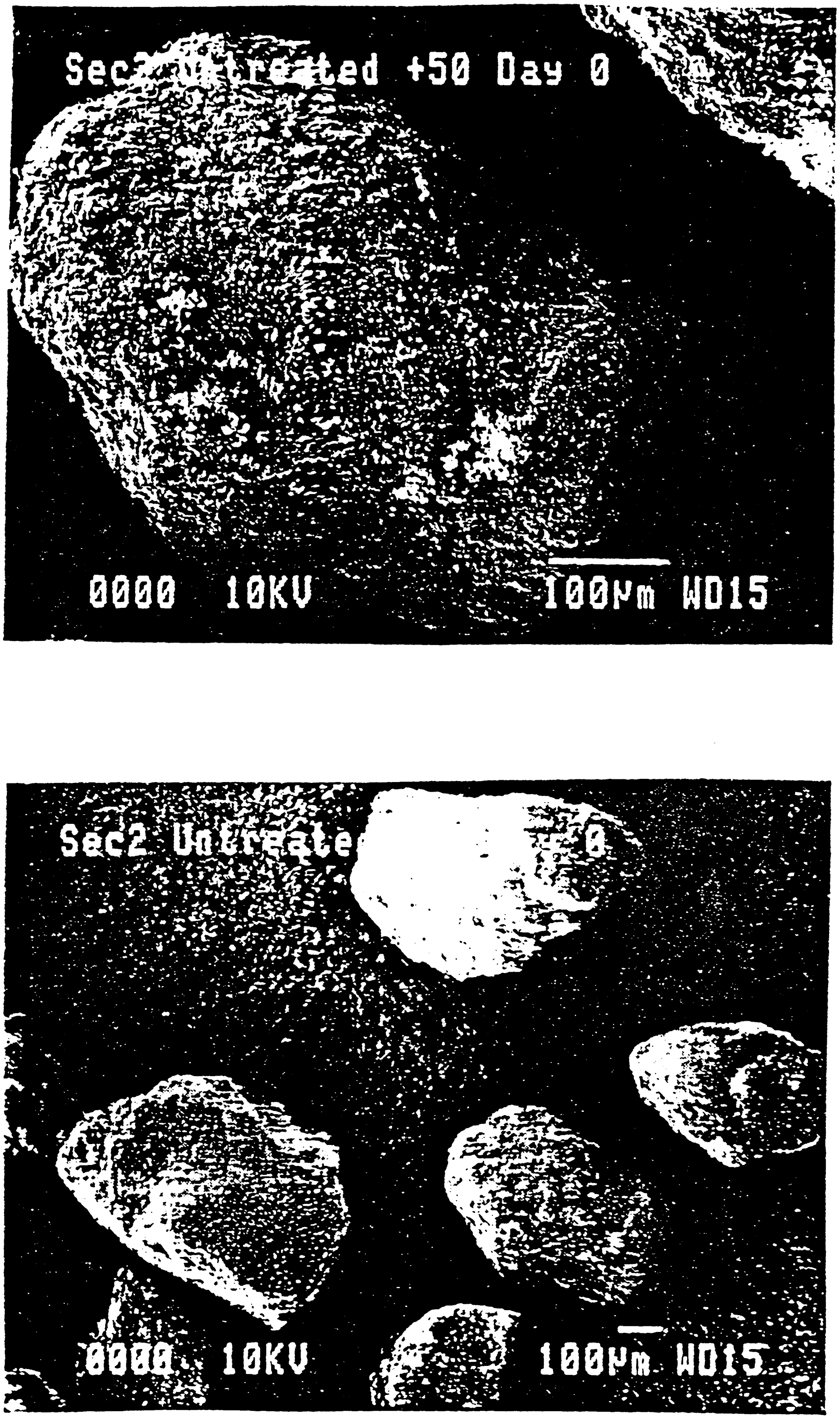
