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HIGHWAY RESEARCH REPORT

INVESTIGATION OF MACHINES USED FOR ROAD MIXING

INTERIM REPORT

70-11

STATE OF CALIFORNIA

BUSINESS & TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 633296

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads Febuary 1970

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

February, 1970

Interim Report
M&R No. 633296

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is an interim research report titled:

INVESTIGATION OF MACHINES

USED FOR ROAD MIXING

ERNEST ZUBE
Principal Investigator

CLYDE G. GATES
J. A. MATTHEWS
Co-Investigators

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

February, 1970

Working Paper

Ref No. 62/3[illegible]

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[illegible]IFICATION OR MACHINES

[illegible] FOR ROAD MAKING

HUBERT [illegible]

Principal Investigator

[illegible]

Co-investigators

Very truly yours

REFERENCE: Zube, E., Gates, C. G., and Matthews, J. A., "Investigation of Machines Used for Road Mixing," State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 633296, February, 1970.

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[illegible] Department of Public Works [illegible]
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[illegible] investigated by seasons and locality [illegible]
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[illegible] report created based [illegible]

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The authors wish to express their appreciation to the construction and materials personnel of Districts 02, 03 and 10 of the California Division of Highways for their assistance in obtaining some of the data for this investigation.

This work was done in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads and their contribution is hereby acknowledged. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CON'T)

INTRODUCTION

The 1969 California Standard Specifications[1] for highway construction require that the cement content in cement treated bases be within a specified tolerance. This allowable variation is ± 0.6 of one percent as determined by Test Method No. Calif. 338[2] (Titration Test). The specifications also require use of a pugmill or auger type mixer for road-mixing cement treated materials. Prior to 1966, the same type of mixing equipment was specified on State highway projects in California where lime treatment was involved. By means of Standard Special Provision 27.10, dated April 18, 1966, the Standard Specifications were modified so that the type of mixing equipment was not specified. The lime content of samples of the finished product mixed by the equipment has been revised and is specified to have a variation of not more than one percent above or below that designated by the Engineer, as determined by Test Method No. Calif. 338. For example, if 4.0% lime is planned, titration tests must show percentages of lime between 3.0% and 5.0%.

Equipment manufacturers have developed machines having one or more transverse shafts somewhat similar in principle to the garden rototiller but much larger in size. These manufacturers claim that their high speed "rotary" mixers will mix a consistently uniform product using lime or cement as a soil additive. These rotary mixers can be manufactured and sold at less cost than the pugmill or auger type machine. The pugmill mixers pick up the material from a windrow on the grade, mix it with water and lime or cement, then deposit the product on the grade. Rotary mixers, instead of picking up material from the grade, cut and mix in-place material (not in a windrow) to a certain depth and width, depending on the design of the equipment. The rotary mixers can operate in a more restricted area and can mix more material in a given time than the pugmill mixers.

The objective of this project is to evaluate the efficiency of the various brands of spreaders and mixers now available.

The Metradon Mixer, two Koehring (P and H) Single Pass Mixers, and one Seaman Mixer (all rotary type) have been investigated. Two brands of pugmill mixers, the Pettibone-Wood Mixer and the Construction Machinery Incorporated Modified Autograder were also included in the study.

Two types of spreaders were investigated to determine the accuracy of the spread of the admixture. One spreader was made by the Brown Company and the other spreader was owned and operated by Universal Transport Company.

CONCLUSIONS

Spreading Equipment

1. Lime spreading equipment currently in use is not capable of spreading the lime uniformly across the roadbed within the

allowable ± 10% deviation from the specified spread rate. A uniform spread rate is vital to a successful lime treatment project.

2. A non-uniform head of lime in the distributor hopper is believed to be the major source of variations in spreading.

3. The tendency for dry, finely ground lime to flow freely like a fluid is another cause of spreading variations.

<u>Mixing Equipment</u>

1. None of the mixers tested were capable of producing a consistently uniform blend of material within the specified ± 1.0% deviation from the planned lime content. The need for uniformity in the mixed product cannot be overstressed.

2. The pugmill type mixers produced a slightly better mix than the rotary type mixers but the pugmill mixers were used only in less cohesive, silty clay soils.

3. The Koehring Single Pass Mixer (formerly P and H) distributed the lime uniformly in a vertical direction.

4. The Metradon Mixer did not distribute the lime uniformly in a vertical direction.

5. None of the rotary mixers redistributed the lime uniformly in the transverse direction. Non-uniform spreading of the lime on the roadbed cannot be corrected by the rotary mixer.

<u>Depth Control</u>

1. Uniform depth control was not adequate with any of the rotary mixers tested.

<u>General</u>

1. A smooth finished surface on the material to be treated would be of advantage in all phases of spreading and mixing.

2. Uniform soil and moisture conditions contribute greatly to the uniformity of the finished product.

We have experienced difficulty in finding spreading and mixing equipment which would offer better or improved ideas when compared to the equipment already investigated. There are other brands of spreaders and mixers on the market today, but there does not appear to be enough difference in the equipment now available for road-mixing operations to pursue this study any further with field testing and evaluation at this time.

IMPLEMENTATION

The following items are recommended for implementation:

1. Better quality lime spreading equipment should be developed through:

   a. Use of a double hopper system to control uniformity of spread.

   b. Use of sensing devices such as "bindicators" to control maximum and minimum head of lime in single hopper systems to keep spread within tolerable limits.

   c. Lowering the lime distributor on spreading equipment to about six inches from the grade.

   d. Use of augers to move lime towards outer edges of distributor to improve uniformity of transverse spread, or

   e. Use of welded steel plates at one foot intervals across width of distributor - This is an alternate method of improving uniformity of transverse spread.

2. Better quality rotary mixer equipment should be developed with:

   a. Tilt control mechanism on all mixers.

   b. Improved depth controls.

3. Supplement the current lime treatment specifications with the following:

   a. Provide for selection of the most uniform soil available for use in "topping off" basement soil.

   b. Perform lime spreading and mixing operations on a smooth finished subgrade surface. Rough subgrade conditions contribute to non-uniformity.

   c. When "pre-ripping" is permitted, smooth the subgrade and lightly roll prior to spreading and mixing operations.

4. Revise the specifications for lime treatment as follows:

   a. Provide a statistical specification for lime spread rate. Include a definite criteria for acceptance or rejection of lime spreads.

b. Provide a statistical specification for lime content of the completed mixture. Include a definite criteria for acceptance or rejection.

c. Provide a uniform plan for corrective measures and/or penalties when specifications are not met.

Recommended specifications for lime treatment will be submitted in a final report after an analysis of contract records on recently completed lime treatment projects.

SPREADING EQUIPMENT

The Brown Spreader

The Brown Spreader, shown in Figure 1, is a trailer-mounted hopper-distributor. It is typical of most of the lime spreaders in use today. It operates on the same principle as a lawn seed or fertilizer spreader, but is much larger in size. The spreader has vanes which are rotated by the turning of the wheels on the spreader. The amount of spread is controlled by a gear box which governs the speed of rotation of the vanes. The spreader is about seven feet wide.

