Development of an Economic Dust Palliative for Limestone Surfaced Secondary Roads

FINAL REPORT

FEBRUARY 1990

IOWA DOT PROJECT HR-297

Sponsored by the Highway Division of
the Iowa Department of Transportation
and the Iowa Highway Research Board.

engineering research institute
iowa state university
ISU-ERI-Ames-90407

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ABSTRACT

This research project was directed at laboratory and field evaluation of sodium montmorillonite clay (bentonite) as a dust palliative for limestone surfaced secondary roads. It had been postulated that the electrically charged surfaces of the clay particles could interact with the charged surfaces of the limestone and act as a bonding agent to agglomerate fine (-#200) particulates and also to bond the fine particulates to larger (+#200) limestone particles.

Laboratory testing using soda ash dispersed bentonite treatment of limestone fines indicated significant improvement of compressive strength and slaking characteristics. It was recommended that the project proceed to field trials and test roads were constructed in Dallas and Adair counties in Iowa.

Soda ash dispersed bentonite solutions can be field mixed and applied with conventional spray distribution equipment. A maximum of 1.5 percent bentonite (by weight of aggregate) can be applied at one time. Higher applications would have to be staged allowing the excess moisture to evaporate between applications. Construction of higher application treatments can be accomplished by adding dry bentonite to the surfacing material and then by dry road mixing. The soda ash water solution can then be spray applied and the treated surfacing material wet mixed by motor graders to a consistency of 3 to 4 inch slump concrete. Two motor graders working in tandem can provide rapid mixing for both methods of construction.

Calcium and magnesium chloride treatments are 2 to 3 times more effective in dust reduction in the short term (3-4 months) but are prone to washboarding and potholing due to maintenance restrictions. Bentonite treatment at the 2 to 3 percent level is estimated to provide a 30 to 40 percent dust reduction over the long term (18-24 months). Normal maintenance blading operations can be used on bentonite treated areas. Vehicle braking characteristics are not adversely affected up to the 3.0 percent treatment level.

The bentonite appears to be functioning as a bonding agent to bind small particulates to larger particles and is acting to agglomerate fine particles of limestone. This bonding capability appears recoverable from environmental effects of winter, and from alternating wet and dry periods. The bentonite appears to be able to interact with new applications of limestone maintenance material and maintains a dust reduction capability.

Soda ash dispersed bentonite treatment is approximately 10 times more cost effective per percent dust reduction than conventional chloride treatments with respect to time. However, the disadvantage is that there is not the initial dramatic reduction in dust generation as with the chloride treatment. Although dust is reduced 30 to 40 percent after treatment there is still dust being generated and the traveling public or residents may not perceive the reduction.

INTRODUCTION

In 1971, the Iowa Department of Environmental Quality (DEQ) established "fugitive dust" regulations for the state of Iowa. Dust generated by vehicular traffic on the 70,000 miles of gravel and crushed stone surfaced secondary roads in the state has been, and is, of concern with regard to these regulations. Increased public awareness of the DEQ regulatory actions will undoubtedly lead to increasing pressure brought against county and state highway agencies to address the dust problem of secondary roads.

The Iowa Highway Research Board has acted to address "fugitive dust" under projects HR-151 [1] and HR-194 [2]. This work utilized a number of different palliatives and proprietary products through laboratory screening, and demonstration test sections. Many of the demonstration sections are still in service and being evaluated. A common problem encountered is that many additives are good palliatives, but are not cost effective. The results of past work indicated that the bulk of "fugitive dust" that is airborne past R.O.W. limits is composed of the fine particulates of silt, clay, and colloidal sized materials (minus #200 sieve). Due to the size of these small particulates, the surface area per unit volume is very large. Since all aggregates exhibit a positively or negatively charged surface, the physical chemistry effects occuring between surfaces of fine particulates and chemical dust palliatives become highly significant. Past work [1, 2, 3] also indicated that for a dust palliative to be effective, it is necessary that the fine particulates be flocculated, aggregated or somehow physically bound to larger particulates in order to prevent them from being 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.

Results of a research project [4], conducted for the Iowa Limestone Company, indicated that significant dust reduction of fine crushed limestone particulates could be accomplished by a simple treatment of small amounts of bentonite (sodium montmorillonite). The bentonite is mixed with water using sodium carbonate as a dispersing and stabilizing agent and topically applied. An application rate of 0.4 to 1.0 percent bentonite (by weight of dry aggregate) resulted in a dust reduction of 70 to 80 percent over untreated materials. What is of significance is the mechanism by which the dusting appears to have been reduced. Surfaces of calcium carbonate or limestone particles are known to be positively charged. It had been postulated that introduction of a material of opposite or negative charge, might act to bind the small particulates together. Bentonite possesses a negative charge and was selected for use. Scanning electron microscope and x-ray dot mapping of treated materials revealed the following.

1. Fine dust particles were preferentially bonded to larger particles rather than with each other.

2. Interparticle bonding was created between larger particles.

The results of this work indicated that bentonite treatment might have the potential for functioning as an effective dust palliative and a stabilizing agent for limestone surfaced roads. A laboratory testing program was initiated to determine the feasibility of field test road applications.

LABORATORY TESTING

Test Procedures and Results

One of the prime problems of limestone surfaced secondary roads is the continual abrasion and degradation, under traffic, 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 agglomorates that resist this degradation.

In order to evaluate the potential strength of the interparticle physico-chemical bonding of bentonite treated limestone, laboratory testing was initiated to evaluate the effects of wetting and drying, dispersing agent influence, strength characteristics, and soil influences.

Alden limestone aggregate was crushed and separated into various size fractions. The crushed material was then recombined into a grading which met Iowa Department of Transportation gradation limits for Class A crushed stone as outlined in the Standard Specifications Series of 1982, Section 4120.04 and gradation number 11, Section 4110.03.

Treated samples were prepared using a 10 percent solution of bentonite dispersed with sodium carbonate (soda ash). Application rate was at 2 percent bentonite by dry weight of aggregate. Several five pound samples of untreated and treated limestone samples were tested in a rotary mill charged with ceramic balls as a degradation medium and operated for a period of one hour. Averages of dry and washed sieve analysis test results indicated a seven fold increase in the percent passing the #200 sieve. Only minor differences were noted in the amount passing the #200 sieve between untreated and treated samples. For the treated dry sieve analysis material, dust coatings on coarse aggregate particles was observed as well as a "balling" of fines on the plus #200 sieve. Dry sieving, however, appeared to remove the adhered dust on large particles as well as destroy the "balling" of the fine fraction. Additional treated and untreated samples were prepared and subjected to rotary milling without the ceramic balls as a charge (self milled). The average of several sieve analysis results indicated about a 3 fold increase in the percent passing the #200 sieve. Again, however, only small differences between treated and untreated samples were noted. In an attempt to determine if the dispersing agent was influencing the bond strength, a series of samples were prepared using arquad as a dispersing agent. Results of these milling and sieve analysis tests, again indicated little difference in the fine fraction between untreated and treated samples.

In order to evaluate the strength of the bonding among the fine particulate fraction, a series of tests were initiated using various curing methods to simulate extremes in field exposure of temperature and moisture. One inch by one cube samples were prepared using crushed Alden limestone fines passing the #40 sieve. Treatment level was a 10 percent solution of bentonite (dispersed with both soda ash and arquad) applied at a rate of 2 percent bentonite by weight of aggregate. Water was adjusted so that the consistency of the mixes was uniform between mixes. Batches of 20 cubes were molded at a time.

Table 1 presents the results (average of at least 2 specimens) of slaking, strength, and moisture content tests on air cured samples of untreated and treated limestone fines. The bentonite treated samples were prepared using both arquad and soda ash as a dispersing agent. Slaking tests were conducted by completely submerging the samples over an open mesh support and measuring the time it took for the sample to collapse through the mesh. Comparison of the slaking data in Table 1 indicates that the arquad dispersed

Table 1. Slaking and strength properties, bentonite treated limestone fines, air cured

	Untreated Control			Arquad Dispersant			Soda Ash Dispersant		
Age (days)	Slaking Time (min)	Comp. Strength (psi)	Moist. Cont. (%)	Slaking Time (min)	Comp. Strength (psi)	Moist. Cont. (%)	Slaking Time (min)	Comp. Strength (psi)	Moist. Cont. (%)
4	3	65	0.1	25	195	0.2	255	180	0.2
6	3	-	-	17	-	-	215	-	-
8	4	-	-	15	-	-	235	-	-
9	4	50	0.2	13	165	0.4	185	205	0.5
12	2	75	0.4	13	135	0.7	170	200	0.6
14	2	60	-	13	120	-	180	175	-

bentonite samples improved slaking time by a factor of 3 to 8. The soda ash dispersed bentonite samples extended slaking time 40 to 90 times that of the untreated material. Compressive strength development using the soda ash as a dispersant was 2 to 4 times higher than for untreated material. These data indicate that soda ash dispersed bentonite treatment of limestone fines significantly increases compressive strength development and resistance to slaking.

In order to evaluate the influence of temperature on the slaking and strength characteristics, a series of samples were prepared and oven cured at 110 °F for 4 days. Samples were then removed from the oven and allowed to cure additional time both in air and in a dessicator. Table 2 presents the results which are the average of at least 2 specimens. Again, soda ash dispersed bentonite treatment was superior to arquad treatment and showed significant improvement in slaking and compressive strength characteristics over the untreated fines. These data together with the data from Table 1 indicate that the slaking and strength properties of soda ash dispersed bentonite treatment are significantly improved over a wide range of curing conditions.

Direct shear testing of treated and untreated samples prepared using minus #40 limestone fines was also conducted. Tests of partially saturated samples indicated that at low confining pressure the treated material exhibited much higher shear strength.

To investigate the influence of subgrade soil intrusion on granular surfacing material, fines samples were prepared using limestone fines combined with 20 percent by dry weight of an oxidized glacial till soil and a loess soil. Results of slaking tests on air cured and oven cured samples are given on Tables 3 and 4. Test result comparison again show significant

Table 2. Slaking and strength properties, bentonite treated limestone fines, initial 110 °F oven cure for 4 days

Added Cure	Untreated Control			Arquad Dispersant			Soda Ash Dispersant		
	Slaking Time (min)	Comp. Strength (psi)	Moist. Cont. (%)	Slaking Time (min)	Comp. Strength (psi)	Moist. Cont. (%)	Slaking Time (min)	Comp. Strength (psi)	Moist. Cont. (%)
Air 1 day	3	10	0.1	4	95	0.4	120	160	0.4
Air 5 days	3	15	0.2	7	95	0.3	40	160	0.4
Dessicator 1 day	3	15	0	5	155	0	120	185	0
Dessicator 5 days	3	15	0	4	80	-	65	145	0

improvement in slaking characteristics of the treated material, and indicate that the influence of subgrade soil intrusion may not affect the stabilizing characteristics.

Table 3. Slaking tests, 20% Loess and 80% limestone fines, bentonite treated

Cure	Slaking Time, Minutes Untreated Control	Soda Ash Dispersed
Air, 4 days	3	100
110 °F, 4 hours	2	7

Table 4. Slaking tests, 20% Glacial till and 80% limestone fines, bentonite treated

Cure	Slaking Time, Minutes Untreated Control	Soda Ash Dispersed
Air, 4 days	3	105
110 °F, 4 hours	2	7

Conclusions and Recommendations

Compressive strength and slaking characteristics of bentonite treated (soda ash dispersed) limestone showed highly significant improvements over untreated materials. This was consistent over a wide range of curing and testing conditions. Slaking characteristics of treated limestone fines plus different subgrade soils were also substantially improved. This implies that the treatment is acting as a stabilizing agent for the fine fraction, and hence, would be expected to function as an effective dust palliative. It was our opinion and recommendation that the project proceed to field trials.

TEST ROAD SELECTION

Based on crushed limestone surfacing materials source data and proximity to Ames, 26 counties were solicited by letter for interest in project participation. Ten responses were received from engineers indicating possible county interest. After phone discussion with the engineers, six counties were selected for field inspection.

The location of the counties where field inspection of test road candidates was conducted are shown on Figure 1.

Test road evaluation and selection considered the following factors.

- Road topography
- Traffic count
- Subgrade soil type
- Surfacing material source
- Distance from Ames
- County equipment type and availability

Based on field inspection observations, and discussions with the county engineers a road in Dallas County was selected for initial field trial. A road in Adair county was selected for later construction.

DALLAS COUNTY TEST ROAD

Location

The road is part of secondary road R-30 running southeasterly from Woodward and intersecting Iowa Highway 141 near Granger. Figure 2 shows the

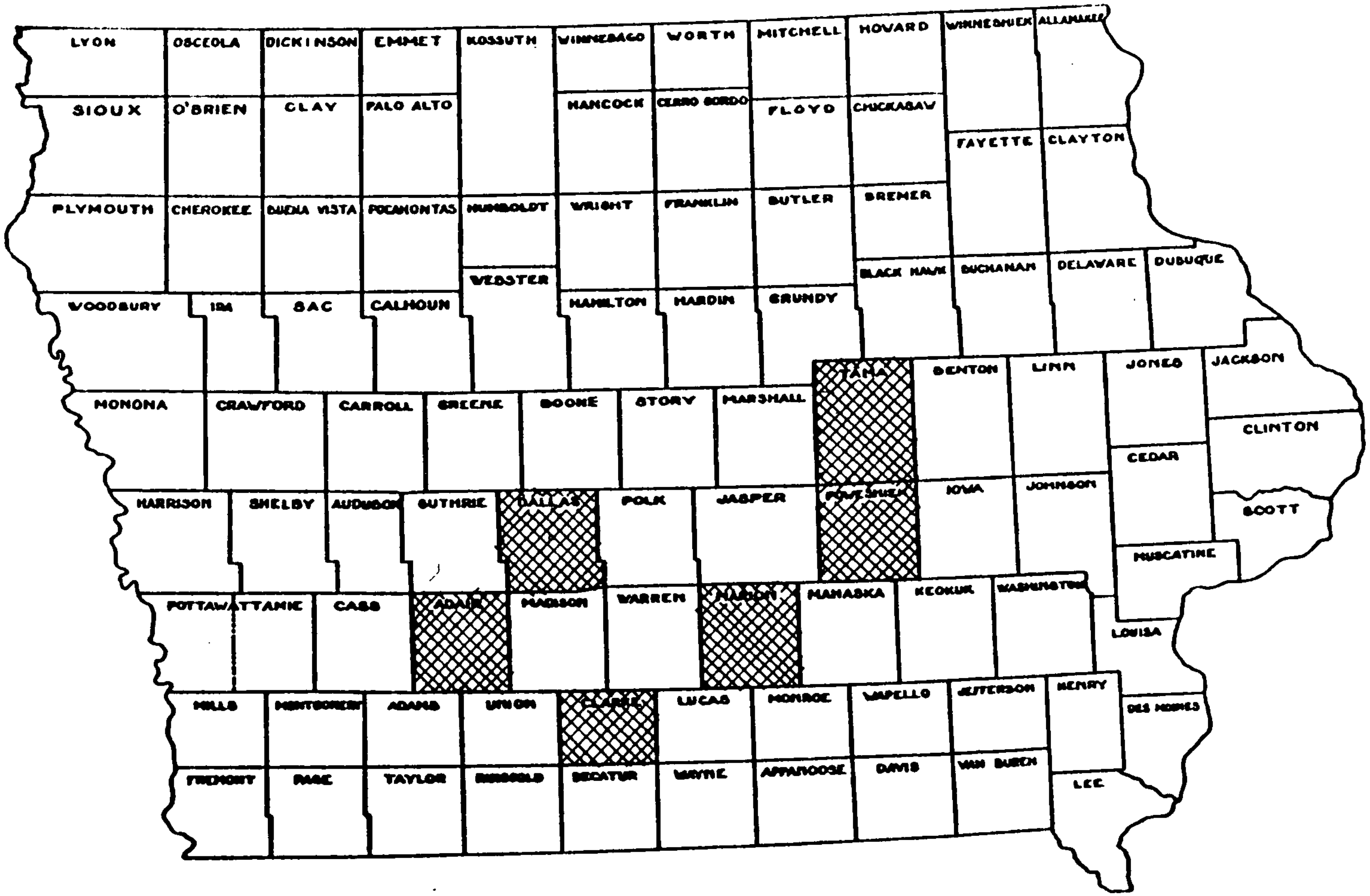


Figure 1. Counties selected for field inspection of test road candidates

DALLAS COUNTY
IOWA

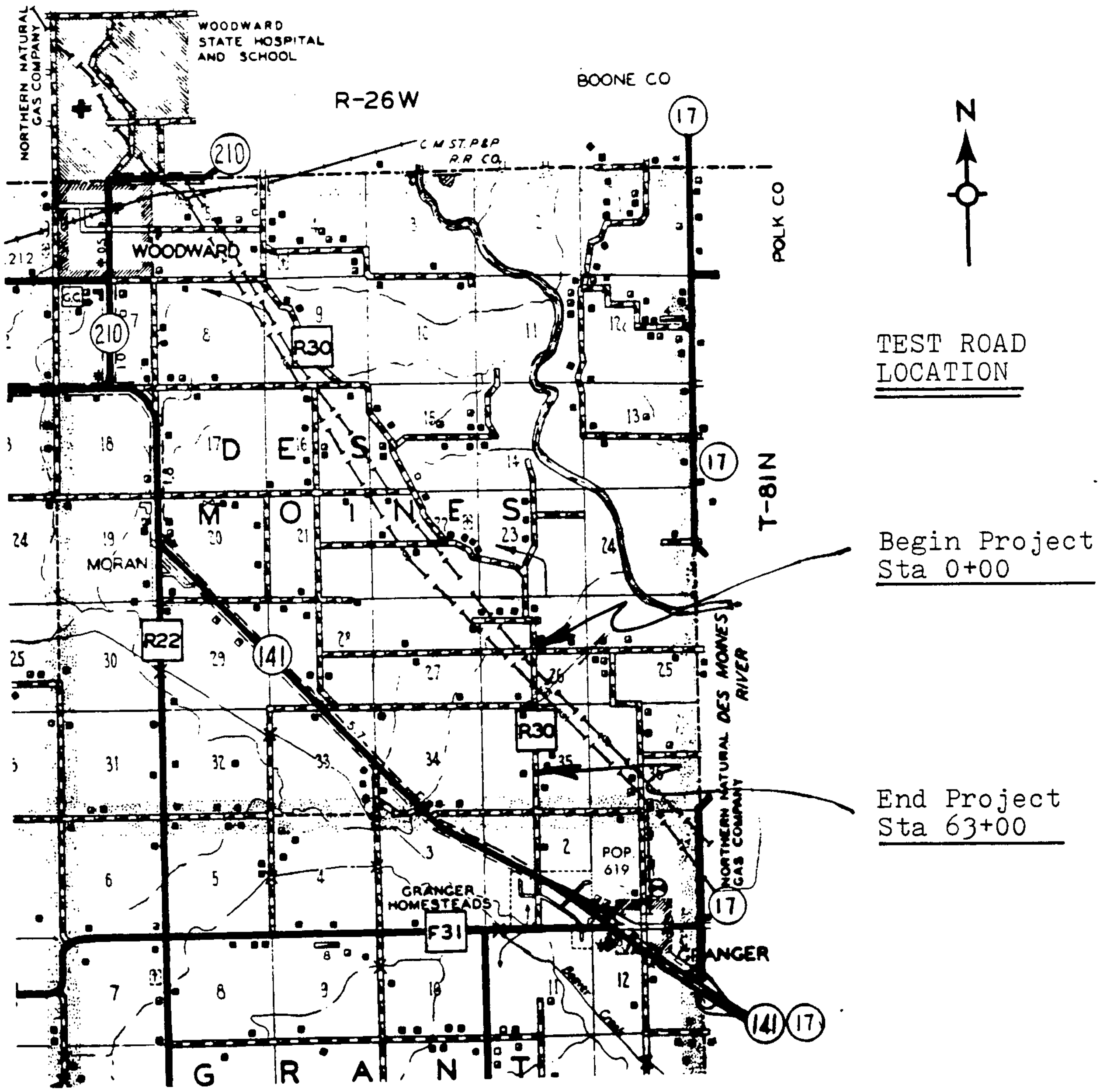


Figure 2. Test road location

location of the test road.

The road was selected because it had relatively flat topography with few bordering trees that might influence dust collection data. The road has a relatively uniform cross section and subgrade soils throughout its length. It is approximately 25 miles from Ames. Traffic counts from the Iowa Department of Transportation 1984 data indicated 75 vehicles per day (vpd).

The county engineer indicated the road was surfaced with limestone from Martin Mariettas quarry two to three years ago at an application rate of 1400 tons per mile. Maintenance limestone surfacing was applied in 1986 at approximately 300 tons per mile. Field observations indicated that gravel may have been used as a base material sometime prior to the crushed limestone surfacing applications.

Construction

During the course of road inspections and visits with county engineers, it was learned that Laverty Supply, Inc. of Indianola, Iowa might be interested in participating in test road construction. Subsequent meetings and discussions with personnel from Laverty Supply, and Dallas county engineer Gene Hardy resulted in their assistance with application of the various treatments. As a result of these meetings, it was also decided to add a 1050 foot section of magnesium chloride treatment in addition to the calcium chloride test section.

