Final Report

Bentonite Treatment For Economical Dust Reduction on Limestone Surfaced Secondary Roads

January 1995

Sponsored by the Highway Division of the Iowa Department of Transportation
and the Iowa Highway Research Advisory Board
Iowa DOT Project HR-351

Iowa Department of Transportation

report

ERI Project 3643

ISU-ERI-Ames 95-408

College of Engineering
Iowa State University

Bentonite Treatment for Economical Dust Reduction on Limestone Surfaced Secondary Roads

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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 was postulated that the electrically charged surfaces (negative) of the clay particles could interact with the charged surfaces (positive) 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.

One mile test roads were constructed in Tama, Appanoose, and Hancock counties in Iowa using Bentonite treatment levels (by weight of aggregate) ranging from 3.0 to 12.0 percent. Construction was accomplished by adding dry Bentonite to the surfacing material and then dry road mixing. The soda ash/water solution (dispersing agent) was spray applied and the treated surfacing material wet mixed by motor graders to a consistency of 2 to 3 inch slump concrete. Two motor graders working in tandem provided rapid mixing. Following wet mixing the material was surface spread and compacted by local traffic.

Quantitative and qualitative periodic evaluations and testing of the test roads was conducted with respect to dust generation, crust development, roughness, and braking characteristics. As the Bentonite treatment level increased dust generation decreased. From a cost/benefit standpoint, an optimum level of treatment is about 8 percent (by weight of aggregate). For roads with light traffic, one application at this treatment level resulted in a 60-70 percent average dust reduction in the first season, 40-50 percent in the second season, and 20-30 percent in the third season. Crust development was rated at two times better than untreated control sections. No discernible trend was evident with respect to roughness. There was no evident difference in any of the test sections with respect to braking distance and braking handling characteristics, under wet surface conditions compared to the control sections.

Chloride treatments are more effective in dust reduction in the short term (3-4 months). Bentonite treatment is capable of dust reduction over the long term (2-3 seasons). Normal maintenance blading operations can be used on Bentonite treated areas.

Soda ash dispersed Bentonite treatment is conservatively estimated to be more than twice as 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 significantly after treatment there is still dust being generated. Video evidence indicates that the dust cloud in the Bentonite treated sections does not rise as high, or spread as wide as the cloud in the untreated section. It also settles faster than the cloud in the untreated section. This is considered important for driving safety of following traffic, and for nuisance dust invasion of residences and residential areas.

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

INTRODUCTION

This final report presents the results of research project HR-351 entitled, "Bentonite Treatment for Economical Dust Reduction on Limestone Surfaced Secondary Roads."

Surfaces of fractured calcium carbonate or limestone particles are known to exhibit a positive electrochemical surface charge [1]. It had been postulated that introduction of a material of an opposite surface charge might function as an "electrochemical glue". The oppositely charged particle may act to bind small limestone dust particles together in an agglomerate that would not become airborne dust under traffic. The oppositely charged particles might also bind small limestone dust particles to surfaces of larger particles, again preventing them from becoming airborne dust under traffic.

Previous laboratory research studies, [2] using a sodium montmorillonitic clay (Bentonite) as the negatively charged material appeared promising for use to reduce dusting in a commercial manufacturing application. Initial laboratory and field application for limestone surfaced secondary roads was conducted under Iowa DOT project HR-297 [3]. This project focused on development of field construction and application procedures using up to 3 percent Bentonite (by weight of loose surfacing material). The percent Bentonite treatment was kept low in this project due to concern with the influence that Bentonite might have on vehicular handling, braking, and stopping distance. Results of this project indicated that Bentonite treatment could be accomplished using conventional equipment available to most counties. Braking and handling characteristics were not adversely affected. A 30 to 40 percent long-term (18-24 months) dust reduction was observed.

The purpose of project HR-351 was to evaluate the effectiveness of higher levels of Bentonite treatment relative to dust generation, crust development, roughness and braking characteristics on limestone surfaced roads. The project was separated into two phases.

Phase I: This phase involved additional laboratory testing to optimize the application amount of the sodium carbonate (soda ash) disposing agent and construction of a test road using up to 9 percent Bentonite treatment.

Phase II: The result of Phase I were used to evaluate the feasibility of high application rates and guide application amounts and construction procedures for additional test road construction. Additional test roads were constructed in Appanoose and Hancock counties.

The following report presents the research results for Phase I and Phase II of the HR-351 project.

LABORATORY TESTING

In order to separate the bentonite (clay) particles in a bentonite/water solution, a dispersing agent is necessary. Sodium carbonate (soda ash) was used and acts to temporarily neutralize clay particle charges, which minimizes agglomeration of the bentonite during the application process. The following laboratory testing was conducted to optimize the amount of soda ash solution to use as the dispersing agent for the bentonite treatments.

The standard hydrometer test specified by ASTM D 422 was modified and used to evaluate effectiveness of the soda ash compared to the standard dispersing agent sodium hexametaphosphate (Calgon). Modifications of the test were as follows.

1. Sample size was reduced from 50 grams to 25 grams.
2. Hydrometer readings were replaced with particle settlement observations.

Soda ash concentrations of 0.4, 0.8, 1.2 and 1.6 percent (by weight of water) were prepared. Table 1 summarizes observations made during laboratory preparation of the samples.

Figure 1 presents the results of settlement observations of the standard Calgon solution as a function of time. After 280 hours, the Calgon was acting to maintain most of the small particles in suspension with only 15 ml of clear water observed in the hydrometer (1000 ml - 985 ml). However, particle flocculation began to occur at 37 hours and continued to increase over time as indicated by the dark bands at the bottom of the bars on Figure 1.

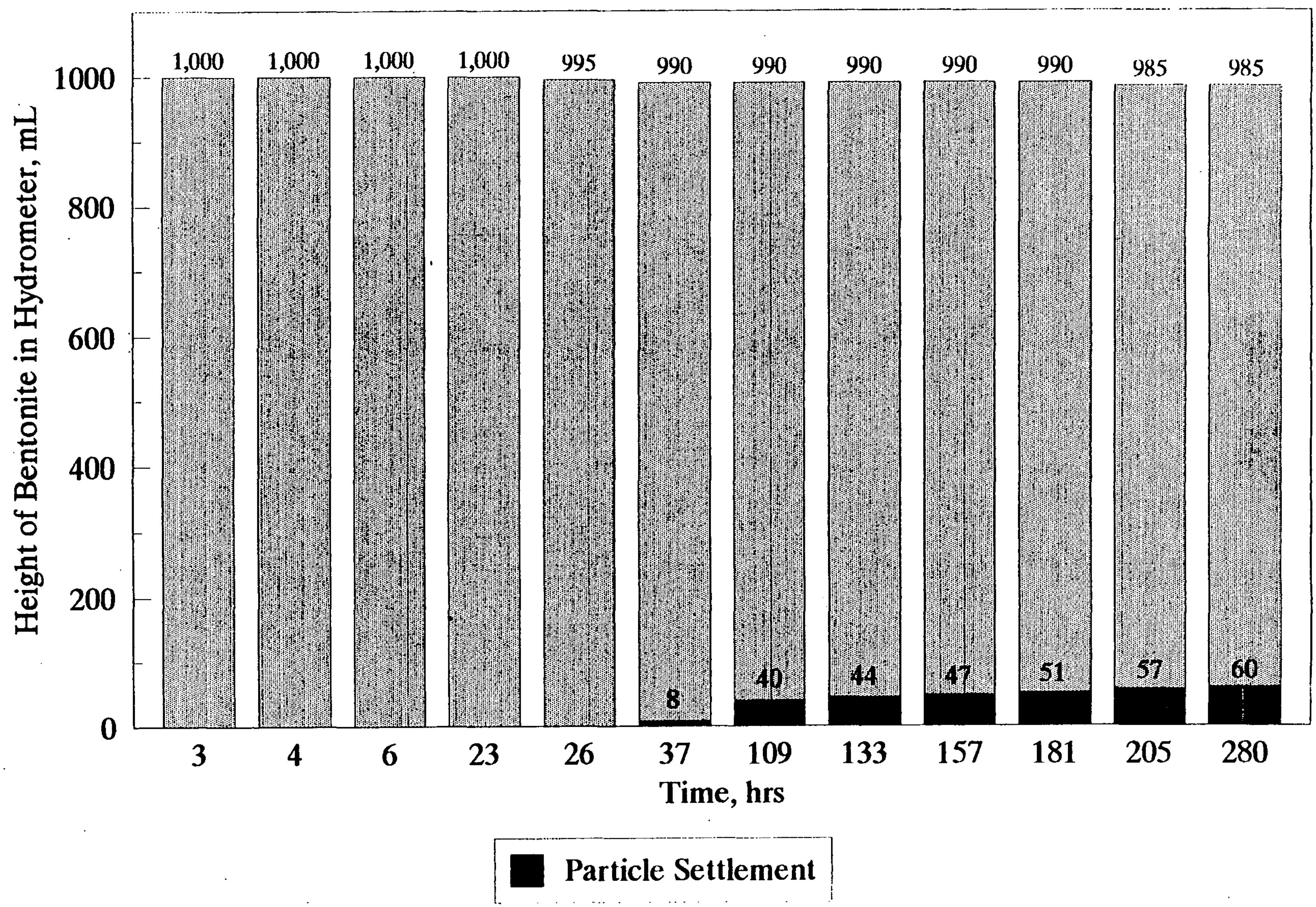

Figure 1. Settlement of Bentonite in A Sodium Hexametaphosphate (Calgon) Solution

Table 1. Observations made during hydrometer sample preparation.

Solution	Initial Mixing	Air Jet Mixing
0.8% Calgon	• Dispersed easily with a few small clumps left after stirring.	• Mixed very well. • Sample was very liquid like.
0.4% Soda Ash	• Did not mix very well. • Many clumps left after stirring.	• Sample stuck to the sides of the hydrometer during mixing. • Had to add an extra 50 ml of water in order to get the sample to disperse. • Sample was very thick after mixing.
0.8% Soda Ash	• Did not mix very well. • A few clumps left after stirring. • Some material stuck to the sides of the hydrometer.	• Mixed okay, but sample was still very thick. • Had to add an extra 50 ml of water to make it mixable.
1.2% Soda Ash	• Mixed okay. • Dispersed easily with a few small clumps left after stirring.	• Sample mixed very well. • Sample was liquid like after mixing. • A few clumps were noticed after mixing.
1.6% Soda Ash	• Mixed very easily. • Dispersed very well into a liquid with only a couple clumps left after stirring.	• Sample mixed very well. • Sample was liquid like after mixing.

Figures 2 through 5 present the results of the soda ash tests. There was no evidence of flocculation and observable sediment at 280 hours for any of the treatment levels. This indicates that the soda ash is highly effective at preventing agglomeration and flocculation of the bentonite particles.

The soda ash treatments were not as effective in maintaining the clay particles in complete suspension for an extended period. This is evidenced by the clearing of the solution at the top of the hydrometer and is shown on Figures 2 through 5. With increased soda ash concentration, the solution clearing becomes more pronounced, especially after five hours. Since construction proceeds rapidly, however, this should not be problematic in the field. The soda ash appears highly effective at relatively low concentrations. Based on these results, construction proceeded using the 0.4 percent soda ash solution. Observations during field construction, however, indicated this may need to be adjusted, and will be discussed later in the report.

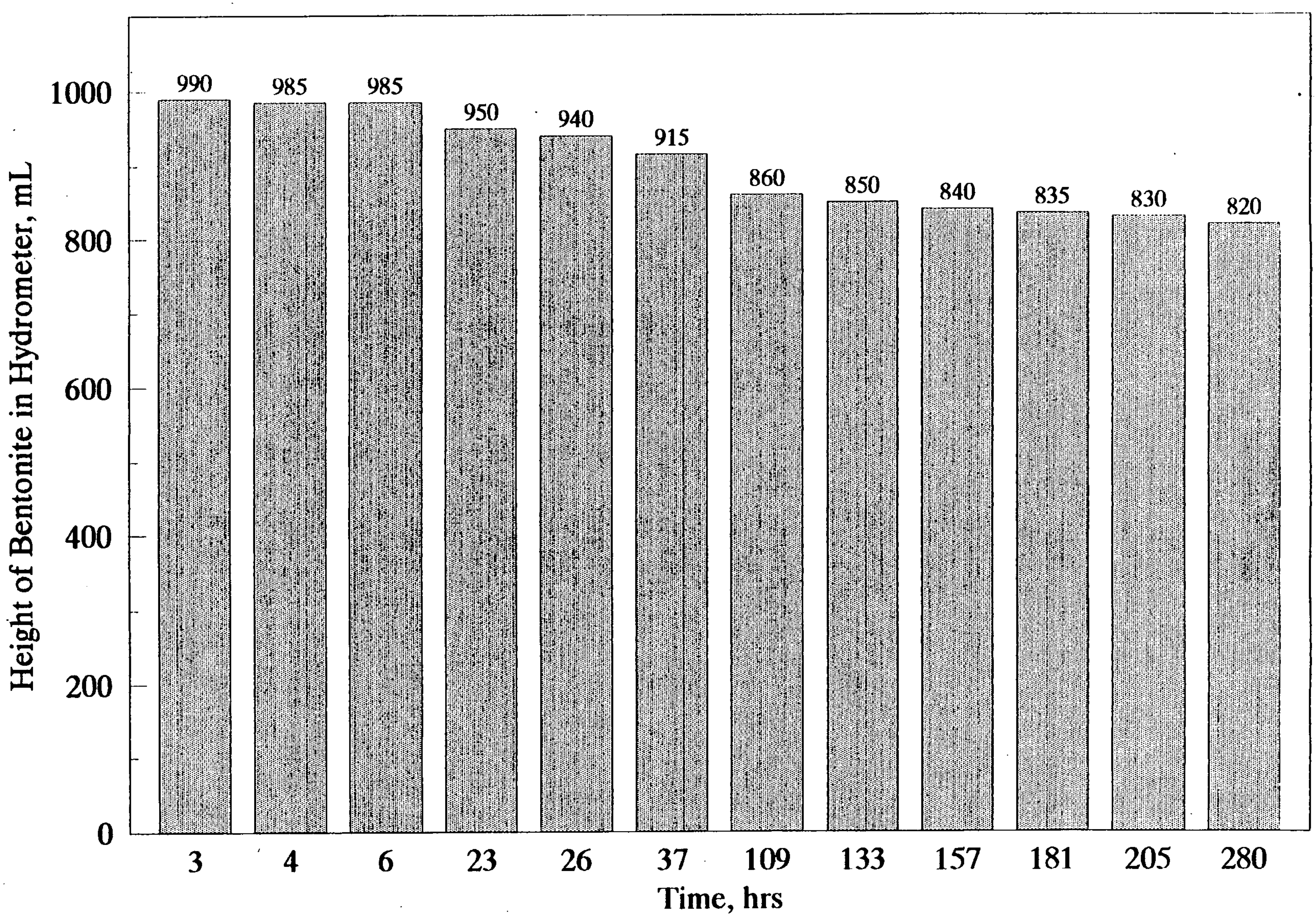

Figure 2. Settlement of Bentonite in a 0.4 Percent Soda Ash Solution

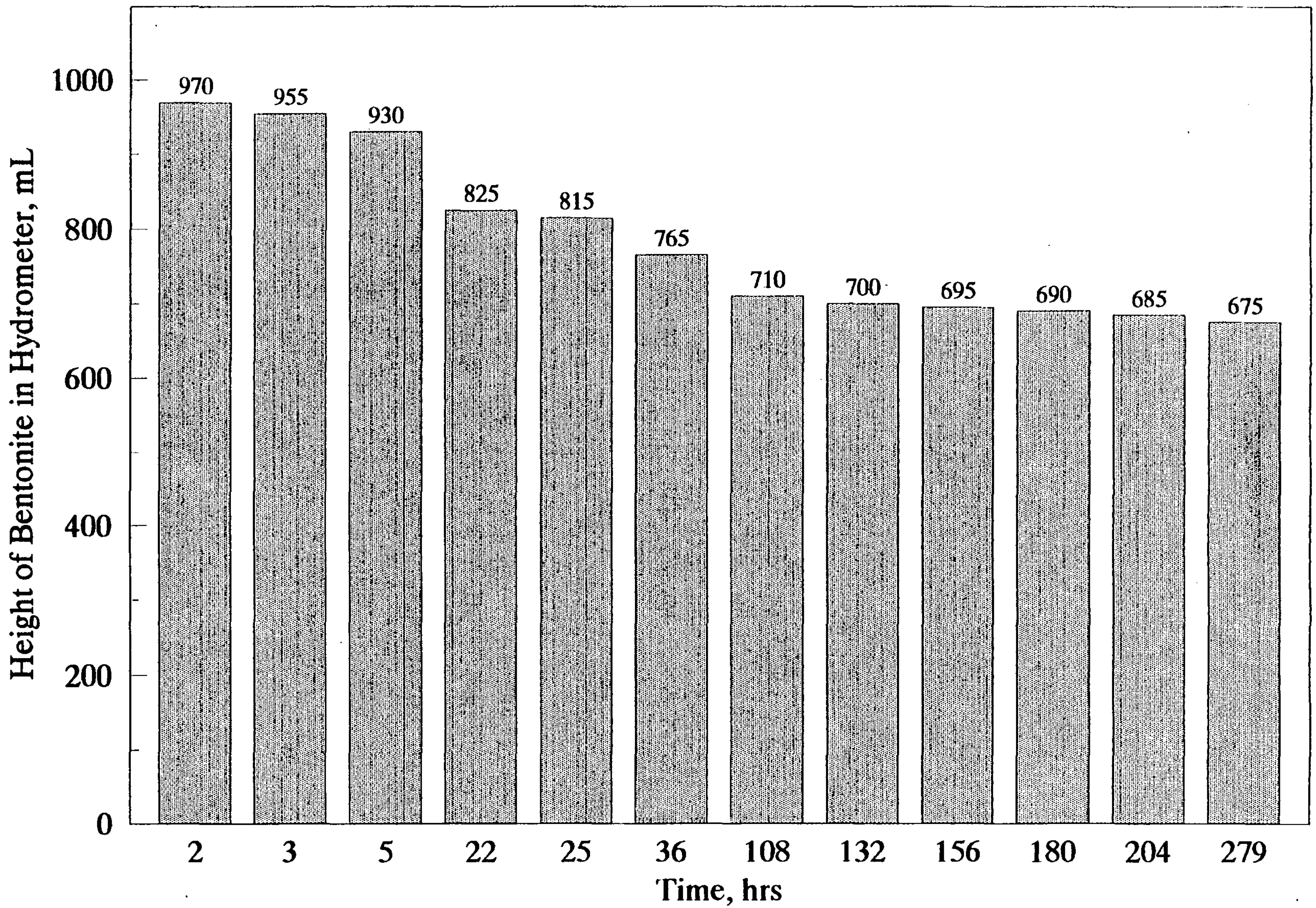

Figure 3. Settlement of Bentonite in a 0.8 Percent Soda Ash Solution

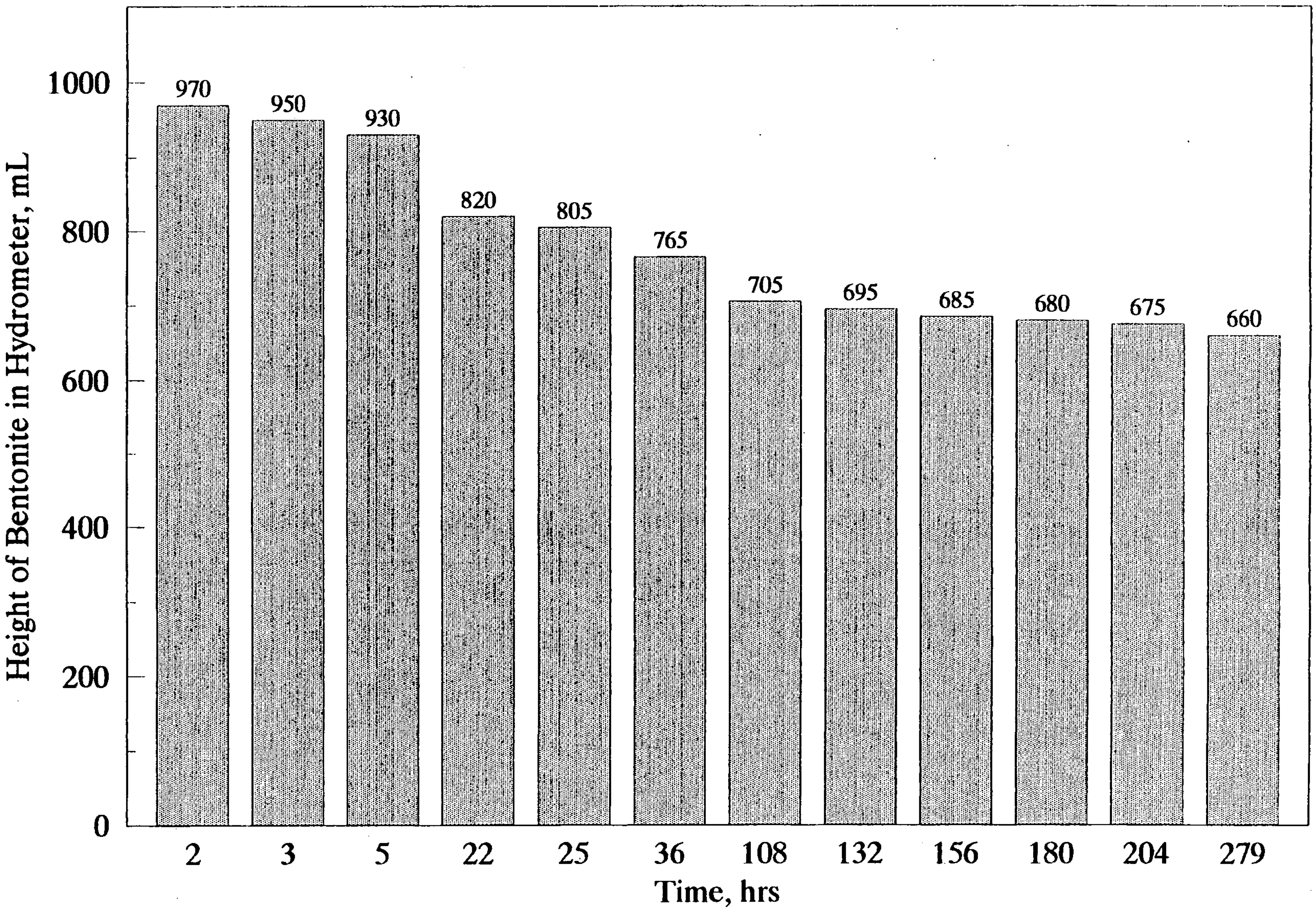

Figure 4. Settlement of Bentonite in a 1.2 Percent Soda Ash Solution

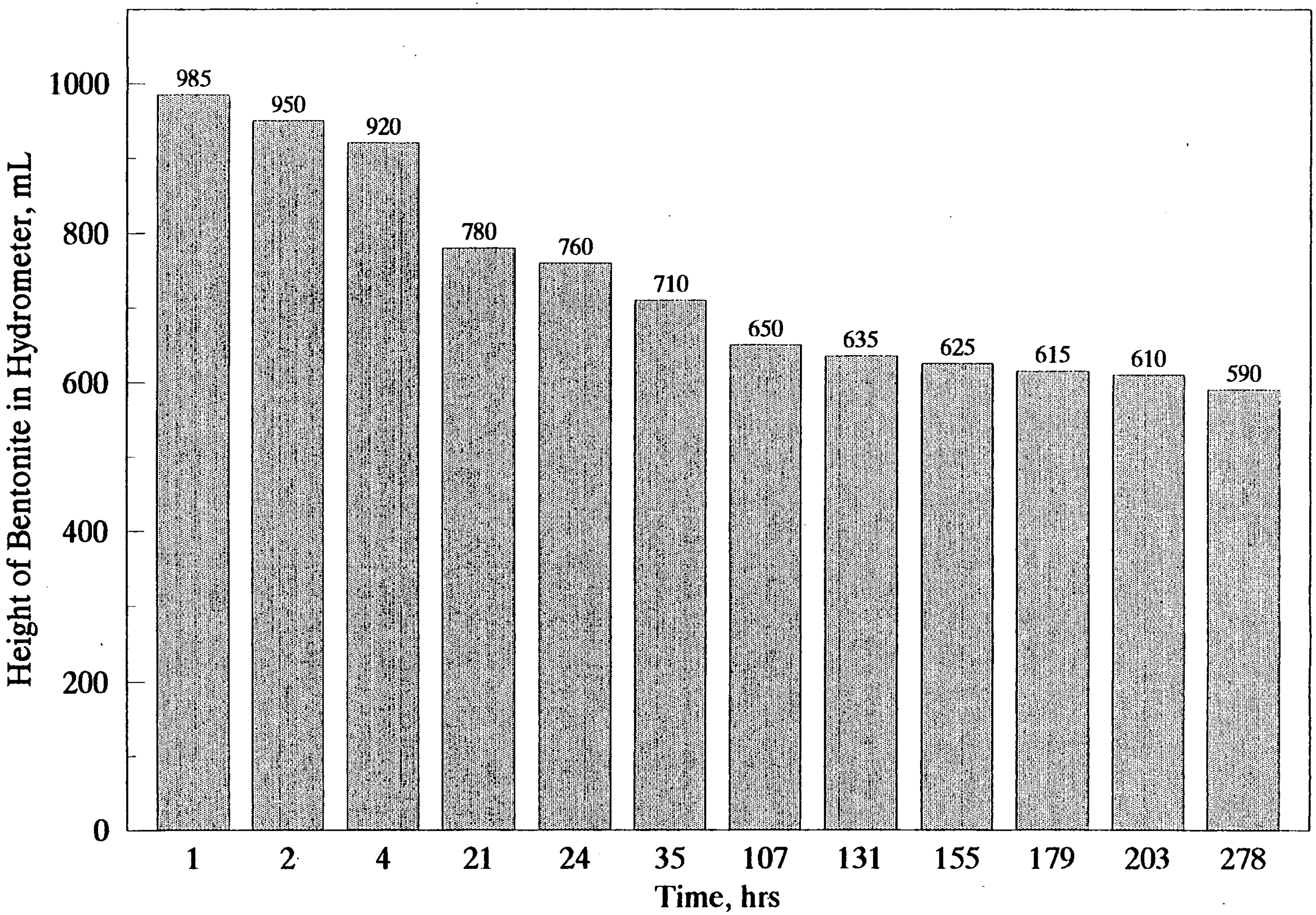

Figure 5. Settlement of Bentonite in a 1.6 Percent Soda Ash Solution

TEST ROAD SELECTION

Desirable criteria for test road selection, in Phase I, included relatively flat topography and uniform subgrade soils. A traffic count in the vicinity of 70 vehicles per day (vpd) and a minimal number of residents was also desirable. The criteria used in Phase II was the same as that used in Phase I except with the following changes. First, a higher traffic count (around 200 vpd) was desired. Second, more truck traffic containing heavier loads was desirable. The engineers in Appanoose and Warren County were visited for potential participation. The roads in Warren County did not meet the desirable criteria. Appanoose County expressed a strong interest in participation.

Tama County Test Road (Phase I)

The test road is a north-south road located one mile north and one-half mile west of the town Garwin, Iowa. It lies between sections 2 and 3, T85N and R16W in Tama County as shown on Figure 6. The road exhibited a typical amount of crushed limestone surfacing material and is reasonably flat with few residents along the road. The 1989 traffic count obtained from the Iowa Department of Transportation (Iowa DOT) was 60 vpd.

The aggregate present was classified as an impure limestone from x-ray fluorescence analysis. The aggregate is from the Montour quarry in Tama County. This aggregate has an abrasion value of 38 which was obtained from the Iowa DOT quarry information. The abrasion value of 38 is below 45 which is the maximum specification for a grading B in the American Association of State Highway and Transportation Officials (AASHTO) T96 [4] and 4120.04 specification from the Iowa DOT [5].