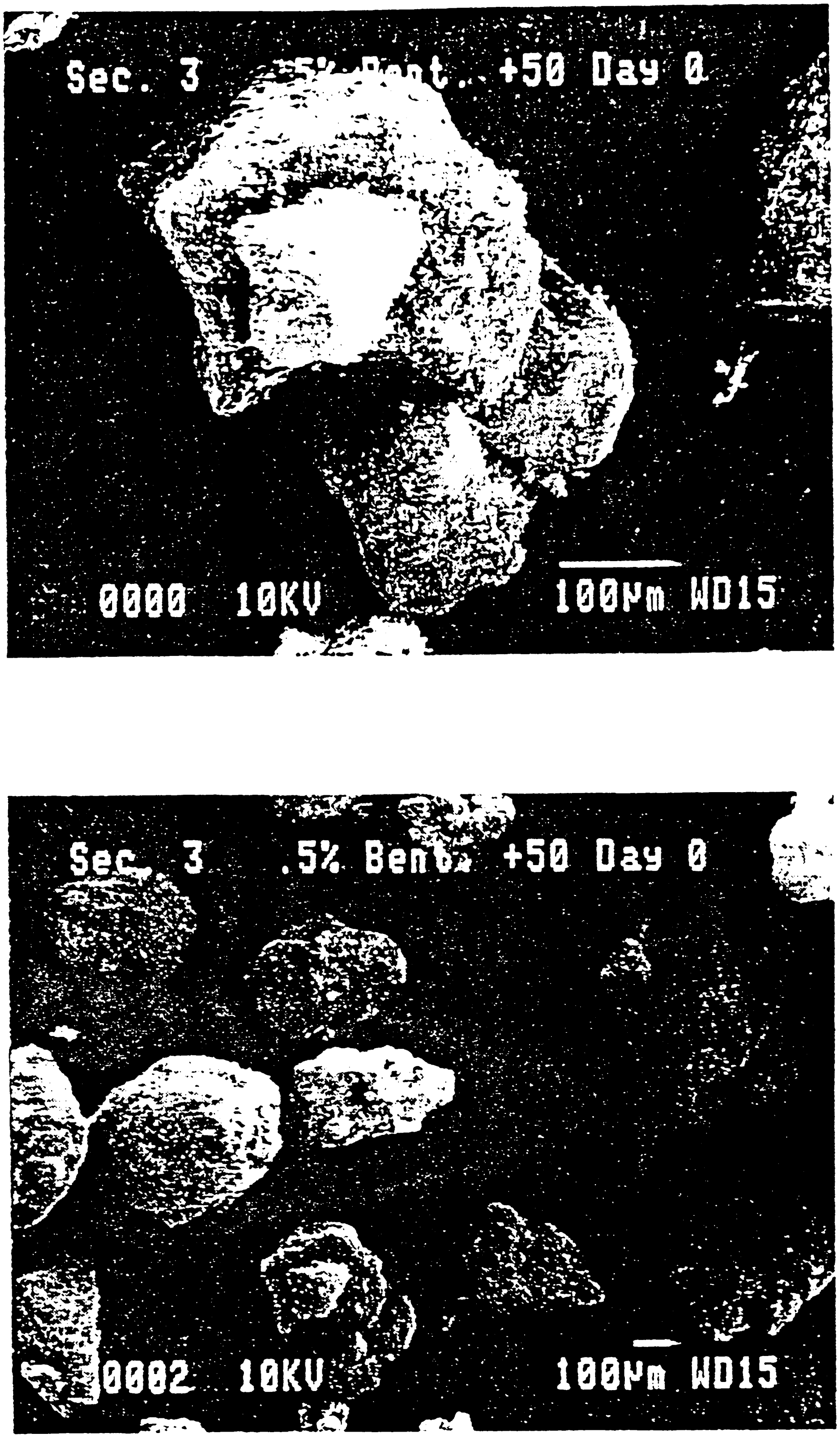