The "as constructed" test road layout is shown on Figure 3. Construction was accomplished the first of October, 1987.

Materials

Iowa Limestone Company of Alden, Iowa supplied bentonite for the project. The soda ash (sodium carbonate) dispersing agent was obtained for the project from Chemserve Corporation, Detroit, Michigan.

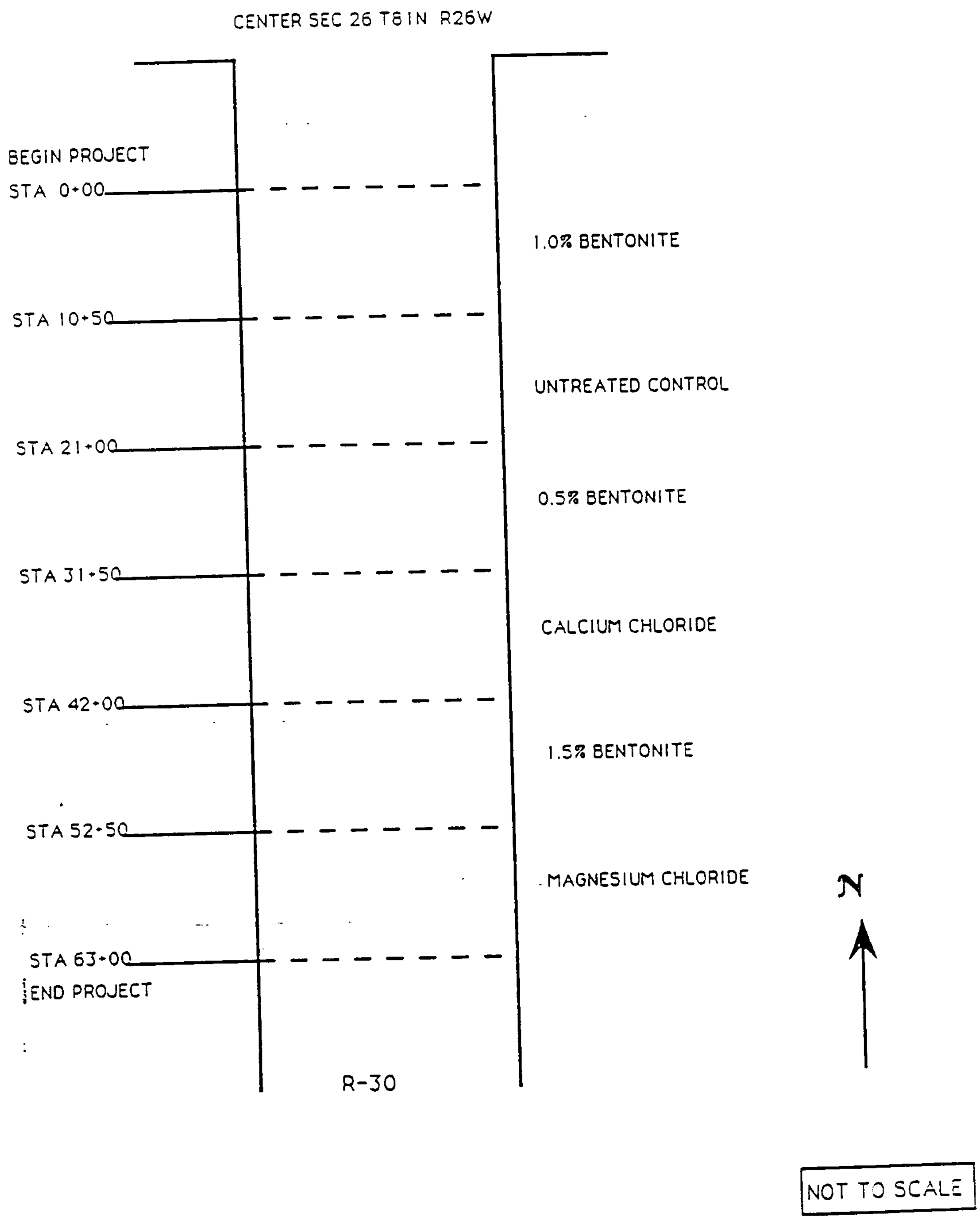


Figure 3. Dallas County Test Road Layout, as constructed

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 equipped with 200 gallon per minute centrifugal circulating pumps and had a capacity of 2500 gallons each. The center spray bars were eight feet long and equipped with eight No. 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 procedure for both the calcium chloride and magnesium chloride sections was the same. All loose surfacing material was tight bladed into a windrow along one side of the road. This material remained there. 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 percent) was applied at 0.76 gallons per lineal foot calculated for a 20 foot width. This yielded 800 gallons of magnesium chloride solution for the 1050 foot test section. The calcium chloride solution (39 percent) was also applied at 800 gallons for the 1050 foot test section.

Bentonite Section

Sample bentonite solutions of 5.0, 7.5, and 10 percent by weight had been provided to Laverty Supply personnel for their evaluation of the feasibility of spray application. They recommended field trial using the 7.5 percent solution.

For construction of the bentonite sections, all loose surfacing material was tight bladed and windrowed to one side. 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 per mile of loose surfacing materials. For each 1050 foot section about 75,000 lbs of aggregate required treatment.

Bentonite solutions were field mixed in the distributors in 1250 gallon batches at a 7.5 percent bentonite 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 three inch 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 allowed to circulate approximately 10 minutes. Fifty pound bags of bentonite were then slowly added to the discharge stream until 750 pounds had been incorporated. This was then allowed to circulate and mix for an additional 30 minutes. In general, field mixing and application of the bentonite solution proceeded very well with the conventional equipment.

For application the windrow was spread out to an approximate eight 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 1.0 percent (by dry weight of aggregate) bentonite treated section required 2500 gallons of the 7.5 percent bentonite solution. The treated material was damp to wet. In order to obtain a 3 percent applied bentonite treatment, the material would have been much too wet. It was a field decision to change the 2 and 3 percent treated sections to 0.5 and 1.5 percent respectively. Construction was completed on that basis.

Field Testing

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

1. Fugitive dust tests (in and out of wheelpaths) using high volume air sampling of dust generation under traffic.

2. Braking tests to evaluate the influence of treatment on stopping distances.

Air Sampling

Two high volume stationary air samplers manufactured by General Metal Works were purchased for use on the project.

The high volume 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 [5].

The high volume sampler holder consists of three main parts, shown in Figure 4.

- A blower 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 4.

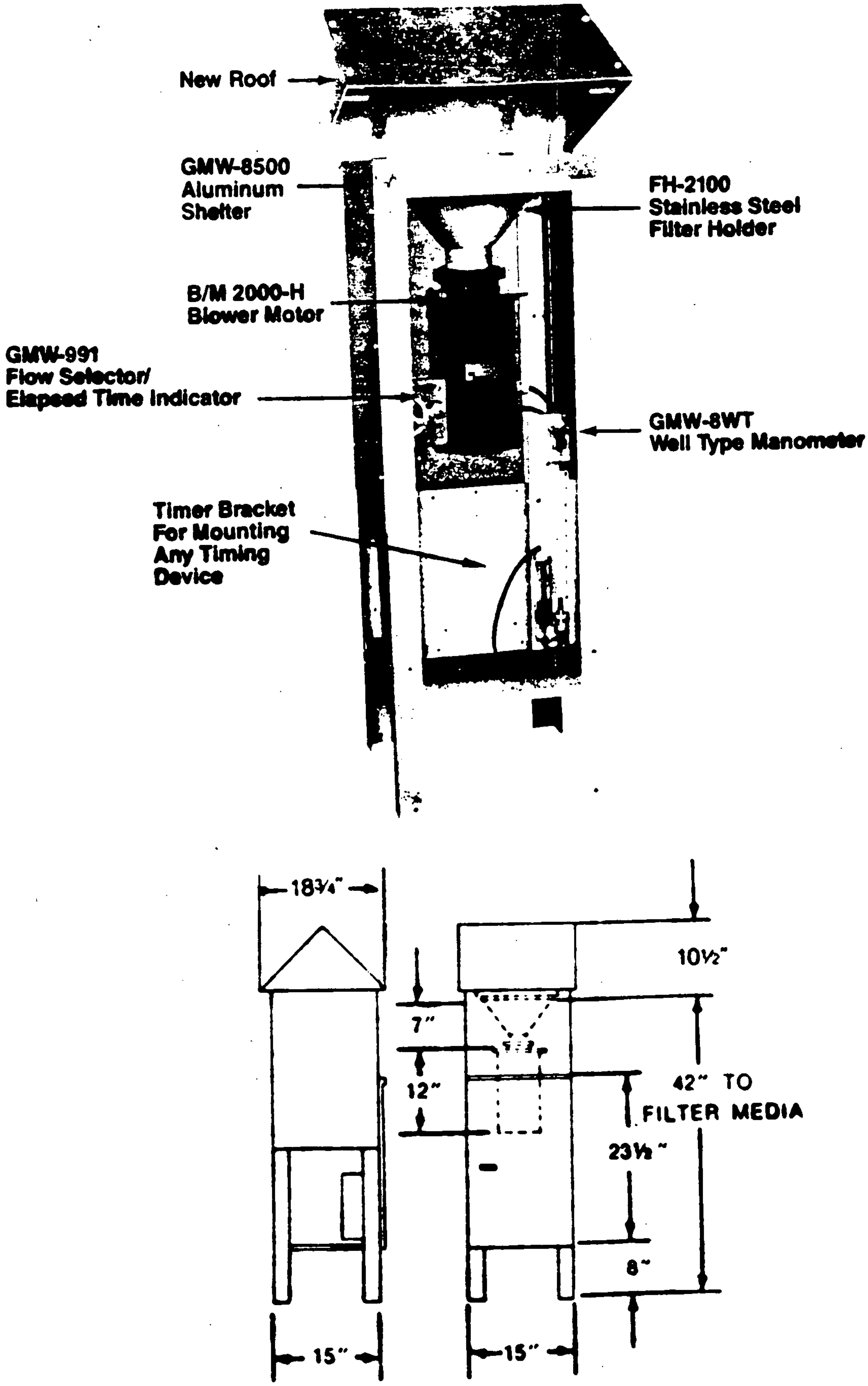


Figure 4. General Metal Works high volume air sampler

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

- A flow system. The system provides a continuous flow measurement.

- A flow controller. The controller controls the flow through the sampler to $\pm$ 1 ft^3/min under variation in filter loading.

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 percent for particles 0.30 mm in diameter. These filters were purchased for this project from General Metal Works Corporation.

Dust testing was conducted periodically as weather permitted. Both air samplers were placed in the center of each test section one on each side of the road. The sampler blower motors were powered by a gas generator. Ten passes of a vehicle, traveling at 40 to 45 mph were made between the samplers for each test on each section. The filters with the collected dust were sealed in the field and returned to the laboratory for testing.

Results of dust generation data obtained from October 1987 through August of 1989 are shown on Figures 5 through 14. Dust testing in wheelpaths was initiated immediately after construction. Testing out-of-the-wheelpaths was initiated in the spring of 1988 to evaluate treatment effects on loose surfacing material. Results shown are relative (plus or minus) to the results obtained for the untreated sections for each series of tests. Dallas County applied 300 tons of new Class A limestone maintenance surfacing to the road in August 1988.

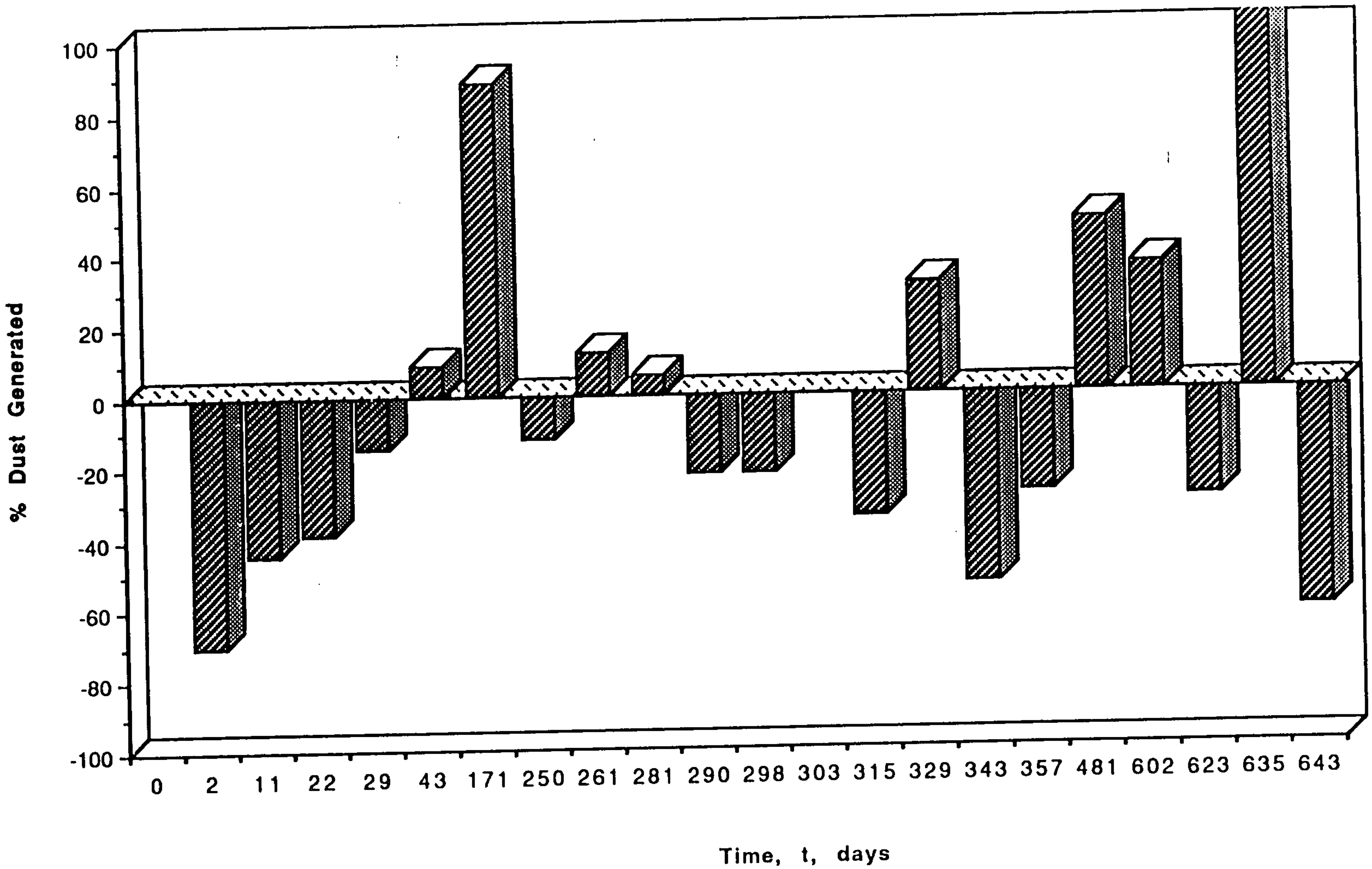


Figure 5. Dallas Co. test road dust generation for 0.5% Bentonite treatment, in wheel paths

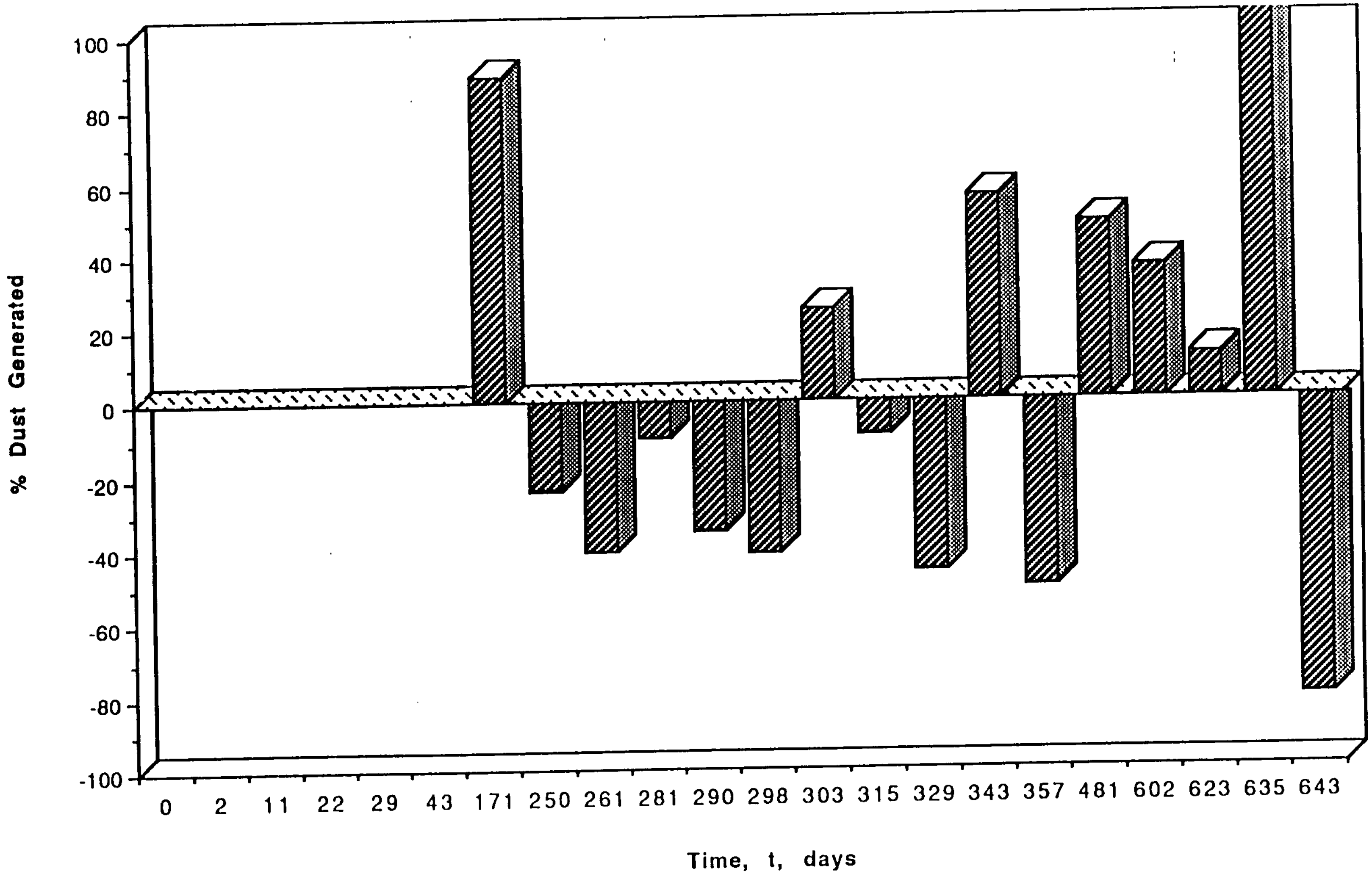


Figure 6. Dallas Co. test road dust generation for 0.5% Bentonite treatment, out-of-wheel paths

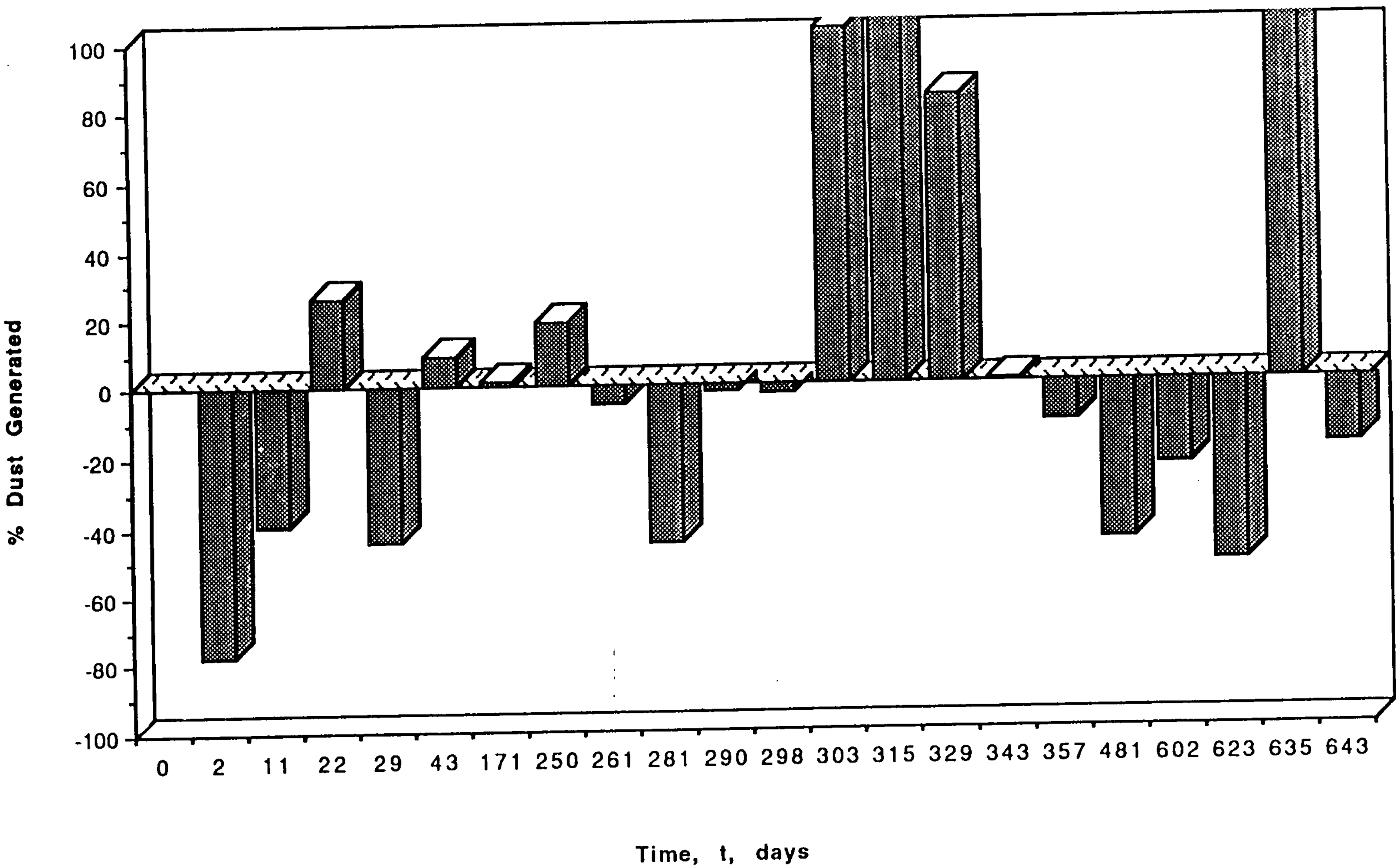


Figure 7. Dallas Co. test road dust generation for 1.0% Bentonite treatment, in wheel paths