Appanoose County Test Road (Phase II)

The test road is a north-south road located two and one-half miles west of Highway 5 on J46. The road is located in sections 15 and 22, T68N and R18W, in Appanoose County as shown on Figure 7. The test road is on T20 from J46 to the landfill located approximately two and four-tenths miles south of J46. The road is reasonably flat with nine residents along the test sections. The 1990

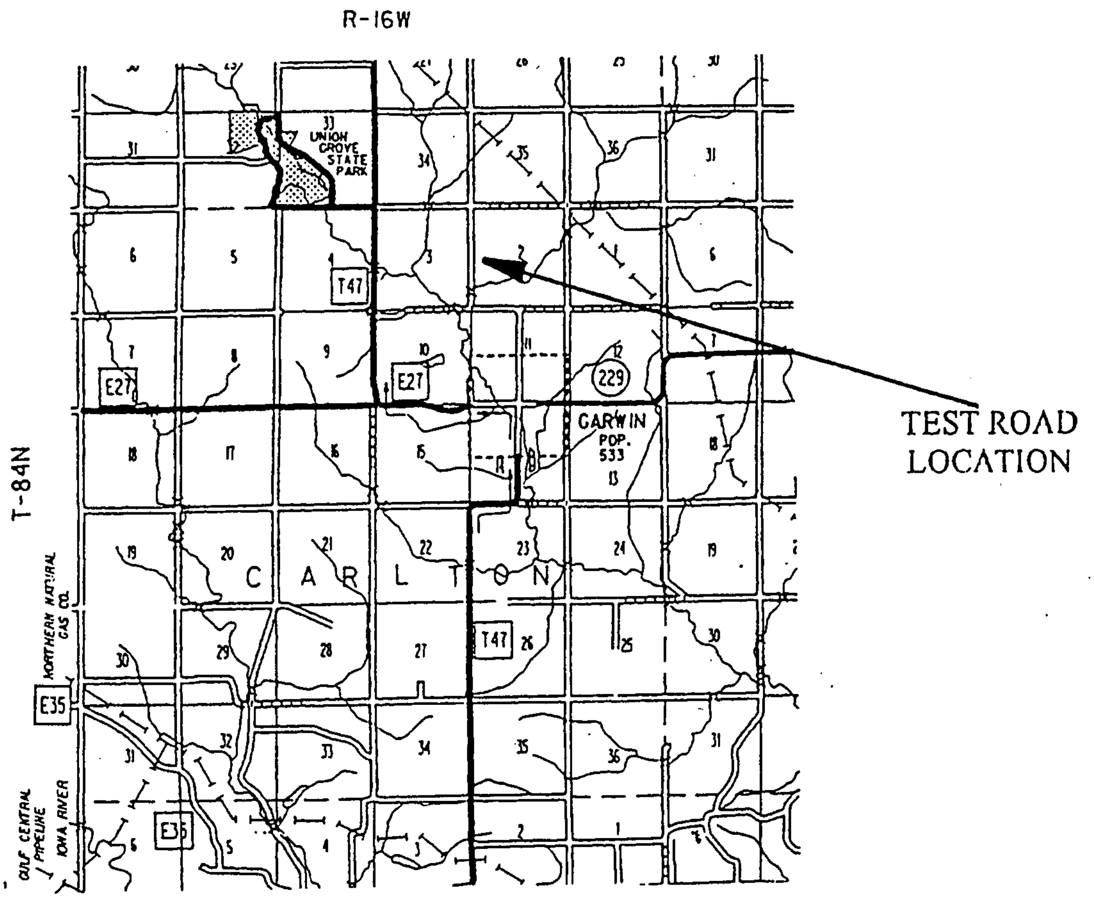

Figure 6. Test road location in Tama County.

traffic count obtained from the Iowa DOT was 200 vpd with approximately 10 to 30 percent being truck traffic.

The road was being reconstructed during preliminary evaluation. It was estimated that 600 tons per mile of crushed limestone was to be applied to the road. The road reconstruction was completed on June 21, 1993. After the road was compacted by a roller and then a week of traffic compaction, the road was treated with Bentonite.

The agregate present was classified as a limestone from x-ray fluorescence analysis. The aggregate is from the Lemley East #5 quarry in Appanoose County. This aggregate has an abrasion

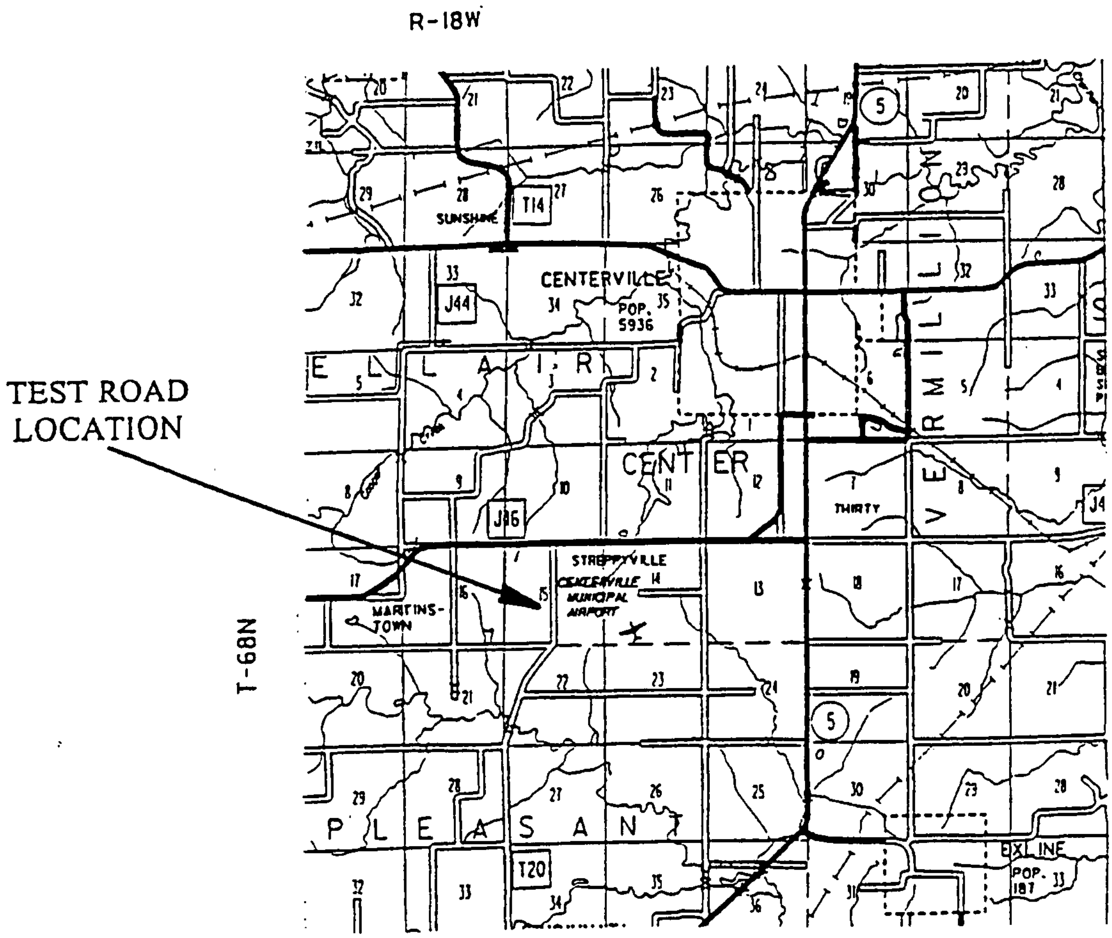

Figure 7. Test road location in Appanoose County

value of 26, which is an average of six tests conducted by the Iowa DOT from 1991 to 1993. The abrasion value of 26 is below the specified maximum specification of 45.

Hancock County Test Road (Phase II)

Hancock County also expressed strong interest in participating in the research project. The test road is a north-south road located south of Highway 18, six miles west of Britt. It lies between sections 32 and 33, T96N and R26W in Hancock County as shown on Figure 8. The 1991 traffic count obtained from the Iowa DOT was 110 vpd.

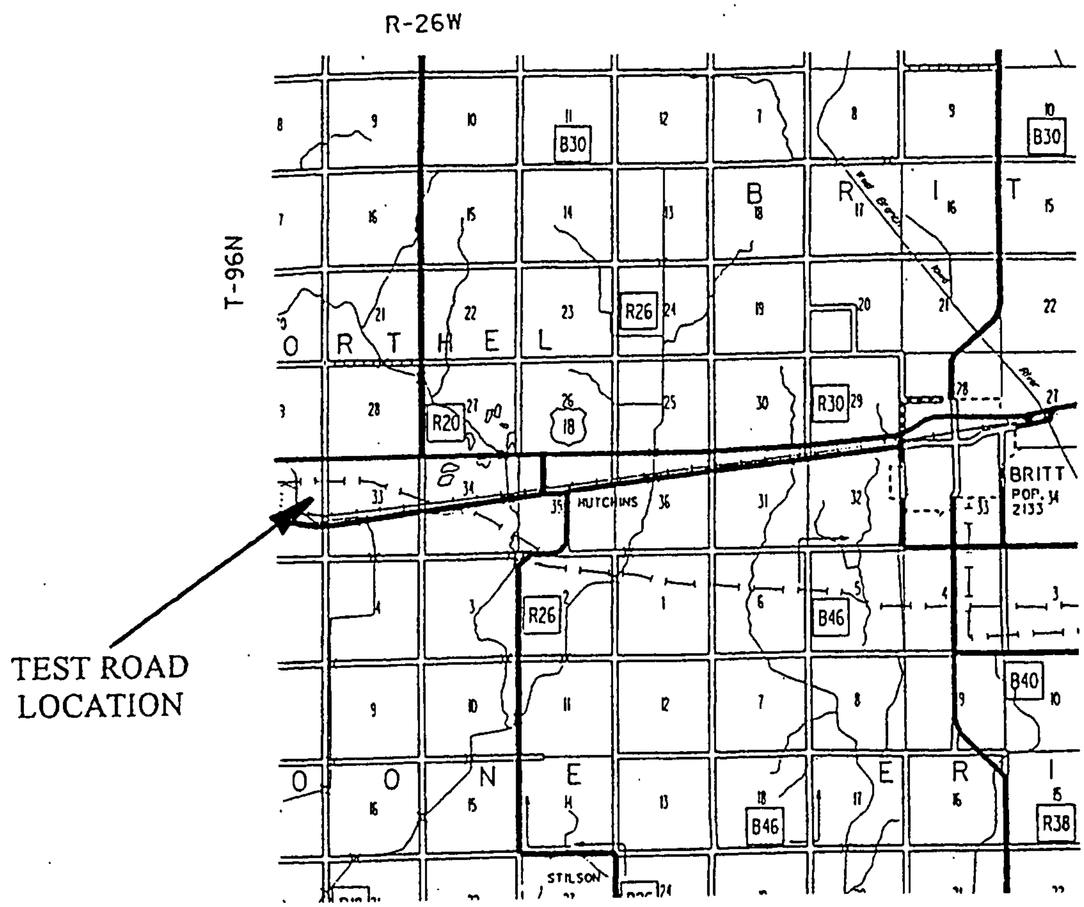

Figure 8. Test road location in Hancock County.

The road was surfaced with gravel, which had to be removed. The County engineer, J. William Waddingham, agreed to remove the gravel. Once the gravel was removed, approximately 150 tons per mile of crushed limestone surfacing material was applied. The road is reasonably flat with only two residents and a golf course along the road.

The crushed limestone that was applied to the road is classified as a dolomite limestone. The aggregate is from the Garner North quarry located in Hancock County. This aggregate has an abrasion value of 25 which is an average of six tests conducted by the Iowa DOT from 1991 to 1993. Again, this abrasion value of 25 is below the maximum specification of 45.

TEST ROAD CONSTRUCTION

Tama County Layout

Construction of the one mile test road was completed on August 5, 1992. The test section layout is shown in Figure 9. The layout indicates the locations of the control section, and various Bentonite treated sections.

Tama County Construction

Materials and Equipment

The construction materials consisted of the existing limestone surfacing materials, Bentonite, soda ash, and water. The limestone surfacing materials were from the Montour quarry. The Bentonite (feed grade) was purchased from the Iowa Limestone Company of Alden, Iowa and the soda ash was purchased form Harcos Chemical of Omaha, Nebraska. The water for the project was supplied by the City of Garwin.

Equipment and personnel consisted of one maintainer for blading operations, a dump truck for Bentonite distribution, and two operators all supplied by Tama County. A 3000 gallon water truck distributor and operator were supplied by Peterson Construction Incorporated.

Procedure

All loose surfacing material was tight bladed and windrowed to one side of the road. Several cross-section windrow measurements were taken to estimate the amount of loose limestone surfacing material present to calculate the amount of Bentonite needed for treatment.

The spacings of the 50 pound Bentonite bags were calculated for 3, 5, 7 and 9 percent treatment, by weight of air dry aggregate. The bags were placed manually at the calculated spacings and then were manually spread on top of the windrowed aggregate. The aggregate and Bentonite were dry mixed by blading the windrow four times followed by a center spread of the windrow. Application of the soda ash solution and blade mixing proceeded simultaneously until a consistency of a 2 to 3 inch slump concrete was obtained. This material was blade mixed a minimum of four times after each soda ash application. After final mixing, the treated material was center spread and

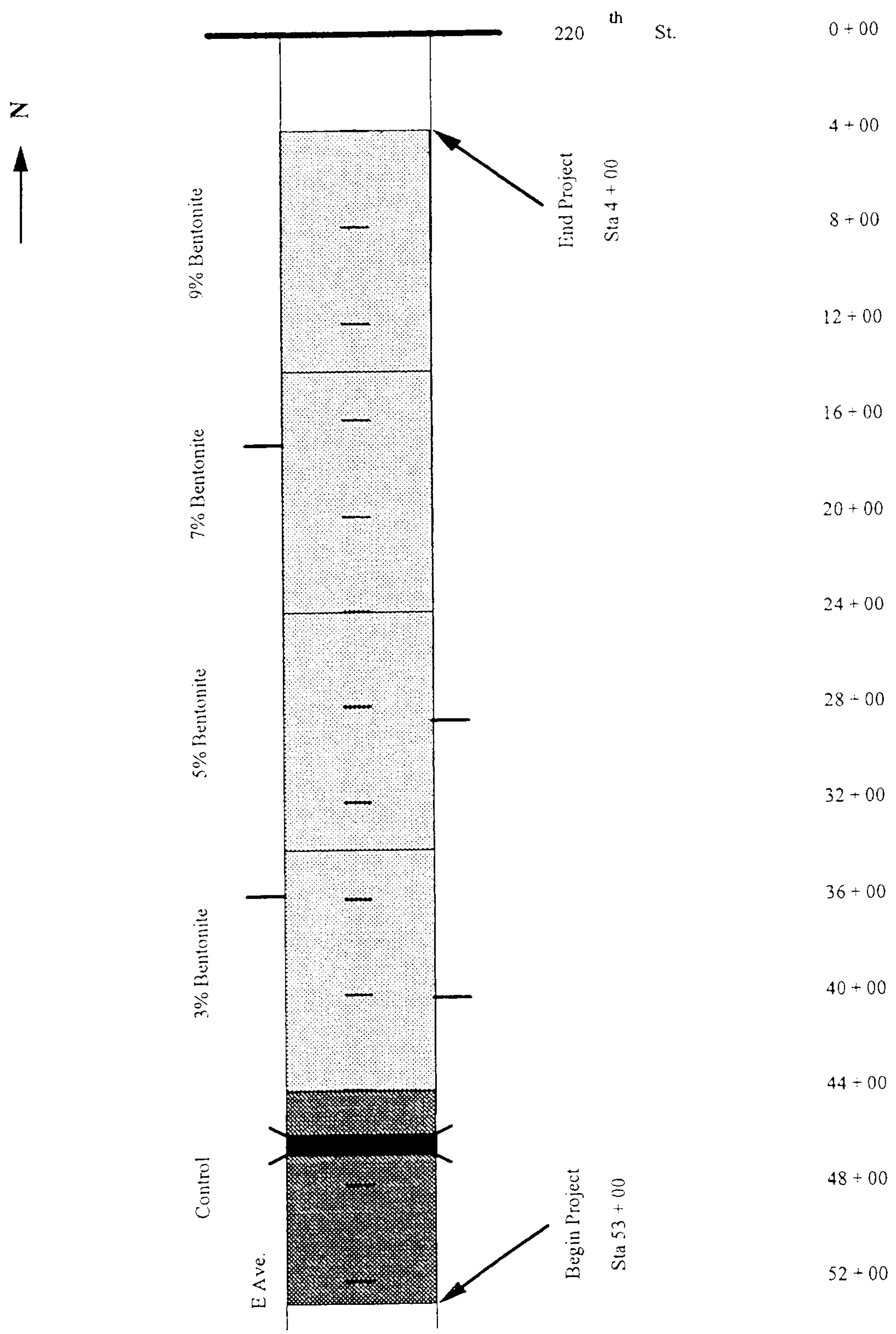

Figure 9. Tama County test road layout.

left for compaction by traffic.

Observations

The following observations were made during construction of the Tama County test road. Construction was completed in one day. More expedient construction could be obtained using two blading patrols. Agglomeration and balling of Bentonite treated materials occurred in the 5 percent section and became more pronounced in the 7 percent and 9 percent sections. The use of two blading patrols and a 1.2 percent soda ash solution were recommended after the construction of the Tama County test road.

Appanoose County Layout

Construction of the 1.4 mile test road was completed on June 28, 1993. The test section layout for construction of the road is shown in Figure 10. The layout indicates the locations of the control section, calcium chloride section and various Bentonite treated sections.

Appanoose County Construction

Materials and Equipment

The Bentonite (50 pound bags) used for the project was obtained from the Iowa Limestone Company of Alden, Iowa and the soda ash from Harcros Chemical of Omaha, Nebraska. Water was supplied by the city of Centerville.

Two motor graders, a flat bed truck for the distribution of Bentonite, and three operators were supplied by Appanoose County. Two 1000 gallon water distributors were used, with one provided by Appanoose County and the other provided by the city of Centerville. Two more operators were provided by Appanoose County for the water distributors

Procedure

The procedure was the same as that used at the Tama County site, with the exception that two motor graders were used and different percentages of Bentonite were also applied. The average of

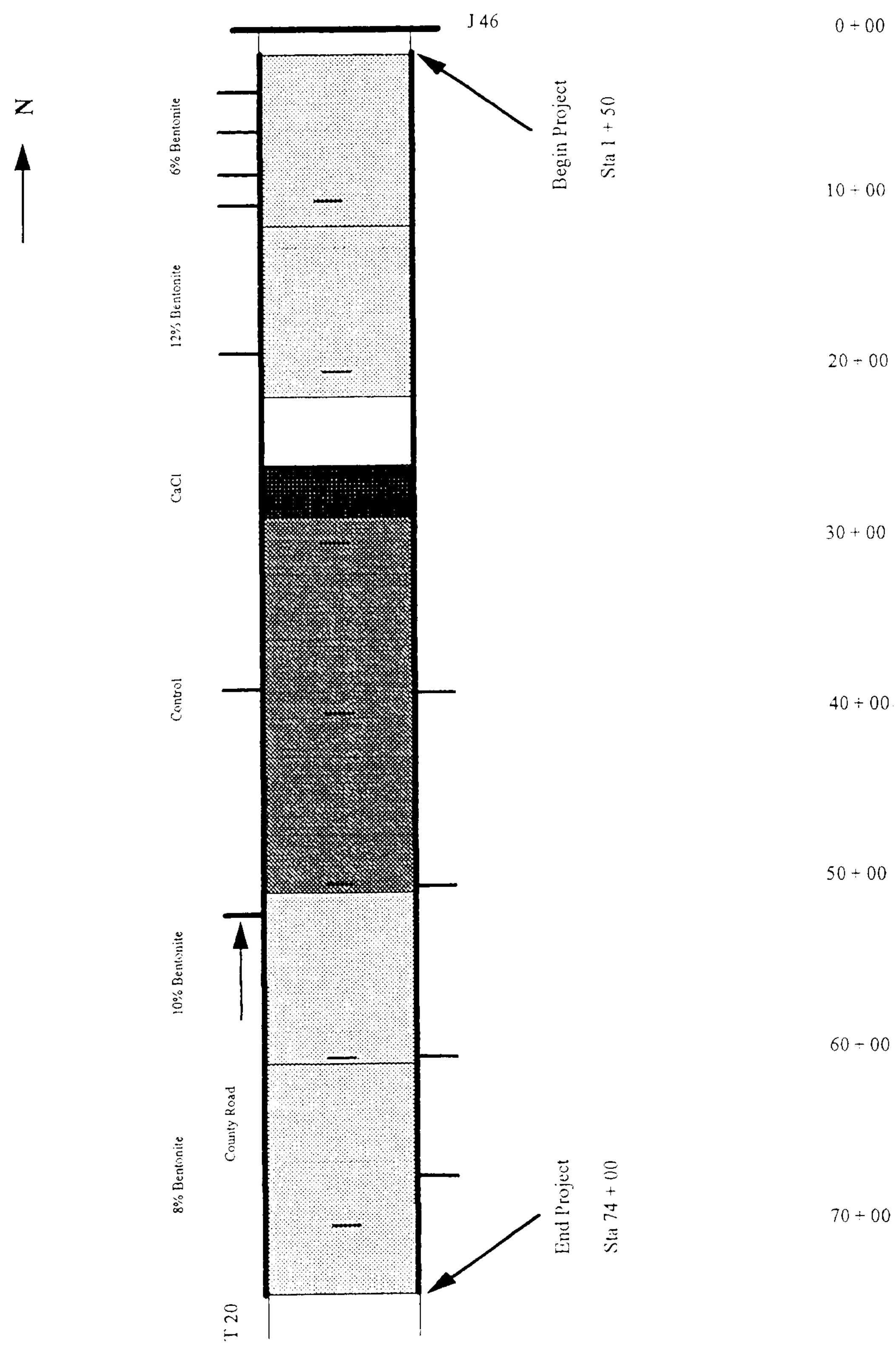

Figure 10. Appanoose County test road layout.

the different sections indicated an approximate range of 94 to 146 tons per mile of loose surfacing material. After windrow measurements were taken, Bentonite bag spacings were calculated for 6, 8, 10, and 12 percent (by weight of air dry aggregate) of Bentonite treatment. Mixing was performed the same way as in Tama County. The amount of solution added to the sections was as follows: approximately 1500 gallons of solution added to the 6 percent Bentonite treated section, 2000 gallons to the 8 and 10 percent sections, and 2500 gallons to the 12 percent section.

Observations

Construction proceeded rapidly and was completed in one day. Bag placement, bag spreading, and dry mixing was completed in approximately 1 hour and 40 minutes. Using two patrols expedited this part of the construction considerably. The most time consuming part was waiting for the water trucks to fill up and return to the site to unload. For the four sections, it took approximately five hours to complete the water application and wet mixing. It is recommended that a 3000 or 5000 gallon water distributor be utilized to speed up this part of the process.

Slight agglomeration of the Bentonite was observed in the 12 percent Bentonite treated section. The other sections did not show much evidence of agglomeration. This was mainly due to the increased percentage of soda solution that was recommended after the Tama County test road construction. Overall, the construction procedure worked very well.

Hancock County Layout

Construction of the 0.6 mile test road was completed on June 22, 1993. The test section layout for construction of the road is shown in Figure 11, and indicates the control section and various Bentonite treatment sections.

Hancock County Construction

Materials and Equipment

The Bentonite and soda ash used for the project were obtained from the same sources as those used for the Appanoose County project. Water was supplied by the city of Britt. One motor

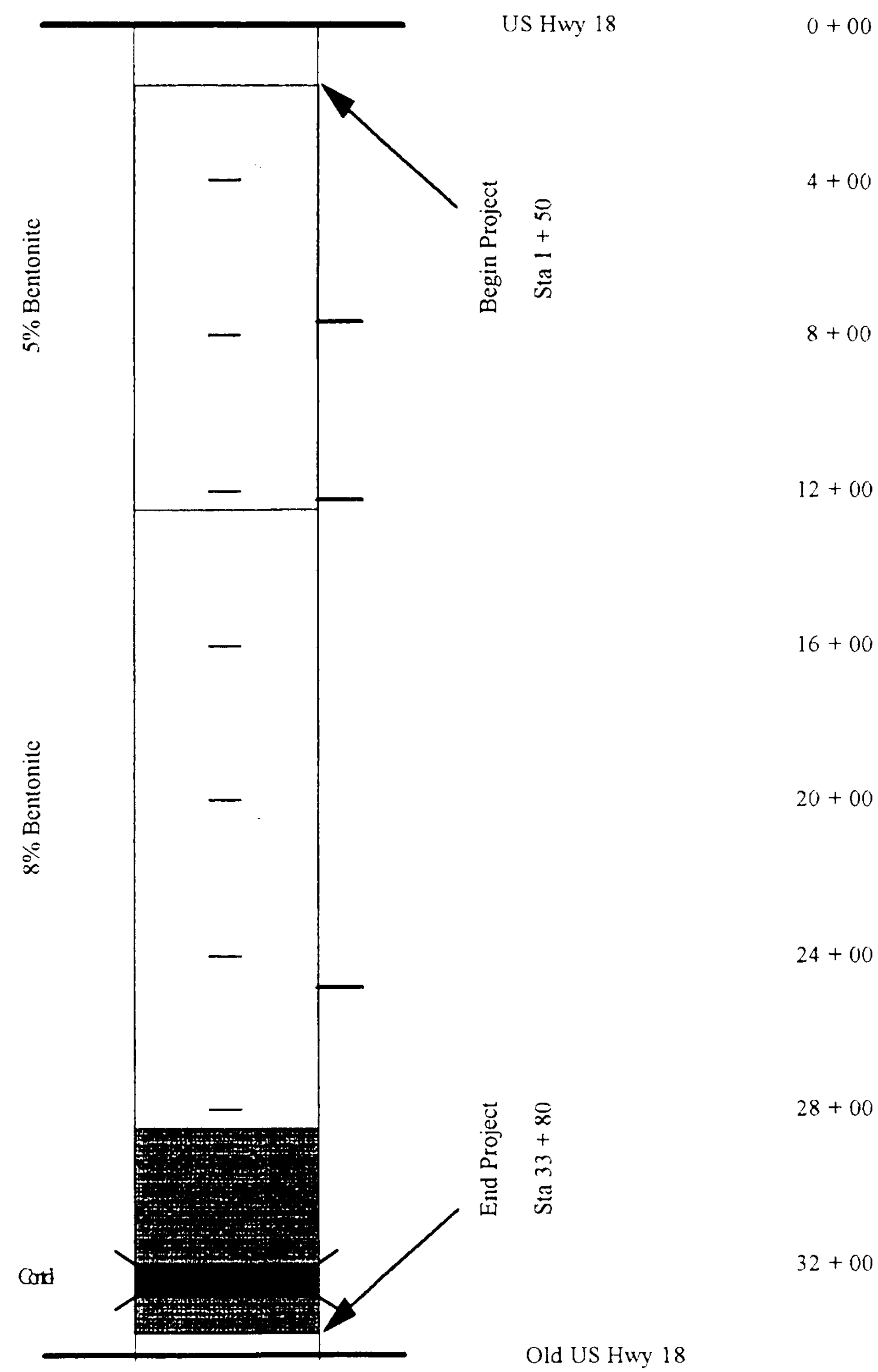

Figure 11. Hancock County test road layout.

grader, a dump truck, and flat bed trailer for the distribution of Bentonite, a 1000 gallon water truck, a tractor and roller, and three operators were supplied by Hancock County.

Procedure

The procedure was the same as that used in Tama County. The average loose surfacing material present for the different sections ranged from 90 to 96 tons per mile. Bentonite bag spacings were calculated for 5 and 8 percent Bentonite treatment. The construction process was the same as the Tama County procedure. Approximately 2000 gallons of solution were added to each section. After final mixing, the treated material was center spread and then compacted by one pass of a roller.

Pre-construction work and construction proceeded rapidly and were completed in one day. Pre-construction consisted of tight blading the loose surfacing material to one side, taking windrow measurements, obtaining a loose unit weight, and then calculating bag spacings. Once this was completed, construction proceeded with bag placement, spreading of Bentonite, dry mixing, soda ash solution application, and final mixing.

Observations

The construction could have been expedited by using a 3,000 or 5,000 gallon water truck and two patrols, but personnel were limited due to such a short notice to proceed with the construction. Slight agglomeration of the Bentonite was noticed in the 8 percent Bentonite treated section.