The Universal Transport Spreader

This spreader (Figure 2) is a self-propelled unit. It has an internal circulating system which supposedly aids in achieving a uniform spread of lime for the full width of the distributor. The distributor is eight feet wide, but when used to full width, the dry lime flows out the sides giving a spread nine feet wide. The outer six inches on each end of the distributor was blocked off resulting in a seven foot distributor depositing an eight foot wide spread of lime due to "spillover."

MIXING EQUIPMENT

The Metradon Mixer

This is a single transverse axle rotary mixer. Figure 3 is a photograph of the mixing machine being pulled by a tractor. The mixer is pulled at a rate of about 1½ miles per hour and mixes a swath 6½ feet wide. The machine has facilities for adding water while mixing. The rotary mixing blade revolves at 1200 RPM. A sawtooth plowshare cutting bar digs up the soil to a given depth and feeds it into the rotary cutting blades (Figure 4). The saw-toothed cutting bar on this machine was high in the middle resulting in a ridged, non-uniform grade (Figure 5). The depth of cut was controlled by a hydraulic drawbar on the tractor.

The Koehring Single Pass Mixer (formerly P and H or Harnischfeger Mixer)

This mixer (Figure 6) is a self-contained, self-propelled unit capable of mixing an eight foot wide strip to 0.5 foot or more in depth. The mixing machinery consists of four transverse shafts with cutting blades (Figures 7 and 8). A high speed cutting rotor cuts and pulverizes small increments of soil as the mixer travels forward. A blending rotor picks up the loose material and casts it through a water spray. Two transverse pugmill rotors with wide-faced paddles, which rotate in opposite directions, give the soil a final mixing. Two mixers were actually used on this project. The first machine was a twenty year old P and H Mixer (Figures 9 and 10) which the contractor used on a trial section of road to establish this proposed procedure while he was waiting for delivery of the new Koehring Mixer. The maximum forward speed of the first mixer was approximately 25 feet per minute; however, in order to obtain a well pulverized material to a uniform depth with one pass of the mixer, it was necessary to operate in second gear at a forward speed of only 12½ feet per minute.

The Seaman "Duo-Stabilizer"

The Seaman Model DS730 "Duo-Stabilizer" (Figure 11) manufactured by the Seaman Corporation of Milwaukee, Wisconsin, is a single transverse axle rotary mixer combined with a compactor. The six rubber tired wheels (Figure 12) of the compactor act as the rear wheels of the mixer. In front of the mixer is a set of six scarifiers (Figure 13) mounted on a hydraulically controlled drawbar. The mixer rotor (Figure 14) has 80 bevel edged tines which are claimed to be especially suited for mixing clayey and silty soils. The rotor is powered by a separate 90 HP diesel engine. The mixer mixes a swath 7 feet wide by 8 inches deep at speeds of 50 to 200 feet per minute. This particular mixer was used on the 03-Yol-1196-CR Contract (Yolo County Road 30).

The Pettibone-Wood Mixer

The Pettibone-Wood Model 54S Mixer (Figure 15) is a self-propelled unit with a single longitudinal axle pugmill mixer mounted on a road grader chassis. This mixer is powered by an International Harvester 190 HP diesel engine. The machine picks the material up from a windrow, mixes it, and deposits the mixed material in a windrow at the rate of 11.1 to 28.4 feet per minute. The mixer is manufactured by Pettibone-Wood Company of North Hollywood, California.

The Construction Machinery Incorporated (CMI) Mixer

The CMI Mixer (Figures 16 and 17) is actually a CMI Autograder which has been modified. The front auger has been removed and replaced by two transverse pugmills. Each pugmill is 11' 6" long and 3' 3" in diameter. The windrowed material is picked up through a six foot wide opening in the front outer portion of the pugmill (Figure 18). Thirty-two paddles mounted on a transverse shaft mix the material and move it toward the center of the machine (Figure 19). The mixed material is then deposited on the subgrade through a 3½ foot opening in the bottom and back of the pugmill. The pick-up and discharge openings are offset by 24 inches so that all material passing through the mixer is in the pugmill for a minimum distance of 2 feet (Figure 20). An auger mounted immediately behind the pugmill spreads the material outward to grade. Water is added through four nozzles in the top of the pugmill. The grade of the auger for spreading and trimming is controlled by a wire set a fixed distance above the final grade. The grade for each pugmill is independently controlled by small sleds sliding on the subgrade near the center and in front of the machine.

The forward speed of the machine, while mixing a 4 inch lift of CTB, was 25 to 30 feet per minute. This is a mixing capacity of 900 to 1000 tons per hour for the two pugmills combined. This same machine is used for the final trimming of the CTB. The pugmills were raised up and the trimming was done with the rear auger. A material spreader was not used with the mixer.

TESTS PERFORMED DURING INVESTIGATION

Checking the Spread

The spread of admixture was determined by laying 3 foot wide heavy wrapping paper (Figure 21) transversely and longitudinally in the path of the spreader. The admixture was then recovered (Figure 22) and weighed in 3 or 4 equal parts. This was done at several locations and weight per unit area comparisons were made to determine if the patterns of spread in a transverse and longitudinal direction were uniform. The percentage of the admixture spread was calculated from the depth of mixing, weight of the admixture per unit area and the dry unit weight of the soil.

Checking Depth of Mixing

In order to check the depth of mixing, one method employed was to place a string line across the road and make three or more height measurements down to undisturbed subgrade prior to the pass of the mixer (Figure 23). After the mixer had passed, the loose material was removed and height measurements were again made at the same locations down to the new undisturbed subgrade. The difference in height gave the actual depth of mixing.

Another method of giving some indication of the depth and uniformity of mixing (Figures 24, 25 and 26) was to trench across the road after the treated layer was compacted and then lightly spray phenolphthalein at several locations down the side of the trench. The pink color will indicate the presence of lime. The depth of the pink color was recorded as the depth of mixed material. This procedure was performed only on Contracts 03-061754 and 03-100944.

Checking the Uniformity of Mixture

The uniformity of a completed mixture of cement or lime and aggregate or soil in a transverse and vertical direction was checked by using the titration test (Test Method No. Calif. 338). Samples were taken at three or more locations transversely across the road (Figure 27). One sample was obtained from the upper part of the layer and one sample from the lower part of the layer at each location. On one project, as many as four samples were taken at each location where the total uncompacted loose-mixed depth of treatment was 0.8' or greater. Samples were also taken longitudinally.

Pulverizing Clay Clods

District construction personnel performed check grading tests to determine a rotary mixer's ability to pulverize clay clods. In general, all three brands of rotary mixers investigated did an acceptable job of pulverizing clay clods to a nominal one inch maximum size when properly operated. There were some exceptions when highly cohesive, dry clays were encountered. However, it was generally possible to effectively control the maximum size of clay clods by relating the rate of travel of the mixer to the rotating speed of the cutting blades on the mixer shaft.