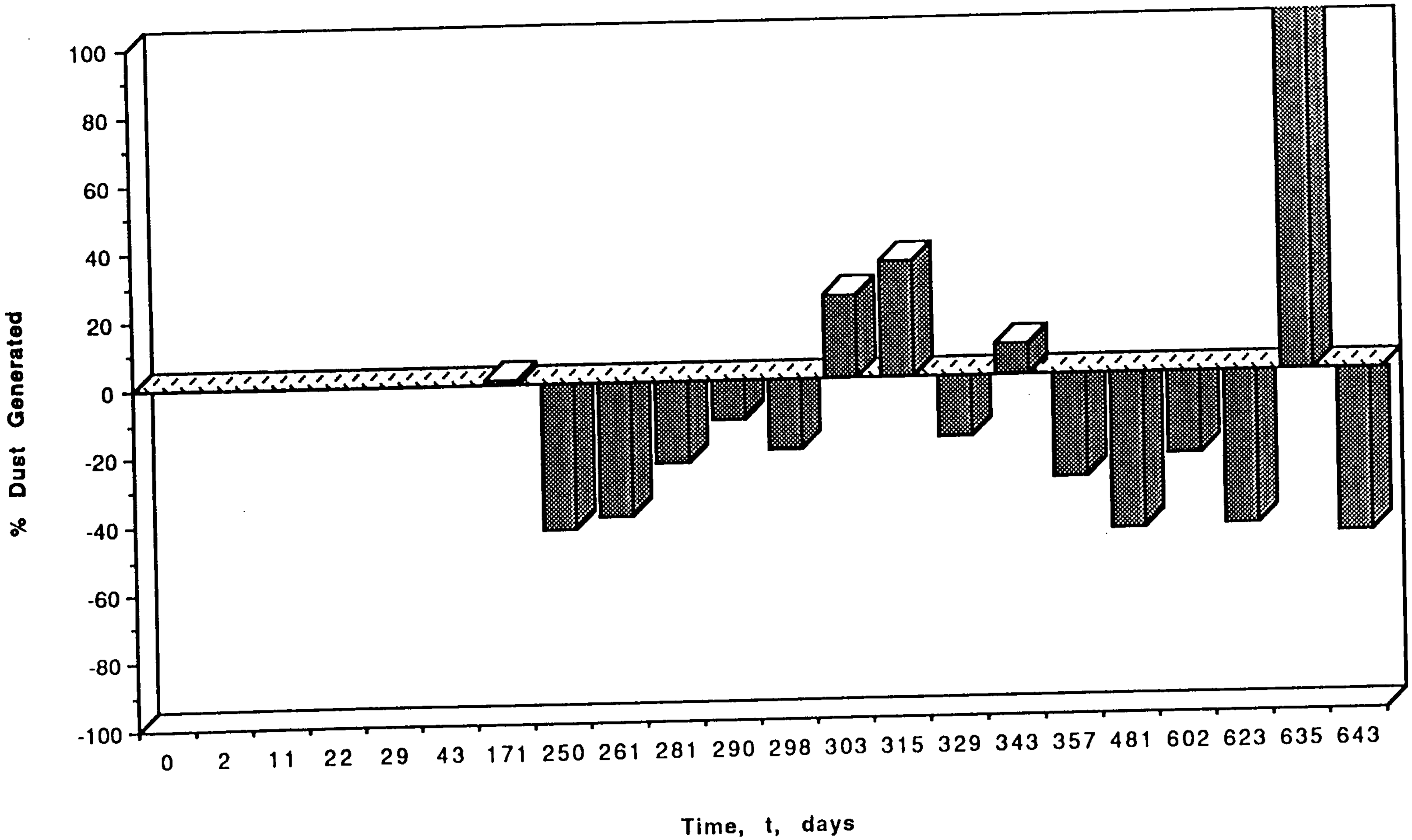


Figure 8. Dallas Co. test road dust generation for 1.0% Bentonite treatment, out-of-wheel paths

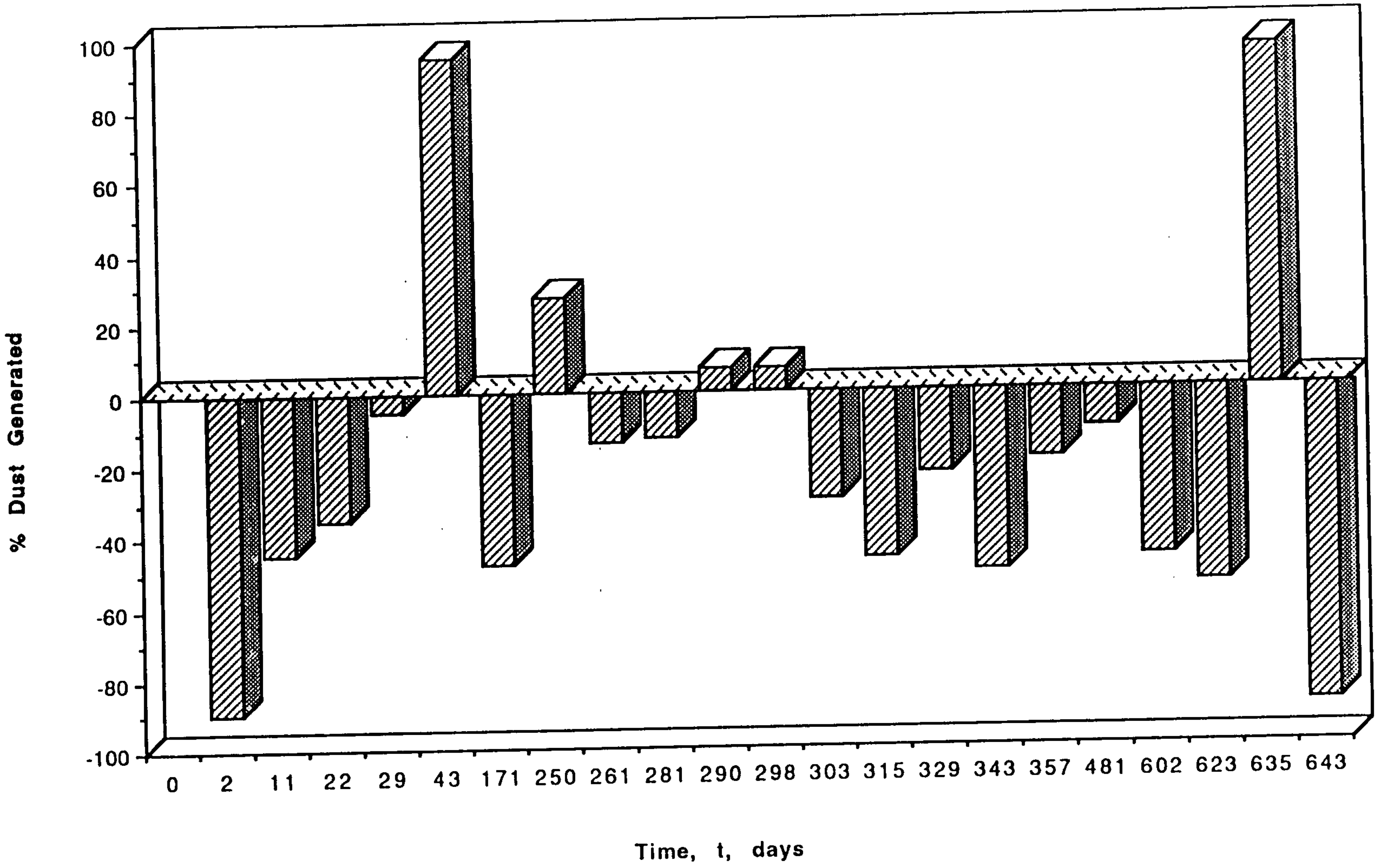


Figure 9. Dallas Co. test road dust generation for 1.5% Bentonite treatment, in wheel paths

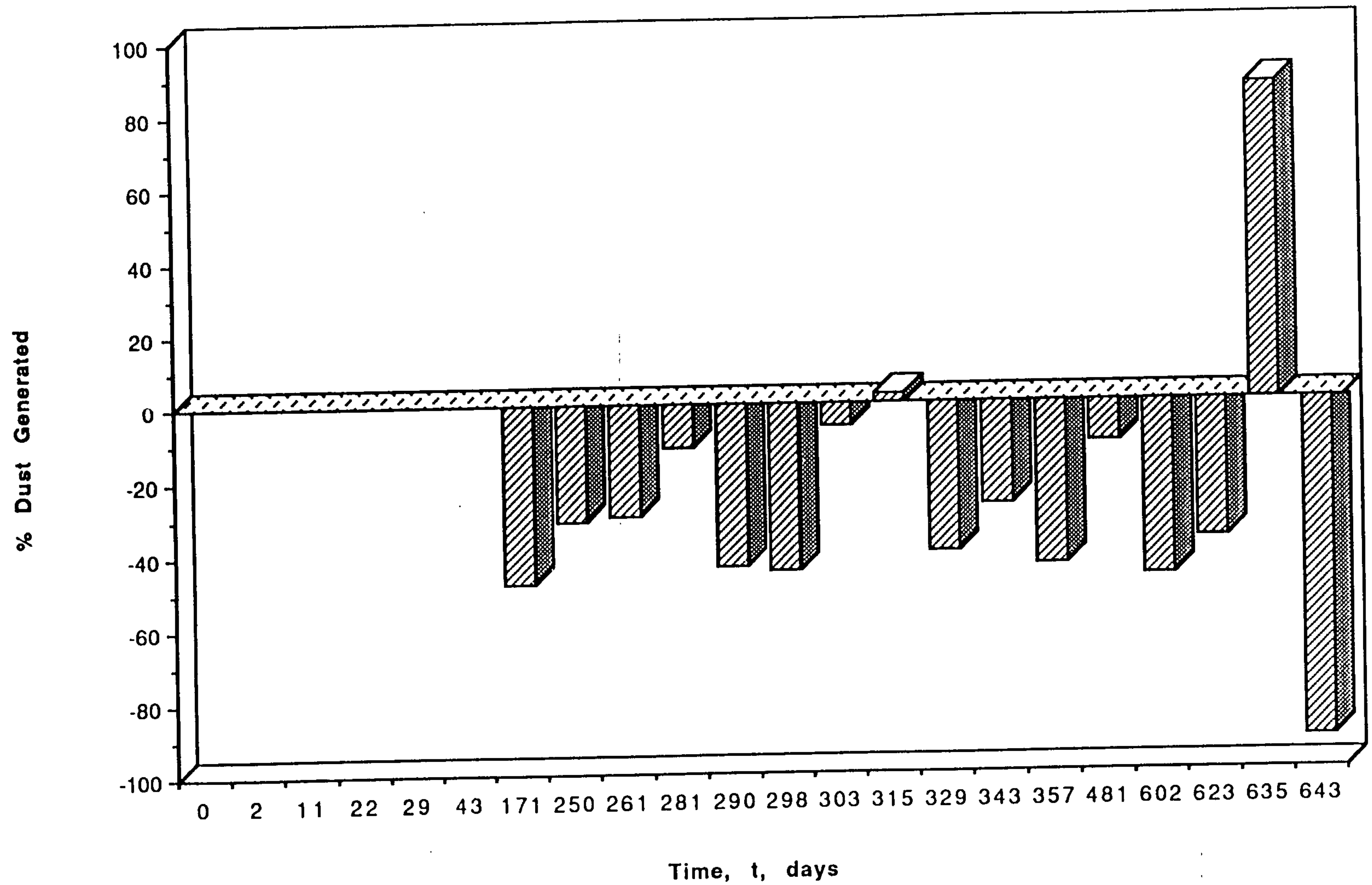


Figure 10. Dallas Co. test road dust generation for 1.5% Bentonite treatment, out-of-wheel paths

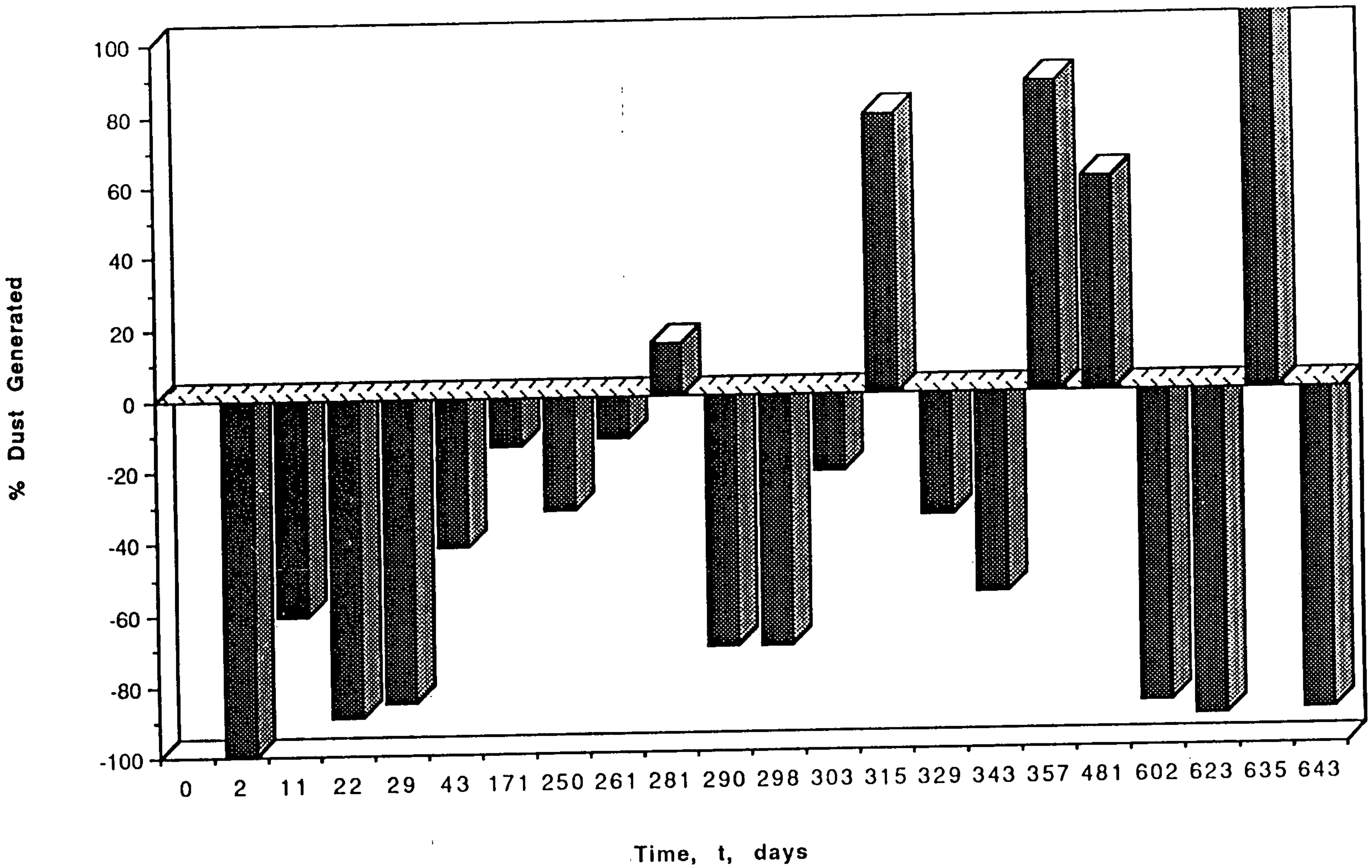


Figure 11. Dallas Co. test road dust generation for calcium chloride treatment, in wheel paths

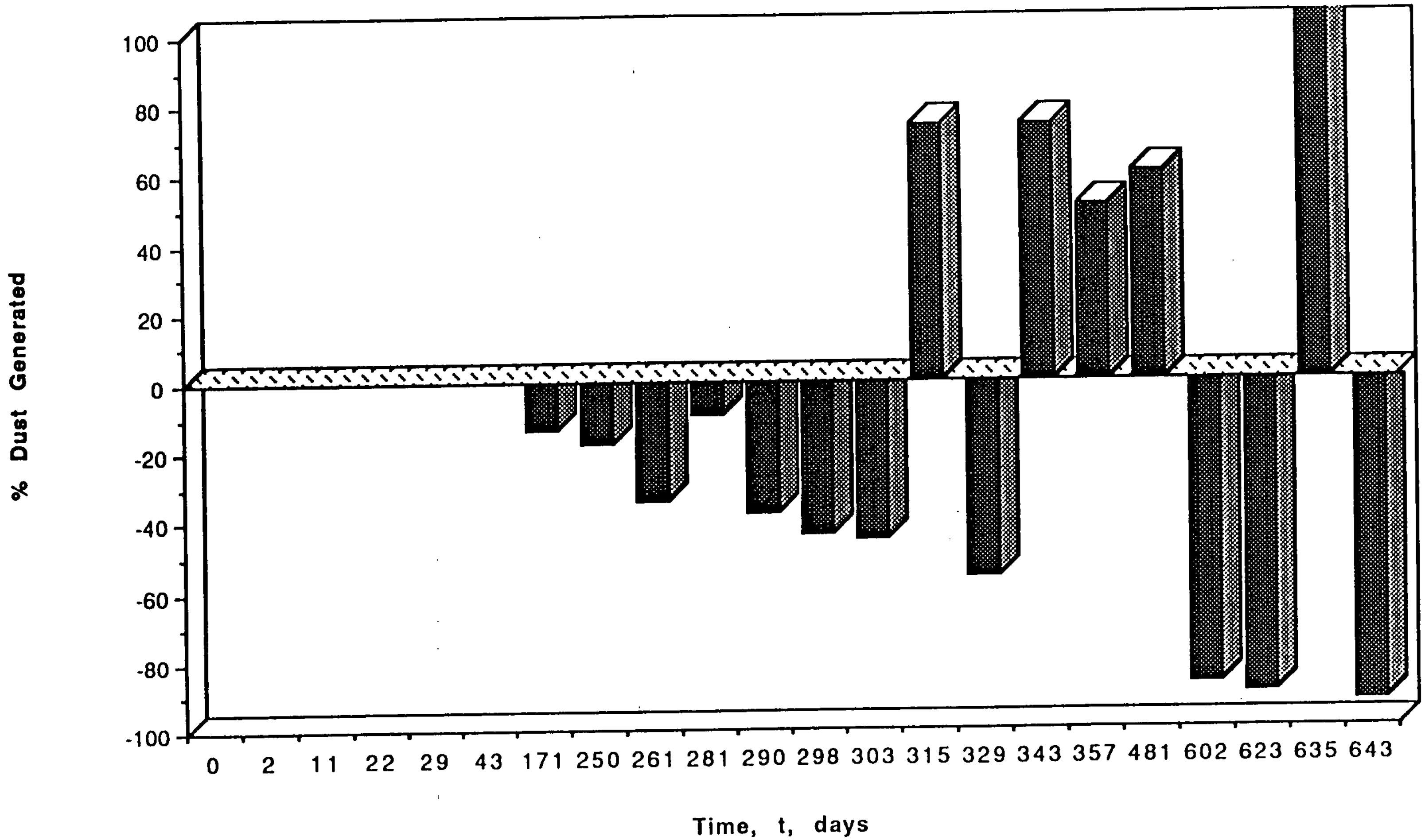


Figure 12. Dallas Co. test road generation for calcium chloride treatment, out-of-wheel paths