FIELD EVALUATION

Field evaluation consisted of qualitative evaluation of dust generation, crust development, roughness and braking characteristics. Evaluations began on August 7, 1992, and continued through November 12, 1992, for Phase I. A relatively wet fall limited the number of observations of the road under dry surface conditions for Phase I. Evaluations started up again on June 14, 1993, and continued through October 6, 1993, for the three sites of Phase II. With an extremely wet summer and relatively wet fall there were a limited number of observation days available when the roads were under a dry surface condition. Evaluation of the Tama and Appanoose Counties test roads during 1994 started in May and continued until September.

Panel Selection

The following individuals assisted in conducting periodic qualitative evaluations for Tama, Appanoose and Hancock Counties.

Dwight Surber	Assistant County Engineer	Tama County
Gary Harris	Materials Research Assistant	Iowa DOT
Kenneth Bergeson	Associate Professor	Iowa State University
Stacy Brocka	Graduate Research Assistant	Iowa State University
Jay Waddingham	Graduate Research Assistant	Iowa State University

Evaluation Criteria

An evaluation form was developed by Iowa State University personnel and was used by all the panelists for their observations. The form contained the following information: weather conditions (day of and day prior to evaluation), maintenance conditions and surfacing material conditions either dry, damp or wet. The panel evaluated the amount of dust generation for each Bentonite treated section compared to the control section and evaluated the crust development and roughness of each section. The dust generation was expressed as a percentage of the control with the control having a value of 100 percent. The crust development and roughness were evaluated on a rating system from 0 to 5 with 0 being poor and 5 being excellent. Copies of the forms used in Phases I and II are shown in Appendix A.

Visual Inspection

Visual inspection was initiated at the end of construction of the Tama County road in 1992. It was used as one method to evaluate the effectiveness of the Bentonite treatment and was continued throughout the 1992, 1993, and 1994 testing seasons to evaluate the duration of the treatment.

Visual Evaluation Procedure

For visual evaluation of dust generation the test roads were driven in both directions and the effectiveness averaged between the two directions. Each test section was approached at 45 mph and evaluated through the rearview mirror. Criteria included the opaqueness of the dust cloud produced, time it takes the cloud to settle, and the distance the dust cloud traveled perpendicular to the road.

Visual inspection included the roughness of the road, crust development, maintenance conditions, and other notes that concern the roads conditions and dust generation. The roughness was evaluated to determine if the clay addition to the surface material created washboarding or other effects which may cause a hazardous driving environment. The crust development was evaluated to give an indication of the wheel path size as compared to the control section's surface. Maintenance conditions included such things as: approximations of the last blading, windrow size and which side of the road, and how well maintained the road surface was kept.

Visual Evaluation Results

Tama County, Appanoose County, and Hancock County evaluations are tabulated in Appendix B for the 1992, 1993, and 1994 testing years.

Shown in Tables 2 and 3 are the average year end results from observation at the Tama County, Appanoose County, and Hancock County test road locations, respectively. All three evaluation years are shown with the averages for dust reduction, crust development, and roughness. The averages tabulated are for dry surfacing materials only.

Dust Generation

The dust generation value represents the comparison in dust reduction for the treated sections compared to the untreated control section. The results tabulated are qualitative evaluations of the conditions in the field. Caution must be taken in interpreting the results from visual observations.

The 1992, 1993, and 1994 dust generation results tabulated in Table 2 are also shown on Figure 12 for the Tama County test road. Shown in Figure 12 is the dust generation percentages for

Table 2. Visual evaluation averages for dry surface materials in Tama County.

Evaluation Category	Treatment	1992 / I Average (n=19)	1993 / II Average (n=2)	1994 / II Average (n=7)
Dust Generation	Control	100	100	100
	3	55	30	76
	5	44	28	69
	7	39	45	78
	9	32	50	79
Crust Development*	Control	1.4	2.0	1.7
	3	2.2	4.0	3.0
	5	3.2	4.5	3.4
	7	3.1	3.0	3.3
	9	3.1	2.5	3.0
Roughness*	Control	3.7	2.5	3.7
	3	3.9	4.0	4.1
	5	3.9	5.0	4.3
	7	3.7	3.5	4.0
	9	3.2	2.5	3.9

*The rating system used goes from 0 to 5 with 0 being poor and 5 being excellent.

dry surfacing materials averaged over the testing season for each year. As can be seen the dust generated in each of the test sections is less than the dust generated in the control section. In the 1992 testing year the control had the most dust generated with each Bentonite section showing a consecutive reduction. In 1993 only 2 observations were conducted due to a wet testing period. The two observations showed the 3 percent and 5 percent had a slight increase in efficiency with the 7 percent and 9 percent Bentonite treatment levels showing a loss in efficiency. This maybe attributed to the 7 percent and 9 percent sections being on the steeper slopes of a hill and the Bentonite may have been washed down by the rain onto the 3 percent and 5 percent treatment sections increasing

Table 3. Visual evaluation averages for dry surface material in Appanoose and Hancock Counties.

Evaluation Category	Treatment	1993 / II Appanoose Average (n=3)	1994 / II Appanoose Average (n=5)	Treatment	1993 / II Hancock Average (n=2)
Dust Generation	Control	100	100	Control	100
	6	52	85	5	80
	8	47	89	8	73
	10	43	90		
	12	25	82		
Crust Development*	Control	4.0	3.4	Control	1
	6	4.0	3.4	5	2
	8	4.0	3.4	8	2
	10	4.3	3.2		
	12	4.7	3.6		
Roughness*	Control	2.3	2.6	Control	3.5
	6	2.3	2.6	5	3.5
	8	2.3	2.6	8	3.5
	10	2.3	2.6		
	12	2.0	2.6		

*The rating system used goes from 0 to 5 with 0 being poor and 5 being excellent.

the amount of Bentonite and thus increasing the efficiency. Another possibility is that the 7 percent and 9 percent lost some of its efficiency due to the routine addition of surfacing material during the spring of 1993. The 1994 testing season also showed an increase in dust generation. This could be due to addition of surfacing material in 1994 or washout of the Bentonite out of the system. From Figure 12 we can see that the Bentonite treatment is still partially effective after three seasons of testing and two additions of surfacing materials.

The 1993 and 1994 results tabulated in Table 3 for Appanoose County are also shown on Figure 13. Figure 13 shows a similar trend as the Tama County test road showed for the first year.

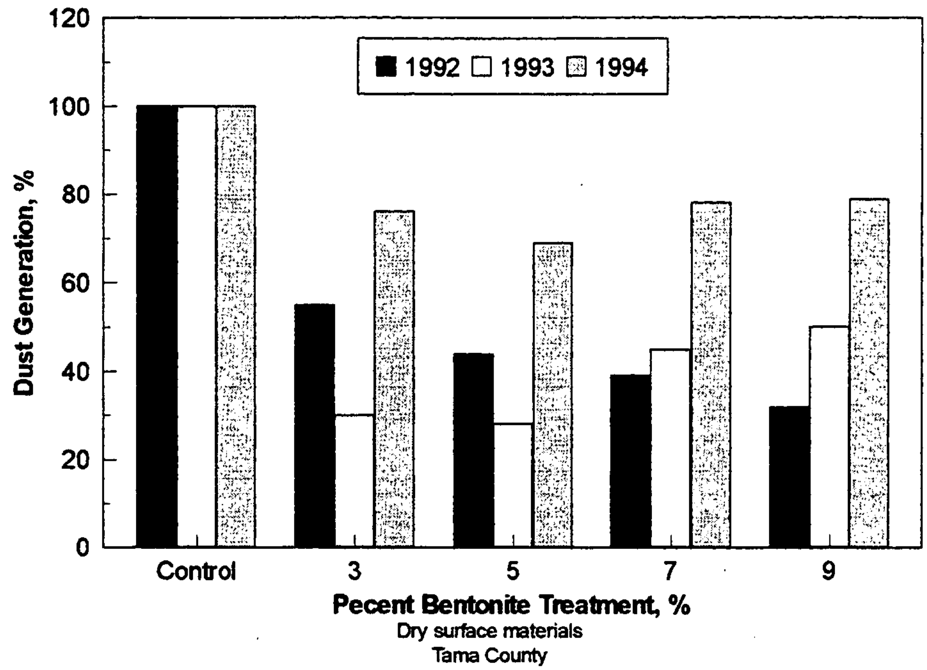

Figure 12. Dust generation for the Tama County test road.

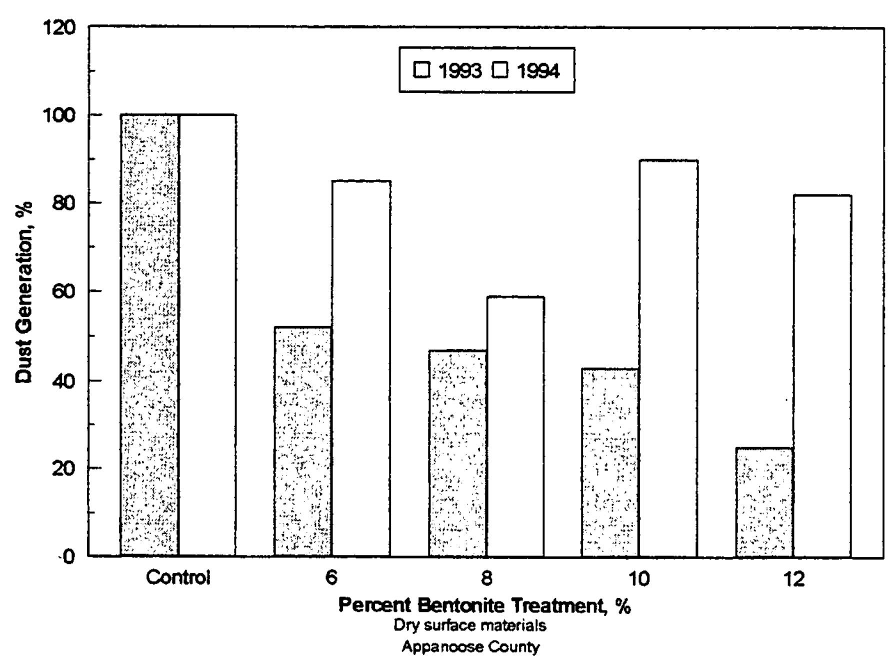

Figure 13. Dust generation for Appanoose County test road.

The control section had the most dust generated with the Bentonite treated sections having less dust generated. As the Bentonite treatment level increased for 1993 the dust generated decreased. The trend was the same, but the Bentonite treatment at Appanoose County was not as effective as the Tama County treatment. The Tama County location had reductions greater than 60 percent for the 7 percent and 9 percent section where the Appanoose County Test road had reductions only slightly greater than 50 percent. In 1994, the Appanoose County location showed a much greater increase in the dust generated in the treated sections. This increase may be due to the high fines content in the Appanoose County surfacing materials and the higher amount of truck traffic on the test road. Even though there was a greater increase in the dust generated on the Appanoose County test road the treated sections all showed reductions in dust generated after two testing seasons as compared to the control section.

The high fines content and increased truck traffic of the Appanoose County test road may not be the only reason this Bentonite treatment was less effective than the Tama County test road. During construction of the Appanoose County test a 1.2 percent soda ash solution was used compared to the 0.4 percent soda ash solution used during the Tama County test road construction. This increased soda ash solution may have kept the bentonite dispersed longer. The longer dispersion may have allowed the heavy rains during the summer of 1993 to wash the Bentonite from the surfacing material. If the Bentonite did get washed out of the surfacing materials the amount of Bentonite available to stabilize the limestone fines would be decreased. If there is not enough Bentonite present there would be an increase in dust generation.

The dust generation observations for 1993 in Hancock County are also shown in Table 3. The Hancock County test road also shows a decrease in dust generation with an increase in Bentonite treatments. The effectiveness of the treatments is not as good as the other two sites for this testing year. This is probably due to having some loose gravel still remaining on the road, as well as a gravel crust, that may affect the ability of the Bentonite to bond with the fine limestone particles. This might be the case since gravel has a net negative surface charge which repels the Bentonite from attracting to particles effectively because Bentonite also has a net negative surface charge. A thin layer of fine gravel particles was observed beneath the limestone surfacing material on the road.

To validate the visual evaluations a dust collector was developed to try and quantify the amount of dust generated by a moving vehicle. This dust collector had a variability of +/- 10 percent so exact quantitative evaluation wasn't possible. The dust collector could be used for qualitative information and comparison to visual evaluations.

Shown on Figure 14, are the results of the 1994 visual evaluations and the dust collector data. Both Tama and Appanoose Counties results are shown. The data is also presented in Table B9 of Appendix B. The visual evaluation of dust generated displayed on Figure 14 are the average values for the days the dust collector was used. This shows that most of the differences of the two evaluation techniques are within the range of the error of the dust collector. The results of this testing validates the use of the visual method as an evaluation tool.

Crust Development

Crust development was evaluated by rating on a scale from 1 to 5. A rating of 1 would be an area with no crust and just having loose surfacing materials on the surface of the road. A rating of 5 would be an excellent crust development with little loose surfacing stone present in the wheel path area. This rating system was used throughout field testing.

The Tama County average results of the 1992, 1993, and 1994 testing seasons for crust development which were tabulated in Table 2 are shown on Figure 15. The control section exhibits less crust development than the Bentonite treated sections. In 1992, the 3 percent section had approximately one and a half times more crust development than the control and the 5 percent, 7 percent, and 9 percent sections had approximately twice the crust development as the control. In 1993, the 3 percent and 5 percent exhibited increased crust development and the 7 percent and 9 percent exhibited less crust development possibly due to the Bentonite being washed down the hill by rain or addition of surface material in the 7 percent and 9 percent sections. In 1994, a reduction in crust development was observed in the 3 percent and 5 percent treatment sections. This maybe attributed to the addition of surfacing material to the road. Each year showed a crust

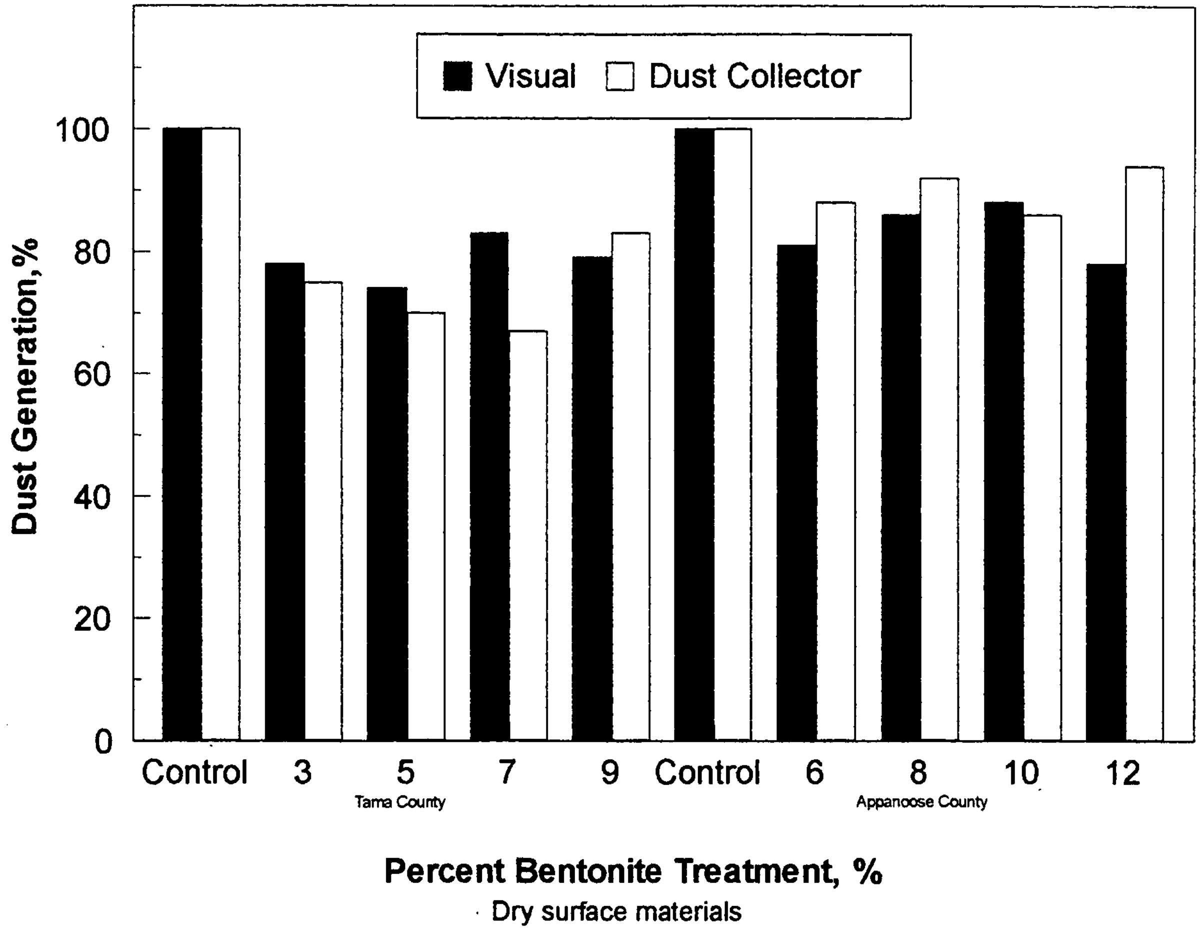

Figure 14. 1994 dust collector and visual evaluation comparison.

development greater than the control section which also indicates the Bentonite treatment is still functioning after three years.

The crust development results that were tabulated in Table 3 for the Appanoose County test road are presented in Figure 16. There are really no trends in the data shown. The crust development is fairly constant for all the test sections for both years. There is a difference between the 1993 and 1994 testing years, but this maybe due to the difference in evaluator determination of crust development. The relatively constant crust evaluations may be attributed to the high amount of fines and the truck traffic present on the Appanoose County test road. The Appanoose County test road did not appear to be bladed as frequently as the Tama County test road. If blading operations

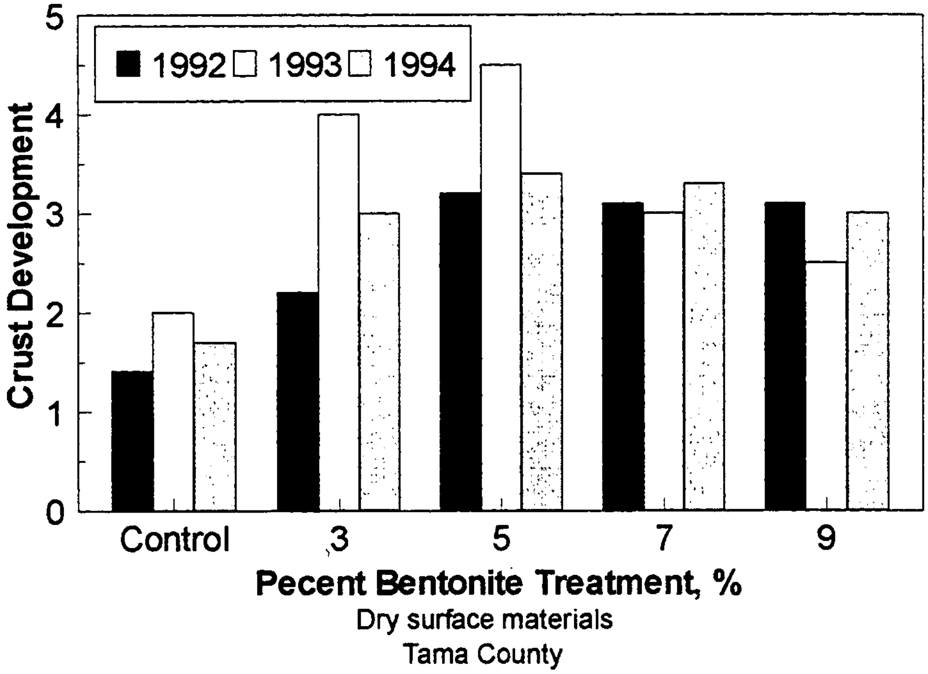

Figure 15. Crust development for Tama County.

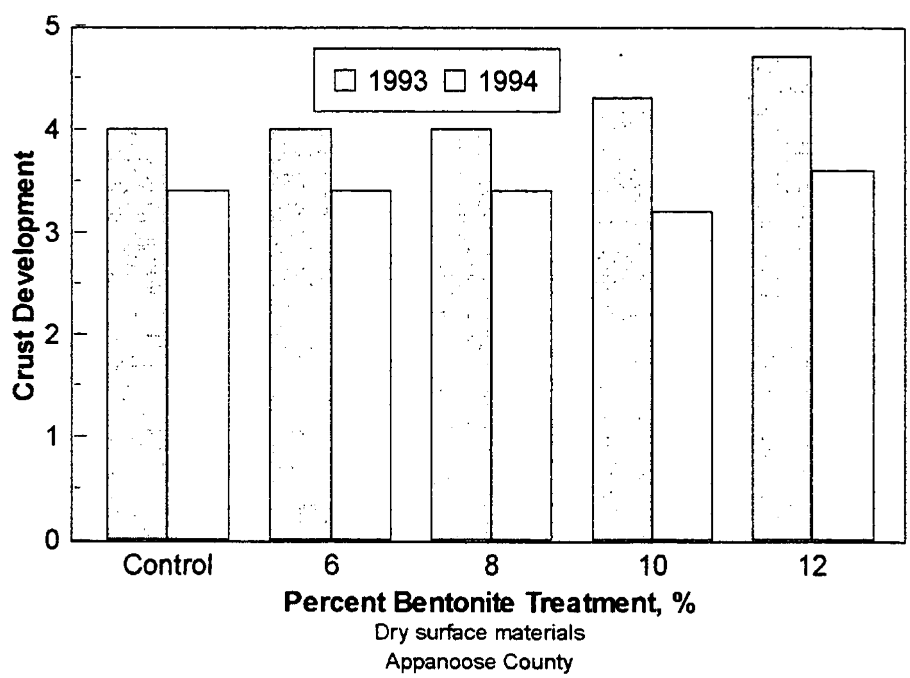

Figure 16. Crust development for Appanoose County.

weren't as frequent the surfacing material would stay locked up in the crust and have a more uniform crust evaluation. The observations in Hancock County show that the development was not very good even though the treated sections were two times better than the control. Again it is anticipated that the presence of gravel inhibited any wheelpath development.

Roughness

Roughness was evaluated on a scale from 1 to 5. A rating of 1 would be a surface with a lot of pot holes and washboarding present. A rating of 5 would be an excellent rating with the surfacing having a smooth ride and absence of potholes and washboarding. This system was also used throughout Phase I and Phase II.

The data in Tables 2 and 3 for Tama and Appanoose Counties are presented on Figures 17 and 18. There are no definite trends present for either Tama, Appanoose or Hancock Counties. The Tama County and Hancock County locations generally had higher roughness ratings meaning the road were smoother to drive down. This could be because the Tama County and Hancock County test roads had less vpd and less truck traffic which would require less maintenance. The Tama County and Hancock County sites appeared to be maintained more frequently which might be a reason for the better roughness ratings.

The roughness of each test road was tested by using the Iowa DOT roughometer to obtain some quantitative values. The roughometer provides a measure of the roughness of a road tested at a speed of 20 mph. The roughness is measured by the movement of a standard wheel on the roughometer trailer. The roughness and revolutions of the wheel are recorded during the test. The roughness of the road, in inches per mile (in/mi), is then calculated.

The intent of this test was to compare the roughness of each treated section at each site. The comparison is not intended to compare the roughness between the different sites, but to compare each section at a particular site.

The roughness was measured in each wheel path, both northbound and southbound. All of the tests were averaged for each section per site and are shown graphically on Figure 19. The actual data obtained from the Iowa DOT is given in Appendix C. The roughness obtained in Tama County

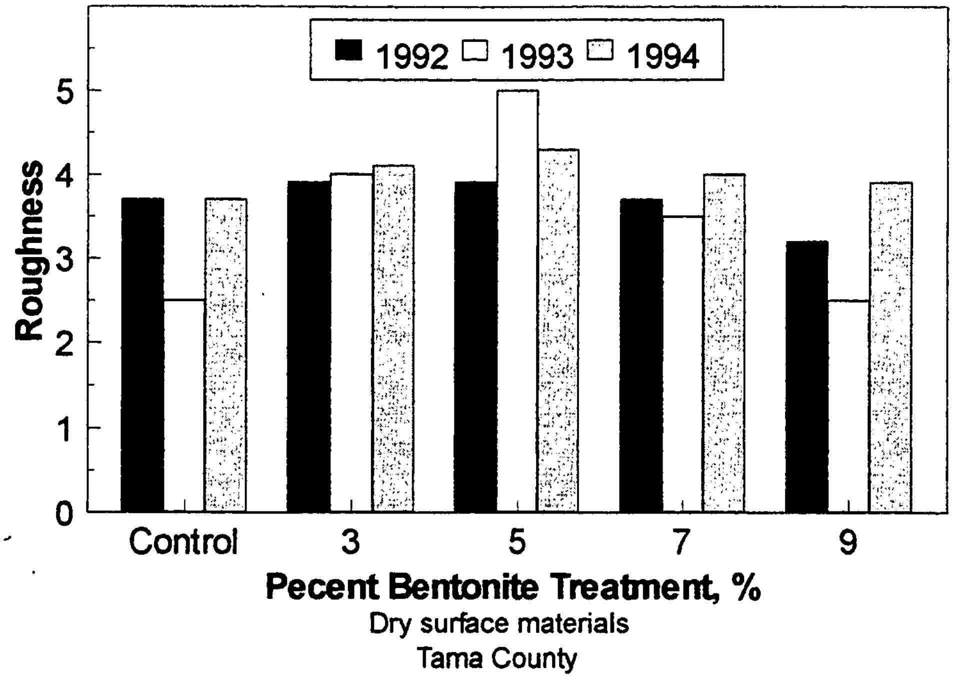

Figure 17. Roughness evaluation forTama County.

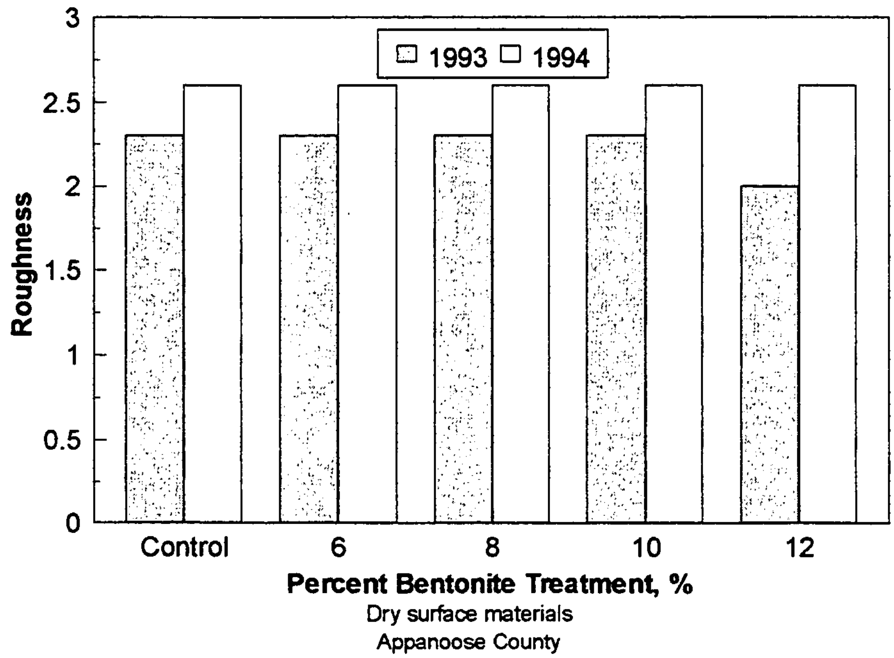

Figure 18. Roughness evaluation for Appanoose County.