Visual observation of streaks of lime or clay clods greater than one inch in size were enough evidence to show that for a given mixer rpm operation, the forward travel speed of the mixer had to be reduced. In some cases it was necessary to allow time for the lime and water to mellow the clay lumps, then perform a second pass with the mixer to obtain a uniform mixture and nominal one inch maximum size clay clods. Uniform soil and moisture conditions contributed greatly to the production of a well-mixed lime treated clay having clods pulverized to the nominal one inch maximum size.

ANALYSIS OF DATA OBTAINED

Spreader Efficiency

On six of the seven contracts investigated (all but Contract 08-049114), spread rate measurements were made by weighing the amount of admixture deposited on a known area of heavy wrapping paper. These measurements were made to determine the efficiency of the two brands of spreaders. Table 1 shows a summary of the data obtained.

It is extremely important that uniformity of spread of the admixture be obtained. Some contractor's personnel are of the opinion that the spread rate is not very critical. They seem to feel that the mixing equipment will "even out" the distribution of lime to a uniform mixture, regardless of the lime spread rate. Our findings did not indicate this to be the case.

Figure 28 shows a comparison of spreader efficiencies. Only 24% of the measurements made to investigate the Brown Spreader were within the ± 10% deviation from the specified spread rate. It was possible to obtain a spread rate measurement by laying heavy wrapping paper on the grade after stopping the spreader. When the spreader started up again it traveled about six feet before depositing lime on the area being sampled. This tended to "dampen out" any irregularities caused by stopping the spreader. Laying the heavy wrapping paper in front of the tractor which pulls the Brown Spreader caused problems. The heavy wheel loads of the tractor most always tore the wrapping paper. This problem was again encountered when attempting to check the spread rate produced by the Universal Transport Spreader, which is truck mounted. This made it more difficult to sample than the Brown Spreader. To obtain a complete sample of the spread, it was necessary to sample its entire width. Ordinary pans or buckets were not satisfactory because they cannot be placed in the wheel tracks of the spreader distributor. This wrapping paper was very difficult to hold in place and was easily torn by the weight of the wheels on the spreader. Also, finely ground lime had a tendency to flow under the edges of the paper resulting in loss of small quantities of lime.

We were able to obtain only eleven reliable measurements from the spread of the Universal Transport Spreader. While this is not as much information as desired, we have utilized the data obtained. Additional measurements would no doubt tend to produce a smoother curve than the one shown in Figure 28 for the Universal Transport equipment. Only two out of eleven or 18% of the measurements obtained from the Universal Transport Spreader met the allowable ± 10% maximum deviation from the planned spread rate.

This leaves much to be desired for the efficiency of either brand of spreader.

One cause of inefficiency in the case of the Brown Spreader occurs because of non-uniform flow. When the hopper is full, the spread is at one rate, but as the level of lime drops in the hopper, the spread becomes lighter. We believe an improvement can be made by developing a device to maintain a constant head of lime in the discharge hopper. This could consist of sensing devices such as "bindicators" to signal when to add lime and when to stop adding lime to the spreader. This would maintain a more uniform head of lime in the hopper. Another method which has possible use is a double hopper system, with a receiving hopper mounted over the discharge hopper. The receiving hopper can be operated to control the level of lime in the discharge hopper, thus providing a constant flow from the discharge hopper onto the grade.

Another inefficiency of present spreaders consists of non-uniformity of the spread transversely across the grade when an abnormal cross slope or superelevation is encountered. As would be expected, a heavier than planned spread of lime occurs on the low side while the reverse is true on the high side. To correct this situation, at least two alternates could be explored.

1. An auger can be mounted above the distributor outlet for the entire width of the hopper with the auger operating to move lime outward both directions from the center.

2. Steel plates can be welded at one foot intervals all the way across the distributor. This would retain the lime within the one foot "chutes" thereby minimizing the uneven spread.

A lowering of the distributor on the spreaders, bringing the distributor outlet closer to the grade, would aid in obtaining a more uniform spread rate.

Mixer Efficiency

The titration test was used to measure the distribution of lime or cement in a road mixed product. Figure 29 shows results obtained with the pugmill or auger type mixers used in treating granular materials for cement treated bases. These aggregates contain not more than 15% passing the 200 sieve.

At $\pm$ 0.6% deviation from planned cement content (specification limit for road-mixed cement treated bases) the pugmill mixers gave an average of about 77% passing tests.

Figure 30 shows results obtained from three rotary mixers and one pugmill mixer which were used to lime treat clay soils. The Pettibone-Wood Mixer (pugmill type) was used to lime treat silty clay soils on two projects in District 03.

Using a $\pm$ 1.0% deviation from planned lime content (specification limit for lime treated soils) the rotary mixers averaged about 58% passing titration tests. Discarding one brand of rotary mixer improves the average to about 71% passing tests.

On two projects, measurements were taken to determine variations in depth of mixing. These results are summarized in Table 2. The planned depth of mixing (thickness of lime treated soil) was 0.50' on both projects. The average of 52 measurements of mixing depths was 0.50' and the overall range was between 0.36' and 0.62'. These measurements indicated that mixing depths had a larger range than desired. An analysis of the data obtained indicates 95% of depth measurements fell within ± 0.12' of the preset or planned depth. For a planned depth of 0.50' this indicates an expected range in mixing depths from 0.38' to 0.62'. This indicates a need for better control of mixing depth.

At times, "pre-ripping" of the clay subgrade was employed prior to spreading or mixing operations. While this practice prolongs the life of mixer cutting blades, it also creates problems for the lime spreader and rotary mixer as well. As the spreader travels over the roughened, uneven subgrade, the side to side tilting action results in an uneven distribution of lime. Even the rubber tired rotary mixer and the track laying rotary mixer are affected by the rough subgrade. As far as mixers are concerned this affects not only mixing depth but the distribution of lime as well. For a specific case, assume a planned mixing depth of 0.50', and further assume that lime is spread uniformly and mixed perfectly. If the actual mixing depth on one side is 0.62', the distribution of lime throughout this greater depth will yield 1.0% less than the planned lime content. (Based on 5% lime treatment with a unit weight of 110 pounds per cubic foot for the clay soil.) This makes for a borderline situation at best (± 1% maximum variation in lime content).

It is believed that the grade upon which the lime is spread and later mixed into the soil should be smooth. "Pre-ripping", if permitted, should be followed by light rolling to obtain a smooth subgrade condition prior to spreading and mixing operations. The Seaman Mixer was rejected on the one project where it was tried. It should be understood that only limited data was available pertaining to the Seaman Mixer and additional trials would be necessary before drawing definite conclusions. The opportunity to do this did not occur during the remainder of this project.