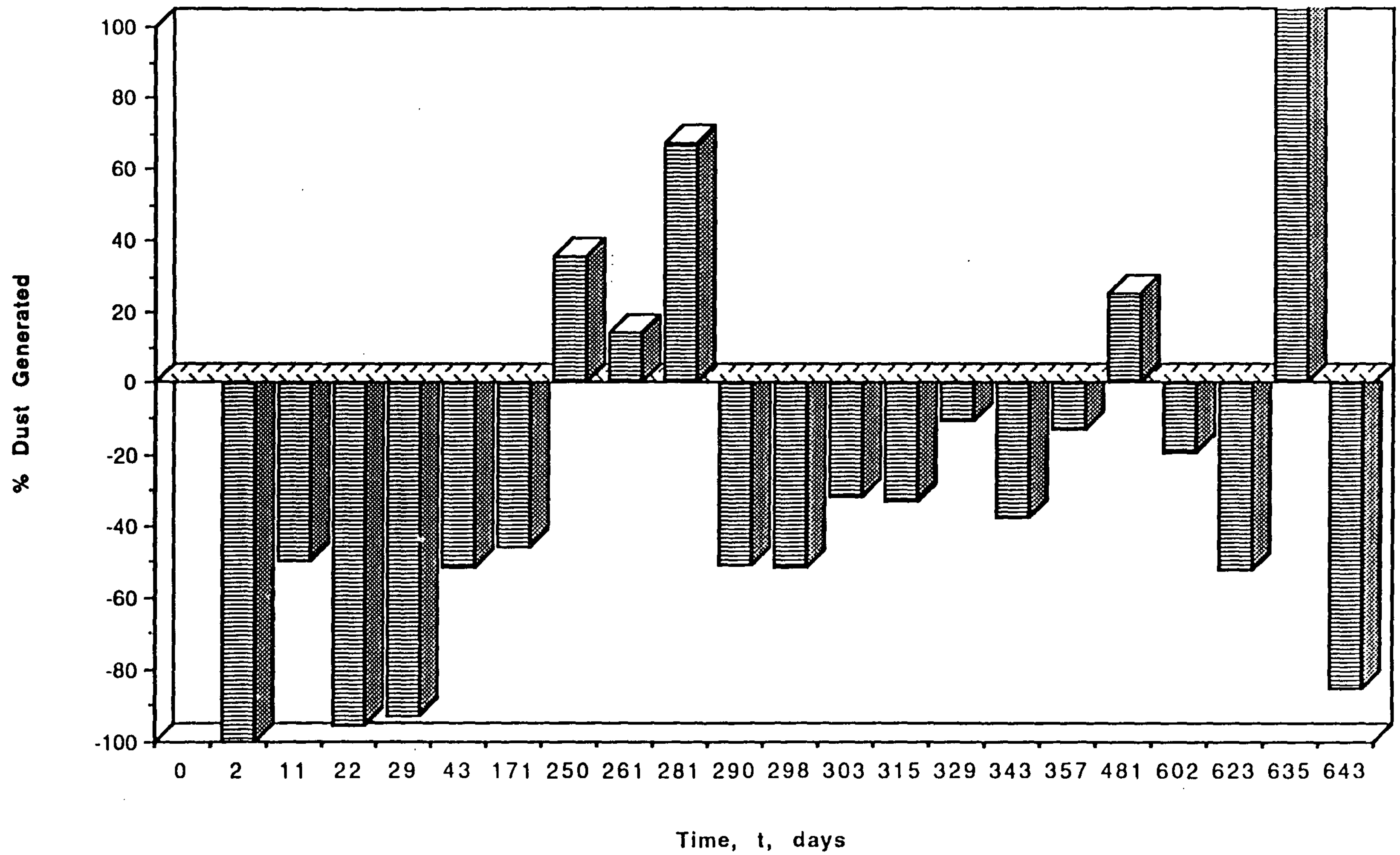


Figure 13. Dallas Co. test road dust generation for magnesium chloride treatment, in wheel paths

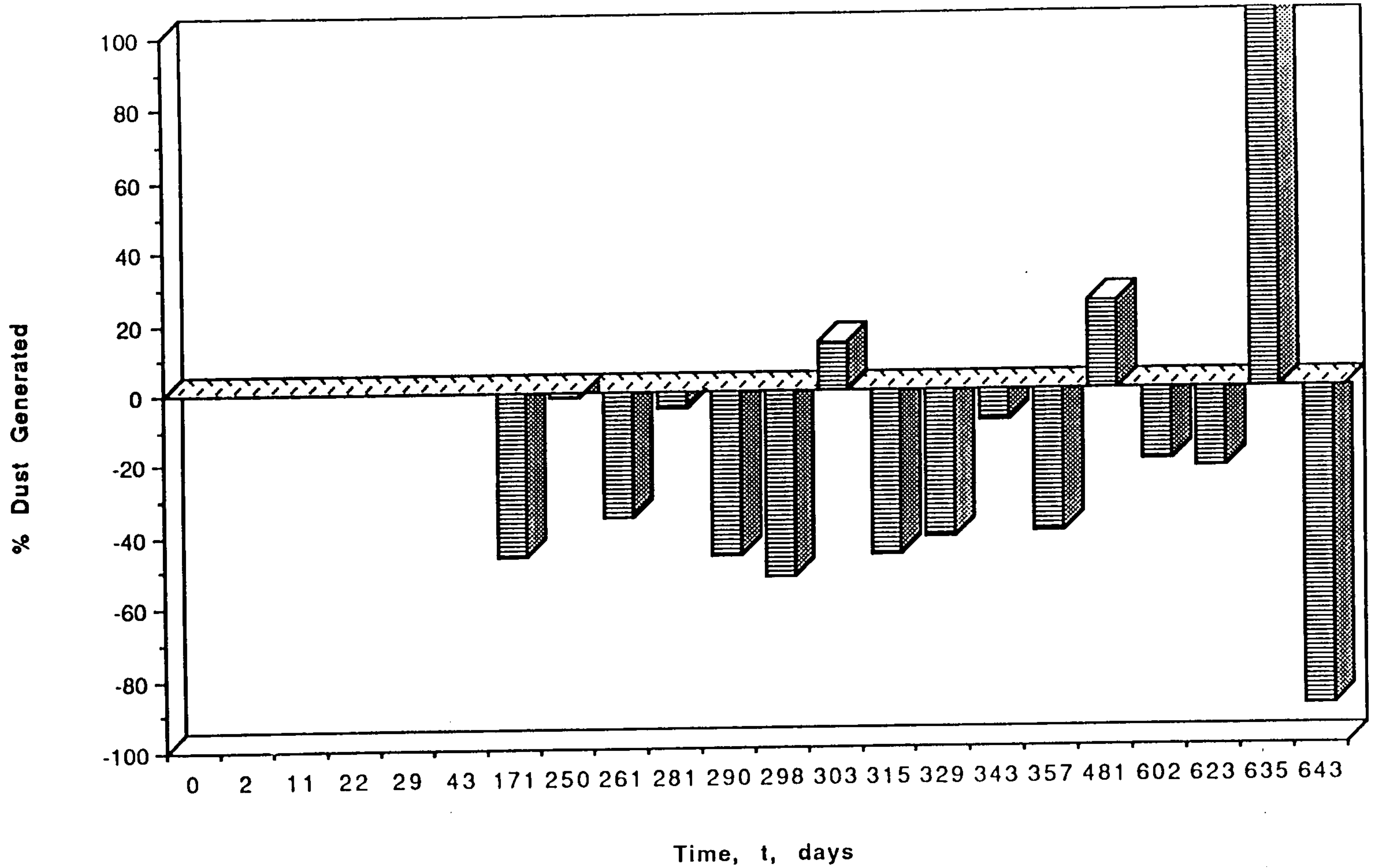


Figure 14. Dallas Co. test road dust generation for magnesium chloride treatment, out-of-wheel paths

It should be recognized that the data shown on the Figures were obtained from a variety of surface moisture conditions. Attempts were made to correlate the results with rainfall data and moisture tests. No trends were observed. Testing was also conducted under all conditions of maintenance ranging from well developed wheelpaths to immediately after grading. Results are therefore variable and should be viewed qualitatively, but do represent actual service conditions.

The data on Figures 5 through 14 indicate that for bentonite treatment, dust was significantly reduced (20 to 50 percent). For out-of-the-wheelpath tests, the 1.0 percent and 1.5 percent treatments showed the best reduction. Results obtained after the Class A stone surfacing addition in August 1988 are interesting. The 1.5 percent bentonite treatment appears to be effectively reducing dust generation in both wheelpath and out-of-the-wheelpath tests. 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 is shown in Figures 11 and 12. These data are similar to the bentonite treated data. The calcium chloride section was treated again at the beginning of summer 1989, which influenced the test data. Both calcium and magnesium chloride sections appeared to be reducing dust out-of-the-wheelpath on the order of 10 to 40 percent. After the addition of the new stone in August 1988, the calcium section did not exhibit a consistent trend. However, after the new treatment in the summer of 1989 the section exhibited a significant dust reduction effect as would be expected. The magnesium chloride section results, shown in Figures 13 and 14 indicated similar trends.

Table 5 presents averages of wheelpath dust reduction, by treatment type, from October 1987 through January 1988.

Table 5. Dust Reduction Averages from October 1987—January 1988

Treatment	%Dust Reduction Wheelpath
0.5% Bentonite	32
1.0% Bentonite	26
1.5% Bentonite	16
Calcium Chloride	76
Magnesium Chloride	80

Table 6 presents the averages of test results for the period from January 1988 up to the new stone application in August 1988.

Table 6. Dust Reduction Averages for January 1988—August 1988

Treatment	%Dust Reduction Wheelpath	%Dust Reduction Out-of-the-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 7 shows data reduction for the period after the new stone application in August 1988 through October 1989.

Table 7. Dust reduction averages for August 1988—October 1989

Treatment	%Dust Reduction Wheelpath	%Dust Reduction Out-of-the-Wheelpath
0.5% Bentonite	8	11
1.0% Bentonite	5	4
1.5% Bentonite	28	24
Calcium Chloride*	+12	+2
Magnesium Chloride*	14	11

*These sections had been treated again at the beginning of summer 1989.

Table 8 shows the average dust reductions for the entire period of testing of two years.

Table 8. Dust reduction averages from October 1987—October 1989

Treatment	%Dust Reduction Wheelpath	%Dust Reduction Out-of-the-Wheelpath
0.5% Bentonite	2	6
1.0% Bentonite	6	15
1.5% Bentonite	8	27
Calcium Chloride	20	6
Magnesium Chloride	22	16

In analyzing these data over the entire project period, it appears that the 1.5 percent bentonite treatment has a potential long-term reduction of dust in the range of 10 to 30 percent even with the addition of new surfacing material.

The results from Table 5 indicated that the 0.5 percent treatment was the most effective of the bentonite treated sections for that period.

However, the data from Table 8 indicated that the 1.5 percent treatment may be more effective from a long-term standpoint.

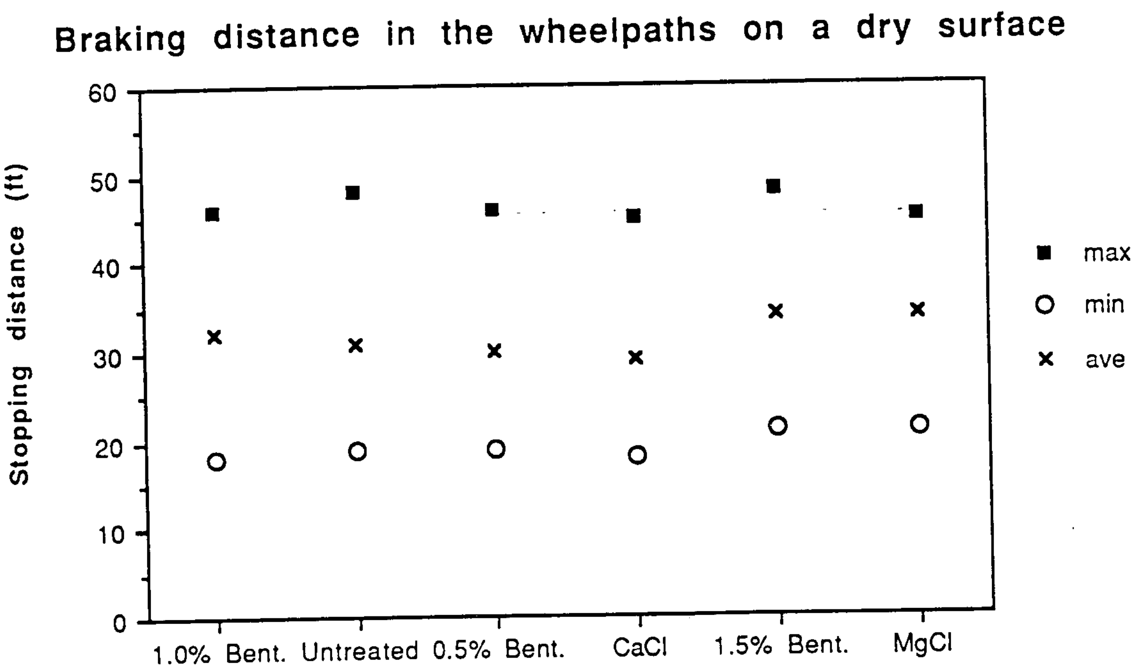
Braking Characteristics

These tests were initiated to determine the effect on the stopping distance compared to the untreated section. The braking test was accomplished using a half-ton pickup. The test was initiated at a vehicle 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 15 and 16 show the data collected for the Dallas County road. The test was conducted under both dry and wet 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. There are not any significant differences in braking distance between the various test sections. The out-of-the-wheelpath tests also show the same trends of the wheelpath tests for all bentonite treatment sections. These results indicate no adverse effect on braking characteristics for the various treatments as compared to the untreated section.

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.



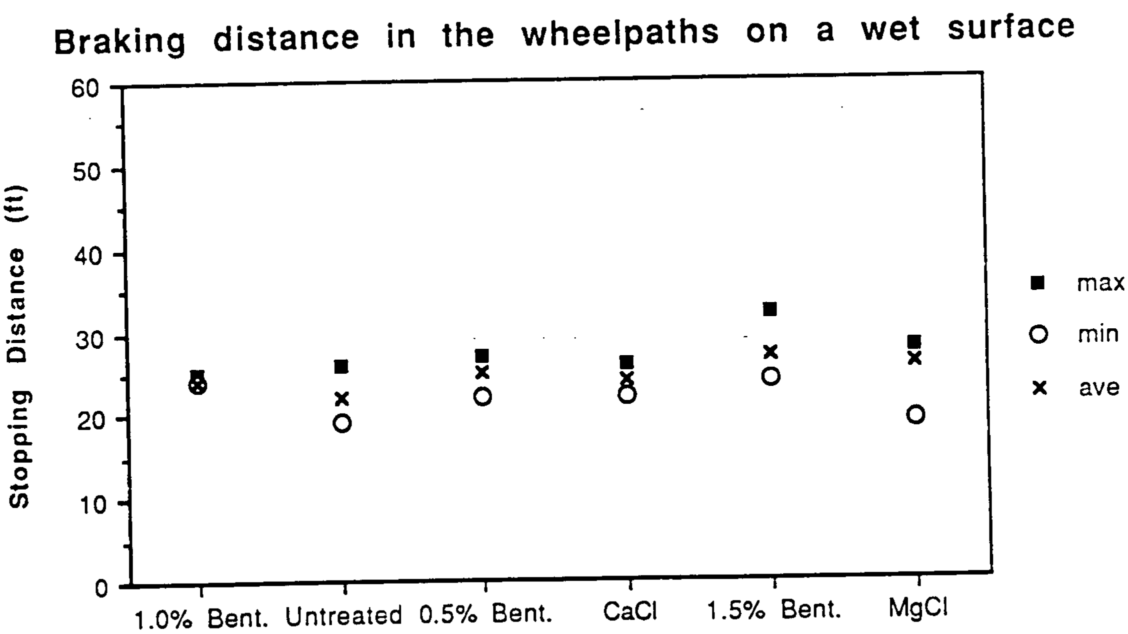
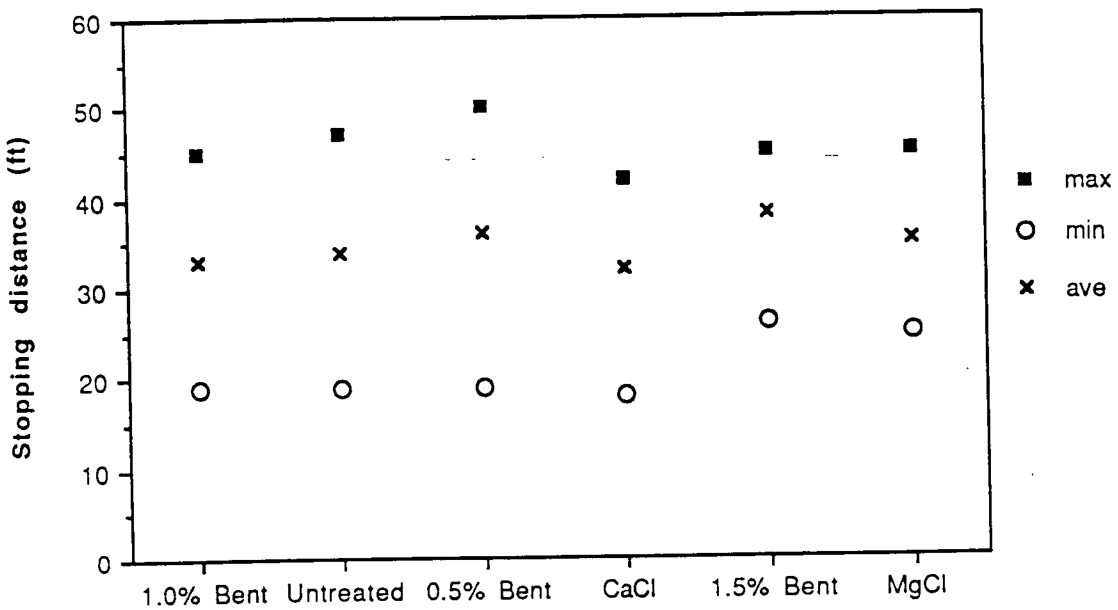


Figure 15. Wheelpath braking distance results for Dallas County Test Road

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



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

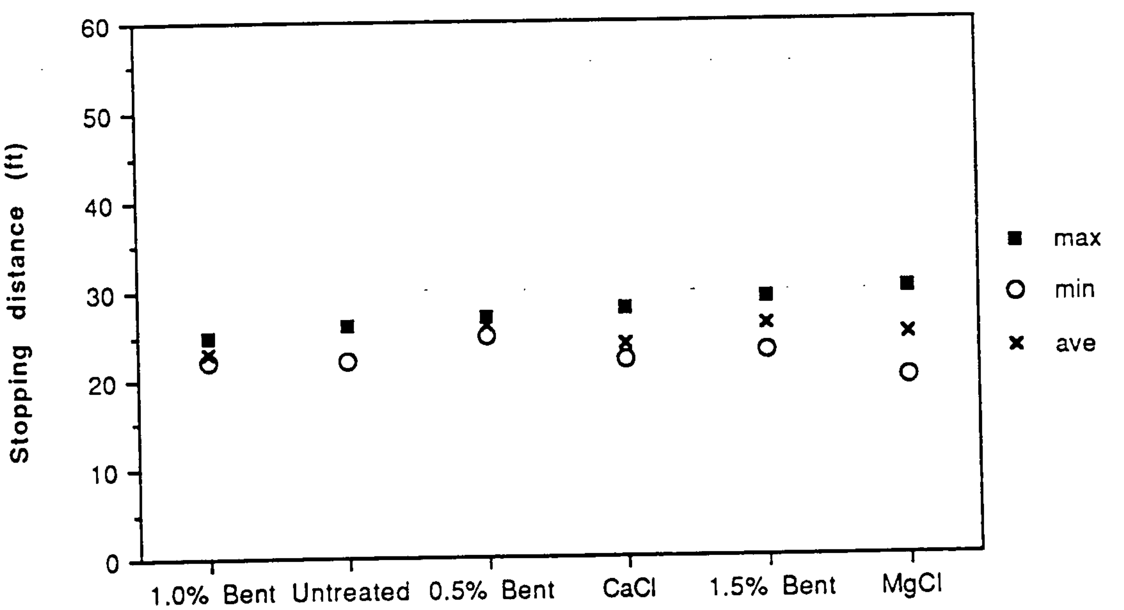


Figure 16. Out-of-Wheelpath braking distance results for Dallas County Test Road

Gradation Analysis

Two methods of gradation analysis were conducted on each sample. Extended dry sieve analysis (10 minutes on a Gilson) followed by wet sieve analysis on each sample. Figure 17 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 is reducing the material to a finer gradation. From Figure 17 it is noted that for the #30, #50, and #200 material, the washed results are slightly higher than the dry sieve results.

Figure 18 shows the gradation results for the 0.5 percent bentonite treatment at the construction time for the Dallas County road. The sample was 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. Figure 19 presents the results obtained from samples of the same sections 60 days after 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 is acting to aggregate the fine particulates. Several other samples were collected periodically over the project period and exhibited similar results.