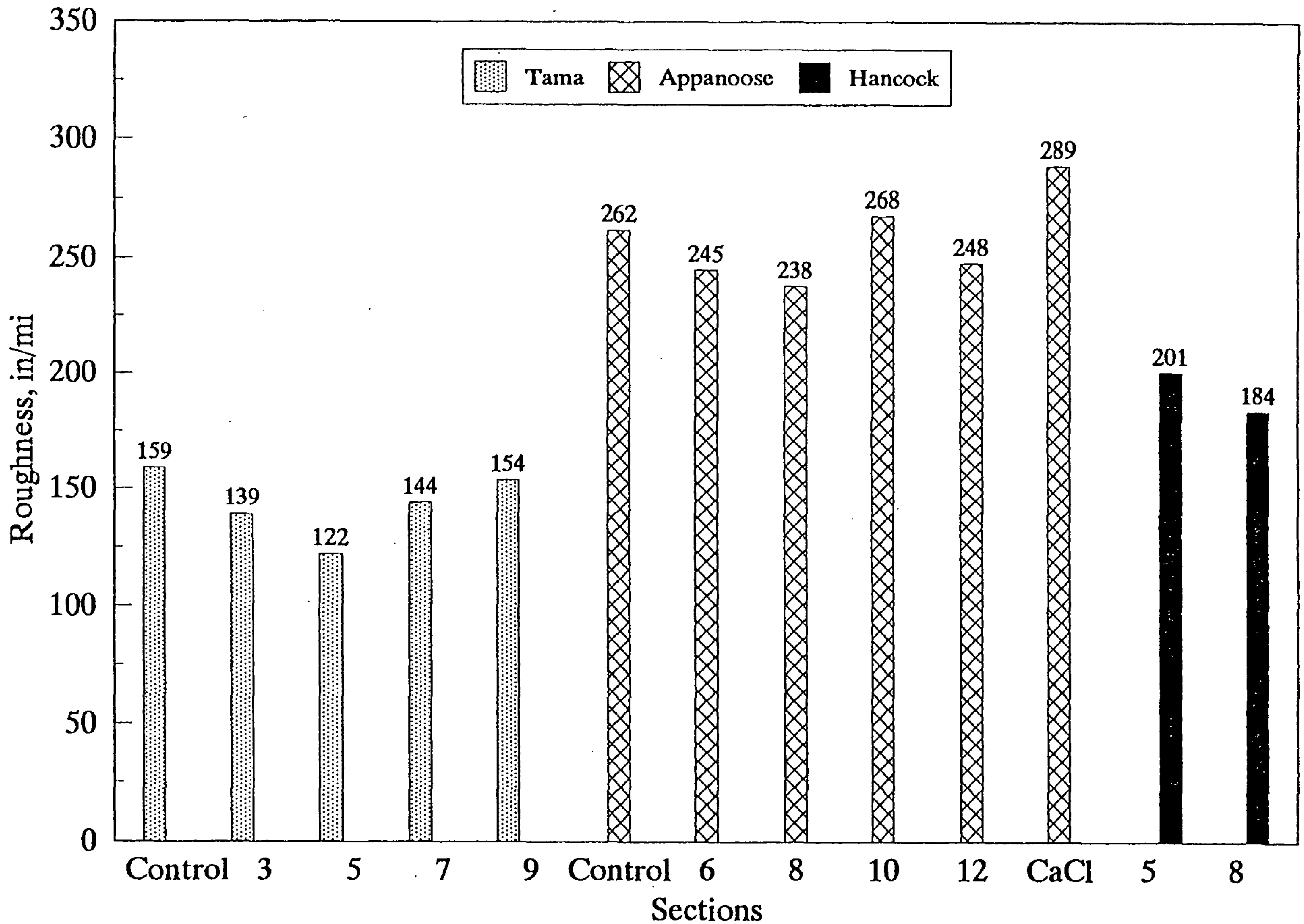

Figure 19. Average roughness measurements by the Iowa DOT roughometer.

ranged from 122.5 to 159 inches per mile. As seen on Figure 19, the 5 percent section is the smoothest. The trend then continues with the 3, 7 and 9 percent sections, followed by the control section. This is the same trend as the qualitative observations.

The roughness measured in Appanoose County does show a similar trend as that observed in Tama County, as shown on Figure 19. The roughness for the treated sections starts out decreasing in roughness with increased Bentonite treatment and then starts to increase with the calcium chloride section being the worst section. The 10 percent section appears to be out of place and maybe due to the turning traffic at the intersection located in this section.

There is a slight decrease in roughness with increased Bentonite treatment for Hancock County as shown on Figure 19. The control section was unable to be tested due to the shortness of the section.

Braking Characteristics

Again, a major concern at the start of the project in Appanoose County was the influence of the high levels of Bentonite treatment on braking characteristics and safety. To test the braking characteristics when the surface material was wet or saturated, a car was driven at 25 mph at which time the brakes were locked to make the tires skid across the road surface. The distance to bring the car to a complete stop from the point of the brakes being locked was measured. Four runs were tested in the wheelpaths in each section right after a heavy rain. These four tests were averaged and then plotted as shown on Figure 20. There is no clear trend evident between braking distance and the amount of Bentonite treatments.

Video Evaluation

A video camera was used to document actual site conditions on each day of testing. The camera was setup in the same position each time which allows for comparison between different testing days and times.

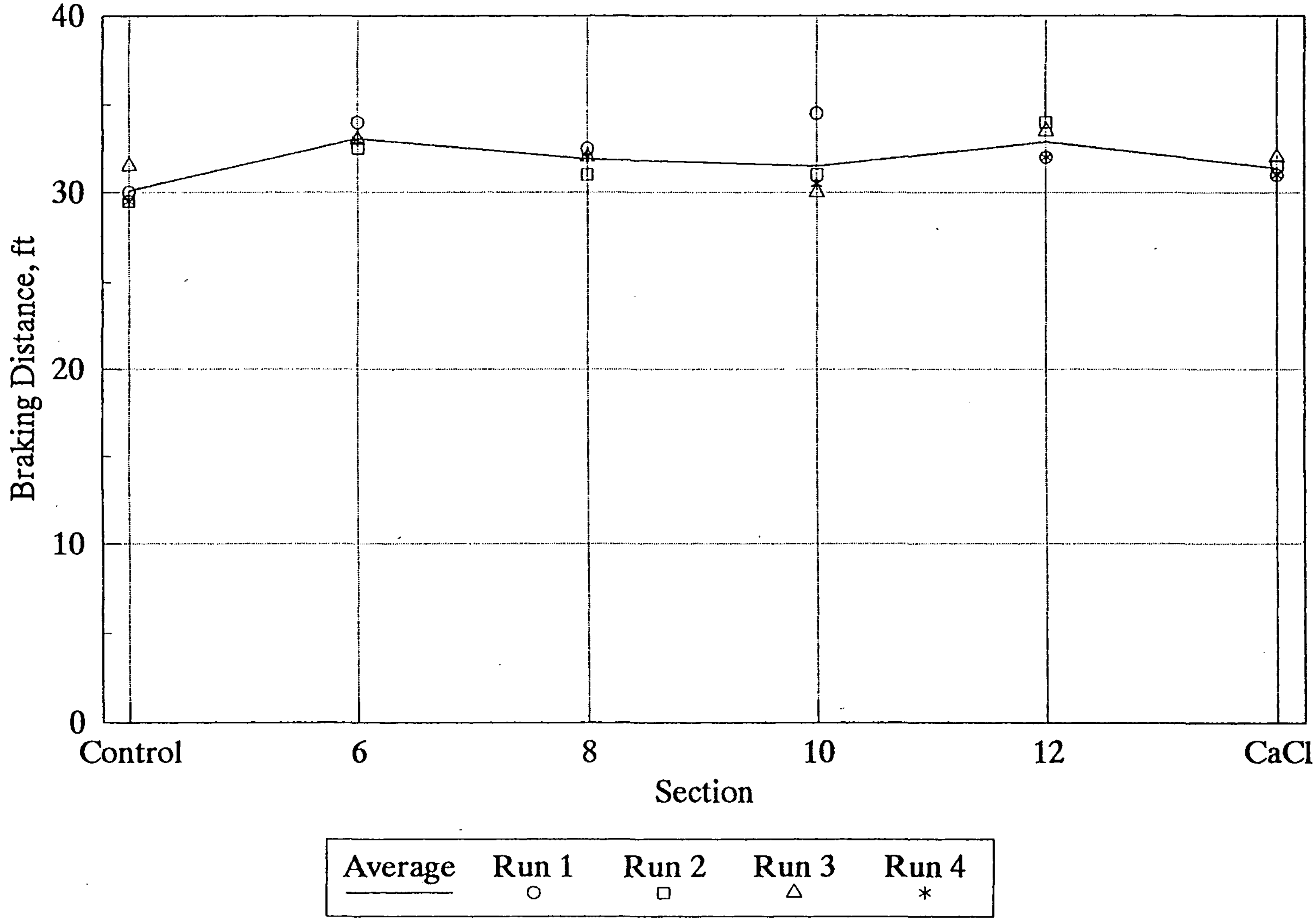

Figure 20. Braking distance per section in Appanoose County under wet surface conditions.

For the 1993 and 1994 testing periods the video camera was setup in the riders seat of the pickup and pointed out the back window. The test road was then driven at a speed of 45 mph and recorded on tape. After driving both directions on the road the camera was used to video tape the crust development of the road as a record of what shape the road surface was in at the time of testing. The crust taping was performed in each section at random intervals.

Some video taping was performed while the pickup operator drove by the camera at 45 mph. This was done to try and evaluate how long the dust was suspended in the air.

The video camera is a powerful tool for evaluating what the conditions are in the field on a particular day. It also allows an evaluator to go back and check the results of his visual inspection and comparison to the dust collector results.

LABORATORY EVALUATION

Laboratory testing was carried out to aid evaluation of the Bentonite treatment and determine how effective the Bentonite treatment will be for a dust suppressant. Washed and air dried gradation tests, hydrometer analyses, X-Ray fluorescence, scanning electron microscopy, thermogravimetric analysis, and x-ray diffraction lab tests were performed. Testing was performed on samples obtained from the test roads described earlier. The gradation samples were obtained by randomly taking two shovel widths across the road to obtain a representative sample from the test road location. The samples where transported back to the laboratory in Iowa DOT sample bags. Each time a sample was taken it was assumed it represented the rest of the material in that particular section. Crust samples were obtained by taking a regular metal chisel and pounding it into the road surfacing crust approximately 1 to 1 1/2" in depth. The chisel was then worked side ways to dislodge a small section of crust material. The samples were placed in small air tight zip-lock bags to maintain moisture and to ensure that none of the sample was lost. This crust procurement procedure was also performed randomly in each section.

Gradation Tests

The random bag samples obtained in the field were quartered down in an aggregate splitter to obtain a sample that could be sieved easily without overloading the sieves. If it was deemed necessary the sample was split into two and sieved separately so the sieves were not over loaded. The washed gradation tests were run in accordance with ASTM C 117-90 and ASTM C 136-84a [6]. The air dry samples were run in accordance with ASTM C 136-84a except that the material was sieved in the air dried state instead of oven drying the materials. Also, the sample size required for both gradations was approximately 2000g by ASTM C 136-84a and some of the gradations were run with slightly less material than required by this standard. The materials were all split before sieving and did not deviate from this weight a great deal so they are assumed to be representative of the material in the field.

Gradation Test Results

The washed gradation test results show a general trend of the treated sections having a lesser amount of fines than the control section. This is attributed to the fines being locked up in the surface crust developed. During the field observations it was documented that the treated sections developed a better crust than the control sections. If more of the fines are locked up in the surface crust this may be part of the reason that there is a dust reduction due to Bentonite treatment.

The washed gradation trends are shown on Figure 21. This shows the treated sections having less fines than the control section for a washed gradation on the Appanoose County test road. The trend was also evidenced by numerous other gradation tests. Some of the washed gradations showed some of the sections having a higher percentage of fines than the control. The higher amount of fines only occurs in the 6 percent and 10 percent sections. In the 6 percent section there are several residences where cars would be turning often which may grind up particles finer and loosen them from the crust. In the 10 percent section there is a reasonably sharp curve which the trucks and cars must maneuver around also churning up the surface crust and loosening materials on the surface. Also, in the 10 percent section there is a steep valley where the Bentonite could have washed down

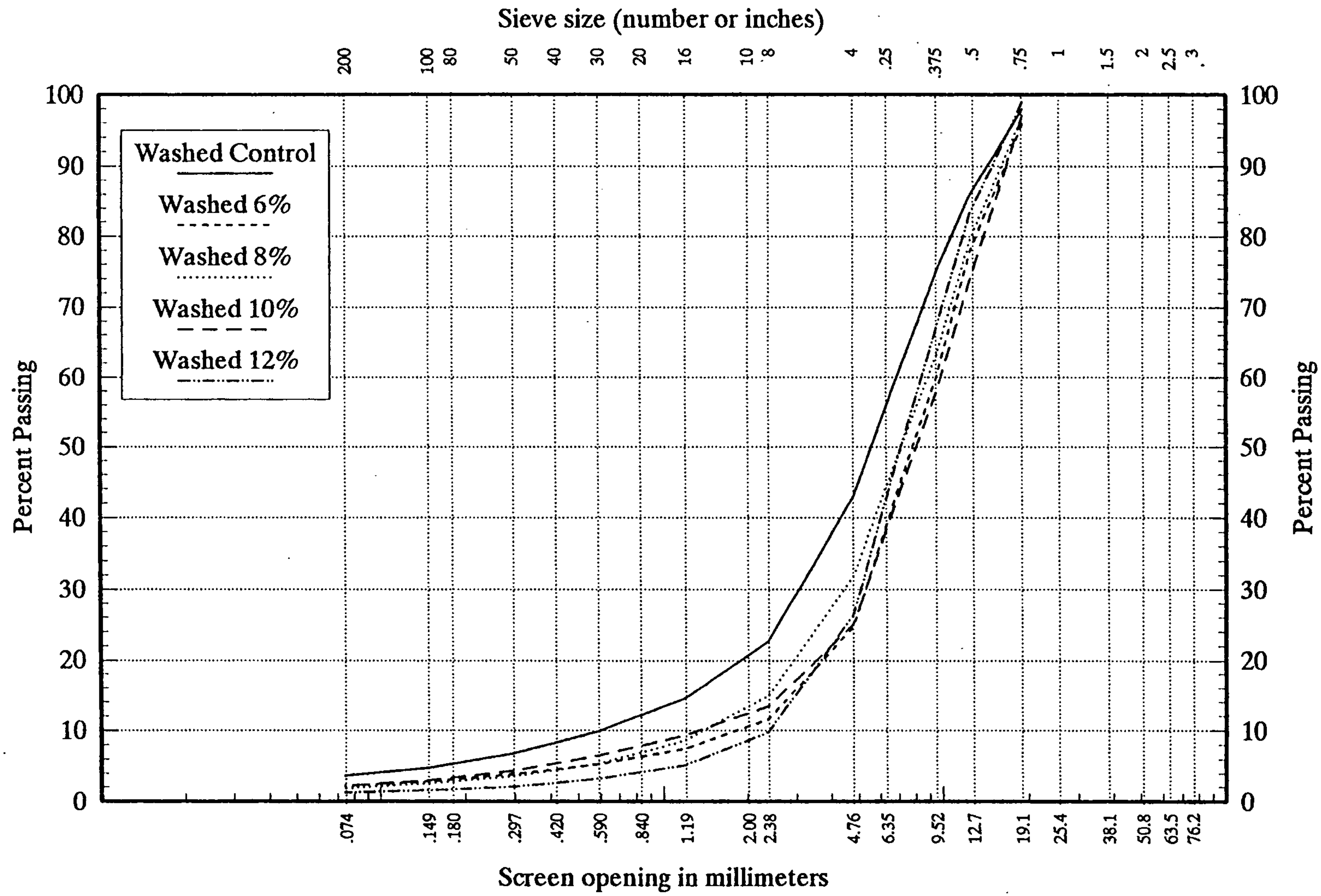

Figure 21. Appanoose County washed gradation from 08/15/93.

the road into the valley during the heavy rains of 1993, reducing the effectiveness of the Bentonite treatment on the slopes of the hills and increasing the number of fines unable to be locked up in the surface crust.

The same washed gradation trend is present in the Tama County test road location. Shown on Figure 22 is a washed gradation plot from 1994. This gradation is from the test roads third year of service. This gradation plot indicates that the Bentonite treatment is still operating three years from the start of the project. Surfacing material was added to the road twice during this three year period and the Bentonite treatment still maintained it ability to lock up material into the crust as shown by Figure 22.

The air dry gradations show a trend of having somewhat less fines than the washed gradations do, shown by comparing Figures 22 and 23. This trend could possibly be caused by the Bentonite agglomerates creating larger particles making the mixture coarser. This would indicate that the Bentonite and limestone are agglomerating to create larger particles which may possibly settle out of a dust cloud faster. This would help back up the observation that the treated dust clouds settle faster than the untreated control section dust cloud.

Hydrometer Test

Hydrometer evaluations were run on some of the samples obtained in the 1994 testing year. The hydrometer analysis was conducted in accordance with ASTM D 422-63 [7]. The hydrometer analysis should give an indication of the amount of clay sized material in the surfacing material. Clay sized particles start around 0.002 mm and with the hydrometer analysis can be determined the amount of material smaller than this size. Shown on Figure 24 is a plot of the hydrometer analysis run on a sample from the Appanoose County test road. The control section has the most material passing the 0.002 mm size. This may be because the Bentonite is agglomerating to the small limestone particles and these bonds are unable to be broken by the dispersant. This trend may also be explained by the clay being in the crust material locking up the fines; therefore, there would be

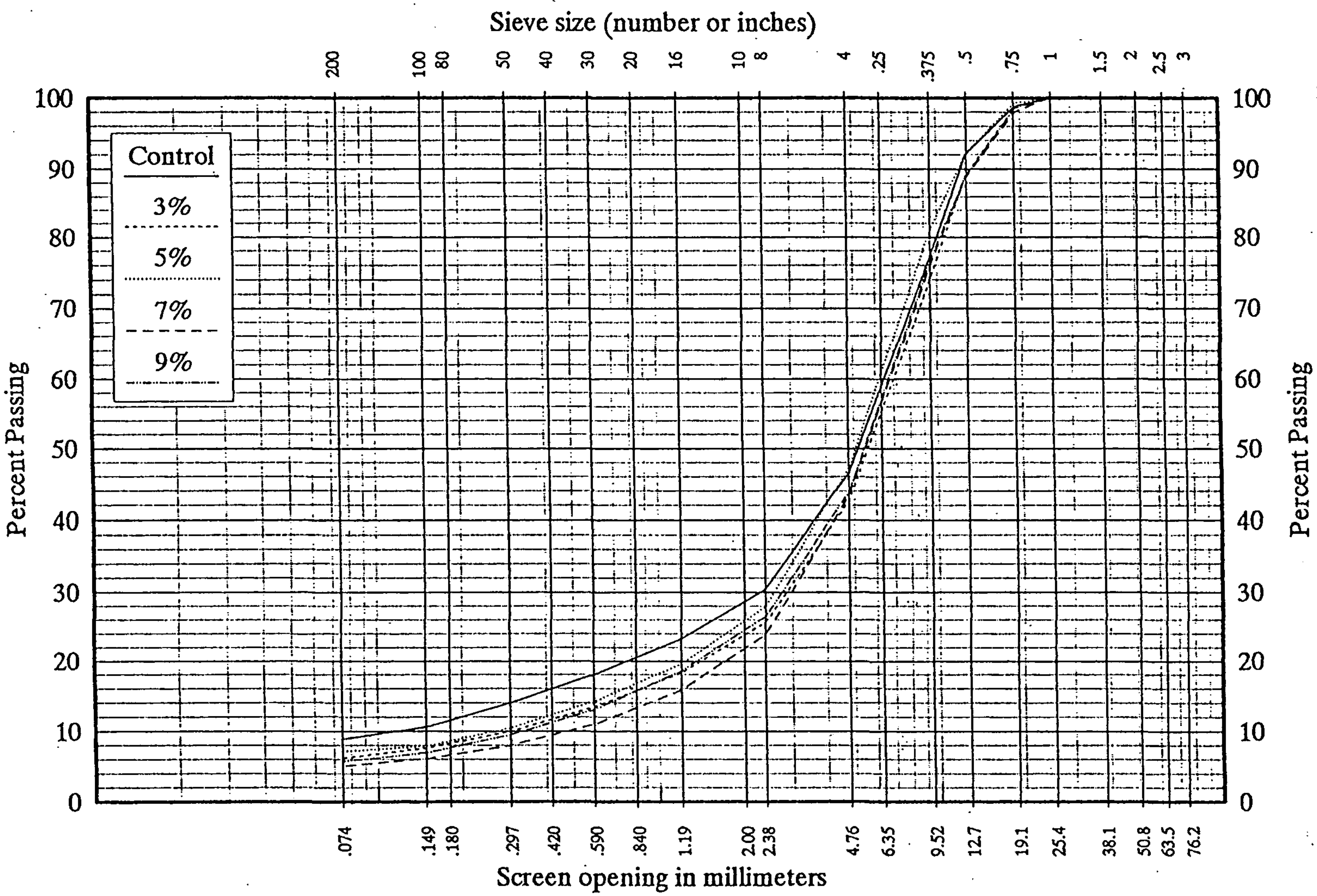

Figure 22. Tama County washed gradation from 05/18/94.

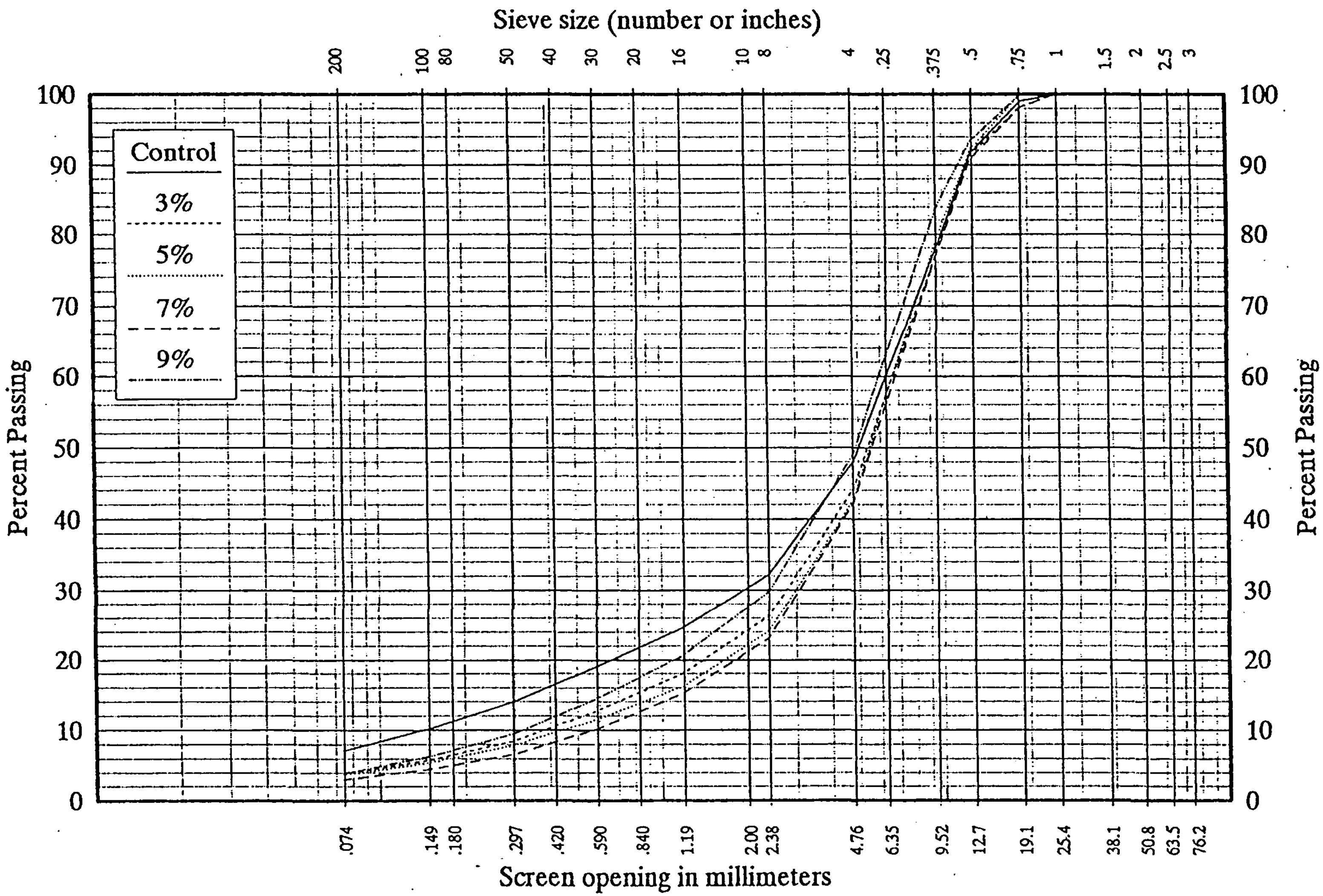

Figure 23. Tama County air dried gradation from 05/18/94.

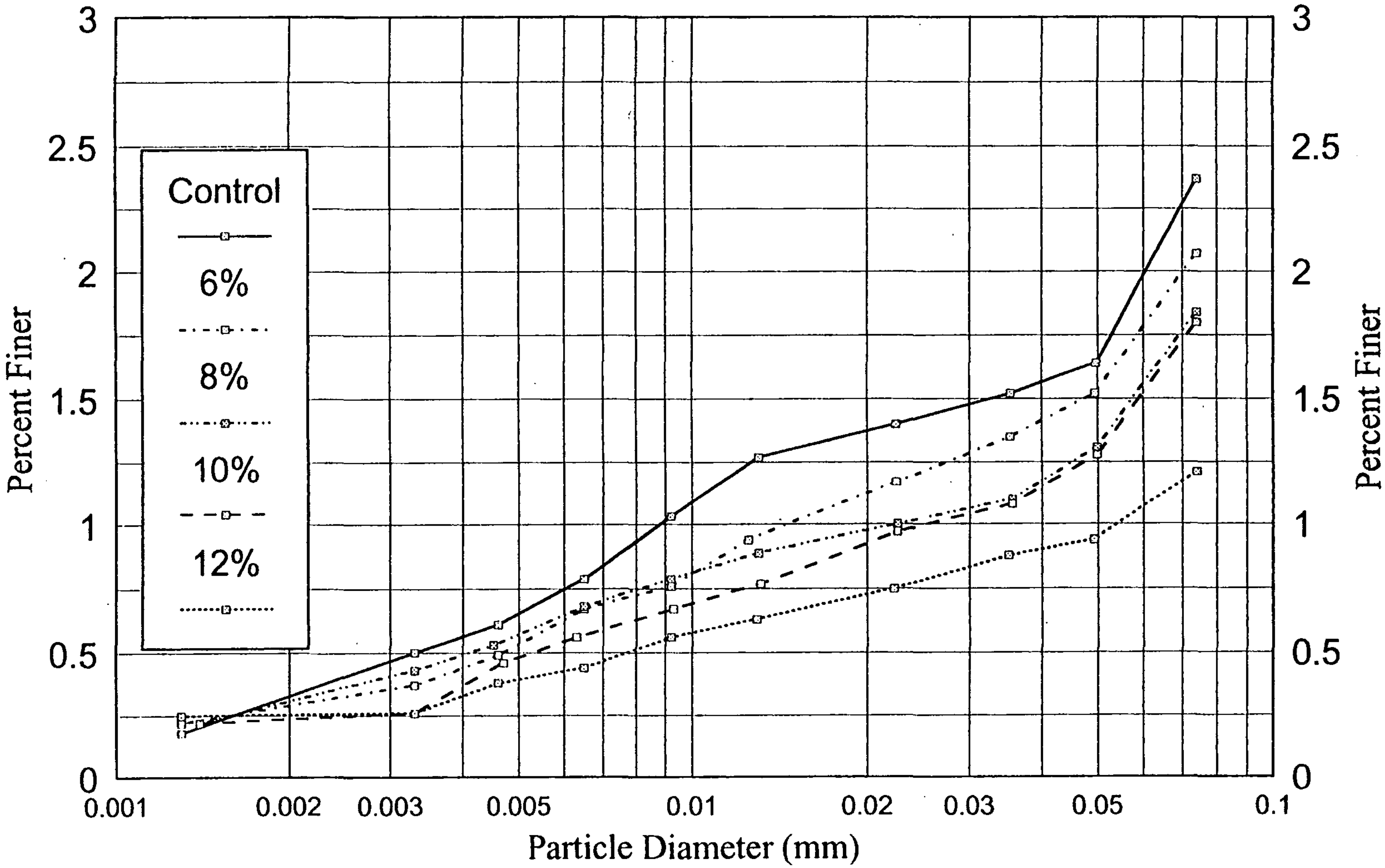

Figure 24. Appanoose County hydrometer analysis from 07/12/94.

less fines in the surfacing material. This testing would back up the results from the washed gradations. The trend is also present in the Tama County material as shown on Figure 25.