Mixer efficiencies are also presented in another statistical form in Table 3. Normally, titration control tests on rotary mixers are taken in groups of three or four to get a good overall picture or measure of the finished product as far as the distribution of lime is concerned. This is perhaps the best manner to check the unformity, or lack of uniformity, of the overall spreading and mixing operations. Table 3 shows the results obtained from each contract by brand of mixer when titration tests were taken in groups of four from across a section after one pass of the mixer.

Table 4 indicates an overall picture of rotary mixer efficiencies based on titration tests from this research project.

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TABLE 1

LIME SPREAD IN POUNDS PER SQUARE FOOT

Contract	Make of Spreader	Spread Rate Planned	Measured Avg. Spread $\bar{x}$	Difference from Planned Spread	Total Range
03-100944	Universal Transport	2.20	3.00	0.80	2.57-3.35
03-061754	Brown	2.20	3.34	1.14	0.88-5.84
03-061754	Brown	1.10	1.03	0.07	0.44-1.75
10-083804	Brown	1.73	1.77	0.04	0.87-2.27
03-100964	Universal Transport	1.92	2.00	0.08	0.37-2.68
02-100764	Brown	1.52	1.74	0.22	0.09-3.98
03-Yol-1196-CR	Brown	2.38	2.95	0.57	0.99-3.90

$\bar{x}$ = arithmetic mean

TABLE 2

ROAD MIXERS DEPTH OF MIXING (FT.)

Contract	Mixer	Depth Planned	No. of Meas.	Avg. Depth Meas. $\bar{x}$	Total Range
03-061754	Metradon	0.50'	33	0.50'	0.37'-0.62'
03-100944	Koehring	0.50'	19	0.50'	0.36'-0.60'

TABLE 3

MIXER EFFICIENCIES AS MEASURED BY TITRATION TESTING

(Groups of four tests across mixer width after one pass of mixer)

Mixer: Metradon
Spreader: Brown

Contract: 03-061754
Planned Lime Content: 4%

Percent Lime from Titration Tests				Lime Content Arith. Mean %	One Std. Deviation %
7.7	4.65	5.3	6.3	5.99	1.15
3.2	5.1	8.45	5.2	5.49	1.89
4.8	3.85	7.4	6.95	5.75	1.47
Grand Mean and ± 1 Std. Deviation				5.74	1.55

Mixer: Koehring
Spreader: Universal Transport

Contract: 03-100944
Planned Lime Content: 4%

Percent Lime from Titration Tests				Lime Content Arith. Mean %	One Std. Deviation %
2.7	2.7	3.2	4.3	3.22	0.65
2.7	3.0	3.5	3.6	3.20	0.37
3.0	3.7	4.0	3.4	3.52	0.37
2.2	3.2	3.0	2.7	2.78	0.38
4.0	3.9	3.6	4.0	3.88	0.16
2.6	2.6	3.2	3.2	2.90	0.30
3.5	3.4	2.9	2.4	3.05	0.44
Grand Mean and ± 1 Std. Deviation				3.22	0.53

TABLE 3 (CON'T)

Mixer: Koehring
Spreader: Universal Transport

Contract: 03-100964
Planned Lime Content: 3.5%

Percent Lime from Titration Tests				Lime Content Arith. Mean %	One Std. Deviation %
4.12	3.37	3.22	2.35	3.26	0.63
2.65	3.05	2.47	2.00	2.54	0.38
1.87	3.30	3.32	2.60	2.77	0.60
Grand Mean and ± 1 Std. Deviation				2.86	0.62

TABLE 4

MIXER EFFICIENCIES AS MEASURED
BY TITRATION TESTS

(Considering all data obtained on this research project)

Spreader-Mixer Combination	No. of Tests	Deviation from Planned Lime Content Arith. Mean Percent Lime	One Standard Deviation - % Lime
Brown-Metradon	50	+1.17	1.978
Brown-Seaman	34	-0.47	1.848
Universal Transport-Koehring	96	-0.68	0.597

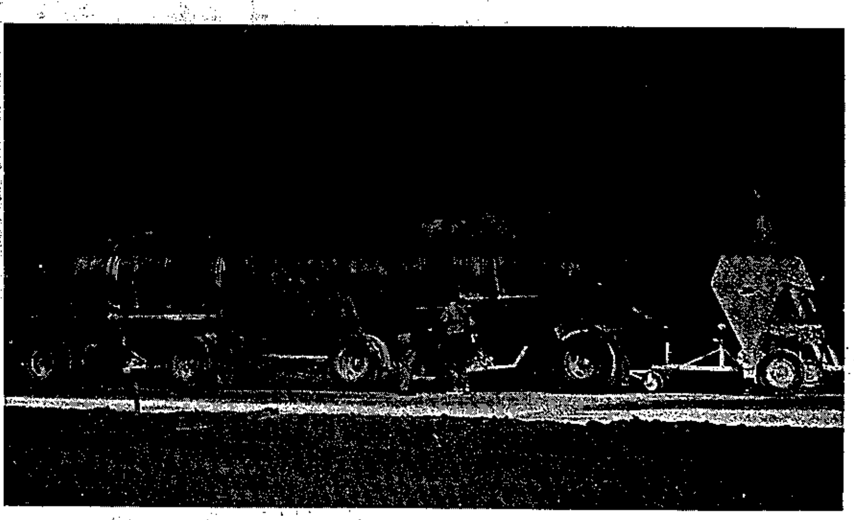


Figure 1
The Brown Spreader pulled by a truck-trailer combination.

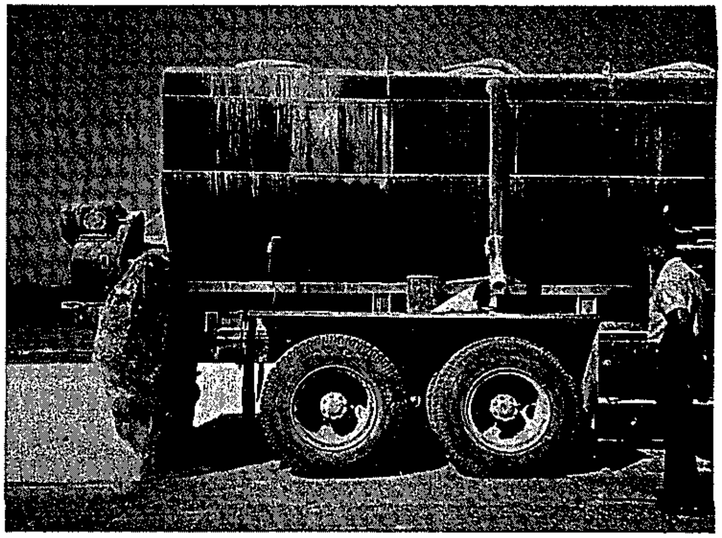


Figure 2
Universal Transport Spreader passing over wrapping paper placed on the surface of the subgrade to check the spread rate.