Scanning Electron Microscopy

In order to verify that particle to particle bonding was taking place with bentonite treatment, samples of the material retained on the #50 sieve were mounted for scanning electron microscopy (SEM) analysis. Typical results are shown on the SEM photos on Figures 20, 21, and 22. Figure 20 is

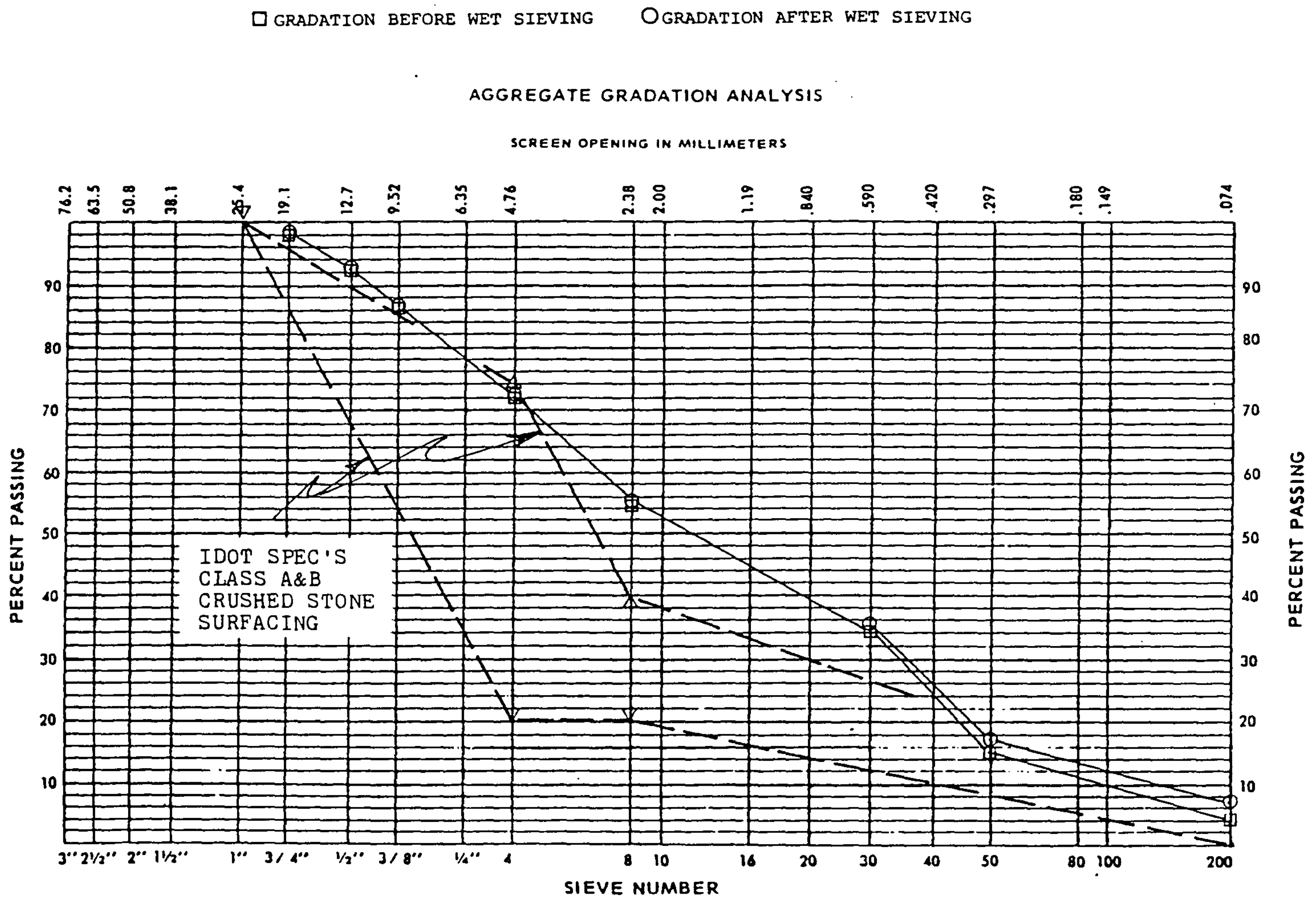


Figure 17. Average gradation test results for all untreated aggregate samples, Dallas Co.

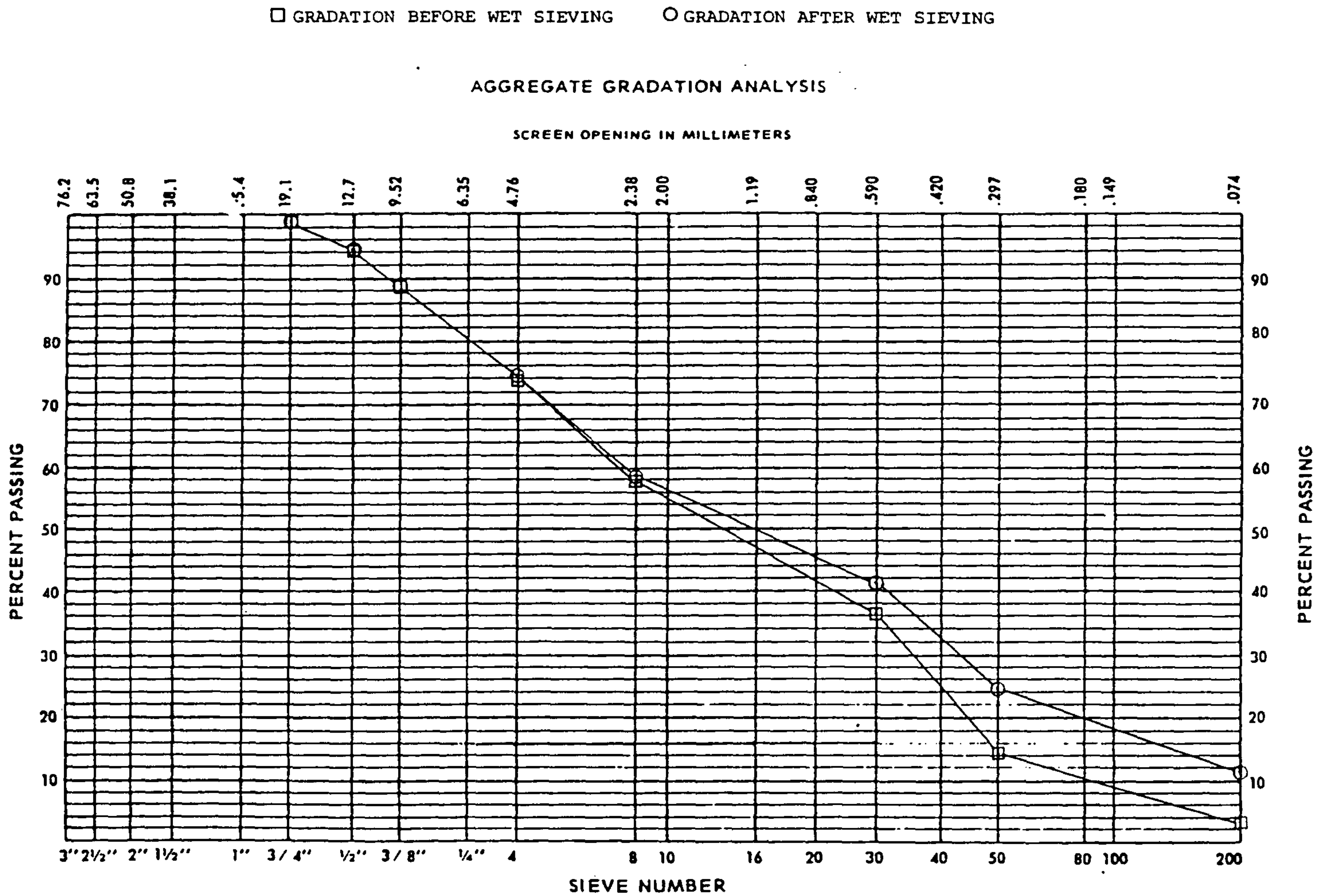


Figure 18. Gradation test results for 0.5% Bentonite treatment, Dallas Co.

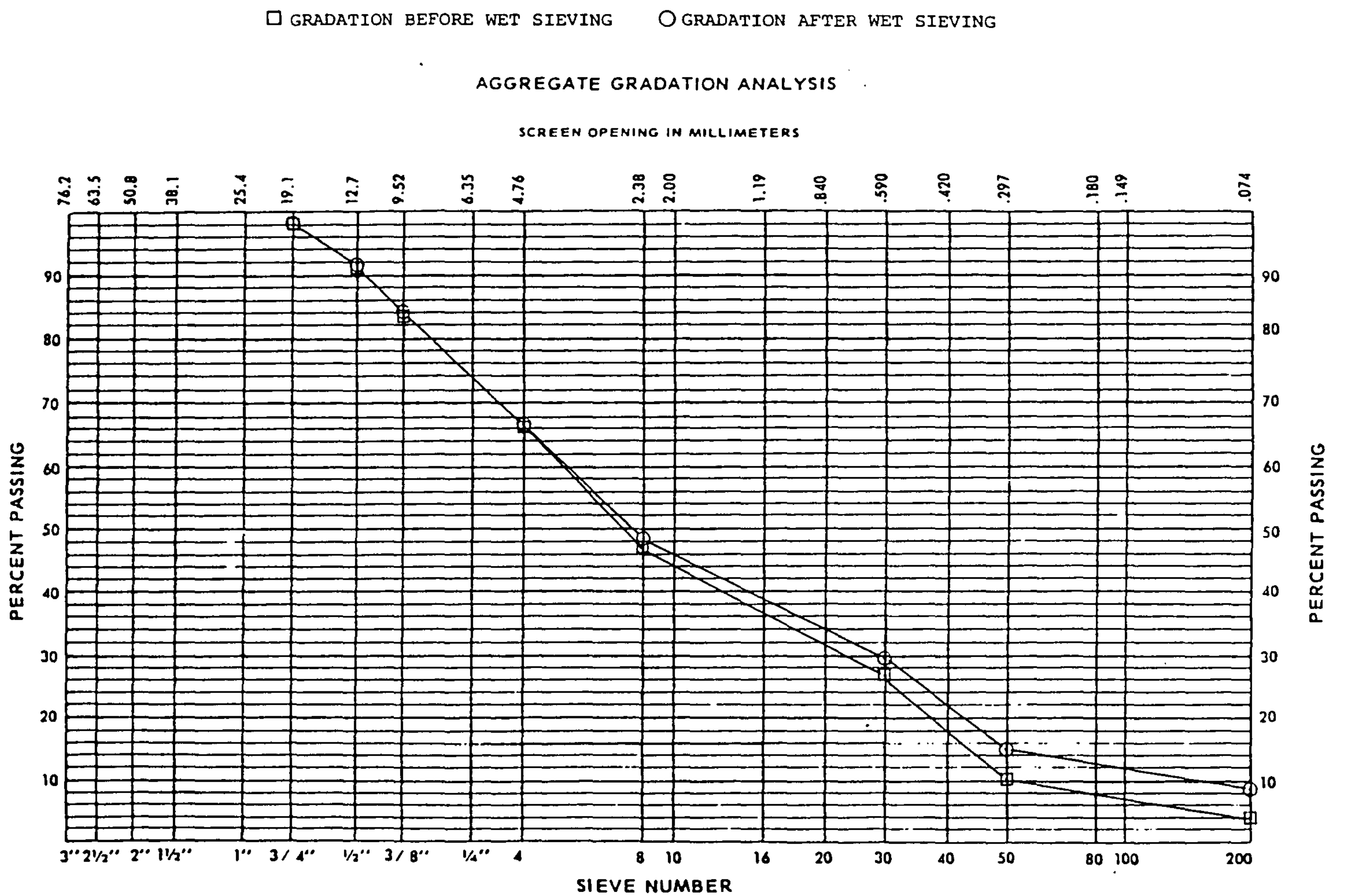


Figure 19. Gradation test results for 0.5% Bentonite treatment after 60 days of construction, Dallas Co.

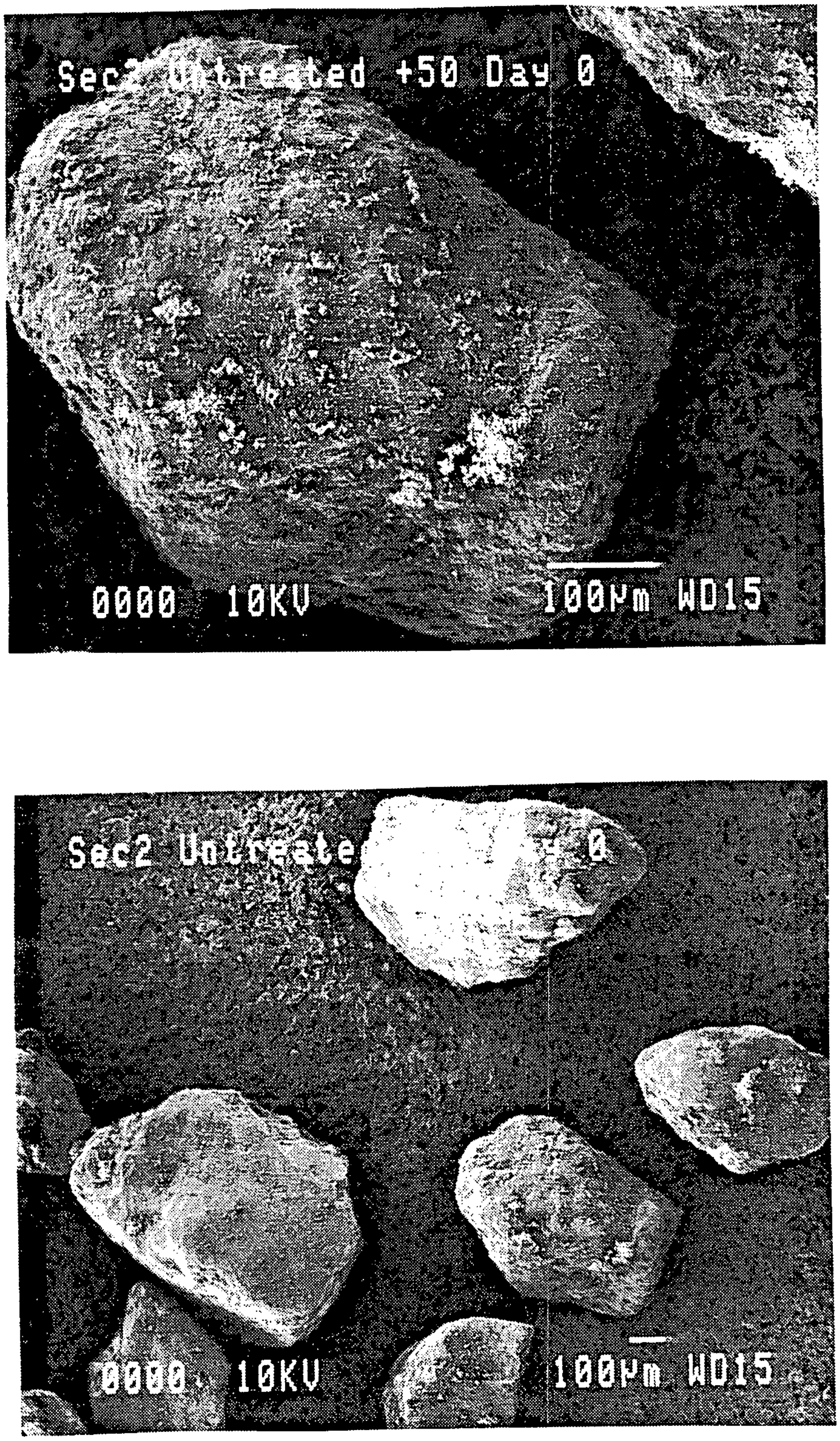
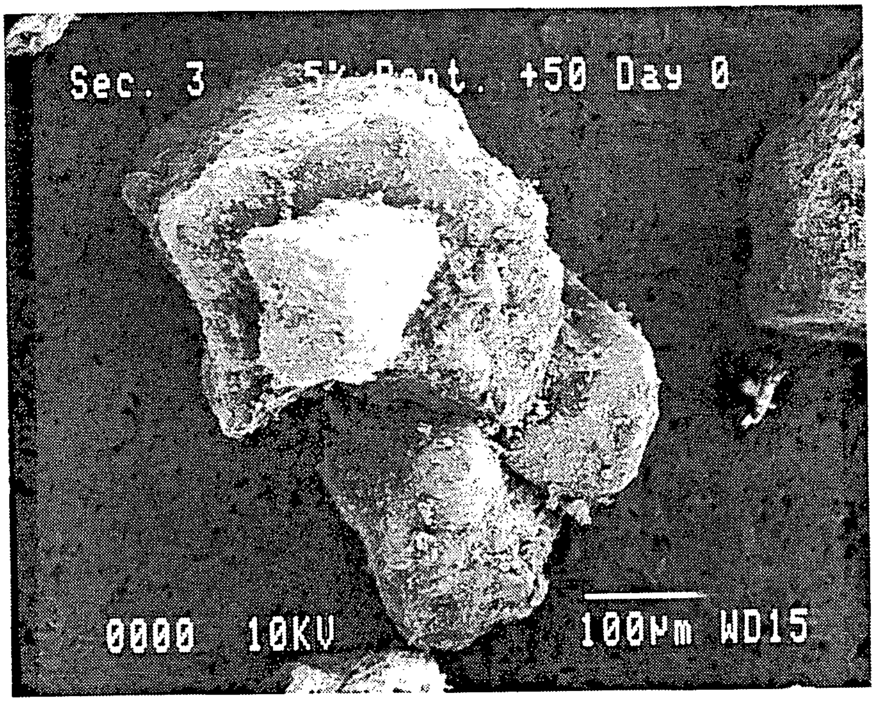


Figure 20. SEM photographs of material retained on the No. 50 sieve from the untreated control section at the time of construction



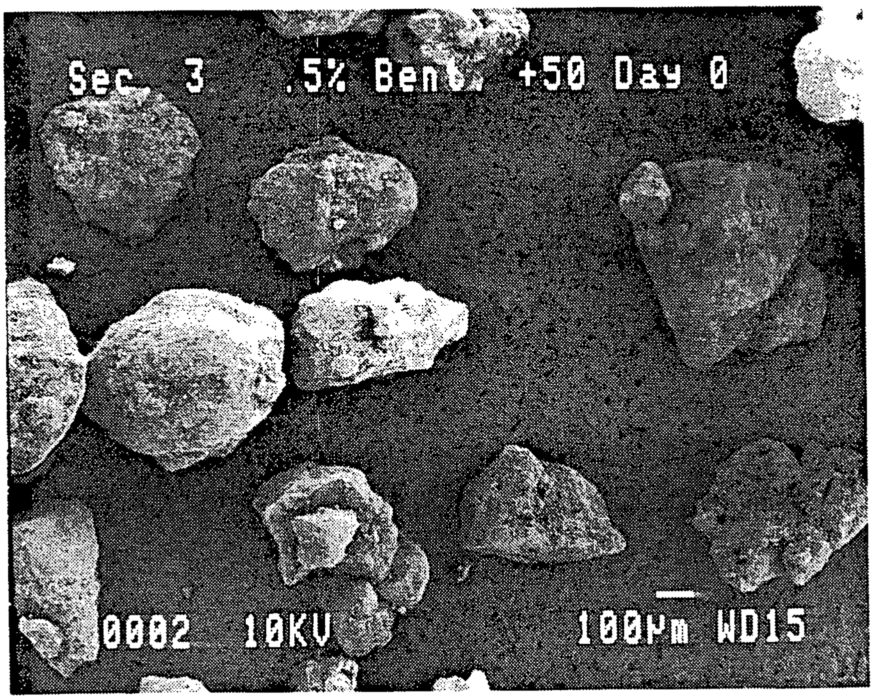


Figure 21. SEM photographs of material retained on the No. 50 sieve from the 0.5% bentonite treated section at the time of construction

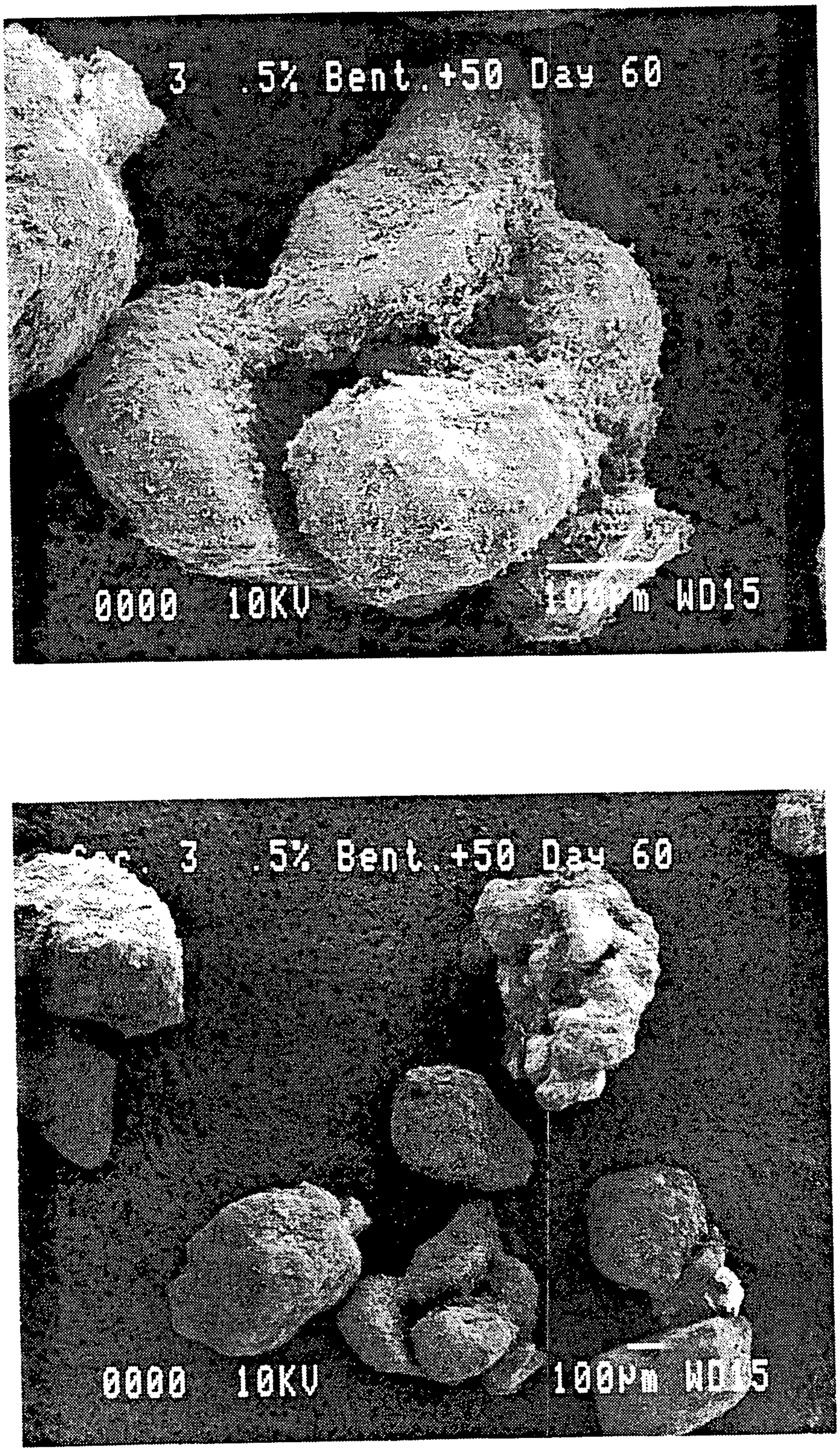


Figure 22. SEM photographs of material retained on the No. 50 sieve from the 0.5% bentonite treated section at 60 days after construction

for the untreated control section with no significant bonding evident. Figure 21 is material from the 0.5 percent bentonite section on the sample obtained at the time of construction. Particle to particle bonding is evident. Figure 22 represents material from the same section sampled 60 days after construction. Again the bonding is evident. These results are typical of numerous SEM observation and study of samples from the #50, #200, and minus #200 sieve fractions obtained throughout the project.