Figure 40. SEM photographs of material retained on #50 sieve from the section at the time of construction (Dallas county)



41. SEM photographs of material retained on #50 sieve from 0.5% bentonite treated section at the time of construction (Dallas Co.)

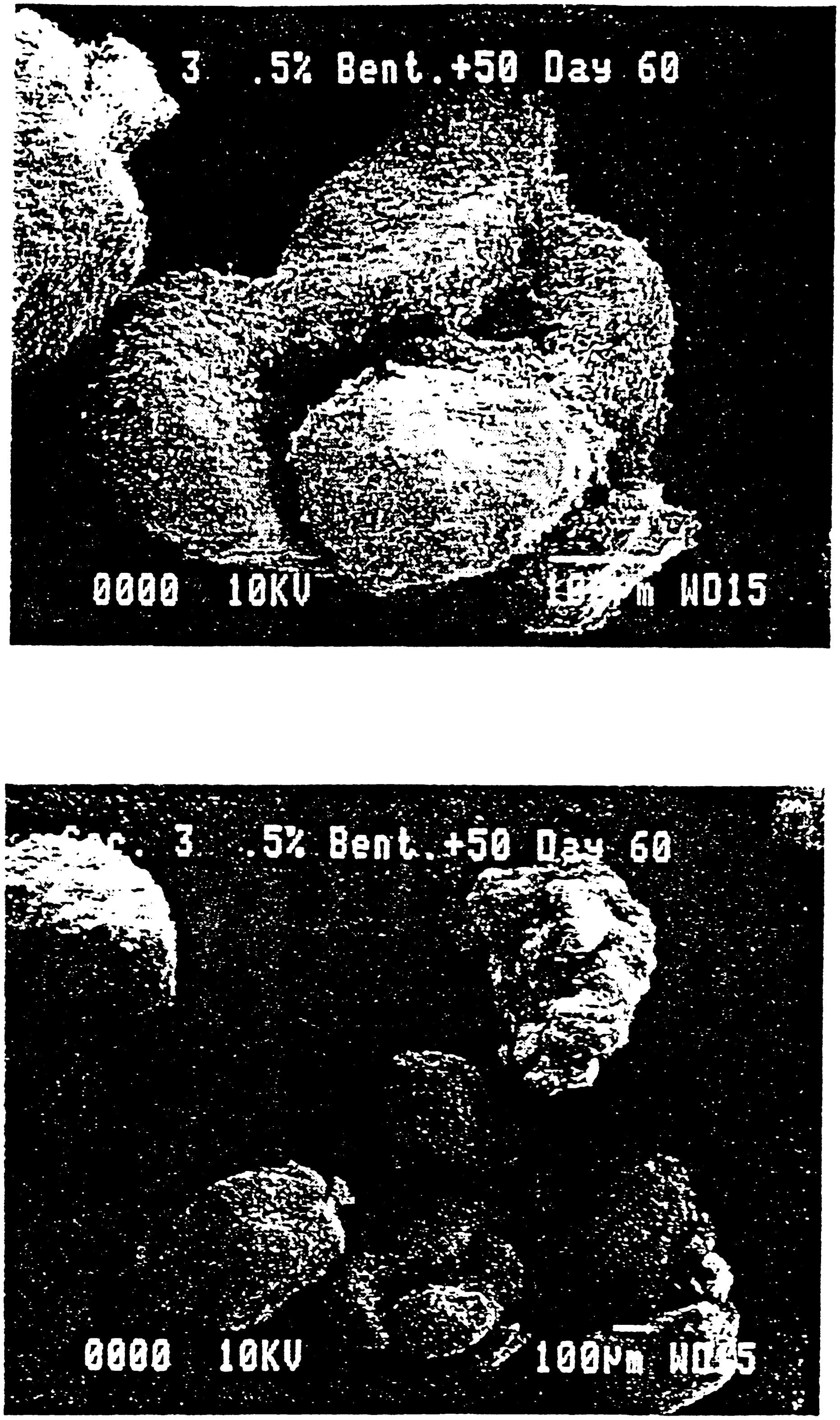


Figure 42. SEM photographs of material retained on #50 sieve from 0.5% bentonite treated section at 60 days after constructions (Dallas

COST ANALYSIS

Cost/benefit studies for fugitive dust are difficult and have many limitations, but are essential for evaluating control strategies (Roberts et al., 1975). In order for the bentonite treatment to be effective in both dust reduction and expense, a cost comparison was performed on each bentonite treatment, and the calcium chloride treatment. The cost of equipment and labor was obtained from private firms. It was assumed that each mile of treatment will take eight hours to finish. Table 6 presents the expense for each treatment per mile.

Table 6. Costs of Bentonite and Calcium Chloride Treatments per mile

Treatment	Equipment, $/hr	Labor, $/hr	Material, $	Total Cost, $
0.5% Bentonite	56	50	2660	3492
1.0% Bentonite	56	50	2790	3622
1.5% Bentonite	56	50	2925	3757
2.0% Bentonite	56	50	3050	3882
2.5% Bentonite	56	50	3160	3990
3.0% Bentonite	56	50	3315	4147
Calcium Chloride	--	--	--	16133

The bentonite treatment cost estimate was based on two motor graders at $23.67/hour each, two skilled operators at $10.55/hour each, two distributors at $4.56/hour each, and three laborers at $9.70/hour each.

Comparison of the calcium chloride and the bentonite treatments in terms of percent of dust reduction for the Adair County test road is presented in Table 7. The two year estimated duration was the total testing period for the Dallas test road. Bentonite treatment showed effectiveness for the the entire two years period therefore the duration was estimated to be two years for Adair.