X-Ray Fluorescence (XRF)

Samples were obtained from the control sections (Phase II) in all three counties. The samples were washed over a 1/2 inch sieve to remove any fines and/or clay particles. Once the plus 1/2 inch material was washed, it was then crushed in a jaw crusher to reduce the size to run them through a grinder. After crushing, the samples were ground to a fine powder. An elemental analysis was performed on the samples by XRF. An elemental analysis was also performed on the powdered Bentonite. The results of those tests are given in Table 4 along with the typical ranges from different quarries located throughout Iowa. The sum is a quick check of the reliability of the analysis since the oxide total should approach 100 percent. All of the values are fairly close to 100 percent, therefore the tests appear reliable. A copy of the XRF report is given in Appendix C.

From the ranges in Table 4, the Tama aggregate would be classified as a limestone with some impurities. Some of the oxides for the Tama County aggregate falls outside some of the typical ranges, but the oxides are much closer to the limestone range than the dolomite range. The Appanoose County aggregate would be classified as a limestone. Almost all of the oxides are the same as the limestone typical ranges. The Hancock County aggregate would be classified as a dolomite. This is evident from the typical dolomite values shown in Table 4.

Thermogravimetric Analysis (TG)

The system that was used for testing was a Hi-Res TGA 2950 thermogravimetric analyzer by TA Instruments. This analyzer is equipped with a 16 sample carousel which allows for many samples to be prepared and tested under automatic operation. A typical TG analysis setup for this project used a scanning rate of 40°C per minute with a resolution = 5, sample mass of 55.5 milligrams, air as the atmosphere at a rate of 100 ml per minute, platinum sample cups, and heated from 30°C to about 850°C.

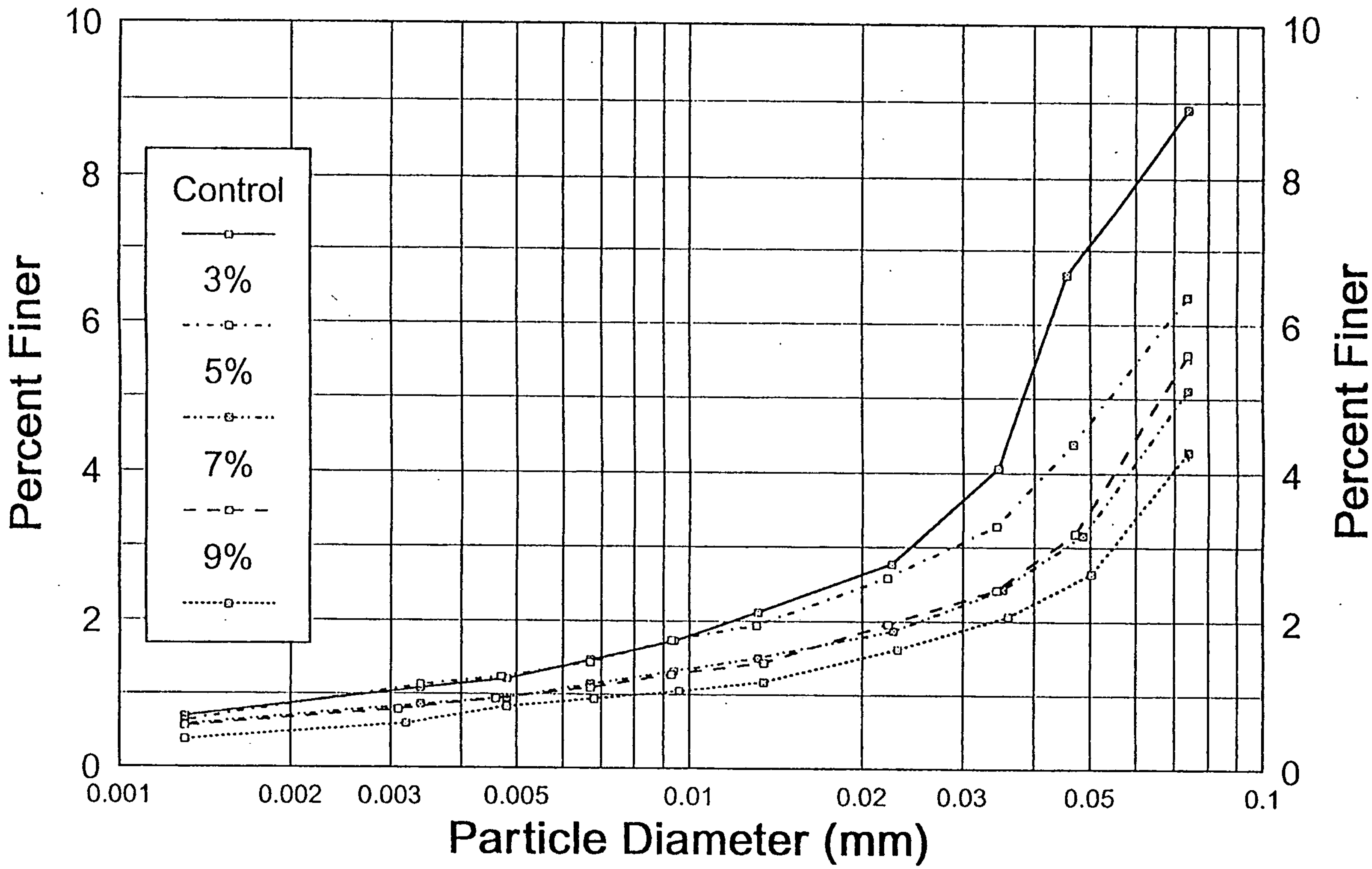

Figure 25. Tama County hydrometer analysis from 05/18/94.

Table 4. Results of XRF analysis on Bentonite and carbonate stone.

Oxides	Bentonite (wt. %)	Tama (wt. %)	Appanoose (wt. %)	Hancock (wt. %)	Typical Iowa Limestone Ranges (6) (wt. %)	Tupical Iowa Dolomite Ranges (6) (wt. %)
SrO_3	0.04	0.02	0.04	0.02	0.02 - 0.04	0.01 - 0.02
MgO	1.61	6.54	0.84	17.09	0.29 - 4.34	13.18 - 18.84
CaO	0.81	43.00	50.79	33.6	47.40 - 54.89	29.76 - 34.38
Fe_2O_3	2.61	1.05	1.02	0.86	0.16 - 0.60	0.20 - 0.94
TiO_2	0.11	0.02	0.03	0.30	<0.01 - 0.02	0.01 - 0.03
SiO_2	43.8	7.26	3.32	1.93	0.16 - 3.99	0.76 - 2.83
SO_3	0.40	0.07	0.08	0.04	<0.01 - 0.20	<0.01 - 0.27
K_2O	0.46	0.06	0.11	0.16	0.01 - 0.14	0.06 - 0.18
P_2O_5	0.04	0.03	0.04	0.02	<0.01 - 0.03	<0.01 - 0.07
Al_2O_3	13.77	0.27	0.63	0.51	0.05 - 0.40	0.16 - 0.48
MnO	-	0.04	0.29	0.05	0.01 - 0.05	0.02 - 0.05
LOI[a]	34.12	40.66	42.00	45.69	42.30 - 44.10	45.00 - 46.80
Sum	97.67	99.02	99.19	100.27		

[a]LOI = loss on ignition @ 950°C

The present method utilized by the Hi-Res TGA analyzer is a dynamic heating rate. This is used to shorten the time needed to run a complete test and allows the heating rate to be varied. Once a mass loss is detected, the heating rate is lowered and after a mass loss is no longer detected, the preset heating rate resumes.

Laboratory Sample Tests

To evaluate TG analysis for application to this project, laboratory samples from Tama County were prepared. The minus number 200 material was obtained from the control section in Tama County. Three different percentages of Bentonite (5, 10, and 15 percent) were added to the control material. The samples were then stirred for a minimum of five minutes to ensure that the Bentonite was equally distributed throughout the sample.

These samples were tested using the previously mentioned test condition parameters. A sample of Bentonite was also tested to obtain its TG curve. The results of those tests are shown on Figure 26. The limestone and Bentonite samples decomposed at about the same temperature. The residues remaining from the control and treated sections were approximately uniformly spaced. This should be the case since a uniform increase of Bentonite was added to the control material. The actual residue amounts, at approximately 825°C, are shown in Figure 27. To confirm the previous tests, another set of samples was prepared in the same manner. The second set of tests confirmed that the analysis is repeatable.

Analysis of Figure 26, indicates a small dip in the curve from approximately 30 to 100°C. This dip is associated with the moisture being removed from the samples. Since Bentonite can retain a large amount of moisture, as shown on Figure 26, it was decided to oven dry the samples before being tested. Drying was accomplished by placing the samples into an oven at 110°C until a constant weight was obtained. Using this procedure the samples all start off at similar moisture contents. Another set of Tama laboratory samples was prepared, oven dried and retested. This process removed the initial dip, as shown on Figure 28.

One can theoretically calculate how much residual material, from the laboratory mixed samples, should remain at the completion of the test. This is done by using linear interpretation and by knowing the actual amount of Bentonite added [8]. There may be some error due to the actual weighing and mixing process. Calculations have shown that the error is very minimal and that the linear interpretation may be utilized to approximate the amount of residual for any percentage of Bentonite at approximately 825°C. Note that linear interpretation is only good for laboratory mixtures and not for samples obtained from the field, since the amount of actual Bentonite remaining in the field samples is unknown.

Field Sample Tests

Since the samples need to be in a powder form, the samples which were obtained from the road were sieved over a number 200 sieve. This material was saved and tagged in a small vial. The samples were then oven dried to remove any moisture that might be present and prepared for testing.

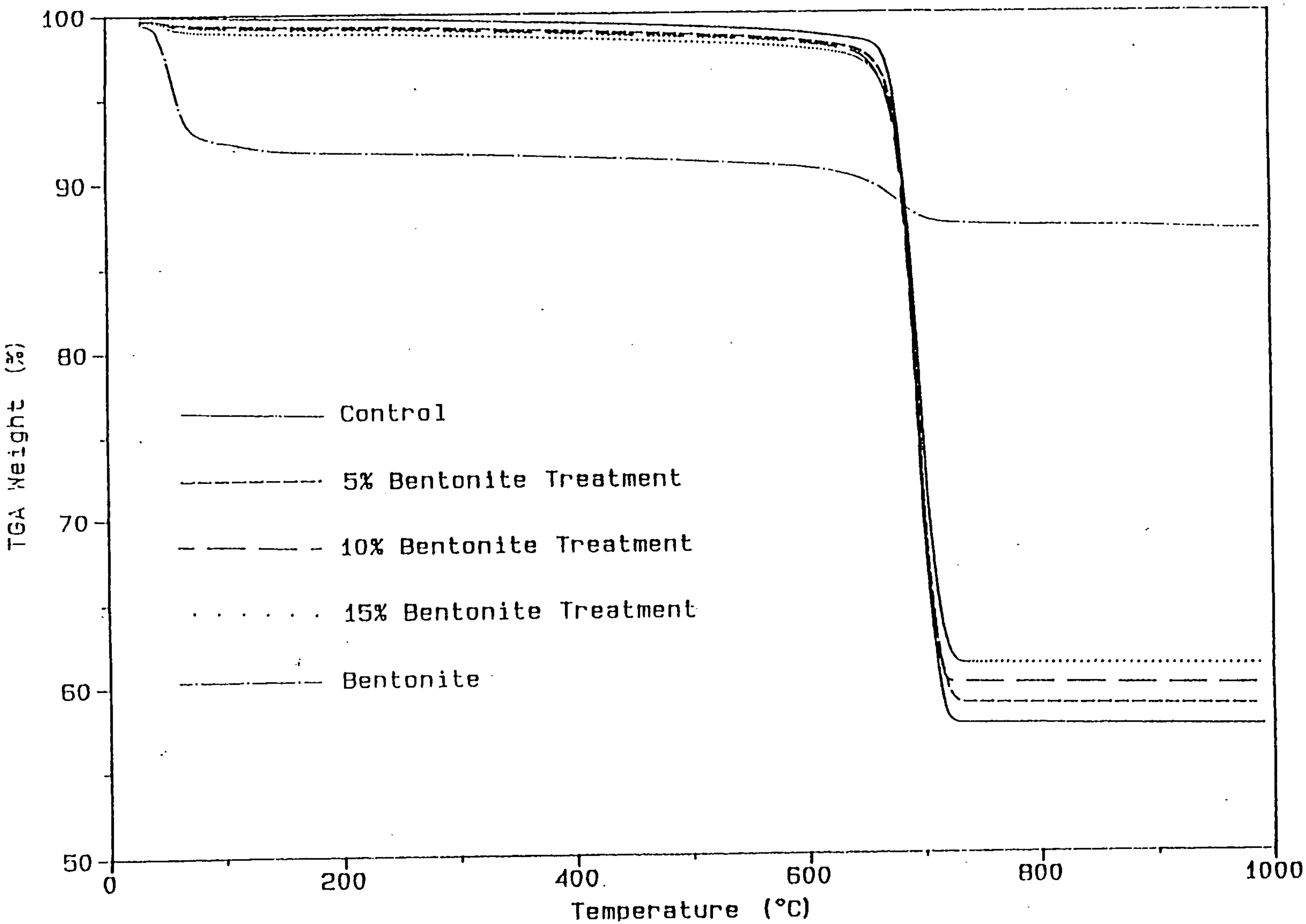

Figure 26. TGA curves of first air dry Tama County samples and Bentonite.

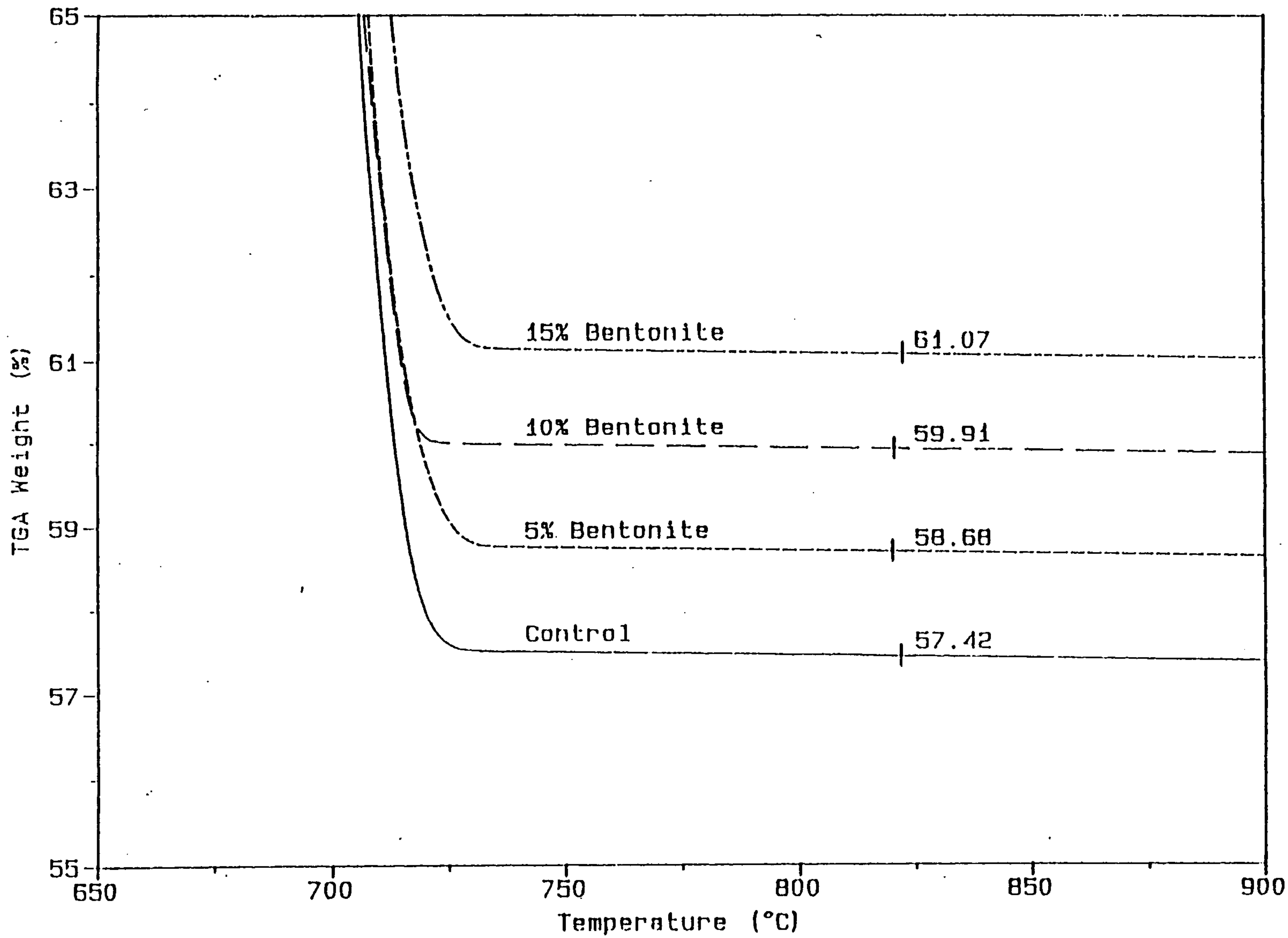

Figure 27. TGA curves of first air dry Tama County samples.

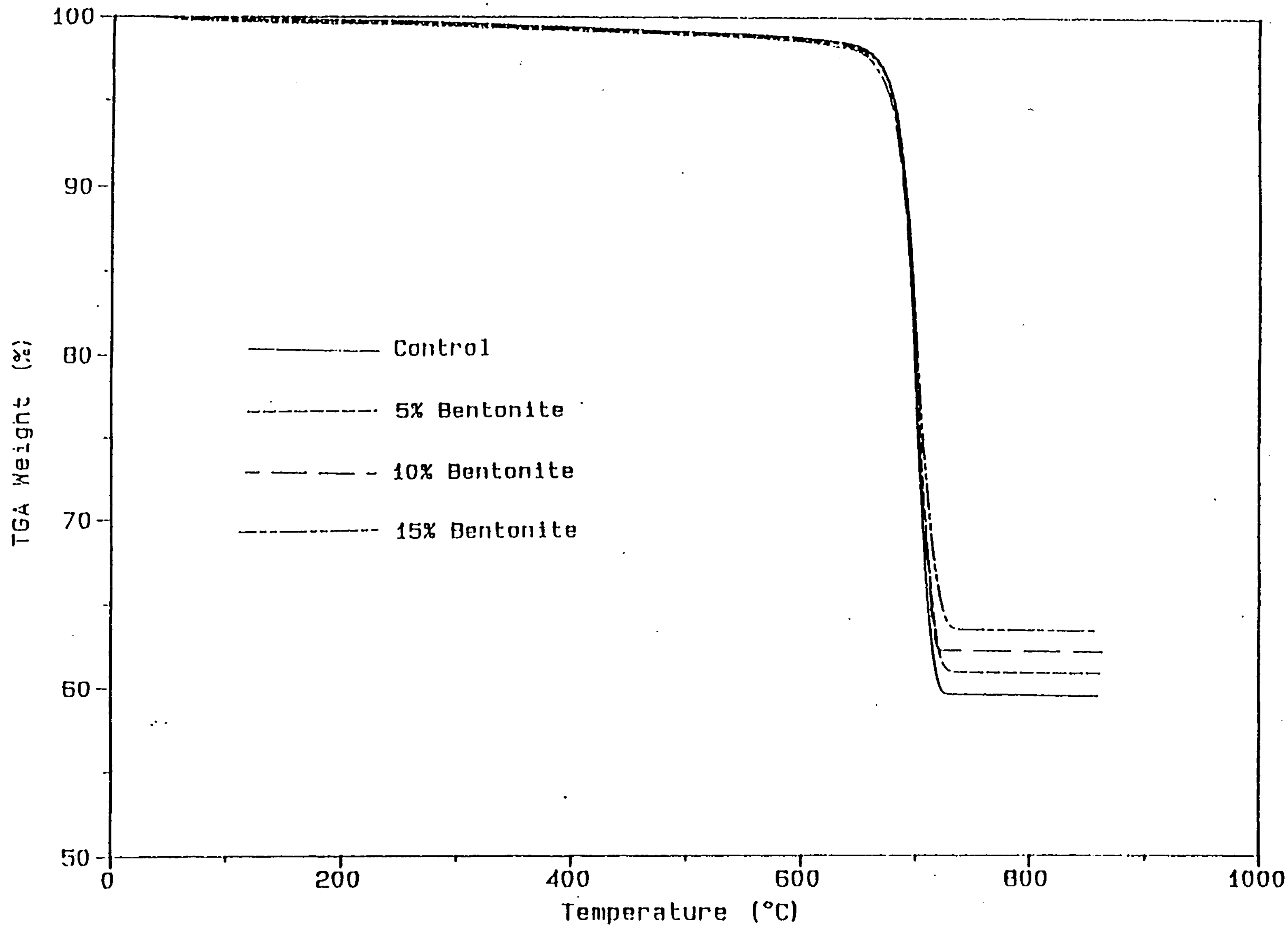

Figure 28. TGA curves of oven dry Tama County samples.

The same operator conducted all of the tests, to minimize any operator errors and variation. The sample masses were kept as close as possible to minimize any errors which might arise from different sample sizes. Using this procedure the curves should be comparable since all of the tests were being conducted under the same parameters. The minus number 200 material from each test section in Tama County was evaluated to determine if any Bentonite could be detected. Tests were conducted on samples obtained on August 18, 1992, July 14, 1993, and August 4, 1993. Since the general shapes of the curves below 700°C are similar to those previously shown, the curves were analyzed at temperatures above 700°C.

The general trend from the Tama County samples which were sampled August 4, 1993, indicated that maybe some of the Bentonite has moved between the sections, as shown on Figure 29. The trend is that the 3 percent section has the most Bentonite, while the 9 percent section has the least. This trend might be true after considering the topography of the road. The 7 and 9 percent sections are located toward the top of the hill with the 5 percent located below the 7 percent section and the 3 percent being located below the 5 percent section towards the bottom of the hill. With these samples being taken after the heavy rains in July, it could be possible that some of the Bentonite has been washed down the hill. To see how much Bentonite there was per section, x-ray diffraction (XRD) analysis was utilized to verify the TG data.

X-Ray Diffraction (XRD)

X-ray diffraction was performed on some of the 1994 crust samples to determine if the Bentonite was helping to lock up the fines in the limestone surface crust as was suggested in the gradation results section. X-ray diffraction tests were run by Materials Analysis and Research Laboratory (MARL) and the results presented on diffractograms.

Figures 30, 31, 32, 33, 34, and 35 are the diffractograms that were run on the samples. Figures 30, 31, and 32 show all four treatments that were run for clay determination. On Figures 33, 34, and 35 the scales on the diffractograms were blown up to show an exaggerated scale. Only the air dry and glycolated treatments are shown on the diffractograms.

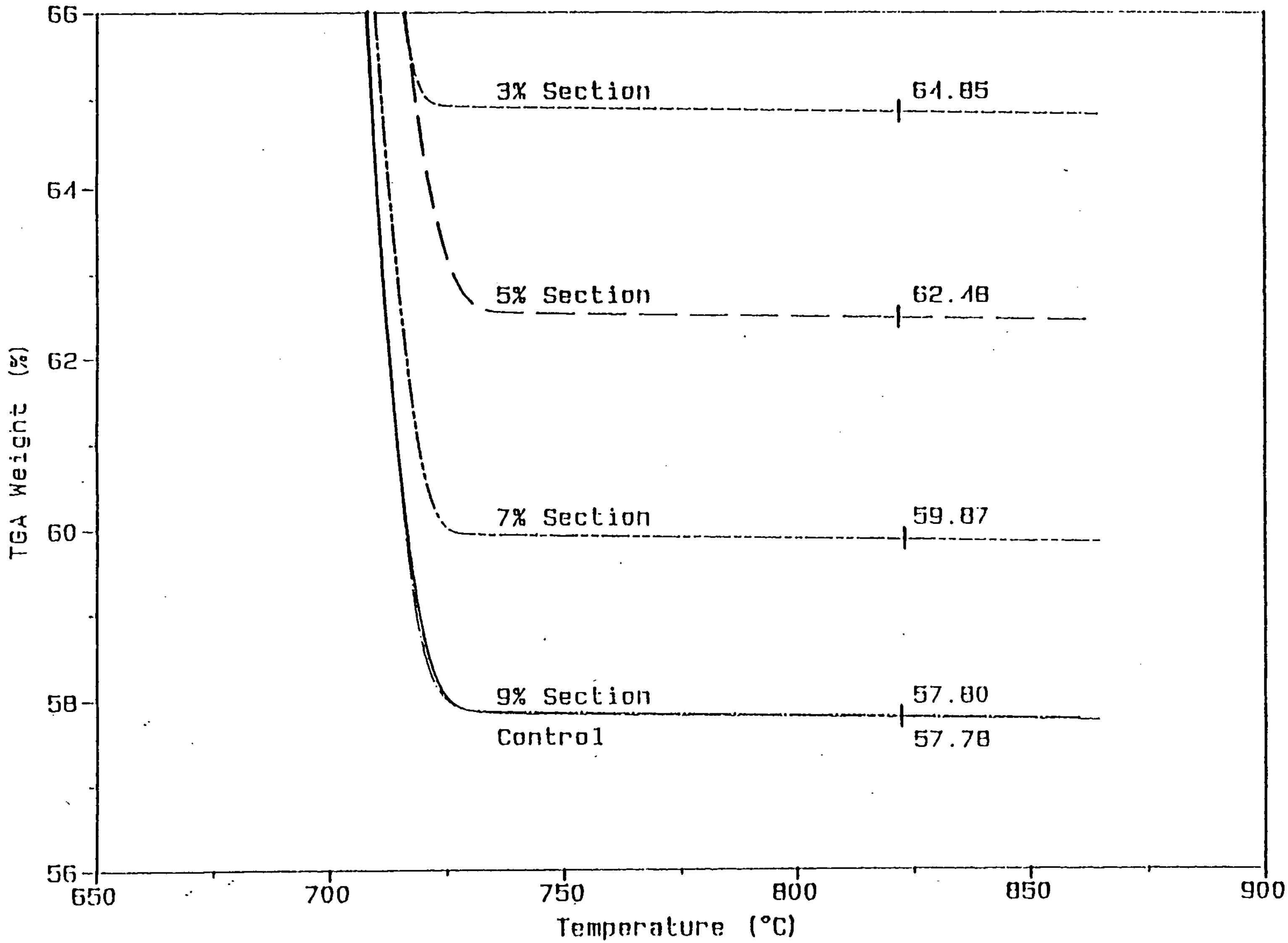

Figure 29. TGA curves of oven dry field samples obtained 08/04/93 in Tama County.