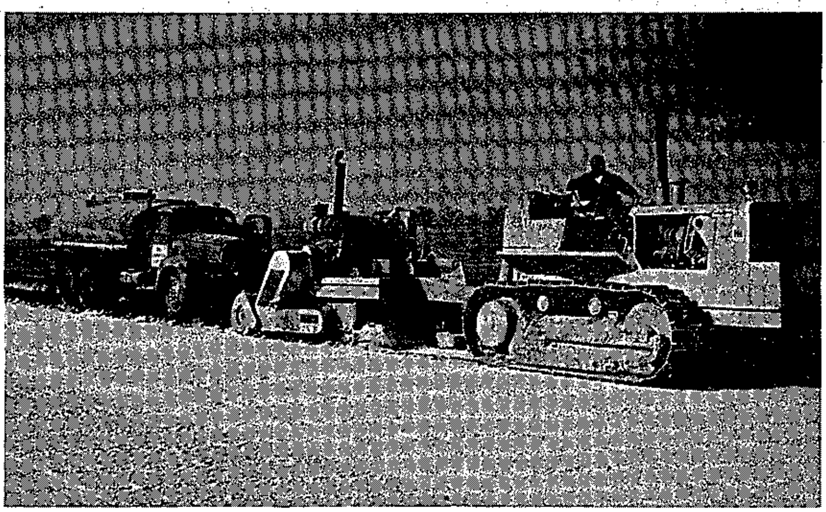


Figure 3
The Metradon Mixer in operation.

Figure 4
Mixing blades and cutting bar of Metradon Mixer. Note that the cutting bar is about 1-1/2 inches high in the middle.

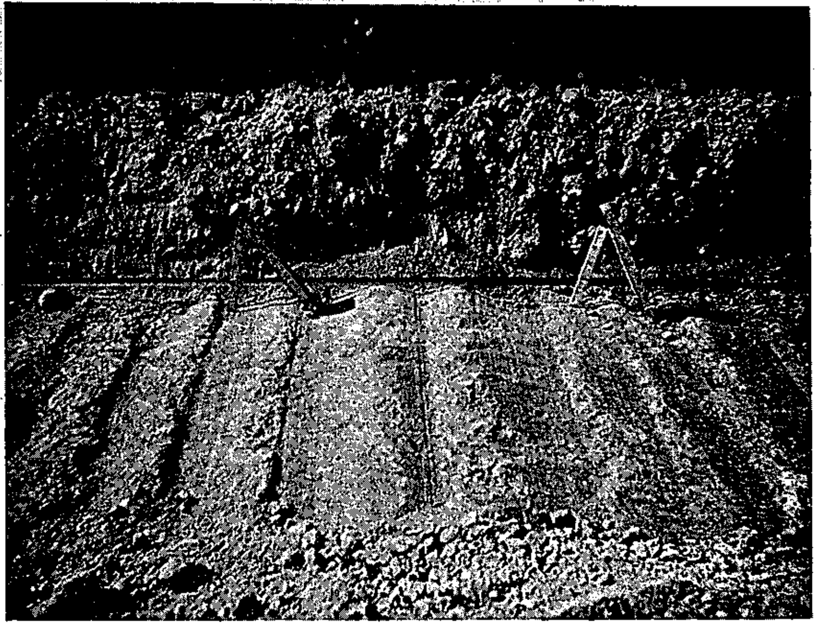


Figure 5
Subgrade after one pass of the Metradon Mixer. Note the ridges and the high spot in the middle.

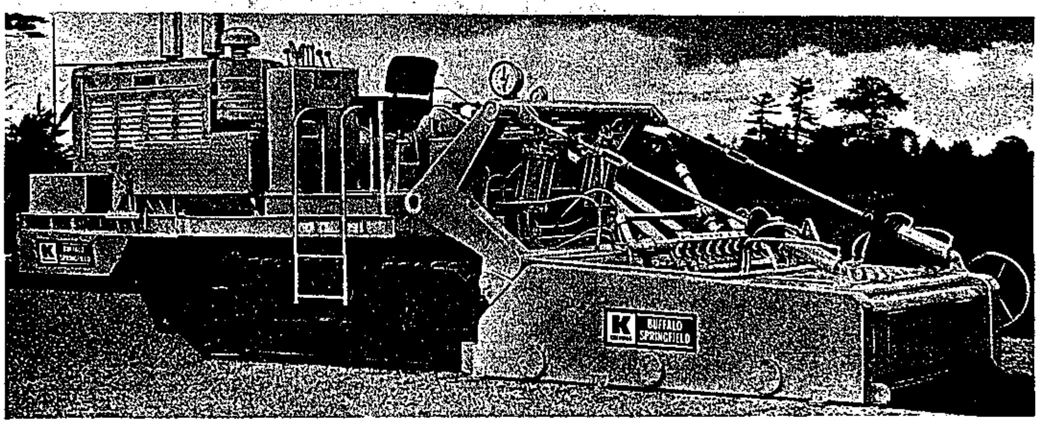


Figure 6
Koehring Mixer

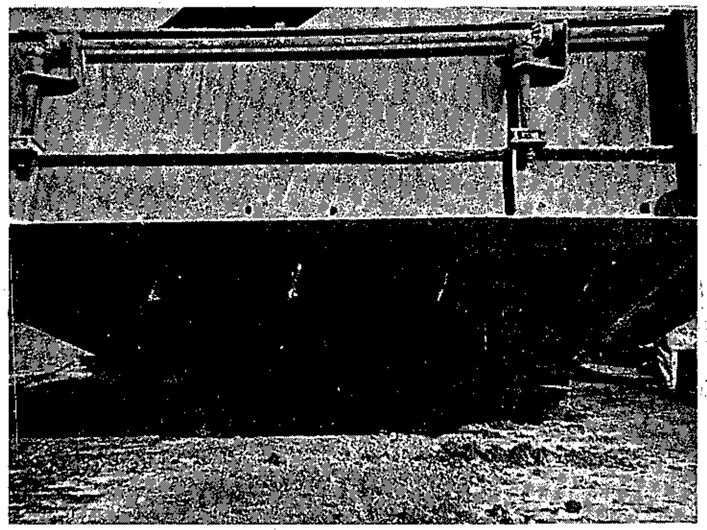


Figure 7

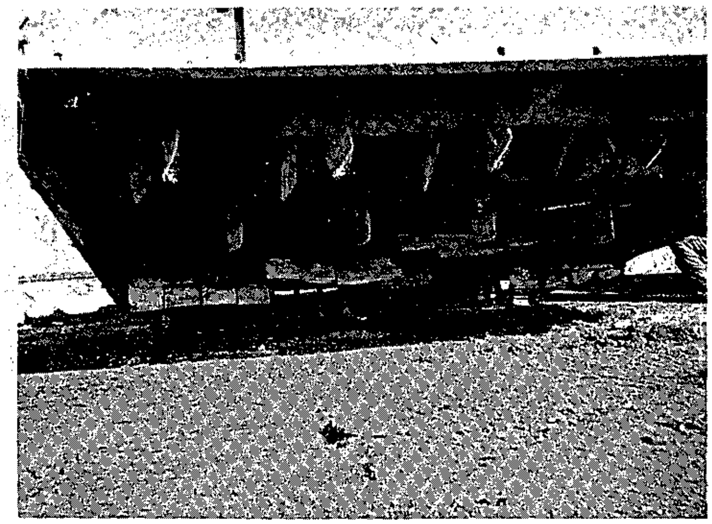


Figure 8

Cutting and mixing blades of the Koehring Mixer.