Summary

Soda ash dispensed bentonite solutions (7.5 percent solution by weight) can be field mixed and applied using conventional spray distributor equipment. Blade mixing of treated material was rapid and adequate. Application up to 1.5 percent bentonite (by weight of aggregate) can be accomplished by this method. Higher application rates would have to be accomplished in stages.

The dust reduction observed in the bentonite treated sections is being accomplished by the bentonite functioning as a bonding agent of fine particles to larger particles (particularly the #30 to #200 sizes) and is acting to aggregate fine particles. Data indicates this bonding appears to be recoverable from effects of weather, traffic, and normal maintenance operations.

The calcium and magnesium chloride treatments were nearly three times more effective in dust reduction, over the short term, than the best section of bentonite treatment.

Pothole and washboard development in the chloride areas required maintenance blading to be initiated approximately twenty days after construction. Normal maintenance blading practice was followed for the bentonite treated sections and washboarding or potholing did not develop.

ADAIR COUNTY TEST ROAD

Location

The Adair County test road is located immediately south of Interstate 80 at Stuart, Iowa. The road intersects County road P-28 and runs 1 1/2 miles east parallel to I-80. Traffic count is about 80 vpd on this road from 1988 Iowa Department of Transportation data. Test road location is given on Figure 23. The road had a relatively good crushed limestone surface and topography.

Construction

Construction of the Adair County test road was completed the first part of July 1989 after several meetings with the County Engineer and materials supply personnel. Based on the experience in Dallas County, the construction method was altered in order to incorporate higher percentages of bentonite treatment levels. A dry bentonite application method was used to accomplish this. The higher levels of bentonite application were used because the Dallas County data indicated a more favorable long-term dust reduction at the 1.5 percent treatment level. The "as constructed" test road layout is shown on Figure 24.

Materials

Iowa Limestone Company of Alden, Iowa supplied bentonite for the project. The soda ash dispersing agent was obtained locally in Ames, and was the same grade as the soda ash used for the Dallas County test road.

Equipment

Two motor graders and operators, and a circulating water tank truck and operator was supplied by Adair County. The tank truck was equipped with a spray nozzle and a spray bar.

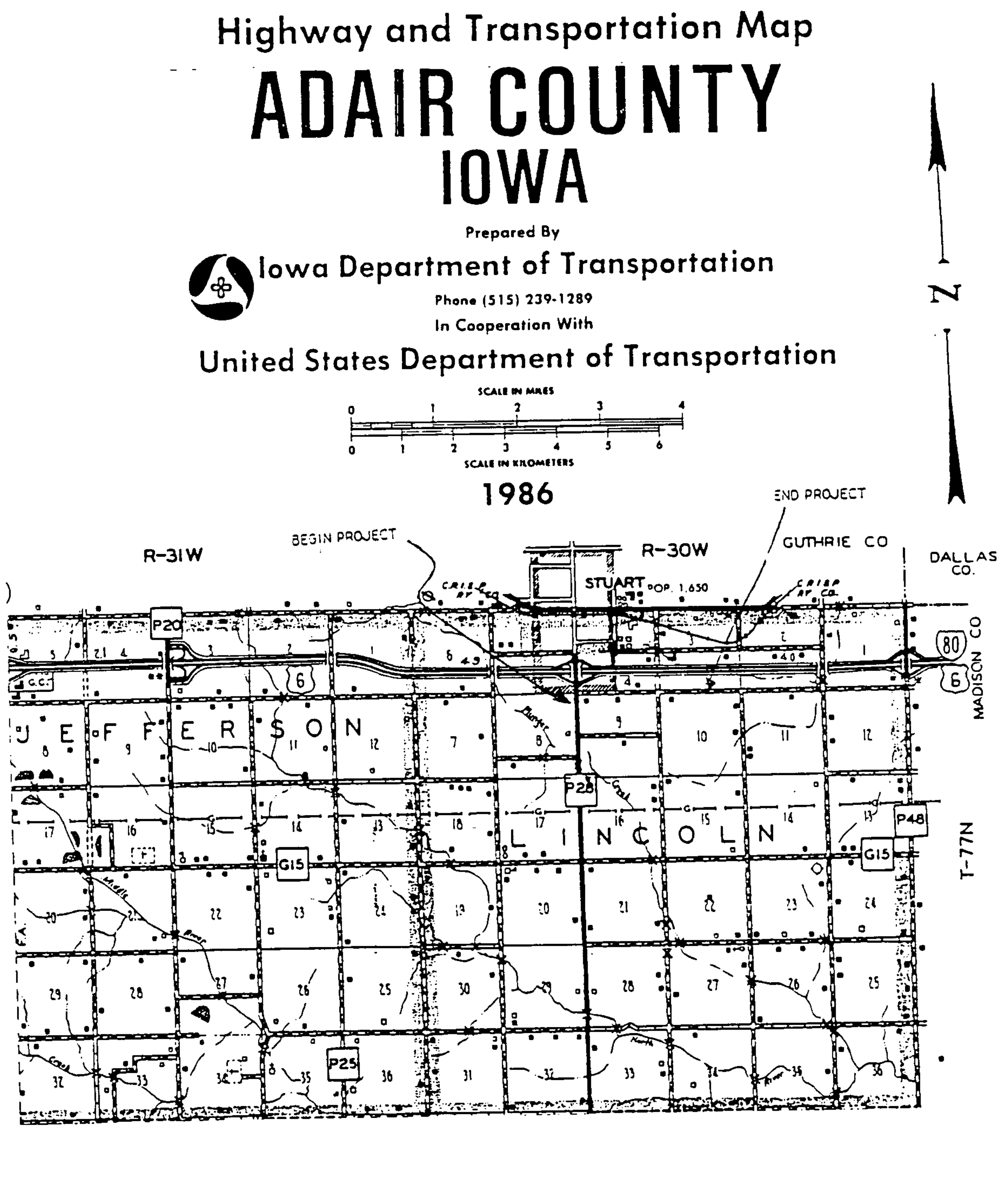


Figure 23. Adair Test Road Location

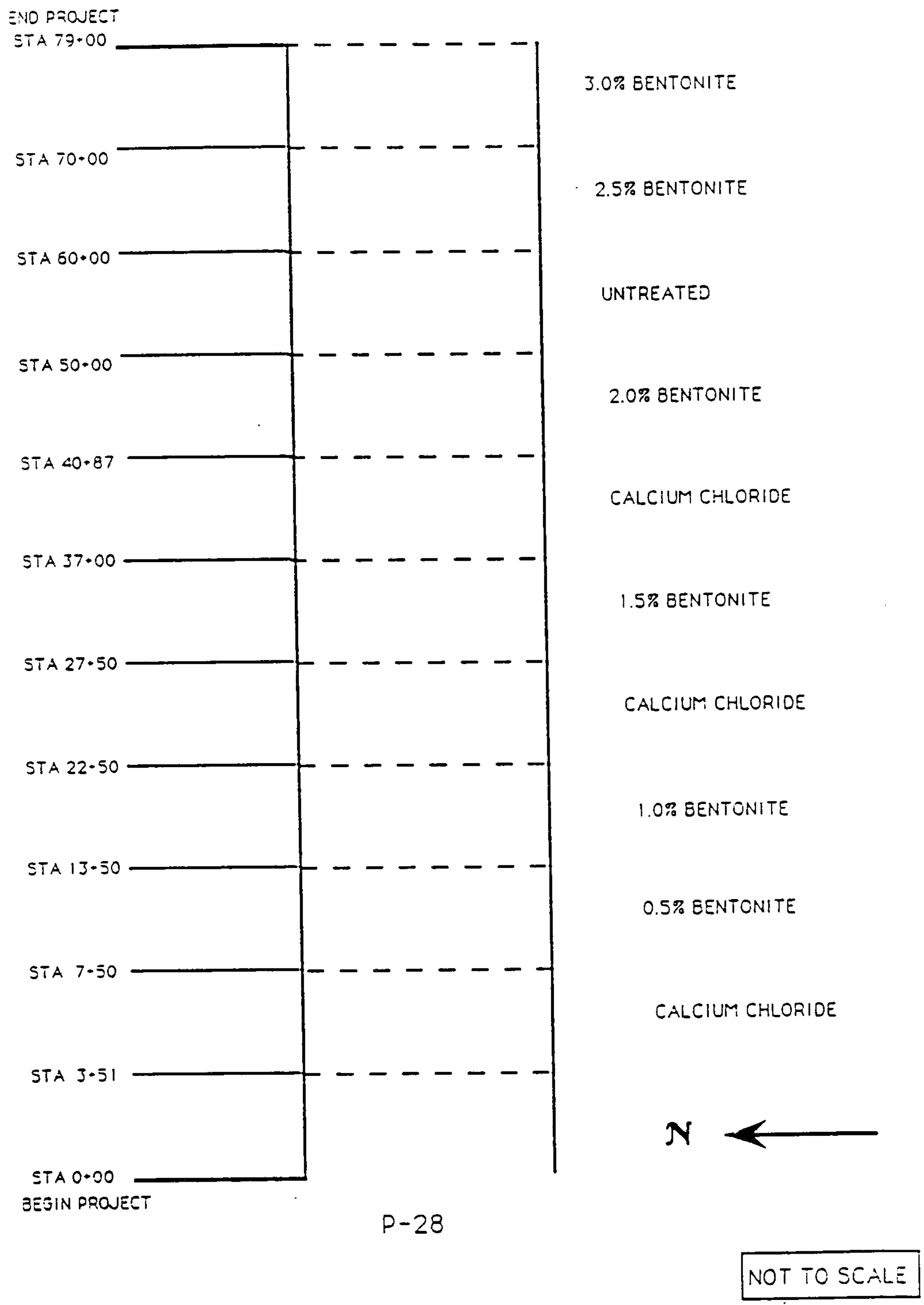


Figure 24. Adair County Test Road Layout, as constructed

Chloride Sections

The calcium chloride treated sections were not constructed as a part of the project. They had been previously treated and were incorporated into the test road layout and testing program.

Bentonite Sections

Prior to construction, Adair County personnel had prepared the test road by tight blading the loose road surface material to a windrow on one side. Several cross-sectional measurements were taken and averaged for each section in order to determine the amount of bentonite needed for each treatment. 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 dry, loose unit weight of crushed limestone, which was determined at the laboratory prior to construction. This was done for every section. The bentonite bags were then distributed along the windrow in each test section. The next step involved distributing the dry material next to the windrow along the entire test road. The bentonite and the loose material (limestone) were thoroughly dry mixed by four passes of the two graders and finally spread in an eight foot wide layer in the middle of the road.

The soda ash was added to the tank truck water at the rate of 20 pounds per 500 gallons of water and thoroughly mixed and dispersed by the circulating pump.

The water with soda ash was spray applied to the eight foot wide strip of bentonite treated limestone and simultaneously road mixed by the two motor graders working in tandem. Application of water with soda ash continued until a consistency of about a 3 to 4 inch slump concrete was achieved. After final mixing the material was spread uniformly over the road surface and opened to traffic.

Field Testing

Dust generation and braking tests were conducted on the Adair County test road beginning in July 1989, and continued through November 1989.

Air Sampling

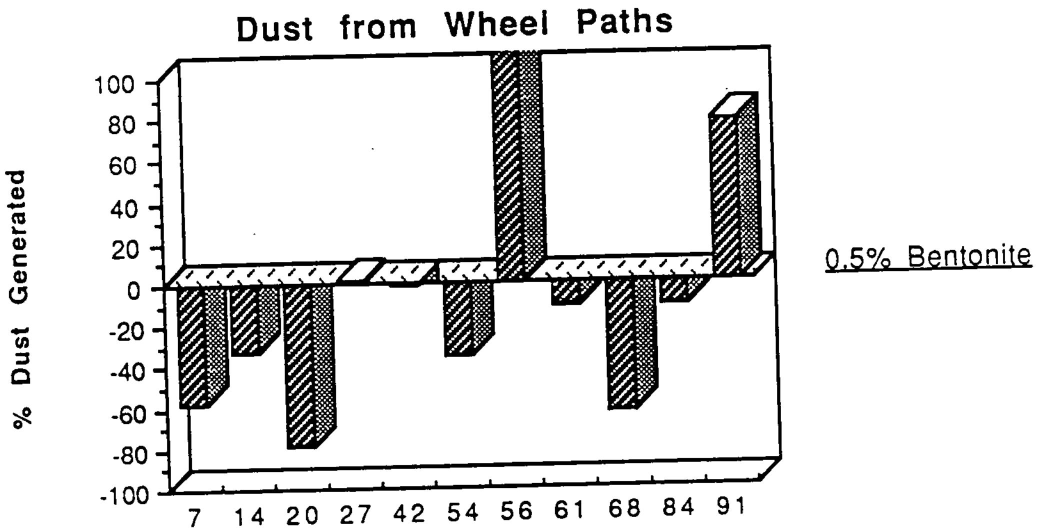
Dust data collected from this test road showed a significant increase in dust reduction at the higher percentages of bentonite treatment. Figures 25 through 32 show the percentage of dust reduction for each section. Table 9 presents rough averages of dust reduction, by treatment type, over the test period from July 1989 through November 1989.

Table 9. Dust Reduction Averages for July 1989—November 1989

Treatment	%Dust Reduction Wheelpath	%Dust Reduction Out-of-the-Wheelpath
0.5% Bentonite	8	9
1.0% Bentonite	11	11
1.5% Bentonite	17	12
2.0% Bentonite	5	4
2.5% Bentonite	10	19
3.0% Bentonite	42	33
Calcium Chloride(both sections)	30	48

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

The results from Table 9 indicate that the higher percentage of treatments are nearly as effective as the calcium chloride treatment.



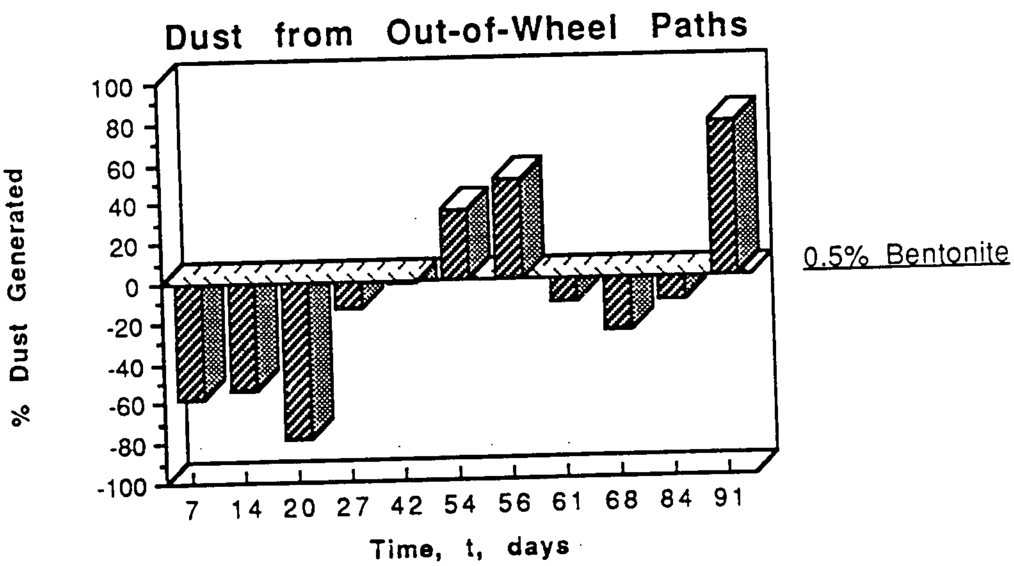


Figure 25. Adair County test road dust generation for 0.5% Bentonite treatment

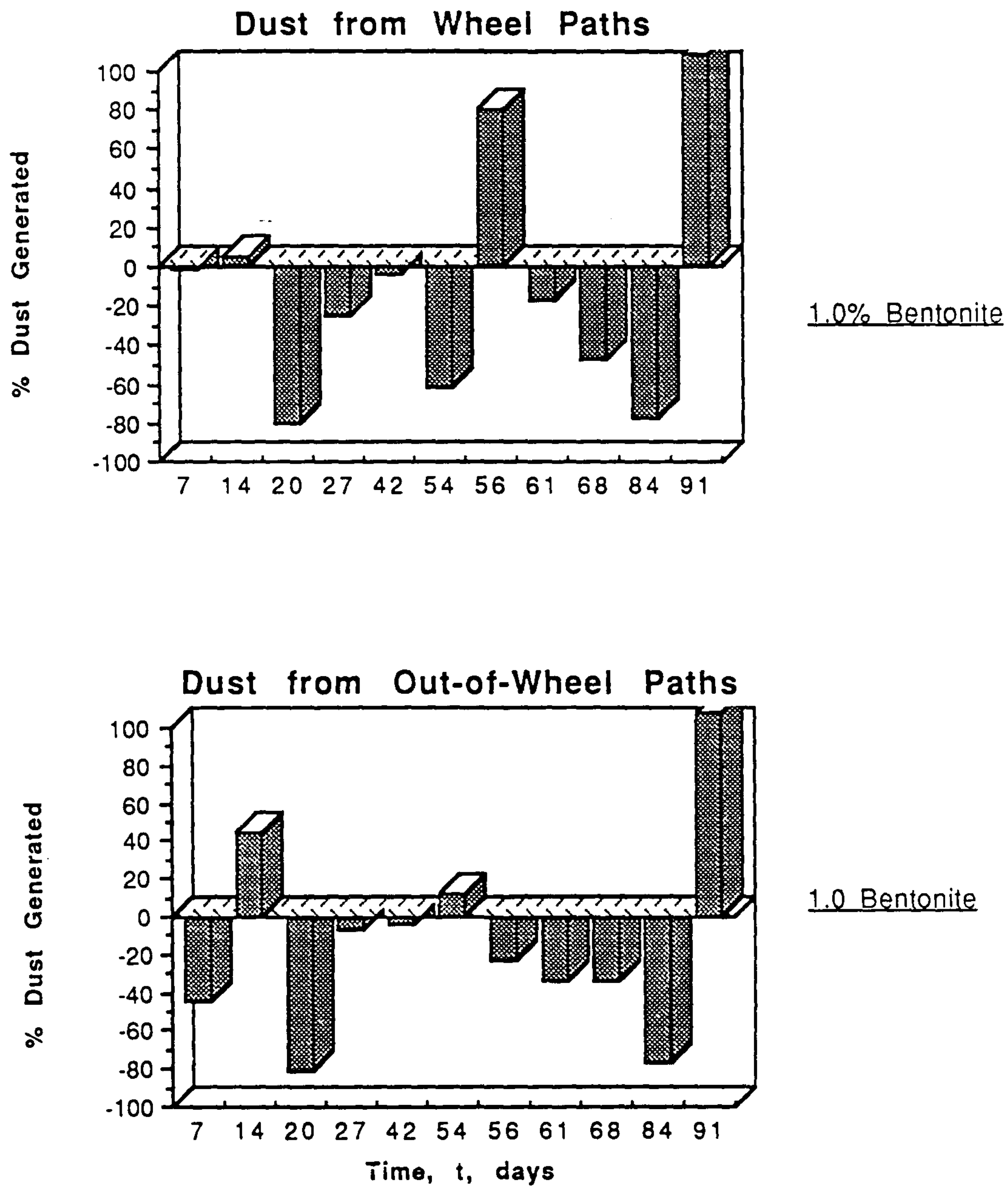
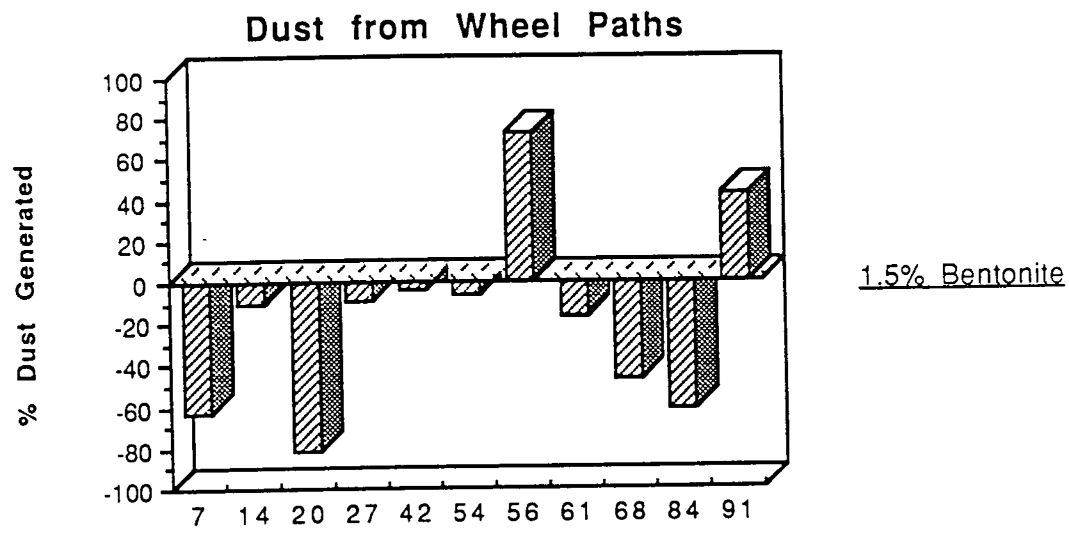