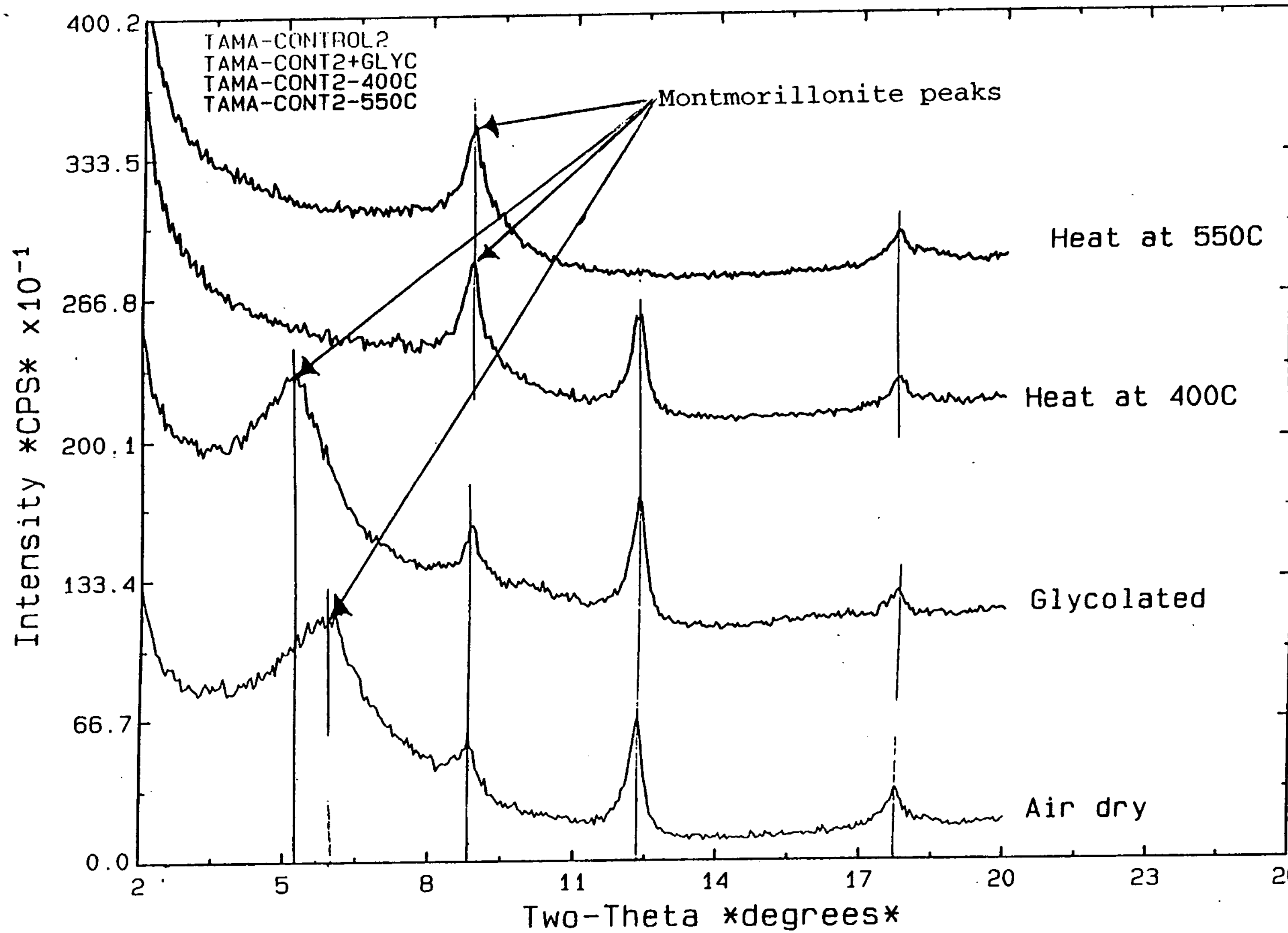

Figure 30. XRD diffractogram of the 1994 Tama County control section.

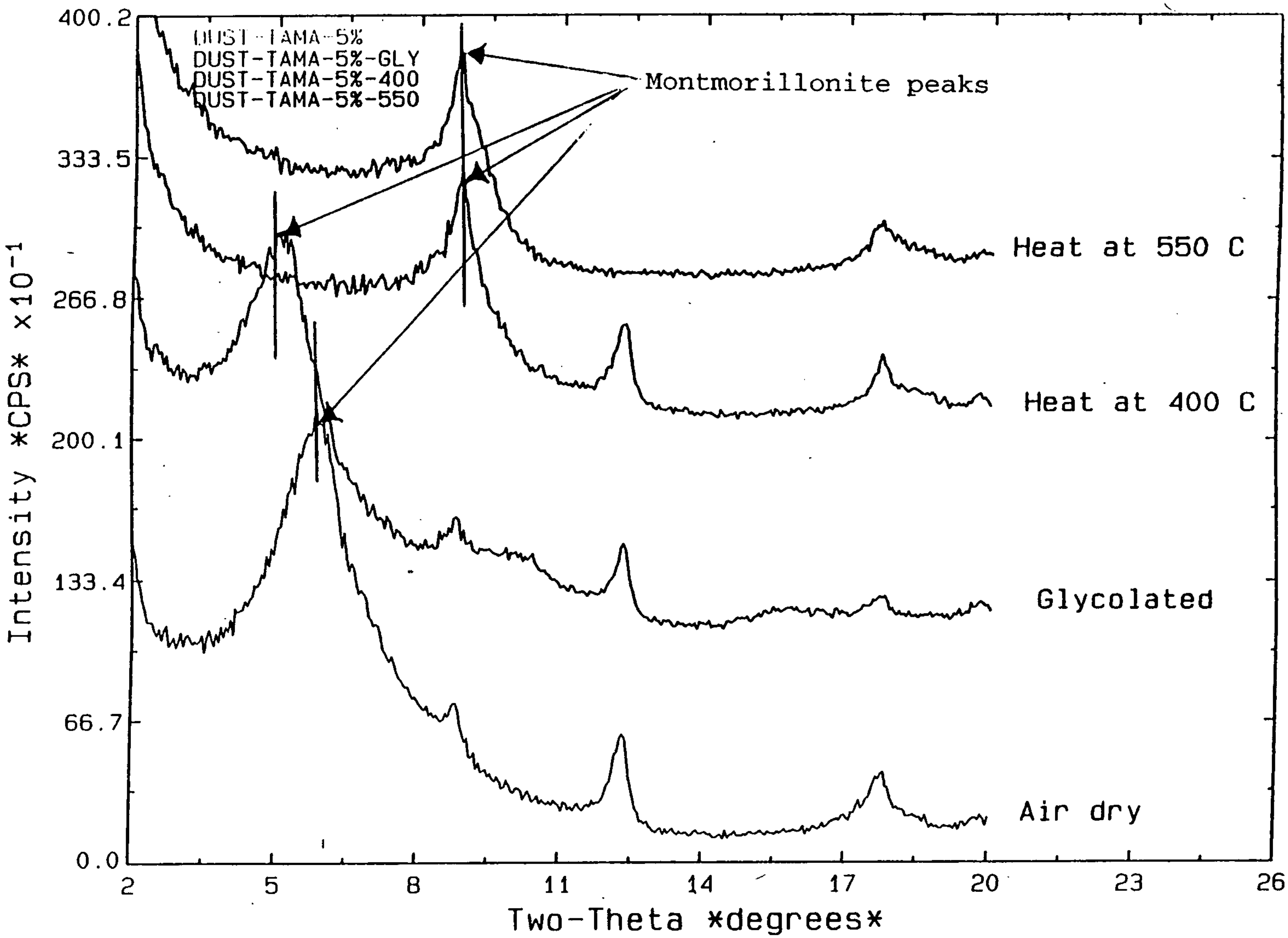

Figure 31. XRD diffractogram of the 1994 Tama County 5 percent section.

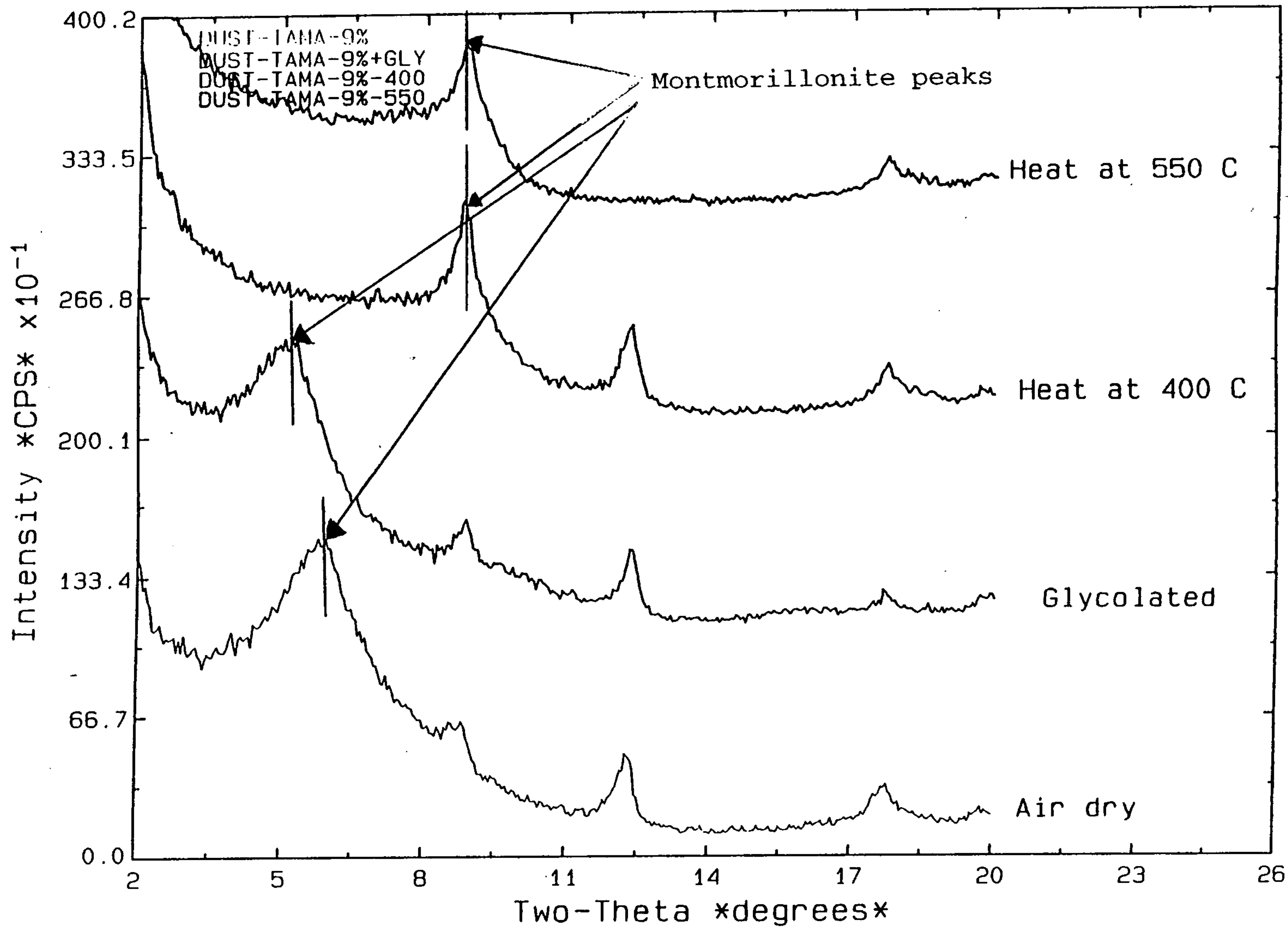

Figure 32. XRD diffractogram of the 1994 Tama County 9 percent section

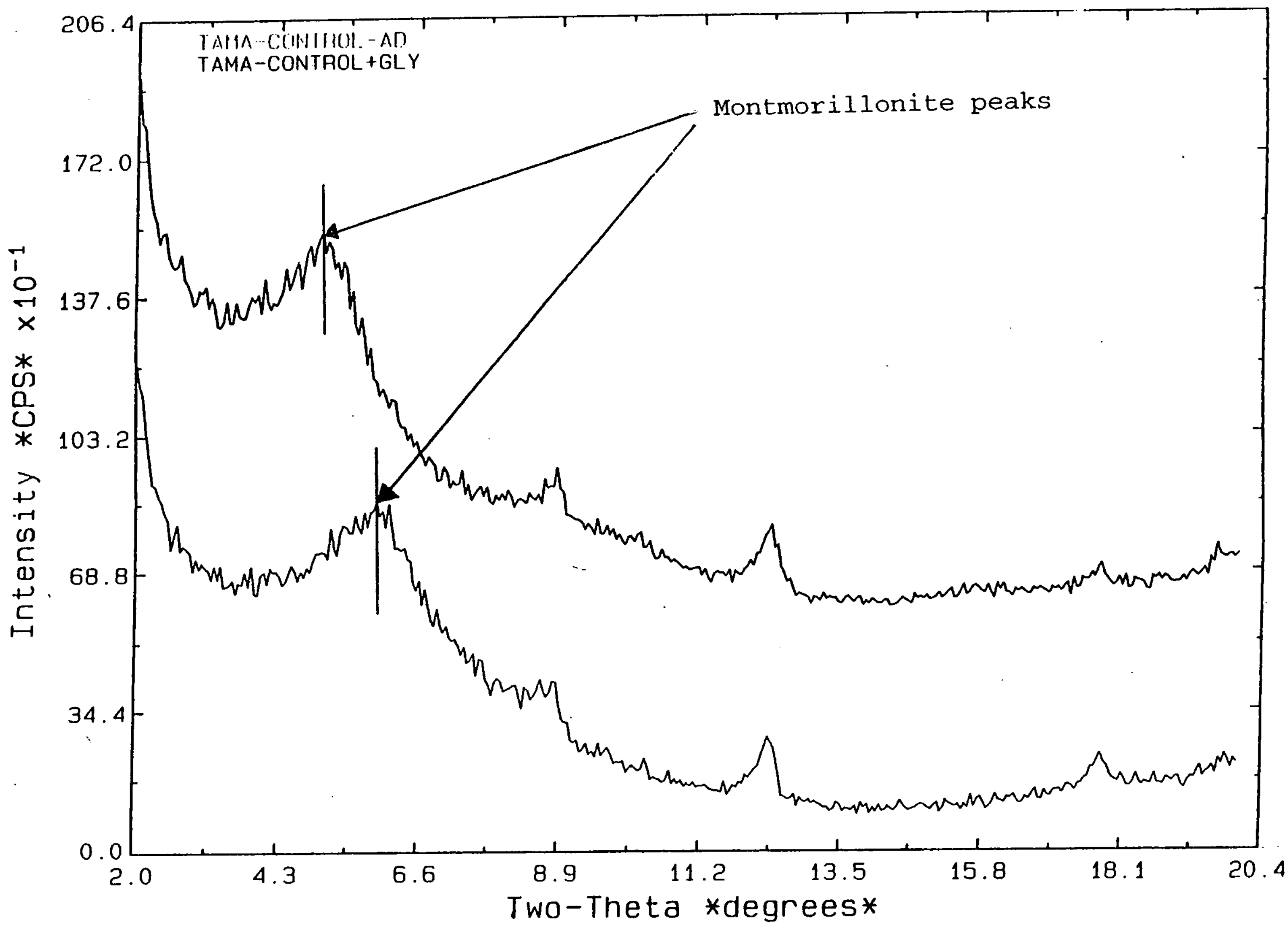

Figure 33. XRD diffractogram of the 1994 Tama County control section.

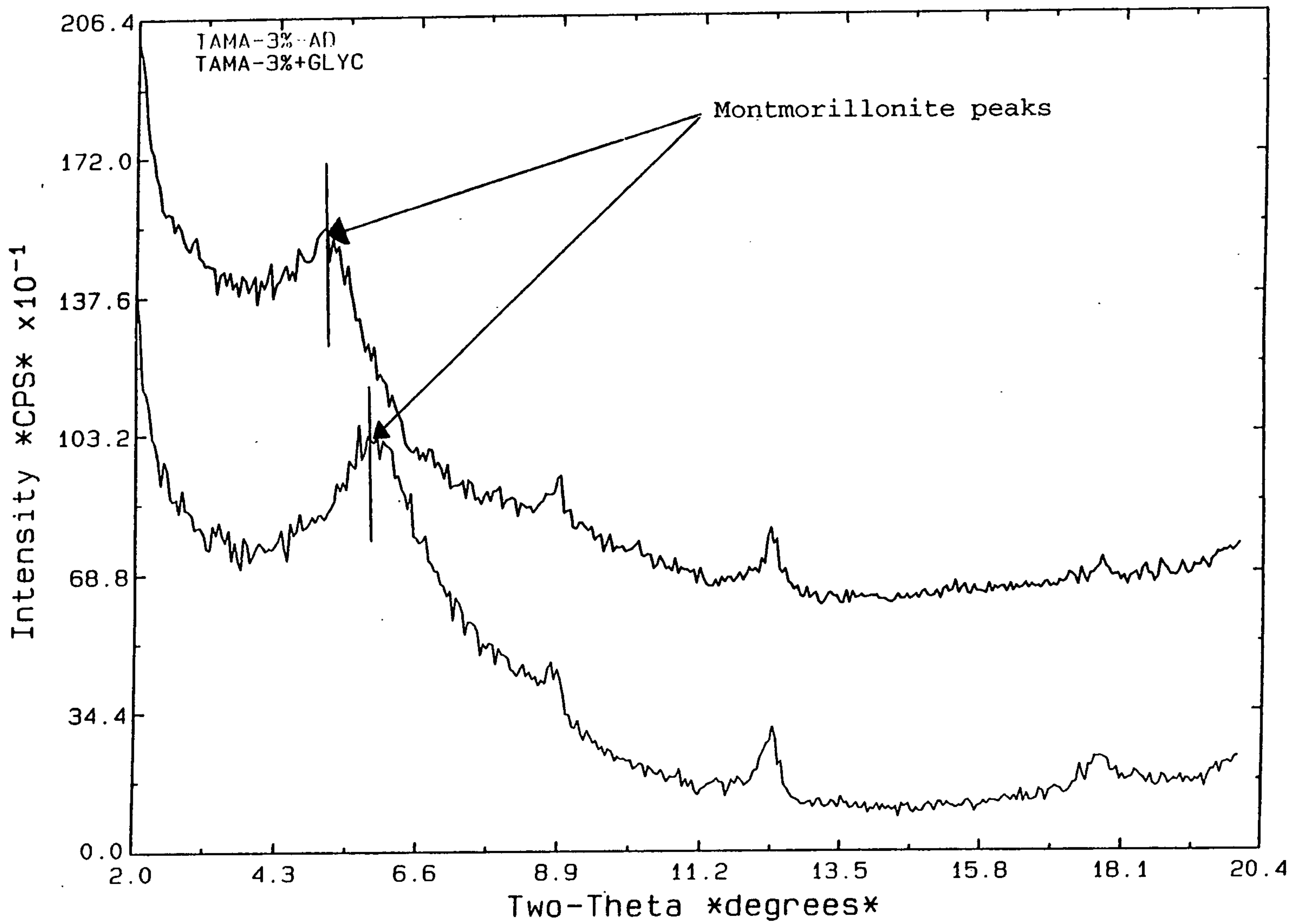

Figure 34. XRD diffractogram of the 1994 Tama County 3 percent section.

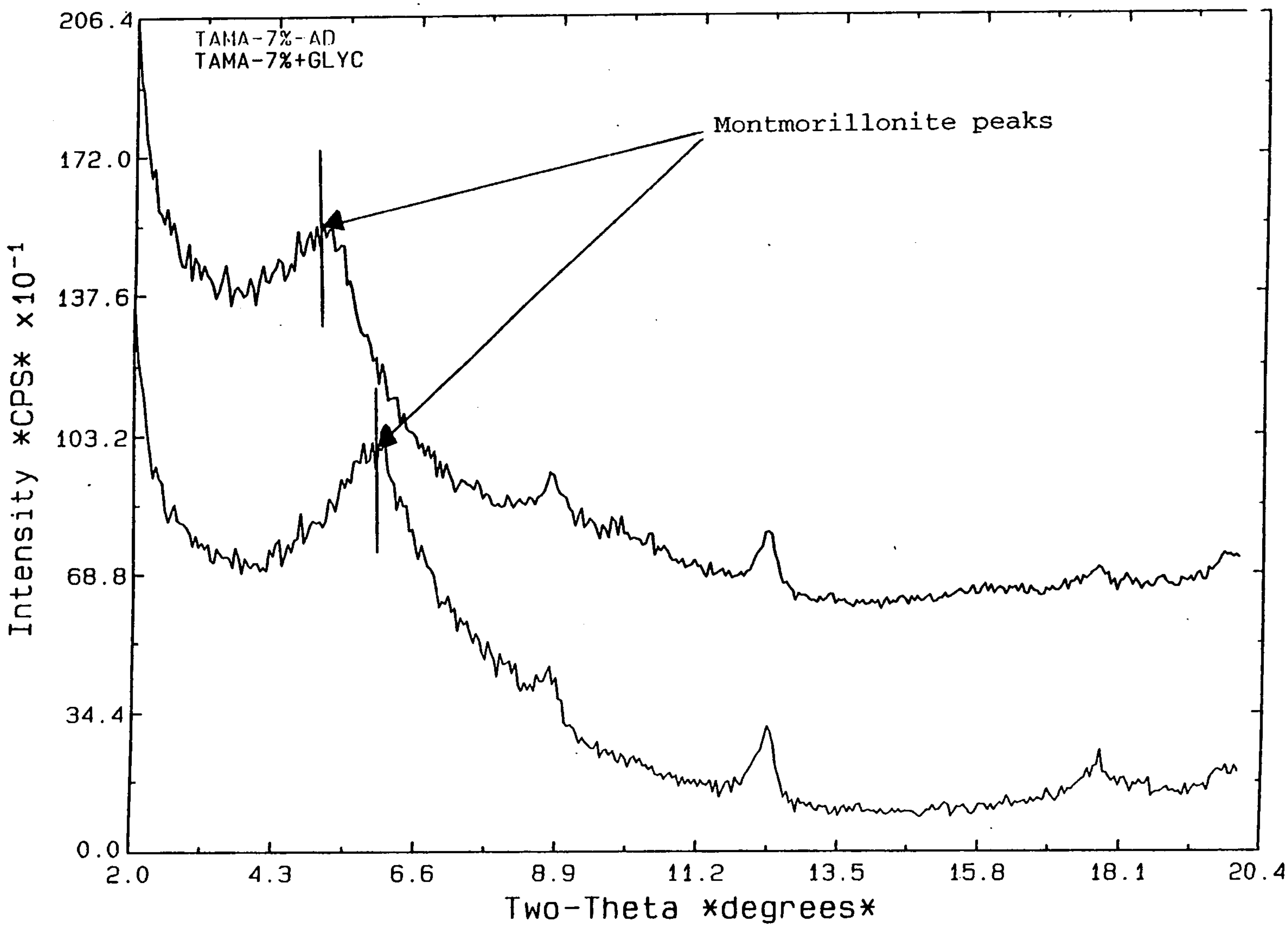

Figure 35. XRD diffractogram of the 1994 Tama County 7 percent section.

The XRD analysis was performed on the Tama County crust samples taken in the 1994 testing year. Figures 30, 31, and 32 show the control section, 5 percent section, and 9 percent section, respectively. Figures 33, 34, and 35 show the control section, 3 percent section, and 7 percent section, respectively. The first peak on the diffractograms is the montmorillonite peak.

By comparing Figures 30 to Figures 31 and 32, the 5 percent and 9 percent sections have more montmorillonite clay than the control section. The 5 percent section has a greater amount of montmorillonite clay than the 9 percent section, which may explain the 5 percent sections better effectiveness in the visual evaluations for 1994. The higher amount of the montmorillonite clay may lead to better crust development which was also shown in the 1994 visual evaluations. This increase in clay content is attributed to the migration of clay down hill from the 7 percent section into the 3 percent and 5 percent sections. The 5 percent and 9 percent sections have more montmorillonite clay than the control section and both sections show a reduction in dust generation and better crust development. There is some montmorillonite clay existing naturally in the subgrade as shown by the control section XRD results. There is a definite increase in the amount of clay in the treated sections which suggests the clay is still in place three testing seasons after the treatment was implemented.

Comparing Figure 33 to Figures 34 and 35 shows that the 3 percent and 7 percent sections also have a higher percentage of clay than the control. Comparing Figures 34 and 35 shows that the 3 percent and 7 percent sections have similar amounts of clay which is attributed to the clay washing down the hill out of the 7 percent section into the 3 percent and 5 percent section. Some of the montmorillonite clay content of the 3 percent section could have also come from the water washing over the road in 1993 since there is montmorillonite present in the native soils. The 3 percent and 7 percent sections both show a dust reduction and have better crust development than the control section.

XRD testing demonstrates that some of the Bentonite treatment is still present after three years of service. Some of the Bentonite shown in the diffractograms could come from the subgrade materials since the chisel used for crust sampling penetrated into the surface 1 - 1 1/2 inches. This testing however does show an increase in the amount of montmorillonite in all of the treated sections and the relative amounts compare to visual observations of dust reduction well.

Scanning Electron Microscopy (SEM)

SEM studies were conducted on samples obtained from the control section and 7 percent Bentonite treated section over three service seasons (1992, 1993, and 1994) from the Tama County test road. testing was performed in a Hitachi low vacuum SEM so the samples could be tested without having to apply special coatings. The system was equipped with an energy dispersive chemical, dot mapping, and elemental analysis capabilities. The samples for testing were obtained from the minus #200 fraction of dry sieve analysis testing of the loose surfacing material. Numerous SEM micrographs were taken. The following micrographs represent the conditions that were observed in the majority of those micrographs.

Figures 36 and 37 are 300x micrographs of samples of minus #200 material from the untreated control section samples taken August 18, 1992, and July 14, 1993 respectively. Very few small particulates are observed adhering to the larger particle surfaces and few agglomerates of smaller particles are seen.

Figures 38, 39, and 40 are 300x micrographs of minus #200 material from the 7 percent Bentonite treated section sampled on August 18, 1992, August 4, 1993, and August 2, 1994 respectively. The abundance of small particulates attached to larger particle surfaces and agglomerates of smaller particulates appears evident.

Figure 41 is a sample prepared in the laboratory using 7 percent Bentonite and minus #200 material from the untreated control section. The morphology is similar to those observed on Figures 38, 39, and 40.

These data indicate that Bentonite is present in the system for a period of at least three seasons and appears to be functioning to adhere small limestone particulates to larger ones and to agglomerate groups of smaller limestone particles.

Figure 36. 300x SEM micrograph (minus #200), Tama County control section, sampled 08/18/92.

Figure 37. 300x SEM micrograph (minus #200), Tama County control section, sampled 07/14/93.

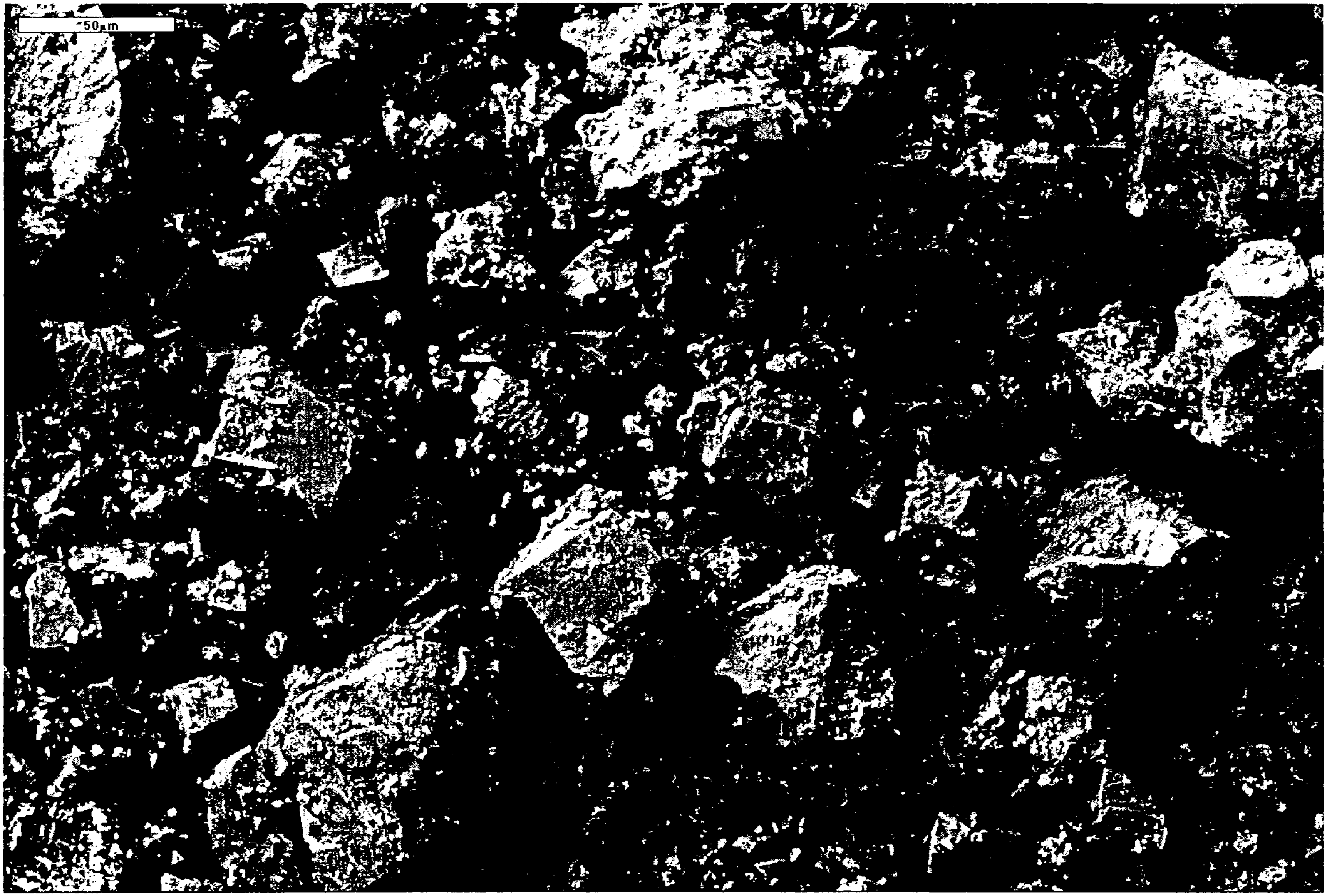

Figure 38. 300x SEM micrograph (minus #200), Tama County, 7 percent section, sampled 08/18/92.