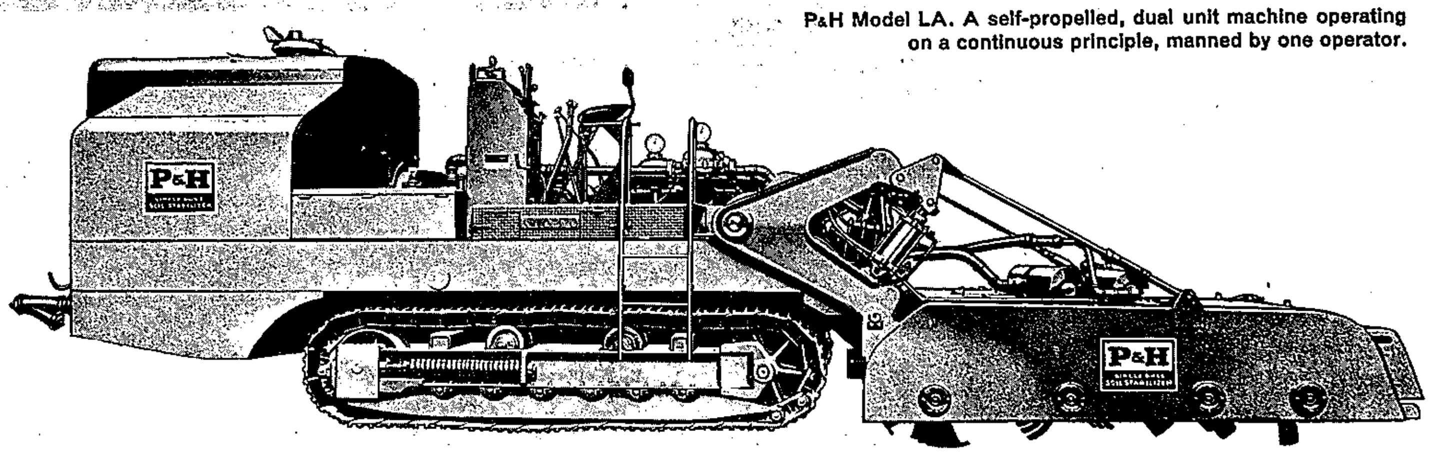


Figure 9
P and H Mixer

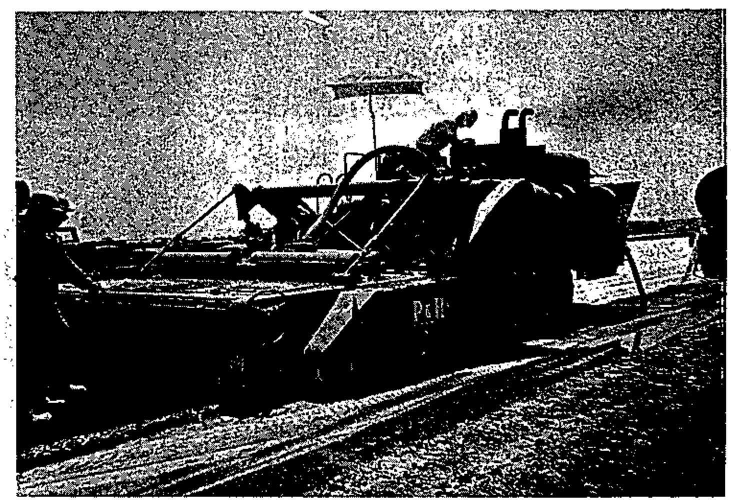


Figure 10
P and H Mixer in operation. Note the connecting hose from the water truck in front of the mixer.

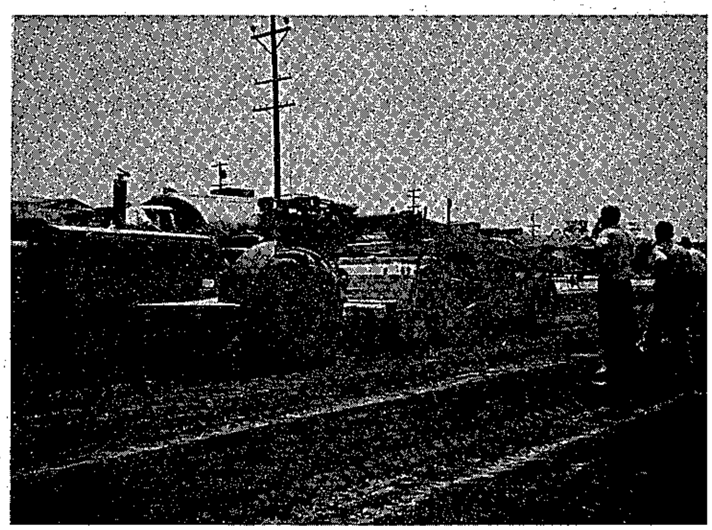


Figure 11
The Seaman Mixer.

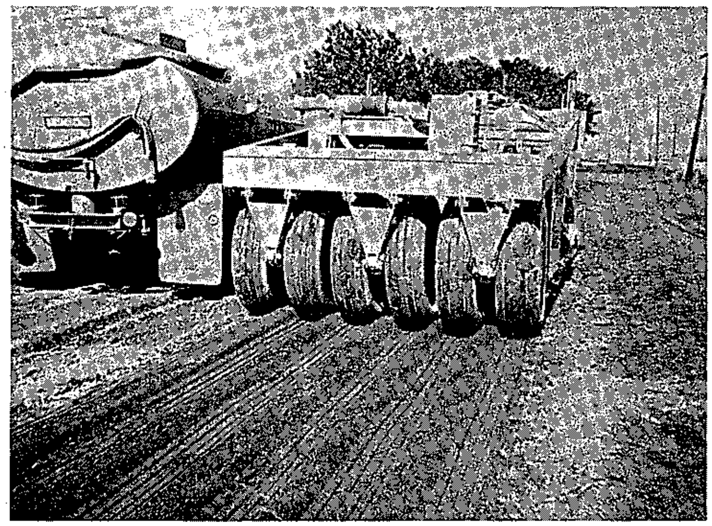


Figure 12
Rear view of the Seaman Mixer. The rear wheels also provide compactive effort.