Figure 26. Adair County test road dust generation for 1.0% Bentonite treatment



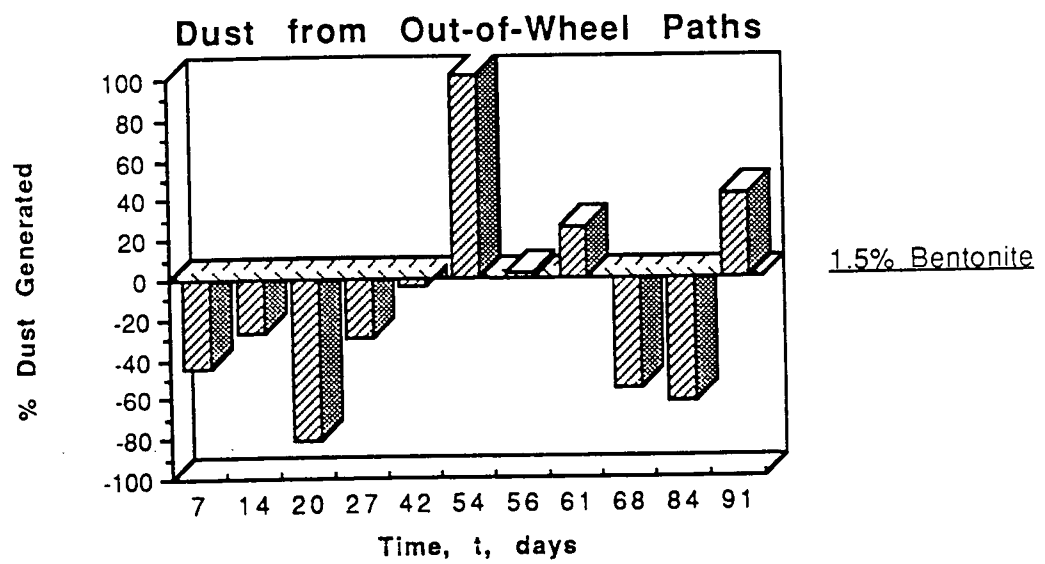


Figure 27. Adair County test road dust generation for 1.5% Bentonite treatment

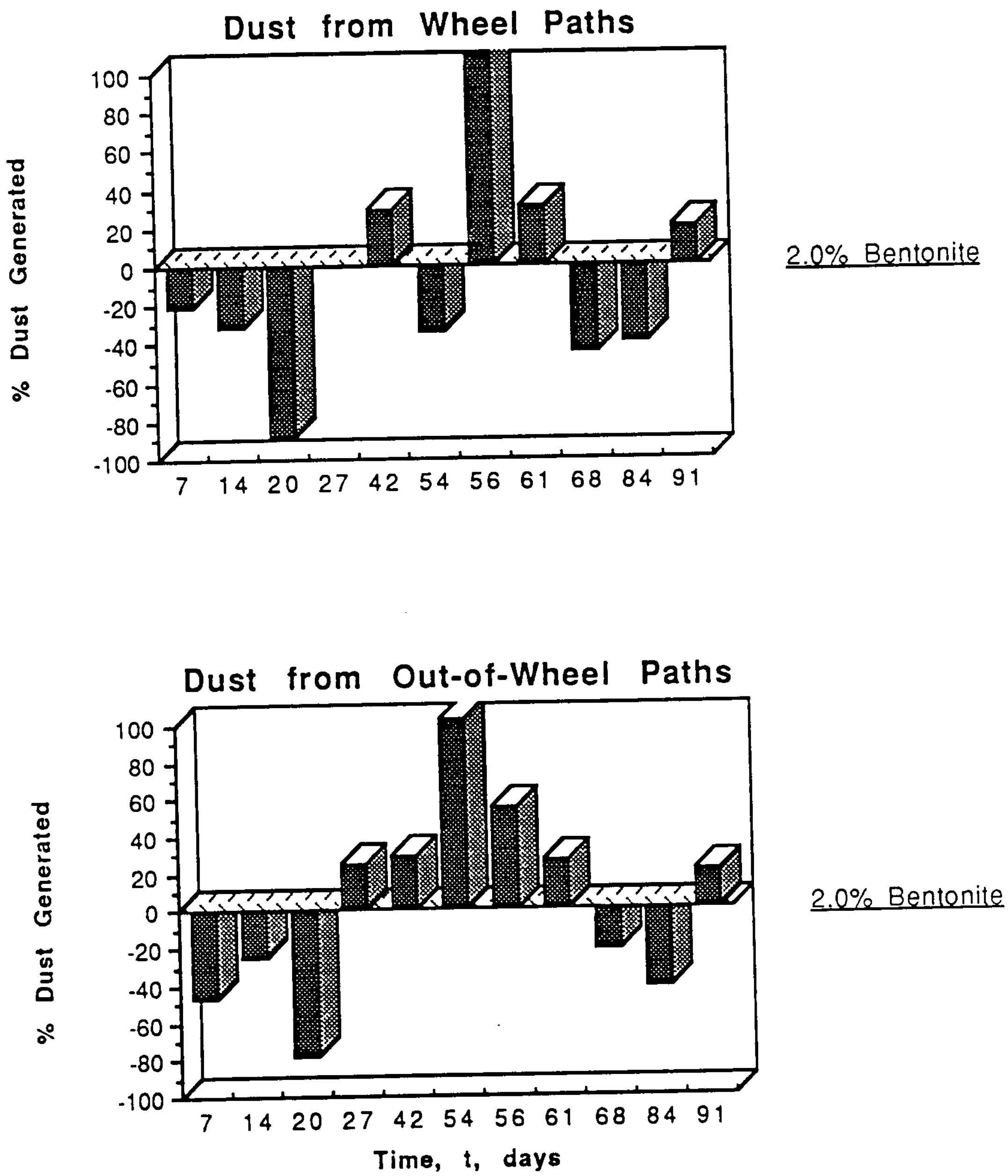
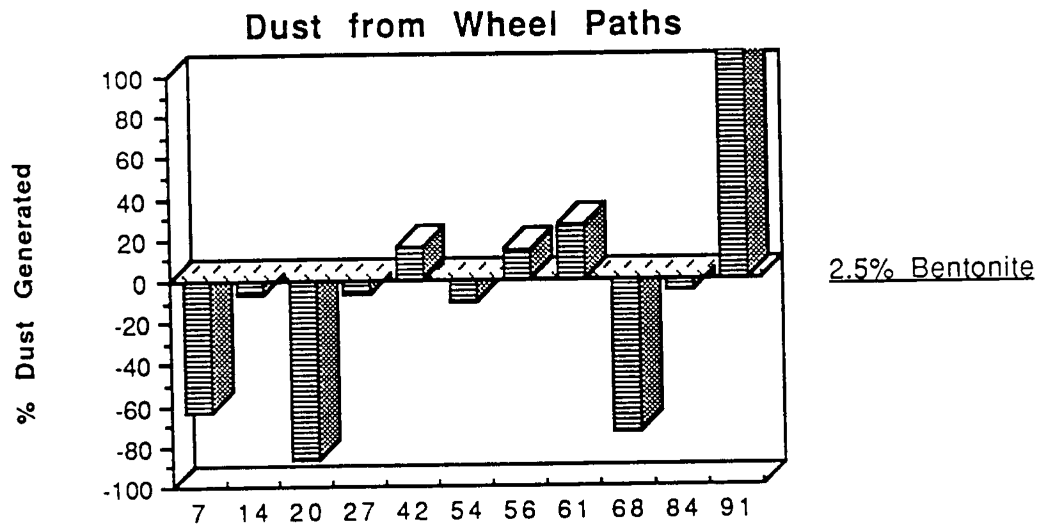


Figure 28. Adair County test road dust generation for 2.0% Bentonite treatment



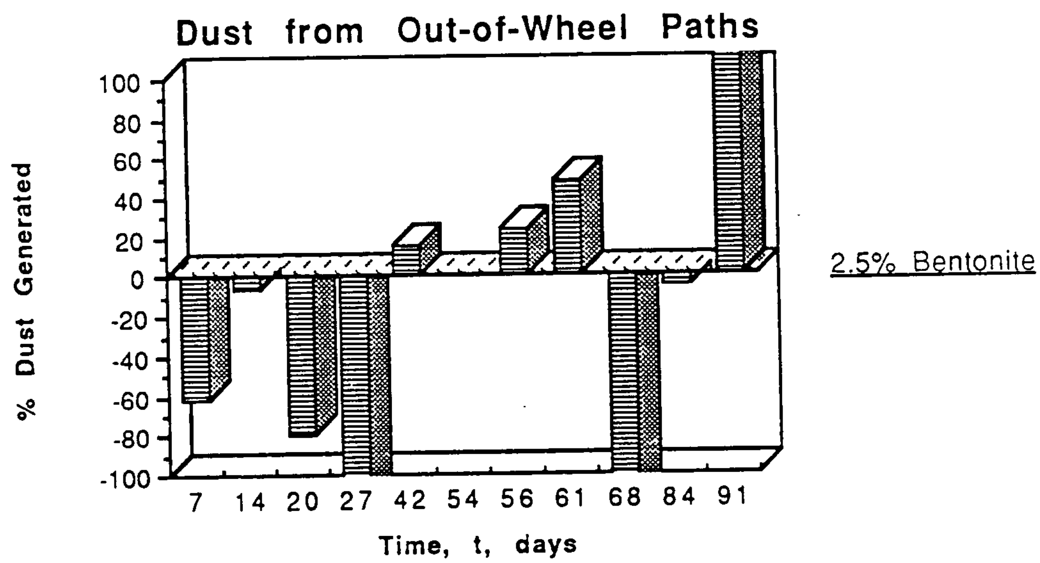
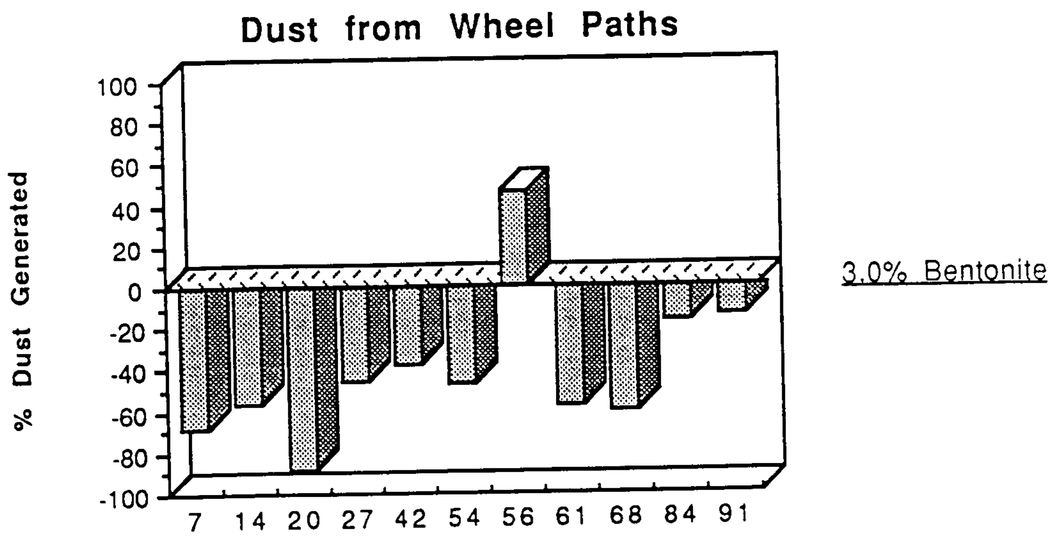


Figure 29. Adair County test road dust generation for 2.5% Bentonite treatment



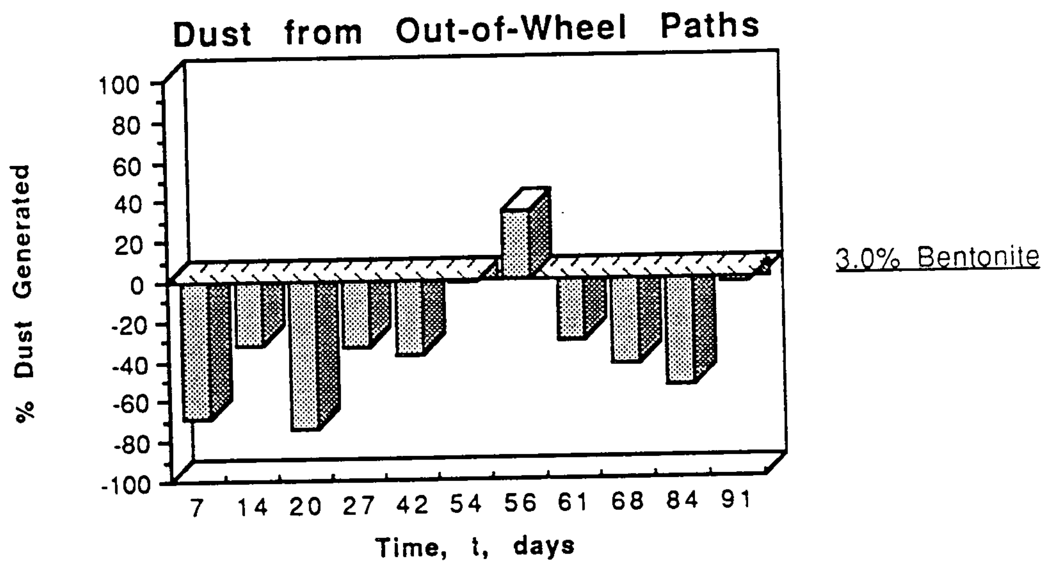
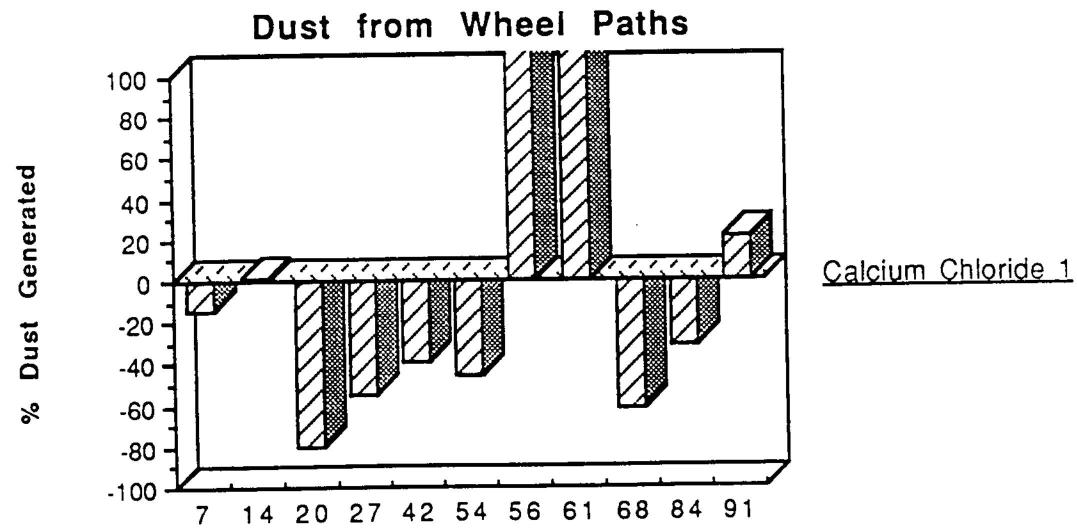


Figure 30. Adair County test road dust generation for 3.0% Bentonite treatment



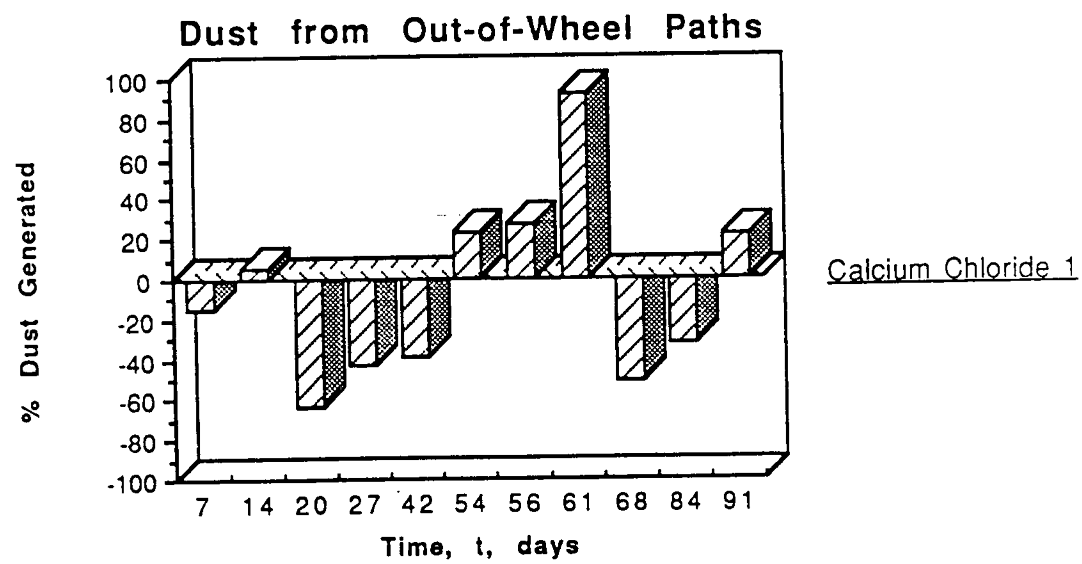
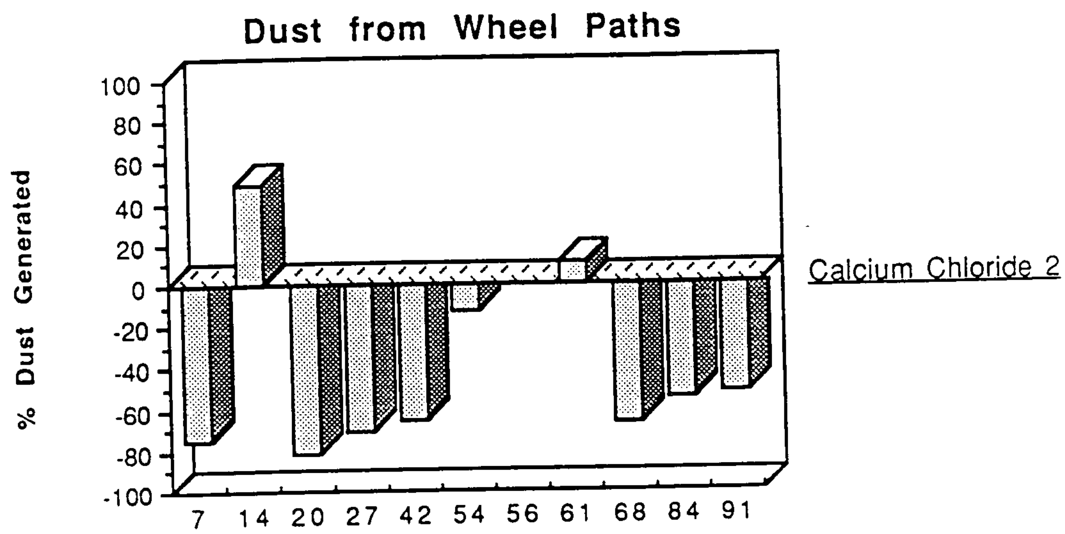