Figure 39. 300x SEM micrograph (minus #200), Tama County, 7 percent section, sampled 08/04/93.

Figure 40. 300x SEM micrograph (minus #200), Tama County, 7 percent section, sampled 08/02/94.

Figure 41. 300x SEM micrograph (minus #200), Tama County, 7 percent hand mixed, sampled 08/02/94.

X-ray fluorescence (XRF) elemental analysis was performed on the control sample taken in 1992 and the 7 percent section sampled in 1992. The Bentonite clay used for a dust palliative should have elements present such as aluminum, sodium, and silica. The limestone should have elements in it like calcium and magnesium. Figures 42 and 43 present the XRF analysis data. The 7 percent treated sections shown on Figure 43 has much higher silica and aluminum peaks than the control section shown on Figure 42 does compared to the calcium peak in both plots. Also, in the 7 percent section, there is a slight increase in the sodium peak which would be expected if there was a clay addition. The results of this testing indicate that there was clay in the system.

ECONOMIC EVALUATION

Cost Determination

A cost evaluation was conducted for each section of Bentonite treatment and was compared to calcium chloride treatment.

The Tama County Bentonite treatment costs are based on one motor grader plus operator at $42.50 per hour, tandem dump truck plus operator at $20.00 per hour, and water truck plus operator at $25.00 per hour. The Appanoose County construction costs for the Bentonite treatments are based on two motor graders plus two operators at $45.00 per hour per machine, flat bed truck plus operator at $35.00 per hour, and two water trucks plus operators at $35.00 per hour per truck. The Hancock County construction costs are based on one motor grader plus operator at $50.00 per hour, tandem truck with trailer plus operator at $47.00 per hour, and water truck plus operator at $25.00 per hour.

Material costs varied due to the fluctuations in the amount of surfacing material present in each test section. They also varied due to the different lengths of each section and the different amounts of water added to each section. The cost for the removal of the gravel and the addition of limestone, prior to construction in Hancock County, was not considered in order to be able to compare the construction costs with the other counties. Table 5 presents the break down of the costs per section and per mile for the Tama County test road. Costs for Appanoose and Hancock counties were determined in the same manner. For comparison each test section cost was normalized to a

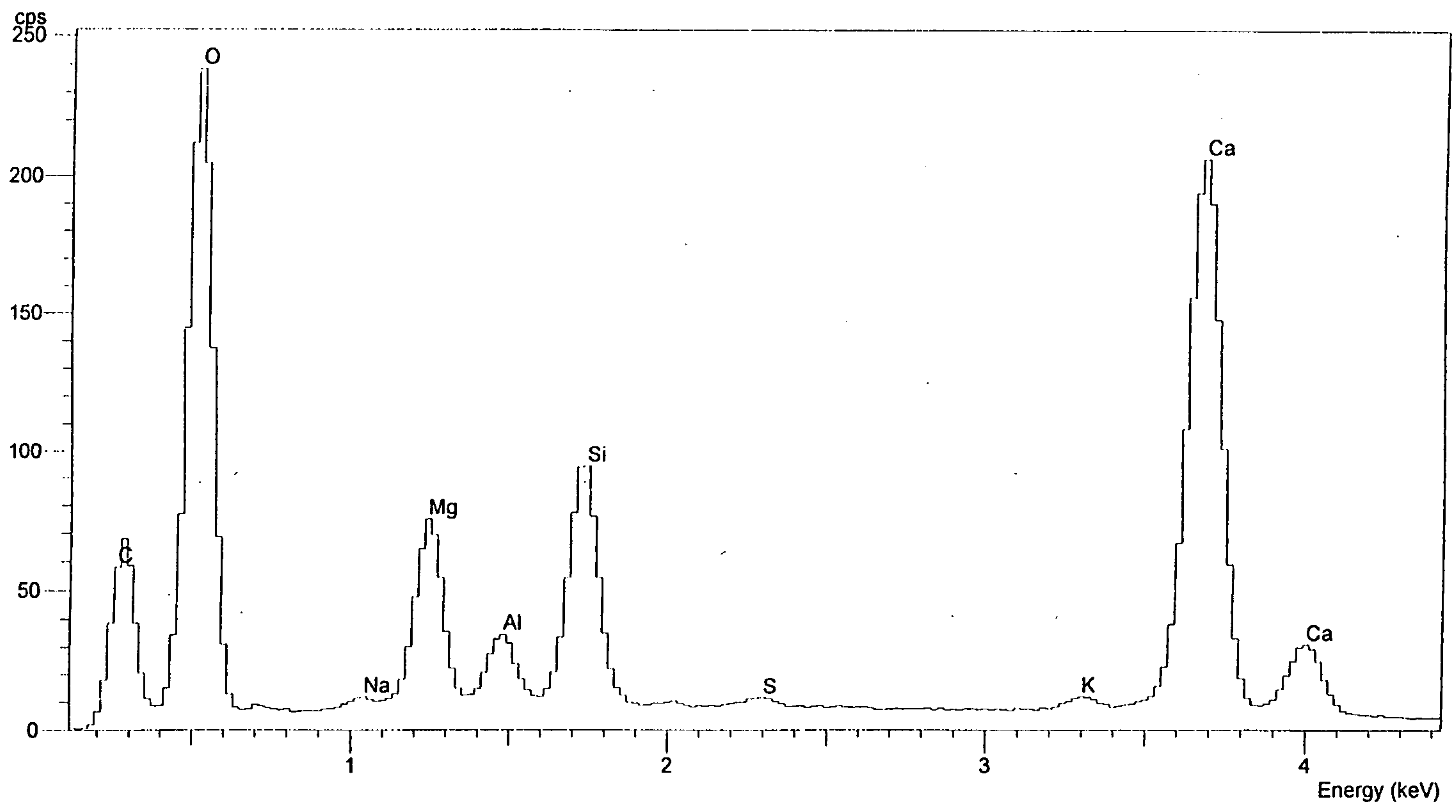

Figure 42. XRF data, Tama County untreated control section, sampled 08/18/92.

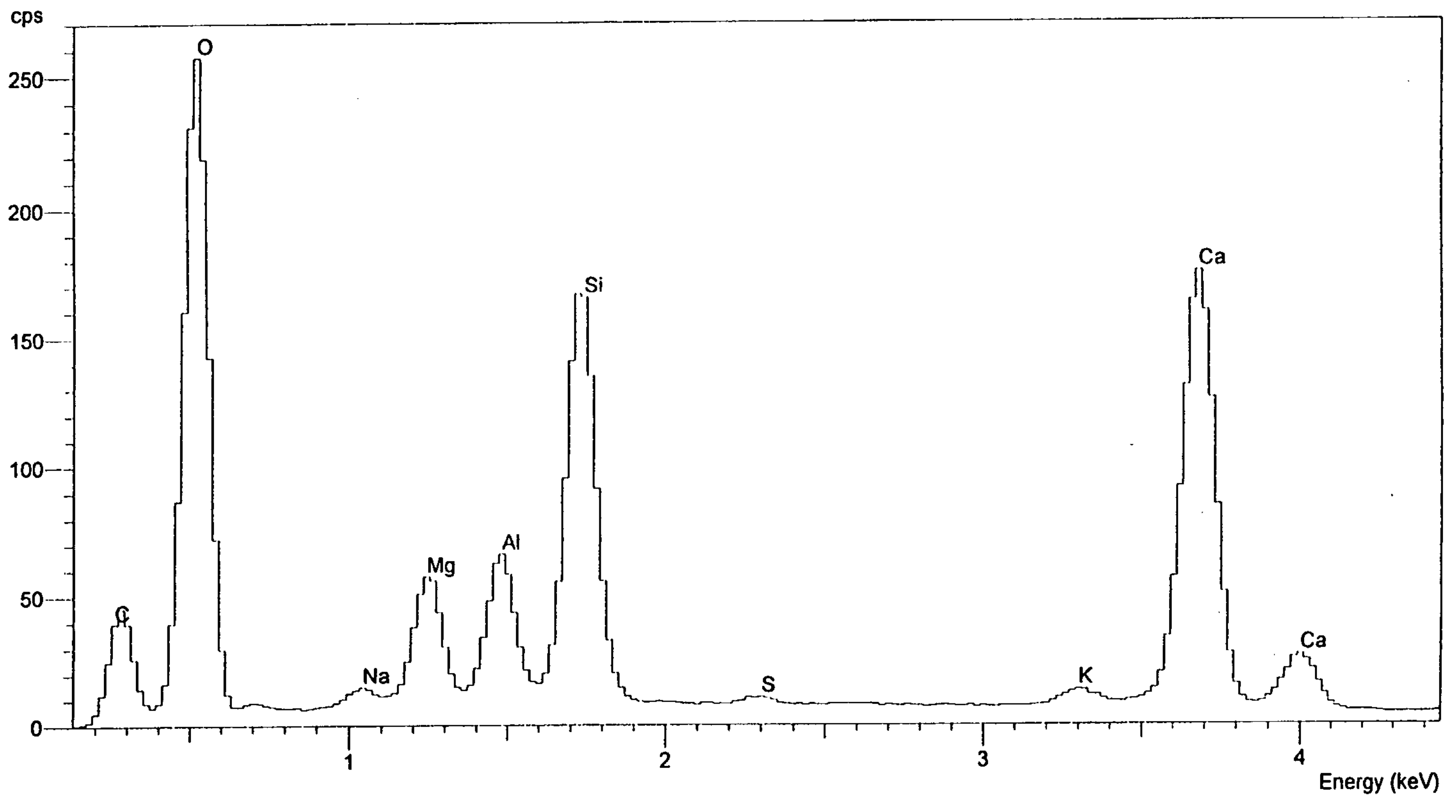

Figure 43. XRF data, Tama County 7 percent Bentonite section, sampled 08/18/92.

Table 5. Tama County test road breakdown of construction costs per 1000 feet and per mile.

	3% Bentonite		5% Bentonite		7% Bentonite		9% Bentonite	
	Cost for		Cost for		Cost for		Cost for	
	1000 ft.	1 mile	1000 ft.	1 mile	1000 ft.	1 mile	1000 ft.	1 mile
Bentonite	57	300	85	450	102	540	261	1,377
Soda Ash	6	30	6	30	6	30	11	60
Water	7	37	7	37	7	37	14	74
Grader + operator	64	340	64	340	64	340	64	340
Tandem truck + operator	10	40	10	40	10	40	10	40
Water truck + operator	37	200	37	200	37	200	37	200
Actual Cost* of Construction	181	947	209	1,097	226	1,187	397	2,091
Normalized Cost Based on 125 tpm**	**189**	**990**	**233**	**1,222**	**276**	**1,447**	**332**	**1,750**

*Estimated amount of limestone present:
3% section ⇒ 109 ton/mile
5% section ⇒ 98 ton/mile
7% section ⇒ 124 ton/mile
9% section ⇒ 167 ton/mile

**The shaded row presents normalized costs based on a typical secondary road average of 125 ton/mile of loose limestone surfacing material basis of 125 ton per mile of loose limestone surfacinf material, which represents a typical secondary road.

Table 6 presents the comparison between the annaul normalized Bentonite treatment costs (for all test roads) and calcium chloride costs per mile. Information on calcium chloride costs was obtained from Jerico Services of Indianola, Iowa. The calcium chloride cost is based on two applications per year at a standard application rate of 0.25 gallons per square yard of a 38 percent concentration of calcium chloride. Two applications were recommended by the suppliers, and is considered to be the minimum. The number of applications depends on the climatic conditions and the number of vehicles using the road. Therefore, the cost for calcium chloride given in Table 6 would be a minimum for the year. For cost comparison purposes, the Bentonite treated sections are estimated to last for one year. This is believed to be a very conservative estimate since the Bentonite treatment longevity is not yet exactly known. Evidence indicates it acts to reduce dust over an extended period of time (greater than one year). As seen in Table 6, the Bentonite treatment costs are considerably less than the calcium chloride treatment.

Table 6. Annual costs of Bentonite and calcium chloride treatments.

County	Treatment	Total Cost $ / mile / year
Tama	3% Bentonite	990
	5% Bentonite	1,222
	7% Bentonite	1,447
	9% Bentonite	1,750
Appanoose	6% Bentonite	1,485
	8% Bentonite	1,720
	10% Bentonite	1,950
	12% Bentonite	2,200
Hancock	5% Bentonite	1,340
	8% Bentonite	1,650
	Calcium Chloride	3,228

At the time this report was written, the longevity of the Bentonite treatments in Tama County was at least 14 months and probably be longer. Calcium chloride has been estimated to last approximately 3 to 4 months [8]. To compare the cost effectiveness of Bentonite treatments to calcium chloride, the total construction costs, estimated dust reduction efficiency, and duration is used. The total construction costs used here are for Tama County as shown in Table 5. The estimated dust reduction efficiencies used were the estimated dust reduction levels from Phase I data. The dust reduction values from Phase I were used because there were more data available for this test road than during Phase II.

Cost Evaluation

It is difficult to develop a reasonable way to compare the costs of the different treatment types. It was necessary to base the evaluation on the amount of dust reduction, but still show the decrease in efficiency of the treatments over time. It was considered valid to compare the cost for each treatment on a basis of percent dust generated. The average dust generations for the Bentonite treatments were shown in Tables 2 and 3 with the CaCl treatment having an assumed efficiency of 60 percent over its life span. The effectiveness of the Bentonite decreased with time due to addition of materials and possible leaching of materials out of the system. The decreased efficiency made it necessary to evaluate the materials on a testing season basis. This was done by showing the cost/percent dust generated then dividing by the number of months in service after the Bentonite addition was made. To have the CaCl chloride on the same basis as the Bentonite treatment it is necessary to replenish the CaCl section. The number of application of the CaCl was multiplied by the application cost and then divided by the assumed efficiency of 60 percent and then divided by the number of months in service. This method of economic evaluation should give a reasonable estimate of the cost of the treatment methods evaluated.

The results of the economic evaluation for Tama County are tabulated in Table 7. The first testing season at Tama County showed that the 5 percent section was the most economical for the cost of construction and dust generated. During the 1992 testing season the CaCl and the 9 percent

Table 7. Cost / Percent dust generated for test roads.

		$ / % dust generated $ / % dust generated/months of service Treatment Levels				
Months in Service[a]	Number of CaCl Treatments[b]	3%	5%	7%	9%	CaCl
Tama County						
(1992) 3	1	22 (7)	19 (6)	24 (8)	26 (9)	28 (9)
(1993) 14	3	14 (1)	17 (1)	26 (2)	35 (3)	85 (6)
(1994) 26	5	41 (2)	39 (2)	66 (3)	83 (3)	141 (5)

		$ / % dust generated $ / % dust generated/months of service Treatment Levels				
Months in Service[a]	Number of CaCl Treatments[b]	6%	8%	10%	12%	CaCl
Appanoose County						
(1993) 5	1	32 (6)	32 (6)	34 (7)	29 (6)	28 (6)
(1994) 16	3	99 (6)	156 (10)	195 (12)	122 (8)	85 (5)

[a]Months in use at the end of each testing season
[b]Number of CaCl treatments necessary to maintain the CaCl's effectiveness.
$ Stands for Cost.

section had reasonably the same cost per percent dust reduction. In the 1993 testing season the cost per percent dust reduction per month of the 3 percent and 5 percent sections was the same. The CaCl was the most expensive of the alternatives. In 1994, the cost per percent reduction and months of service for the Bentonite treatment and CaCl treatment are shown merging. Also, there was an increase in the cost per percent reduction per month for the Bentonite treatment. This shows that the effectiveness of the Bentonite treatment is diminishing and probably will need to be replenished. This also shows that the life expectancy of the Bentonite treatment is around 3 years (seasons). After the three testing seasons the Bentonite treatment is still more cost effective than the CaCl treatments.

The results of the Appanoose County site are also shown in Table 7. These results are not as favorable for Bentonite treatment as the results from Tama County. The cost per percent reduction per month for the first year are comparable to the CaCl section. However, the second year at Appanoose County the CaCl is more economical. During construction of the Bentonite treated sections at Appanoose County the soda ash to water percentage was increased from 0.4 percent to 1.2 percent. This may have decreased the efficiency of the Bentonite to bond with the limestone or the Bentonite may have been washed off the road surface by the heavy rains in 1993. Also, the road is very heavily traveled by garbage trucks and other vehicles. This may grind up the surfacing materials more. This grinding effect on the surfacing material may overload the system with limestone fines making the Bentonite less efficient. The heavy traffic may influence the CaCl treatment by making the surface washboard and become potholed requiring maintenance of the surface and more applications of CaCl which would increase the cost of CaCl treatment per percent dust reduction per month. Therefore, this may not be a reasonable economic evaluation of the traffic conditions present on the Appanoose County test road.

SUMMARY AND CONCLUSIONS

1. For dust control the results of this study indicated the optimum Bentonite amount, from a cost/benefit standpoint, is approximately 8 percent by dry weight of aggregate. Following are the results at about this level.

   - The Tama County test road had a traffic count of 60 vpd with moderate truck traffic. The following dust reduction averages were observed.

1992	60-70 percent
1993	40-50 percent
1994	20-30 percent

Maintenance surfacing was applied to this road in 1993 and 1994. It is significant that the Bentonite (applied in 1992) was able to interact with the new material and maintain a dust reduction capability.

- The Appanoose County test road had a traffic count of 200 vpd with 10-30 percent truck traffic. The following dust reduction averages were observed.

1993	50-60 percent
1994	10-20 percent

  For this traffic amount and type, dust control effectiveness was significantly reduced. The truck traffic is believed to be abrading and generating more fines than the Bentonite can effectively interact with.

- The Hancock County test road had a traffic count of 1150 vpd with light truck traffic. The dust reduction average was observed.

1993	20-30 percent

  This road had a gravel base to which crushed limestone had been topically applied. The Bentonite and stone were unable to interact with this material to form a wheelpath crust. It is not recommended for use on gravel based roads.

2. Even though dust was being generated after Bentonite treatment, field observations and video evidence indicates the dust cloud does not rise very high or wide and settles rapidly.

   - The dust cloud height reduction combined with increased dust settlement rate would result in improved visibility and traveling safety for the traffic following.

   - The dust cloud width reduction combined with increased dust settlement rate would result in a reduction in nuisance dust invading residences and residential areas.

3. With Bentonite treatment, wheelpath and crust development were improved by a factor of 2 or more which should act to reduce maintenance surfacing requirements over time as well as provide better driveability.

4. Braking and handling characteristics of Bentonite treated sections were not adversely affected under wet surface conditions up to a 12 percent treatment level.

5. The cost of Bentonite treatment (on the efficiency basis of dollars per percent dust reduction) is conservatively estimated at less than one-half that of calcium chloride treatment.

6. Evidence indicates that Bentonite is functioning as a dust suppressant by bonding small limestone particulates to larger limestone particles and agglomerating small limestone particles.

7. The advantages of Bentonite treatment are as follows.
   - Bentonite is a naturally occurring, environmentally sound material.
   - Bentonite is low in cost and readily available.
   - Construction is rapid and can be accomplished using county personnel and equipment.
   - Normal maintenance grading practice can be followed.
   - Bentonite is capable of interacting with new maintenance surfacing material, applied after treatment, and maintaining a dust reduction capability.
   - The dust reduction mechanism is recoverable from season to season and over a wide range of environmental service conditions.

8. The disadvantage of Bentonite treatment is that there is not the initial dramatic reduction in dust as with chloride treatment. Although dust is reduced 60-70 percent there is still dust being generated. Where immediate and nearly total dust reduction is required, chloride treatment would remain the preferred alternative.

GENERAL RECOMMENDATIONS

1. Bentonite treatment for dust suppression would have application to limestone surfaced secondary feeder roads leading into small towns, secondary roads used as shortcuts, or other roads where there are a number of residences located.

2. For roads where traffic is less than about 150 vpd with light truck traffic, the following would be anticipated.

   - For the first season an average dust reduction of 60-70 percent.
   - For the second season an average dust reduction of 50-60 percent (assumes no new maintenance surfacing applied).
   - Retreatment required in the third season (assumes maintenance surfacing will also be needed).

3. For roads where traffic is greater than 150 vpd and/or high truck traffic, the following is anticipated.

   - For the first season an average dust reduction of 50-60 percent.
   - Retreatment may be required in the second season (especially if new maintenance surfacing is required).

4. Prior to treatment, it is recommended that local residents be acquainted with what to anticipate after treatment. For interested parties a video tape is available (at cost) for this purpose.

5. For higher dust suppression, in localized areas, chloride treatment remains the better alternative.

CONSTRUCTION RECOMMENDATIONS

Materials

A. Bentonite - (fine grind or feed grade).

- Apply at 8 percent by weight of loose surfacing (typically 100 to 150 ton/mile).
- Available in 50 pound bag form or 20 ton bulk form (specify a pneumatic tanker).

B. Sodium Carbonate - (soda ash dispersing agent).

- Available in 100 pound bag form.
- Mix with water at a 0.5 percent solution by weight (≈ 50 lbs. per 1000 gallons water).
- Water - any potable supply.

Equipment

A. Two patrols.

B. Dump truck - (for soda ash and bagged Bentonite).

C. Two water tankers with recirculating pumps - (minimum of 1000 gallons each).

Preconstruction

A. Determine Bentonite quantity.

- Tight blade loose surfacing into windrow on one side.
- Take windrow cross section measurements.
- Calculate loose aggregate volume.
- Determine loose unit weight of aggregate (approximately 120 lbs. per cubic foot).
- Determine Bentonite weight needed.

B. Determine Bentonite application rate.

- Calculate bag spacing (if bagged).
- Pneumatic tanker will require field determination of unloading rate.

Construction

A. Bentonite - Apply manually or pneumatically next to windrow. Dry mix with two patrols by moving the windrow from one side to the next a minimum of four times. Spread the dry mixed material over an ±8 foot width on one side of the road.

B. Soda ash - Add to tanker when approximately 1/4 full. As tanker loading proceeds, engage recirculating pump to mix as it is being loaded. Continue recirculation after loading until time for application.

C. Application and wet mixing - Thoroughly saturate ±8 feet of treated surfacing with the water/soda ash solution. Begin wet mixing with patrol. Continue adding solution and mixing until a 2-3 inch slump consistency is obtained. Move the windrow a minimum of four times across the road.

D. After wet mixing, spread the treated material uniformly over the road surface for traffic compaction.

Construction Time

With proper equipment construction is rapid. A one mile section should be easily finished in a half day. Loading and unloading water trucks is the most time consuming.

ACKNOWLEDGMENTS

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APPENDIX A

Phase I and Phase II Evaluation Worksheets

PHASE I - DUST CONTROL EVALUATION WORKSHEET

EVALUATOR: ______________________ **DATE:** __________

COUNTY: ______________________ **TIME:** __________

WEATHER CONDITIONS:

Day of: ______________________________

Day prior: ______________________________

MAINTENANCE CONDITIONS:

____

____

SURFACING MATERIAL CONDITIONS:

Dry: ______________________

Damp: ______________________

Wet: ______________________

Section	% Bentonite	Dust Generation % of Control	Crust Development 0 - 5 Rating	Roughness 0 - 5 Rating
Control	**0**			
1	**3**			
2	**5**			
3	**7**			
4	**9**			

With 5 being best

NOTE: Dust generation percentage may be greater than 100%.

Notes: ____

____

____

____

____

____

PHASE II - DUST CONTROL EVALUATION WORKSHEET

EVALUATOR: ____________ DATE: ____________

COUNTY: ____________ TIME: ____________

WEATHER CONDITIONS:

Day of: ____________

Day prior: ____________

MAINTENANCE CONDITIONS:

____

____

SURFACING MATERIAL CONDITIONS:

Dry: ____________

Damp: ____________

Wet: ____________

Section	Dust Generation % of Control	Crust Development 0 - 5 Rating	Roughness 0 - 5 Rating
Control	100		
1			
2			
3			
4			
5			
6			

With 5 being excellent

NOTE: Dust generation percentage may be greater than 100%.

Notes: ____________

APPENDIX B

Phase I and Phase II Dust Control Evaluation Data

APPENDIX B (Dust Control Evaluation Data - Phase I and II)

Table B1. Phase I test road evaluations and averages.