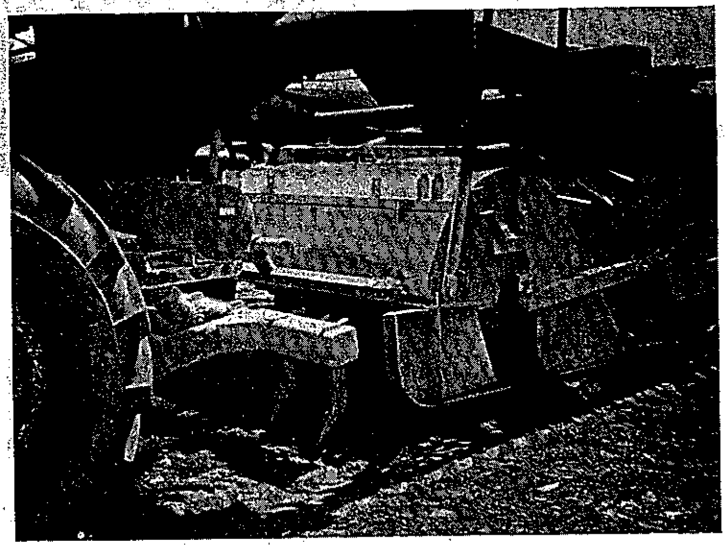


Figure 13
Rippers and mixing box of Seaman Mixer

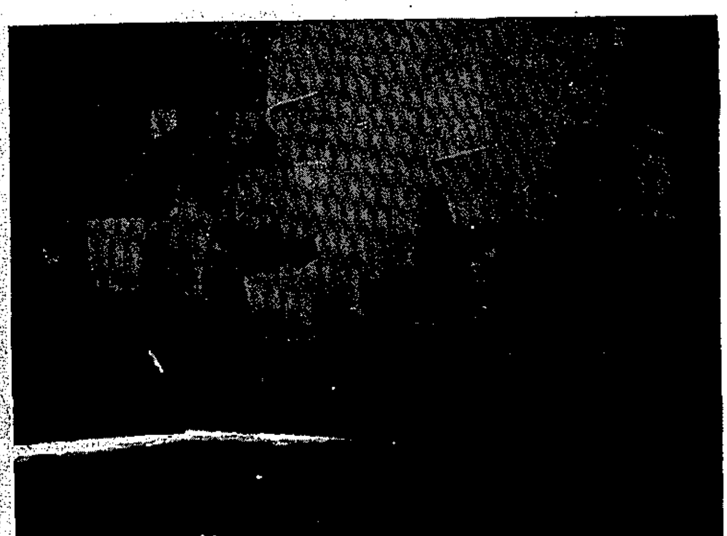


Figure 14
Mixing blades of Seaman Mixer

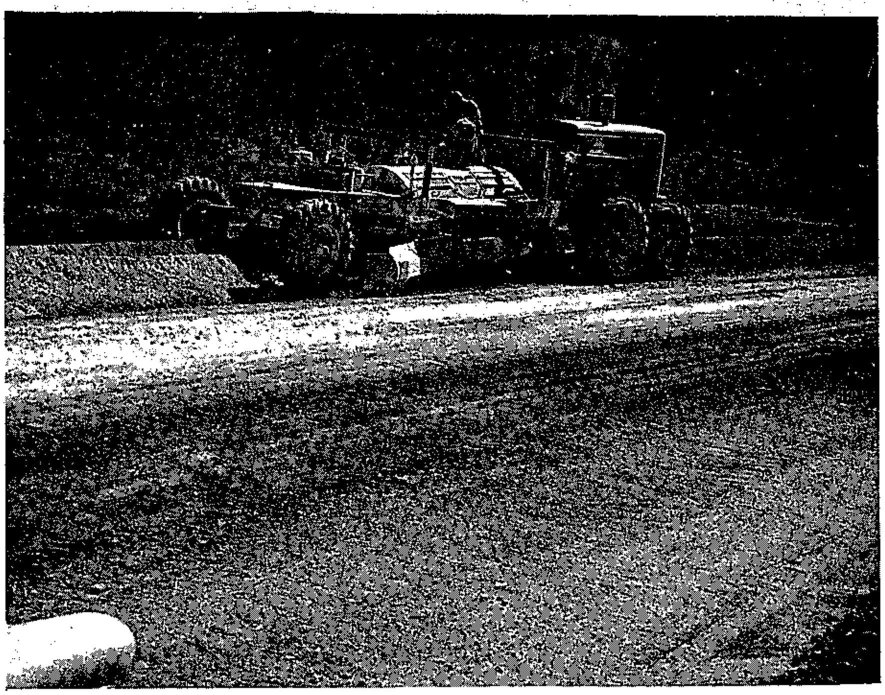


Figure 15
Pettibone-Woods Mixer

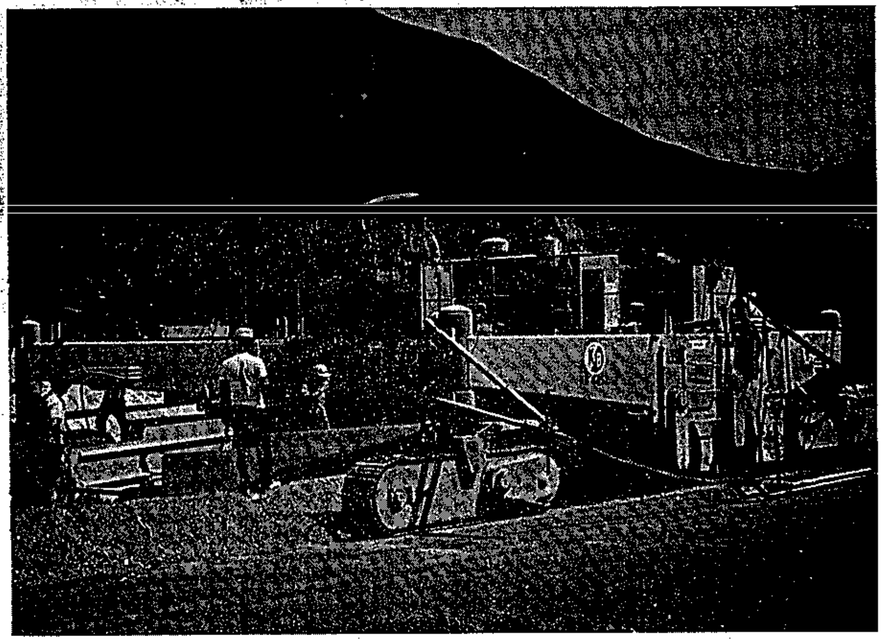


Figure 16
Modified CMI Mixer

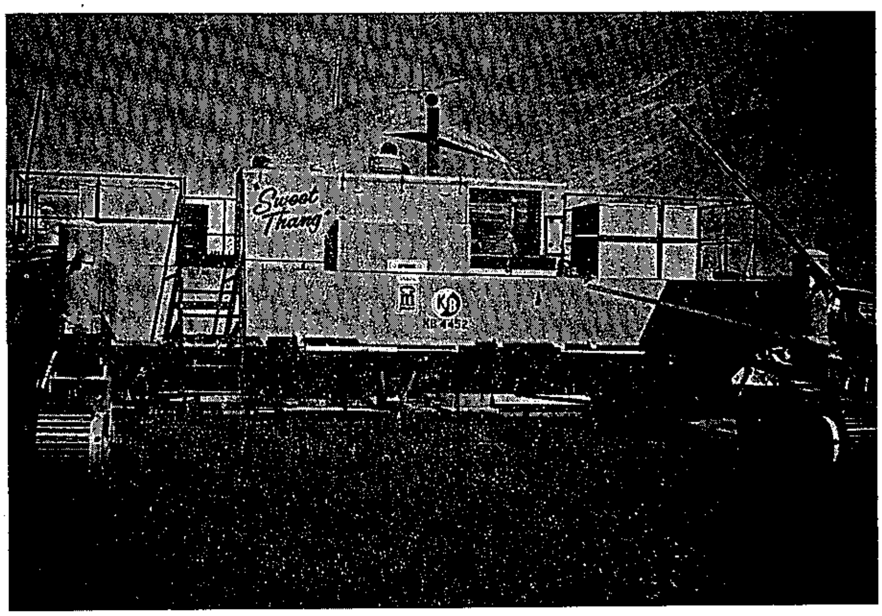