Table 7. Comparison of Calcium Chloride and Bentonite Treatment

Treatment	Estimated Cost ($/mile)	Treatment Efficiency (% Reduction)	Estimated Duration (months)	Comments
Calcium Chloride	16133	50	3-4	Not effective in low relative humidity
0.5% Bentonite	3510	28	18-24	
1.0% Bentonite	3643	26	18-24	Effective in low and high humidity
1.5% Bentonite	3775	30	18-24	
2.0% Bentonite	3902	31	18-24	
2.5% Bentonite	4010	32	18-24	
3.0% Bentonite	4167	45	18-24	

The percent of reduction for this comparison study was only taken for representative data. This comparison shows that the calcium chloride treatment has a better reduction rate; however, the duration is very short compared to the bentonite treatment. If the duration time is considered, the results of the comparison would show that bentonite is the more effective treatment.

In Table 8 a different comparison calculation was conducted. The total cost for each treatment was divided by the maximum estimated duration time and then divided again by the estimated treatment efficiency which gives the treatment cost per mile per percent reduction per month. The treatment efficiency was the average of all similar data parameters over the entire period of testing. The period of efficiency determined the duration for each treatment. As a result, both treatment efficiency and duration are qualitative data and therefore estimated. This table shows that calcium chloride treatment has a higher cost than bentonite treatment, because of the short duration of the calcium chloride treatment. Thus, bentonite treatment is more cost effective in the long-run, the efficiency, however, is less than the calcium chloride treatment in the short-run.

Table 8. **Comparison of Calcium Chloride to Bentonite, considering Duration Time**

Treatment	Treatment Cost Comparison ($/mile/%reduction/month)
Calcium Chloride	81
0.5% Bentonite	6
1.0% Bentonite	7
1.5% Bentonite	6
2.0% Bentonite	6
2.5% Bentonite	6
3.0% Bentonite	5

This table, shows that bentonite treatment appears very economical compared to the calcium chloride in the long-run.

Table 9 presents a comparison between Bentonite and other treatments. The cost and efficiency varies for the different treatments. For example, oiling has the highest cost efficiency ratio, which is the total cost per mile per percent of reduction, and the highest treatment efficiency. The ideal treatment would be the one that has a very low cost efficiency ratio and high percent of reduction.

In Table 9 the bentonite treatment was compared to the oiling, watering and calcium chloride treatments obtained from Hoover et al., 1981. The estimated cost-efficiency ratio for bentonite was calculated by taking the total cost for the construction of one mile of a 3% bentonite treatment (4,167 dollars) and was divided by the the average percentage of reduction (45 percent) which give the 93 cost-efficiency ratio for bentonite. This ratio was then compared to all the other types of treatments and presented in Table 9.

Table 9. Comparison of Bentonite to Other Treatments

Treatment	Estimated Cost-Efficiency Ratio, Total Annualized Cost, $/mile/% Reduction	Treatment Efficiency, % Reduction of Emissions
Oiling	2906	50 to 98
Watering	1302	40
Calcium Chloride	491	60
Bentonite 3%	93	45

These data indicate that bentonite is an economical treatment for dust reduction.

SUMMARY AND CONCLUSIONS

The results of the data for both Dallas and Adair county roads indicate the following:

- Both dry and wet methods can be used in applying a bentonite treatment. However, for higher percentages of bentonite, the dry mixing process must be used.
- Soda ash dispersed bentonite solutions (7.5% solution by weight for wet mixing and 50 lbs. of soda ash to 1000 gallons of water in dry mixing process) can be field mixed and applied using conventional spray distribution equipment. Blade mixing of the loose treated material was rapid and adequate for both test roads.
- From the Adair County test road, the 2.5 and 3.0% treatment appears to be comparable to the calcium chloride treatment in dust reduction.
- Dust reduction observed in the bentonite treated sections appears to be the result of bentonite functioning as a bonding agent to bind particles to larger particles (particularly the #30 to #200 sizes) producing aggregated fine particles.
- The bonding and aggregation mechanism of the bentonite treatments appears recoverable from environmental affects of winter, and from alternating wet and dry periods.
- Braking tests indicate no adverse characteristics for bentonite treated sections over the project period.
- The calcium chloride treatment was very effective in the first three months of testing. However, the effectiveness was much smaller than the bentonite treatment at the end of the testing period.
- The calcium chloride treatment is not as effective in dry weather (low relative humidity) compared to the bentonite treatment.
- Normal maintenance blading practice can be followed for the bentonite treatment.

- Bentonite treatment indicated its effectiveness with the addition of new materials. Dust reduction was still obtained after the addition of 300 tons per mile of aggregate on Dallas County road.

In conclusion, bentonite treatment should be considered as an alternative to calcium chloride for dust palliation for limestone surfaced secondary roads.

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