			Weather Conditions		Surfacing Material	Dust Generation					Crust Development					Roughness				
						Percent Bentonite					Percent Bentonite					Percent Bentonite				
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	3	5	7	9	0	3	5	7	9	0	3	5	7	9
04-Sep-92	03:00 PM	Fichtner	Sunny	Sunny		100	65	60	60	70	1	4	5	3	2	3	5	4	2	1
07-Aug-92	07:00 AM	Surber	Sunny	Sunny	Damp	100	17	15	12	10	5	5	5	5	4	5	5	5	5	4
27-Aug-92	04:15 PM	Brocka & Lapke	Cloudy, 70	Partly cloudy, 75	Damp	100	50	40	30	20	2	3	4	4	5	4	4	3	3	2
03-Sep-92	03:00 PM	Bergeson	Rain	Sunny, 80	Damp						1	2	3	4	5	3	4	5	2	1
10-Sep-92	08:30 AM	Fichtner	Rain	Sunny, Heavy dew	Damp	100	75	75	70	70	2	4	5	1	3	5	4	3	2	1
10-Sep-92	10:50 AM	Brocka & Lapke	Rain, 70	Sunny, 65	Damp	100	55	55	35	20	1	2	2	2	2	4	4	4	4	3
11-Sep-92	07:00 AM	Surber	Sunny	Sunny	Damp	100	89	91	93	95	5	5	5	5	5	5	5	5	4	4
20-Oct-92	01:15 PM	Harris	Cloudy, 45, damp	Sunny, 55, dry	Damp	100	40	40	30	20	0	1	2	2	2	5	4	3	3	3
06-Nov-92	02:00 PM	Harris	Cloudy, 31, flurries	Cloudy, 29, flurries	Damp	100	60	60	60	50	2	2	3	3	3	5	4	4	4	4
12-Nov-92	02:30 PM	Harris		Sunny, 38	Damp	100	20	20	20	20	3	3	3	3	3	4	3	3	3	3
03-Sep-92	02:00 PM	Harris	Rain, 73	Sunny, 83	Damp, Slightly	100	50	40	40	35	1	2	2	2	2	5	5	5	4	3
					Average	90.9	47.4	45.1	40.9	37.3	2.09	3.00	3.55	3.09	3.27	4.36	4.27	4.00	3.27	2.64
					Stand. Deviation	0.0	21.3	22.3	23.8	27.3	1.56	1.28	1.23	1.24	1.21	0.77	0.62	0.85	0.96	1.15
11-Aug-92	10:00 AM	Brocka & Lapke	Sunny, 85	Sunny, 70	Dry	100	40	35	30	25	2	3	4	4	5	4	4	4	3	2
11-Aug-92	12:55 PM	Harris	Sunny, 90	Sunny, 82	Dry	100	80	70	60	50	0	0	0	0	0	5	5	5	5	5
14-Aug-92	03:30 PM	Surber	Sunny	Sunny	Dry	100	40			25	4	4	4	4	4	4	4	4	4	4
17-Aug-92	01:00 PM	Bergeson	Partly cloudy	Partly cloudy, 80	Dry	100	50	40	30	20	2	1	3	4	5	4	5	3	2	1
19-Aug-92	12:30 PM	Brocka & Lapke	Rain, 80	Partly cloudy, 80	Dry	100	50	35	30	20	1	2	3	3	4	4	4	4	3	2
21-Aug-92	02:00 PM	Harris	Sunny, 80	Sunny, 80	Dry	100	80	70	60	50	0	0	0	1	1	5	5	5	5	5
21-Aug-92	07:00 AM	Surber	Sunny	Sunny	Dry	100	95	90	85	80	4	4	4	4	4	4	4	4	4	4
31-Aug-92	07:30 AM	Surber	Sunny	Sunny	Dry	100	98	95	93	90	5	5	5	5	5	5	5	5	5	5
03-Sep-92	03:30 PM	Brocka & Lapke	Rain	Sunny, 75	Dry	100	45	35	30	20	2	3	4	5	5	4	4	3	3	2
11-Sep-92	02:15 PM	Harris	Sunny, 70	Sunny, 80	Dry	100	60	50	40	30	1	1	2	2	2	5	4	4	4	4
17-Sep-92	02:20 PM	Harris	Cloudy, 80	Sunny, 80	Dry	100	50	40	30	20	0	1	3	2	1	4	4	2	4	4
25-Sep-92	02:00 PM	Harris	Mostly cloudy, 73	Mostly cloudy, 70	Dry	100	60	50	30	30	0	1	2	1	1	4	4	3	4	4
25-Sep-92	02:50 PM	Brocka & Lapke	Sunny, 68	Cloudy, 67	Dry	100	55	45	35	25	2	4	4	4	4	3	4	4	4	4
30-Sep-92	04:00 PM	Surber	Sunny	Sunny	Dry	100	40	36	32	30	5	5	5	5	5	4	4	4	4	4
01-Oct-92	12:00 PM	Brocka & Lapke	Sunny, 80	Sunny, 80	Dry	100	65	55	45	30	2	4	4	4	5	4	4	4	3	3
14-Oct-92	02:00 PM	Harris	Mostly Cloudy, 57	Mostly Cloudy, 60	Dry	100	60	50	50	40	0	1	2	2	1	5	4	4	4	4
15-Oct-92	03:00 PM	Bergeson		Cloudy, Cool	Dry	100	60	40	50	60	2	3	5	4	2	2	3	5	4	2
22-Oct-92	02:15 PM	Bergeson	Sunny, 75	Sunny, 75, windy	Dry	100	45	35	35	35	0	3	5	4	2	0	3	5	4	2
22-Oct-92	03:40 PM	Brocka & Lapke	Sunny, 75	Sunny, 75, windy	Dry	100	50	35	30	25	2	3	3	4	4	4	4	4	4	3
27-Oct-92	02:25 PM	Harris	Sunny, 70	Sunny, 63	Dry	100	50	50	50	40	1	2	2	2	2	5	4	3	3	3
29-Oct-92	01:30 PM	Brocka & Lapke	Sunny, 50	Sunny, 50	Dry	100	55	30	45	30	3	3	4	5	5	4	4	4	4	3
01-Oct-92	03:35 PM	Bergeson	Sunny	Sunny, 85	Dry, Very	100	50	40	30	30	1	2	5	3	4	1	2	5	3	4
					Average	100	58.1	46.6	41.8	36.6	1.77	2.50	3.32	3.27	3.23	3.82	4.00	4.00	3.77	3.36
					Stand. Deviation	0	16.1	17.7	17.7	18.5	1.56	1.47	1.46	1.42	1.68	1.27	0.67	0.80	0.73	1.11
25-Aug-92	02:30 PM	Bergeson	Rain	Rain	Wet						1	2	3	4	5	3	5	4	2	1
07-Aug-92	09:30 AM	Surber	Sunny	Rain	Wet, Very	0	0	0	0	0	5	5	5	5	4	5	5	5	5	4
					Average	0	0	0	0	0	3.00	3.50	4.00	4.50	4.50	4.00	5.00	4.50	3.50	2.50
					Stand. Deviation	0	0	0	0	0	2.00	1.50	1.00	0.50	0.50	1.00	0.00	0.50	1.50	1.50

Table B2. Phase I test road notes and maintainance conditions

Date	Time	Evaluator	Maintenance Conditions	Notes
04-Sep-92	03:00 PM	Fichtner		
07-Aug-92	07:00 AM	Surber	Project was done 8/5/92	Section seems to be similar to spots that are chlorided
27-Aug-92	04:15 PM	Brocka & Lapke	Windrow east side	9 % a little washboarding.
03-Sep-92	03:00 PM	Bergeson	Windrow east side, last maint. estimated @ 5 - 7 days	Minor dust, could not tell difference, good wheel path crusting, best to worst 9%, 7%, 5%, 3%, control.
10-Sep-92	08:30 AM	Fichtner	Recently bladed	Very little dust was generated in control section due to previous moisture.
10-Sep-92	10:50 AM	Brocka & Lapke	Recently bladed	
11-Sep-92	07:00 AM	Surber		Because of rain 9/9/92 everything was working well.
20-Oct-92	01:15 PM	Harris	Wheeltracks evident in all test sections	Tested at 40 mph.
06-Nov-92	02:00 PM	Harris		Heavy harvest traffic, no wash boarding or potholes evident, tested at 45 mph.
12-Nov-92	02:30 PM	Harris		Did not notice any braking problems with the high bentonite section.
03-Sep-92	02:00 PM	Harris	Newly bladed	No visible wheel tracks in control section, all others have visible wheel tracks, section 4 has some washboarding
11-Aug-92	10:00 AM	Brocka & Lapke	Bladed day prior	
11-Aug-92	12:55 PM	Harris	Newly bladed	Tested at 40 mph.
14-Aug-92	03:30 PM	Surber		
17-Aug-92	01:00 PM	Bergeson	Windrow east side, several days since maint.	9 % section appears to be developing washboarding - rough, clumps of material still in windrow
19-Aug-92	12:30 PM	Brocka & Lapke	Windrow east side, start of defined wheel paths	
21-Aug-92	02:00 PM	Harris	Newly bladed	Talked to patrol operator about project, he says that control section 4 doesn't blade the same as the other sections
21-Aug-92	07:00 AM	Surber	Test sections have been maintained since placement	Intial signs of washboarding beginning to appear in wheelpaths in portions of section 4(9 % bentonite)
31-Aug-92	07:30 AM	Surber		Can't tell much difference in dust from control to #4 but you can tell it is less in each section.
03-Sep-92	03:30 PM	Brocka & Lapke	Windrow on east side	Good wheel path development in bentonite treated areas with 9 % being best, considerably better than control.
11-Sep-92	02:15 PM	Harris	Well bladed, perhaps recently	Tested at 40 mph, wheel tracks evident last week have been covered up in section 4.
17-Sep-92	02:20 PM	Harris	Well bladed	Crust beginning to develop in section 2 in wheel tracks, some aggregate loss noticed, tested at 40 mph.
25-Sep-92	02:00 PM	Harris	Well bladed except for section 2	Wheel track formation evident in section 2, may need to reblade windrows, tested at 40 mph.
25-Sep-92	02:50 PM	Brocka & Lapke	Windrow east side, bladed within the last week	3%, 5%, 7%, 9 % start of defined well paths, 0 % very little wheel path developed.
30-Sep-92	04:00 PM	Surber	Has been maintained recently	Chloride spot on south end was still better than section 4 but it is starting to get worse
01-Oct-92	12:00 PM	Brocka & Lapke	Bladed week prior	Good wheel path development, first video tape.
14-Oct-92	02:00 PM	Harris	Well bladed	Wheel track formation evident in section 2 and 3, may need to reblade, tested at 40 mph.
15-Oct-92	03:00 PM	Bergeson	Windrow on east side (small)	Very little windrow, appeared during last maintenance he had spread all loose material over road surface
22-Oct-92	02:15 PM	Bergeson	Small windrow on west side	Good wheel path develop in all sections except control, did 9 % section have a lot of loose material to start with.
22-Oct-92	03:40 PM	Brocka & Lapke	Windrow west side, couple of weeks since maint.	Good wheel path development on all 4 sections, video taped, camera set at 3.8 ft above road and 36 ft from road.
27-Oct-92	02:25 PM	Harris		May need to be rebladed as a result of heavy harvest work, tested at 45 mph.
29-Oct-92	01:30 PM	Brocka & Lapke	Not recently maintained	Video taped, camera set at 2.9 ft above the road and 40 ft from west side of the road.
01-Oct-92	03:35 PM	Bergeson	Windrow on east side, no recent grading	No mudballs evident on 9%, washboarding seemed less than in past on 9%, crust develop difficult to distinguish
25-Aug-92	02:30 PM	Bergeson	Windrow east side	5% very slight washboard, 7% slight washboarding, 9 % moderate washboarding, mudballs still present in wind-row on 9% and 7% sections, locked brakes at 30 mph all test sections during heavy rain, observed no noticeable difference in any of the treated sections over control, some treated sections seemed to brake better than control
07-Aug-92	09:30 AM	Surber	Project was done 8/5/92	Seciton # 4 was muddy but it was not slick and seemed to drive OK, all other sections were alright.

Table B3. Phase I test road evaluations and averages for dry surface materials.

Date	Time	Evaluator	Weather Conditions Day Prior	Weather Conditions Day Of	Surfacing Material Conditions	Dust Generation, Percent Bentonite 0	3	5	7	9	Crust Development, Percent Bentonite 0	3	5	7	9	Roughness, Percent Bentonite 0	3	5	7	9
11-Aug-92	10:00 AM	Brocka & Lapke	Sunny, 85	Sunny, 70	Dry	100	40	35	30	25	2	3	4	4	5	4	4	4	3	2
11-Aug-92	12:55 PM	Harris	Sunny, 90	Sunny, 82	Dry	100	80	70	60	50	0	0	0	0	0	5	5	5	5	5
17-Aug-92	01:00 PM	Bergeson	Partly cloudy	Partly cloudy, 80	Dry	100	50	40	30	20	2	1	3	4	5	4	5	3	2	1
19-Aug-92	12:30 PM	Brocka & Lapke	Rain, 80	Partly cloudy, 80	Dry	100	50	35	30	20	1	2	3	3	4	4	4	4	3	2
21-Aug-92	02:00 PM	Harris	Sunny, 80	Sunny, 80	Dry	100	80	70	60	50	0	0	0	1	1	5	5	5	5	5
03-Sep-92	03:30 PM	Brocka & Lapke	Rain	Sunny, 75	Dry	100	45	35	30	20	2	3	4	5	5	4	4	3	3	2
11-Sep-92	02:15 PM	Harris	Sunny, 70	Sunny, 80	Dry	100	60	50	40	30	1	1	2	2	2	5	4	4	4	4
17-Sep-92	02:20 PM	Harris	Cloudy, 80	Sunny, 80	Dry	100	50	40	30	20	0	1	3	2	1	4	4	2	4	4
25-Sep-92	02:00 PM	Harris	Mostly cloudy, 73	Mostly cloudy, 70	Dry	100	60	50	30	30	0	1	2	1	1	4	4	3	4	4
25-Sep-92	02:50 PM	Brocka & Lapke	Sunny, 68	Cloudy, 67	Dry	100	55	45	35	25	2	4	4	4	4	3	4	4	4	4
30-Sep-92	04:00 PM	Surber	Sunny	Sunny	Dry	100	40	36	32	30	5	5	5	5	5	4	4	4	4	4
01-Oct-92	12:00 PM	Brocka & Lapke	Sunny, 80	Sunny, 80	Dry	100	65	55	45	30	2	4	4	4	5	4	4	4	3	3
14-Oct-92	02:00 PM	Harris	Mostly Cloudy, 57	Mostly Cloudy, 60	Dry	100	60	50	50	40	0	1	2	2	1	5	4	4	4	4
15-Oct-92	03:00 PM	Bergeson		Cloudy, Cool	Dry	100	60	40	50	60	2	3	5	4	2	2	3	5	4	2
22-Oct-92	02:15 PM	Bergeson	Sunny, 75	Sunny, 75, windy	Dry	100	45	35	35	35	0	3	5	4	2	0	3	5	4	2
22-Oct-92	03:40 PM	Brocka & Lapke	Sunny, 75	Sunny, 75, windy	Dry	100	50	35	30	25	2	3	3	4	4	4	4	4	4	3
27-Oct-92	02:25 PM	Harris	Sunny, 70	Sunny, 63	Dry	100	50	50	50	40	1	2	2	2	2	5	4	3	3	3
29-Oct-92	01:30 PM	Brocka & Lapke	Sunny, 50	Sunny, 50	Dry	100	55	30	45	30	3	3	4	5	5	4	4	4	4	3
01-Oct-92	03:35 PM	Bergeson	Sunny	Sunny, 85	Dry, Very	100	50	40	30	30	1	2	5	3	4	1	2	5	3	4
					Average	100.0	55.0	44.3	39.1	32.1	1.37	2.21	3.16	3.11	3.05	3.74	3.95	3.95	3.68	3.21
					Stand. Deviation	0.0	10.9	11.1	10.4	11.0	1.27	1.36	1.50	1.45	1.73	1.33	0.69	0.83	0.73	1.10

Table B4. 1993 Phase II test roads evaluations and averages.

Tama County 1993			Weather Conditions		Surfacing Material	Dust Generation					Crust Development					Roughness				
						Percent Bentonite					Percent Bentonite					Percent Bentonite				
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	3	5	7	9	0	3	5	7	9	0	3	5	7	9
14-Jun-93	01:00 PM	Bergeson	Rain	Sunny, Windy, 75	Dry to damp	100	85	75	75	75	1.0	4.0	5.0	3.0	2.0	1.0	4.0	5.0	3.0	2.0
04-Aug-93	10:15 AM	Brocka/Waddingham	Slight Rain, 78	Partly Cloudy, 70	Dry to damp	100	100	95	95	95	1.0	1.0	1.0	1.0	1.0	4.0	4.0	4.0	4.0	4.0
07-Sep-93	01:00 PM	Brocka		Sunny, 75	Dry	100	30	35	50	50	2.0	4.0	4.0	3.0	3.0	3.0	4.0	5.0	4.0	3.0
08-Sep-93	02:30 PM	Bergeson	Sunny, 75	Sunny, 75	Dry	100	30	20	40	50	2.0	4.0	5.0	3.0	2.0	2.0	4.0	5.0	3.0	2.0
07-Sep-93	01:00 PM	Brocka		Sunny, 75	Dry	100	30	35	50	50	2.0	4.0	4.0	3.0	3.0	3.0	4.0	5.0	4.0	3.0
08-Sep-93	02:30 PM	Bergeson	Sunny, 75	Sunny, 75	Dry	100	30	20	40	50	2.0	4.0	5.0	3.0	2.0	2.0	4.0	5.0	3.0	2.0
					Average	100	30	28	45	50	2.0	4.0	4.5	3.0	2.5	2.5	4.0	5.0	3.5	2.5

Appanoose County 1993			Weather Conditions		Surfacing Material	Dust Generation						Crust Development						Roughness					
						Percent Bentonite						Percent Bentonite						Percent Bentonite					
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	6	8	10	12	CaCl	0	6	8	10	12	CaCl	0	6	8	10	12	CaCl
05-Aug-93	01:00 PM	Brocka/Waddingham	Partly Cloudy, 70	Rain, 65	Wet	0	0	0	0	0	0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
11-Aug-93	01:35 PM	Brocka	Partly Cloudy, 90	Mostly Cloudy, 88	Dry	100	60	50	40	25	5	4.0	4.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0	3.0	3.0
24-Aug-93	03:20 PM	Brocka	Sunny, 88	Sunny, 91	Dry	100	60	50	50	20	10	3.0	3.0	3.0	4.0	5.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0
05-Oct-93	02:00 PM	Waddingham	Sunny, 85	Sunny, 90	Dry	100	35	40	40	30	10	5.0	5.0	5.0	5.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0
11-Aug-93	01:35 PM	Brocka	Partly Cloudy, 90	Mostly Cloudy, 88	Dry	100	60	50	40	25	5	4.0	4.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0	3.0	3.0
24-Aug-93	03:20 PM	Brocka	Sunny, 88	Sunny, 91	Dry	100	60	50	50	20	10	3.0	3.0	3.0	4.0	5.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0
05-Oct-93	02:00 PM	Waddingham	Sunny, 85	Sunny, 90	Dry	100	35	40	40	30	10	5.0	5.0	5.0	5.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0
					Average	100	52	47	43	25	8	4.0	4.0	4.0	4.3	4.7	4.0	2.3	2.3	2.3	2.3	2.0	2.3

Table B5. 1993 Phase II test roads notes and maintainance conditions

Tama County 1993				
Date	Time	Evaluator	Maintenance Conditions	Notes
14-Jun-93	01:00 PM	Bergeson	Windrow on east side, unknown when bladed	Dust cloud not heavy, wind made it difficult to estimate
04-Aug-93	10:15 AM	Brocka/Waddingham	Bladed within the past week, windrow east side	
07-Sep-93	01:00 PM	Brocka	Hasn't been bladed recently, windrow on east side	Video taped
08-Sep-93	02:30 PM	Bergeson	No obvious windrow, well developed wheel paths	Mud lower half of 3% section (south)

Appanoose County 1993				
Date	Time	Evaluator	Maintenance Conditions	Notes
05-Aug-93	01:00 PM	Brocka/Waddingham	Not bladed recently	Slight wash boarding in all sections
11-Aug-93	01:35 PM	Brocka	Bladed recently, windrow east side	
24-Aug-93	03:20 PM	Brocka	Hasn't been bladed recently, windrow on west side	
05-Oct-93	02:00 PM	Waddingham	Hasn't been bladed recently	Potholes throughout all test sections

Table B6. 1994 Phase II test roads evaluations and averages.

Tama County 1994			Weather Conditions		Surfacing Material	Dust generation					Crust Development					Roughness				
						Percent Bentonite					Percent Bentonite					Percent Bentonite				
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	3	5	7	9	0	3	5	7	9	0	3	5	7	9
18-May-94	01:10 PM	Waddingham	Sunny, breezy	Sunny, breezy	Dry	100	90	80	80	70	2	3	3	3	4	5	5	5	5	5
06-June-94	10:45 AM	Bergeson	Possible light rain	Sunny, 85, still	Dry to slightly damp	100	90	80	70	70	2	2	3	4	5	3	3	3	3	3
09-June-94	01:00 PM	Waddingham	Cloudy, cool, 70	Sunny, breezy, 75	Dry	100	50	60	90	80	1	4	3	3	2	4	4	4	4	4
02-August-94	12:00 PM	Waddingham	Cloudy, breeze, 70	Humid, hazy	Dry	100	90	85	93	90	2	2	2	2	2	5	5	5	5	5
15-August-94	12:30 PM	Bergeson	Sunny, cool, 70	Sunny, cool, 70	Dry	100	60	50	70	90	1	4	5	3	2	1	4	5	3	2
16-August-94	01:10 PM	Waddingham	Partly cloudy, 80	Partly cloudy, 82	Dry	100	80	70	70	75	2	3	4	4	3	4	4	4	4	4
19-September-94	03:00 PM	Waddingham	Cloudy, 70	Cloudy, 70	Dry	100	70	60	70	75	2	3	4	4	3	4	4	4	4	4
					Average	100	76	69	78	79	1.7	3.0	3.4	3.3	3.0	3.7	4.1	4.3	4.0	3.9

Appanoose County 1994			Weather Conditions		Surfacing Material	Dust generation					Crust Development					Roughness				
						Percent Bentonite					Percent Bentonite					Percent Bentonite				
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	6	8	10	12	0	6	8	10	12	0	6	8	10	12
19-May-94	01:45 PM	Waddingham	Sunny, breezy, 80	Sunny, 80	Dry	100	75	85	75	70	5	5	5	5	5	2	2	2	2	2
14-June-94	03:00 PM	Waddingham	Sunny, breeze, 95	Sunny, breeze, 90	Dry	100	80	85	95	60	3	3	3	2	4	3	3	3	3	3
12-July-94	01:30 PM	Waddingham	Cloudy, still, 80	Cloudy, still, 80	Dry	100	75	80	90	70	3	3	3	3	3	3	3	3	3	3
09-August-94	02:30 PM	Waddingham	Cloudy, breeze, 80	Cloudy, breeze, 80	Dry	100	100	100	100	100	3	3	3	3	3	3	3	3	3	3
17-August-94	03:01 PM	Waddingham	Partly Cloudy, 85	Partly Cloudy, 85	Dry	100	95	95	90	110	3	3	3	3	3	2	2	2	2	2
					Average	100	85	89	90	82	3.4	3.4	3.4	3.2	3.6	2.6	2.6	2.6	2.6	2.6

Table B7. 1994 Phase II test roads notes and maintainance conditions.

Tama County 1994				
Date	Time	Evaluator	Maintenance Conditions	Notes
18-May-94	01:10 PM	Waddingham	Good Condition	
06-June-94	10:45 AM	Bergeson	Wheel path developed, windrow on west, est. 1 wk.	Checked against control on both ends *couldn't tell any difference
09-June-94	01:00 PM	Waddingham	windrow on west side, hasn't been bladed recently	In front of dwy on 7% section produced more dust
02-August-94	12:00 PM	Waddingham	Freshly bladed. Windorw on West Side	
15-August-94	12:30 PM	Bergeson	Well developed wheelpaths on 3,5,7 sec. Windrow W. side	
16-August-94	01:10 PM	Waddingham	Windrow on west side. Crust developed well, bladed 2 wks.	Shrinkage cracks promedent in clay sections and not as well in control
19-September-94	03:00 PM	Waddingham	Well maintained, 2 wks., wheel paths evident	

Appanoose County 1994				
Date	Time	Evaluator	Maintenance Conditions	Notes
19-May-94	01:45 PM	Waddingham	Very poor	6% had better wheel paths due to extra traffic to homes.(Less dust here)
14-June-94	03:00 PM	Waddingham	Bladed recently, windrows on east side	Changed filters in collector without disconnecting tubes
12-July-94	01:30 PM	Waddingham	Maintained approx. 2wks or more prior to observation	Curves are wash boarded and potholed.
09-August-94	02:30 PM	Waddingham	Rocked within 2wks. not bladed recently,	Bottom crust developed well with loose material on top
17-August-94	03:01 PM	Waddingham	Fairly maintained, approx. 1 wk.	

Table B8. 1993 visual and dust collector evaluation results.

Tama County 1993						Visual dust generation					Dust collector dust generation				
			Weather Conditions		Surfacing Material	Percent Bentonite					Percent Bentonite				
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	3	5	7	9	0	3	5	7	9
07-September-93	01:00 PM	Brocka	-	Sunny, Windy	Dry	100	30	35	50	50	100	32	38	53	66

Appanoose County 1993						Dust generation					Dust collector dust generation				
			Weather Conditions		Surfacing Material	Percent Bentonite					Percent Bentonite				
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	6	8	10	12	0	6	8	10	12
19-May-94	01:45 PM	Brocka	Sunny, 88	Sunny, 91	Dry	100	60	50	50	20	100	38	38	32	28

Table B9. 1994 visual and dust collector evaluation results.

Tama County 1994			Weather Conditions		Surfacing Material	Visual dust generation					Dust collector dust generation				
						Percent Bentonite					Percent Bentonite				
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	3	5	7	9	0	3	5	7	9
18-May-94	01:10 PM	Waddingham	Sunny, breezy	Sunny, breezy	Dry	100	90	80	80	70	100	79.87	68.52	73.61	64.84
09-June-94	01:00 PM	Waddingham	Cloudy, cool, 70	Sunny, breezy, 75	Dry	100	50	60	90	80	100	70.72	79.48	69.75	88.08
02-August-94	12:00 PM	Waddingham	Cloudy, breeze, 70	Humid, hazy	Dry	100	90	85	93	90	100	87.77	78.15	76.44	90.49
16-August-94	01:10 PM	Waddingham	Partly cloudy, 80	Partly cloudy, 82	Dry	100	80	70	70	75	100	63.05	55.1	50.04	87.34
					Average	100	78	74	83	79	100	75	70	67	83

Appanoose County 1994			Weather Conditions		Surfacing Material	Dust generation					Dust collector dust generation				
						Percent Bentonite					Percent Bentonite				
Date	Time	Evaluator	Day Prior	Day Of	Conditions	0	6	8	10	12	0	6	8	10	12
19-May-94	01:45 PM	Waddingham	Sunny, breezy, 80	Sunny, 80	Dry	100	75	85	75	70	100	75.65	94.24	98.11	93.02
14-June-94	03:00 PM	Waddingham	Sunny, breeze, 95	Sunny, breeze, 90	Dry	100	80	85	95	60	100	102.8	83.96	97.00	91.42
12-July-94	01:30 PM	Waddingham	Cloudy, still, 80	Cloudy, still, 80	Dry	100	75	80	90	70	100	85.68	86.87	127.5	96.37
17-August-94	03:01 PM	Waddingham	Partly Cloudy, 85	Partly Cloudy, 85	Dry	100	95	95	90	110	100		101.3	119.2	
					Average	100	81	86	88	78	100	88	92	86	94

APPENDIX C

Roughness and XRF Data

APPENDIX C (Roughness and XRF Data)

ROUGHNESS MEASUREMENTS

HR-351, Tama County, Aug. 10, 1993

(Southbound)

Section	Revolutions	Roughness	Roughness (in/mi)
1	142	27	143
2	142	24	127
3	143	30	157
4	144	35	182
control	148	33	167

(Northbound)

Section	Revolutions	Roughness	Roughness (in/mi)
1	145	26	134
2	140	22	118
3	144	25	130
4	144	24	125
control	144	29	151

- All sections are 1000 ft. long.
- The control section was arbitrarily chosen north of sect. 4.

ROUGHNESS MEASUREMENTS

HR-351, Hancock County, Sept. 1, 1993

(Southbound)

Section	Revolutions	Roughness	Roughness (in/mi)
1	162	40	185
	162	41	190
	162	42	194
2	235	55	176
	235	53	169
	235	57	182

(Northbound)

Section	Revolutions	Roughness	Roughness (in/mi)
1	162	46	213
	162	48	222
	162	46	213
2	235	61	195
	234	62	199
	235	62	198

- Section 1 is 1000 ft long.
- Section 2 is 1400 ft long.
- 70° F, sunny and dry

ROUGHNESS MEASUREMENTS

HR-351, Appanoose County Sept. 13, 1993

(Southbound)

Section	Revolutions	Roughness	Roughness (in/mi)
1	145	46	238
	145	48	248
2	142	46	243
	143	45	236
3	45	19	317
	46	20	326
control	313	109	261
	313	118	283
4	145	59	305
	144	66	344
5	193	59	229
	193	64	249

(Northbound)

Section	Revolutions	Roughness	Roughness (in/mi)
1	146	48	247
	146	48	247
2	143	49	257
	142	46	243
3	44	15	256
	47	16	255
control	316	110	261
	314	102	244
4	144	41	214
	144	40	208
5	192	58	227
	193	63	245

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X-RAY FLUORESCENCE REPORT.

CLIENT : Broka Stacy   DATE REC'D : 07/15/93

SAMPLE : Mixed Carbonate Rock Samples   REPORT DATE : 08/13/93

CONTRACT NO. : 474-20-09-00-3643

INSTRUMENT DETAILS

* Siemens SR 200 sequential spectrometer.
* Cr tube operated at 50 kV and 50 MA.
* Spectrometer operated in vacuum mode.
* Fully computer controlled.

Test Results: The results of the XRF study are summarized in Table 1.

Table 1

OXIDES	Bentonite (wt.%)	Hancock (wt.%)	App. (wt.%)	Tama (wt.%)
SrO	0.04	0.017	0.045	0.018
MgO	1.61	17.090	0.836	6.543
CaO	0.81	33.603	50.789	42.999
Fe_2O_3	2.61	0.857	1.019	1.053
TiO_2	0.11	0.030	0.030	0.017
SiO_2	43.80	1.926	3.315	7.265
SO_3	0.40	0.037	0.083	0.074
K_2O	0.36	0.155	0.109	0.064
P_2O_5	0.04	0.015	0.043	0.029
Al_2O_3	13.77	0.513	0.626	0.273
MnO	--.--	0.047	0.294	0.040
L.O.I.	34.12	45.692	41.998	40.659