Figure 31. Adair County test road dust generation for Calcium Chloride 1 treatment



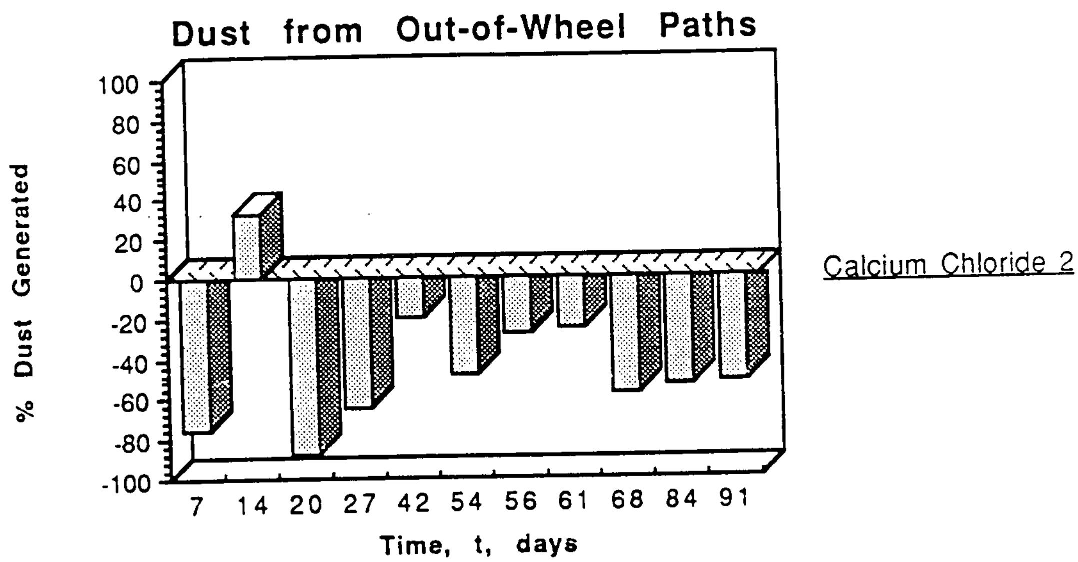


Figure 32. Adair County test road dust generation for Calcium Chloride 2 treatment

Braking Characteristics

Results of the braking tests are shown of Figures 33 and 34 for the wheelpath and for out-of-the-wheelpath testing, respectively. Fourteen tests were conducted on dry surfaces, and six tests were conducted on a wet surface. Although not statistically significant, no discernible trend appeared evident that would indicate an adverse affect on braking distance for the treated areas.

Laboratory Testing

Laboratory testing consisted of gradation analysis and SEM studies to evaluate particulate bonding and aggregation.

Gradation Analysis

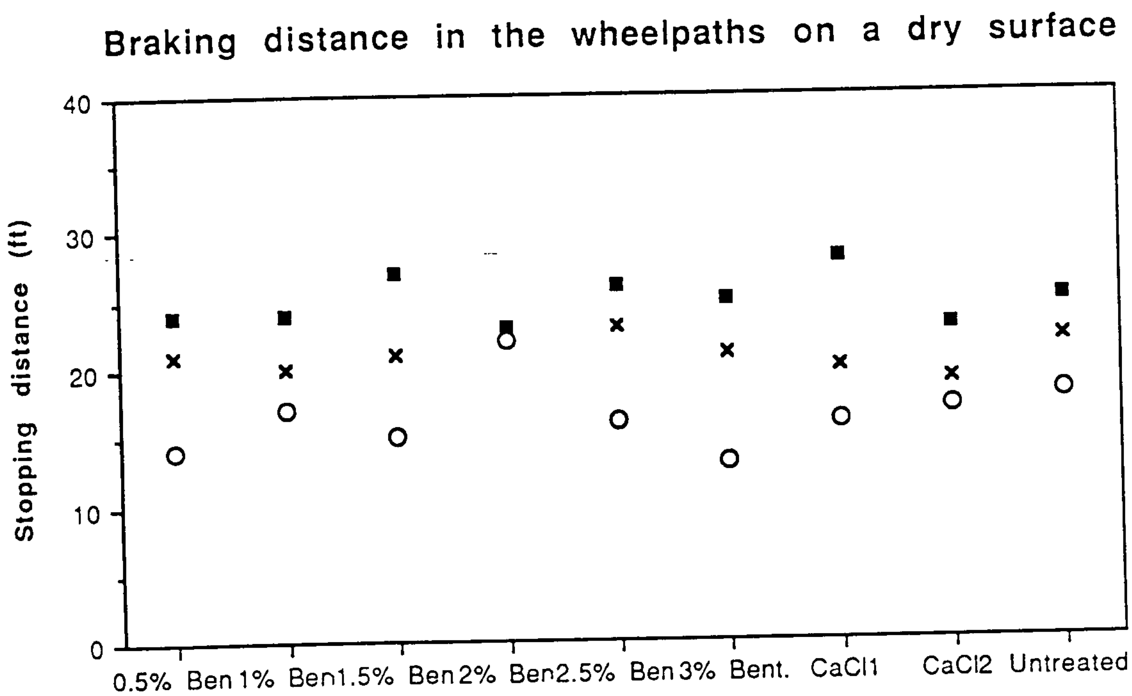
Numerous gradation tests were conducted on samples obtained periodically over the test period. Results were similar to those obtained for the Dallas County test road. The gradation analysis results comparing dry versus wet sieve analysis indicate that particulate bonding is occurring on the finer sieve fractions.

Scanning Electron Microscopy

Several samples of material retained and passing the various fine sieve fractions were investigated using the SEM. Typical results are shown on Figures 35 and 36. Aggregations of particulates was routinely evident in bentonite treated samples and not evident in untreated samples. This appears to confirm the bonding capability of bentonite for fine limestone particulates.

Summary

Higher levels of bentonite treatment can be obtained by dry application and mixing of bentonite with limestone surfacing materials followed by spray



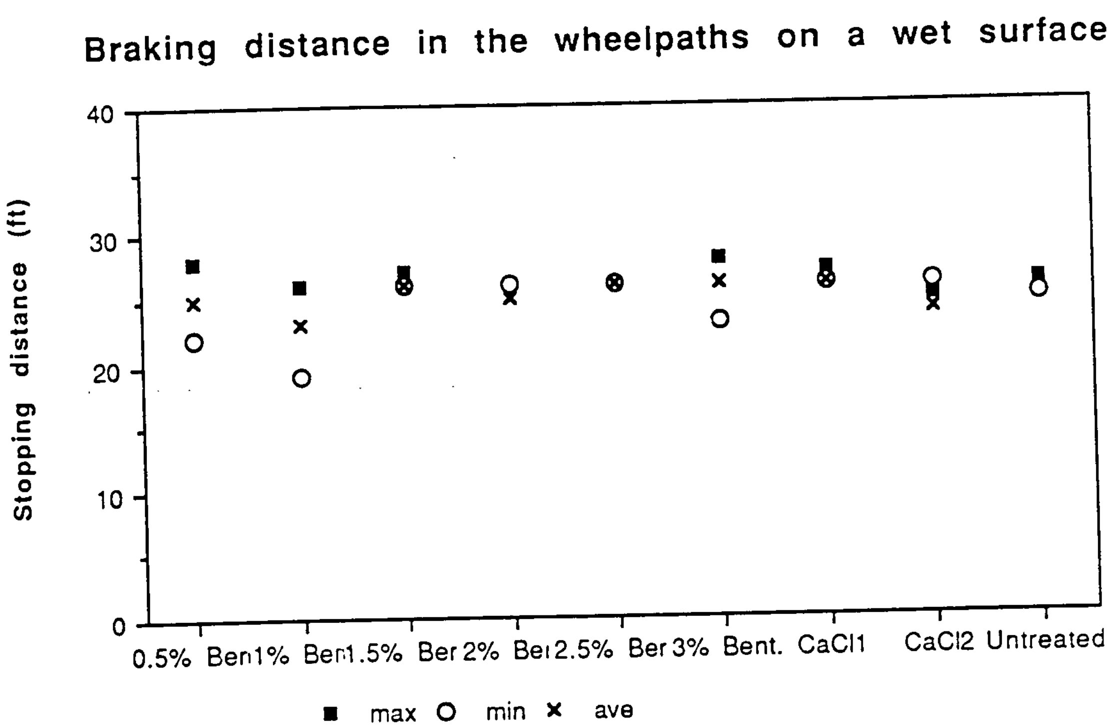


Figure 33. Wheelpath braking distance results for Adair County Test Road

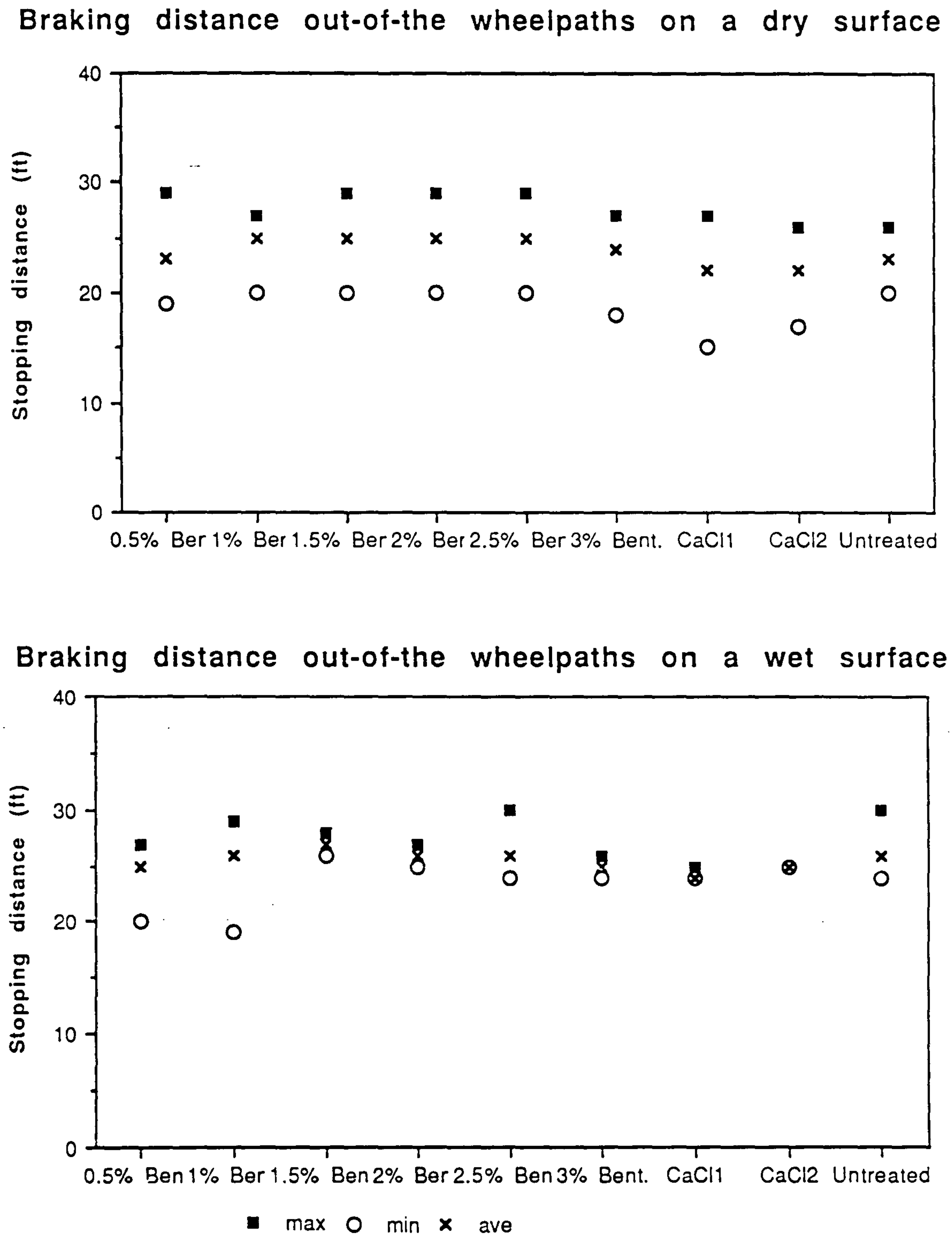


Figure 34. Out-of-Wheelpath braking distance results for Adair County Test Road

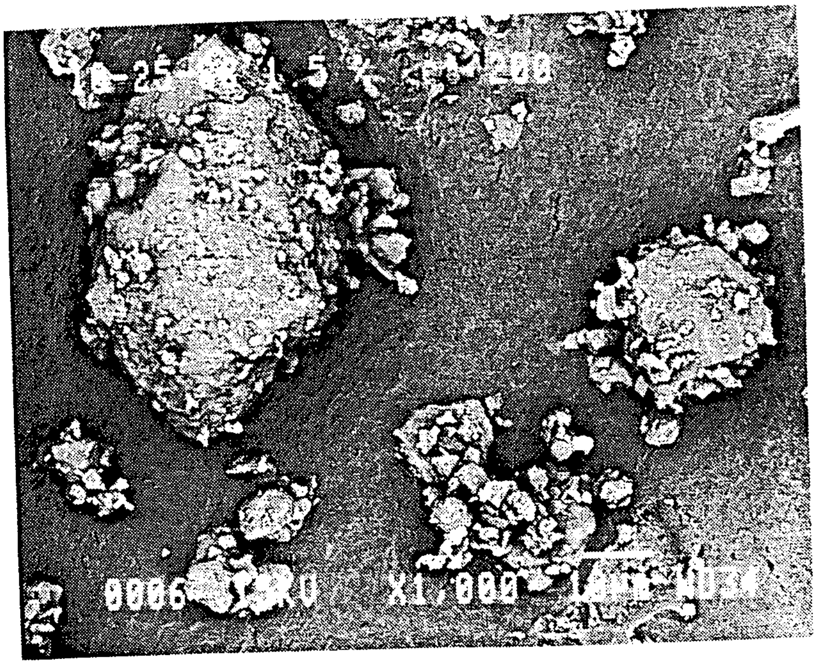


Figure 35. SEM photograph of material passing No. 200 sieve from the 1.5% bentonite treated section

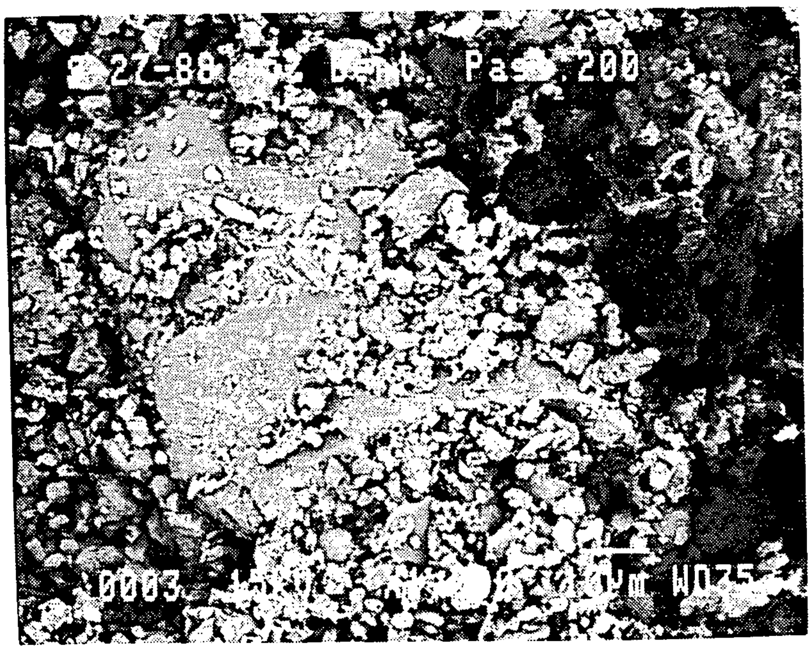


Figure 36. SEM photograph of material passing No. 200 sieve from the 0.5% bentonite treated section

application of water with soda ash and road mixing the treated material to a consistency of 3 to 4 inch slump concrete.

Construction is rapid and can be accomplished with conventional equipment.

Test data indicate that effective dust palliation can be achieved by this method as well as the spray application of dispersed bentonite slurry.

The 3.0 percent bentonite treatment achieved the best dust reduction of bentonite treated sections. Braking characteristics were not adversely affected.

ECONOMIC CONSIDERATIONS

A cost evaluation was conducted for each treatment type. The cost of equipment and labor used is current industry norms.

The bentonite treatment costs are based on two motor graders at \$23.67/hour each and two skilled operators at \$10.55/hour each, two tank wagons at \$4.57/hour each, and three laborers at \$9.70/hour each. The estimate assumes that one mile can be built per day. Calcium chloride cost was obtained from Laverty Supply, Inc. of Indianola, Iowa. Table 10 presents per mile cost estimates of the various treatments.

Table 10. Per Mile Costs of Bentonite and Calcium Chloride Treatments

Treatment	Equipment \$/hr	Labor \$/hr	Material \$	Total Cost \$/mile
1.0% Bentonite	56	50	2,790	3,638
2.0% Bentonite	56	50	3,050	3,898
3.0% Bentonite	56	50	3,315	4,163
Calcium Chloride	—	—	—	16,133

Table 11 presents a comparison of the calcium chloride and the bentonite treatments in terms of average percent of dust reduction and duration.

The percent of reduction for this comparison study was taken from 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.

Table 11. Comparison of Calcium Chloride and Bentonite Treatments

Treatment	Estimated Efficiency Treatment (% Reduction)	Estimated Duration (Months)
1.0% Bentonite	15	18-24
2.0% Bentonite	25	18-24
3.0% Bentonite	35	18-24
Calcium Chloride	70	3-4

The data in Table 11 combined with construction cost data in Table 10 provides the basis for estimating a cost/efficiency value in dollars per mile, per percent reduction, per month. This data is shown in Table 12.

Table 12. Comparison of Treatment Costs considering Duration Time and Dust Reduction

Treatment	Treatment Efficiency ($/mile/%reduction/month)
1.0% Bentonite	12
2.0% Bentonite	8
3.0% Bentonite	6
Calcium Chloride	66

The economical advantage of bentonite treatment is apparent.

SUMMARY AND CONCLUSIONS

The results from this research indicate that bentonite acts as a dust reducing agent. The results of the data for both the Dallas and the Adair county roads indicate the following.

- For bentonite treatment levels up to 1.5 percent (by weight of aggregate) soda ash dispersed bentonite solutions can be field mixed and applied using conventional chloride spray distribution equipment.

- For bentonite treatments above 3.0 percent, dry application of bentonite to surfacing material followed by dry road mixing and spray application of water and soda ash and road mixing to a consistency of 3 to 4 inch slump concrete can be used.

- Tandem motor grader dry and wet mixing was rapid and adequate and can be accomplished under traffic.

- Calcium and magnesium chloride treatments are 2 to 3 times more effective in dust reduction in the short term (3 months) but are prone to washboarding and rutting due to maintenance restrictions.

- Bentonite treatments at the 2 to 3 percent level is expected to provide a 30 to 40 percent dust reduction over a long term (18-24 months).

- A disadvantage of bentonite treatment is that there is not the initial dramatic reduction in dust as with chloride treatment. Although dust is reduced 30 to 40 percent after treatment, there is still dust being generated and the public may not perceive a reduction.

- Normal maintenance operations can be used on bentonite treated areas.

- Braking characteristics are not adversely affected by treatments up to the 3.0 percent level.

- The dust reduction observed in the bentonite treated sections is being accomplished by the bentonite functioning as a bonding agent to bind small particles to larger particles (particularly the #30 to #200 sizes) and is acting to aggregate 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.

- The bentonite appears to be able to interact with new limestone maintenance surfacing material and maintains the dust reduction capability.

- Bentonite treatment is approximately ten times more cost effective than chloride treatment.

ACKNOWLEDGEMENTS

This research was conducted through the Engineering Research Institute of Iowa State University and sponsored by the Iowa Highway Research Board of the Iowa Department of Transportation as project HR-297.

The authors gratefully acknowledge the support and assistance of Dallas County Engineer Gene Hardy and of Adair County Engineer Don Lynan. Mr. Dick Wood and Kenn Blake of Laverty Supply, Inc., Indianola, Iowa are acknowledged for suppling materials and equipment for chloride treatments on the Dallas County test road. Mr. Dirk Axe of Iowa Limestone Company, Alden, Iowa provided bentonite for both the Dallas County and the Adair County projects.

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