Figure 17
Lime treated material after passing through CMI Mixer

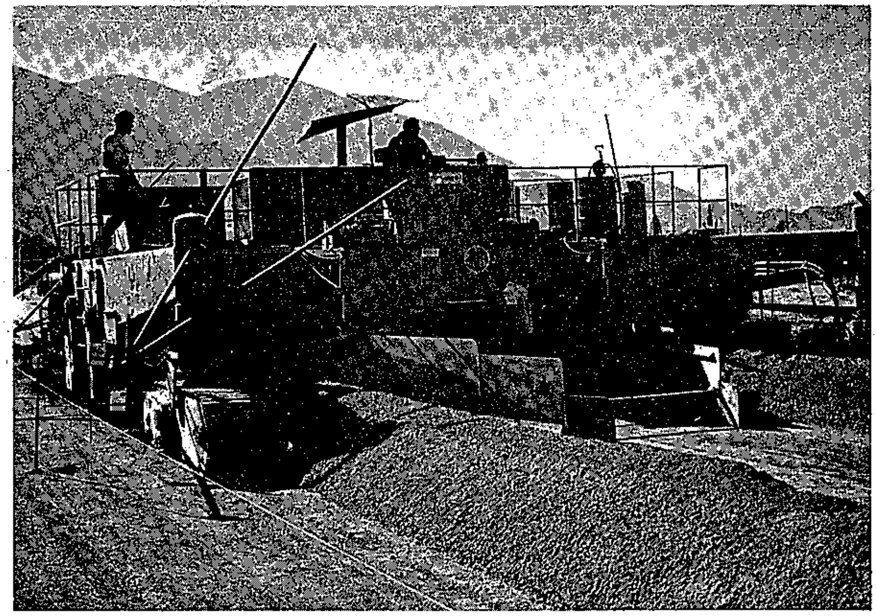


Figure 18
Modified CMI Mixer picking up two windrows of material

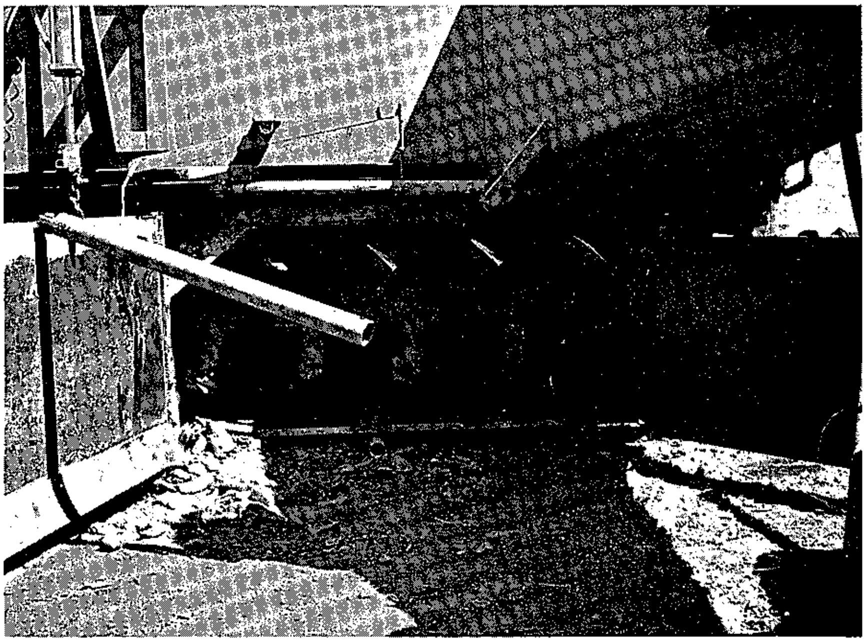


Figure 19
Pugmills of modified CMI Mixer

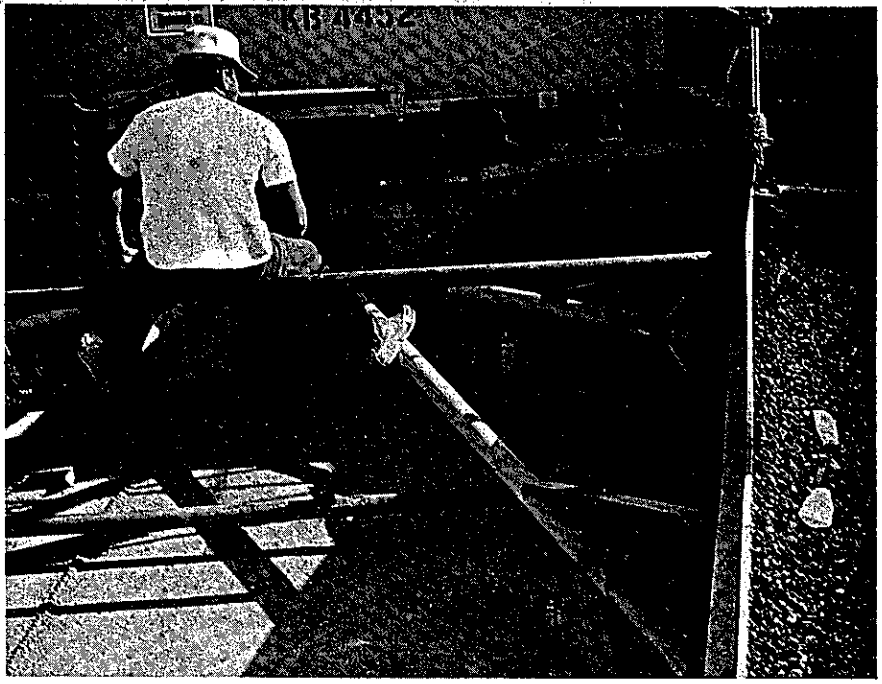


Figure 20
Pugmill housings and pickup of CMI Mixer

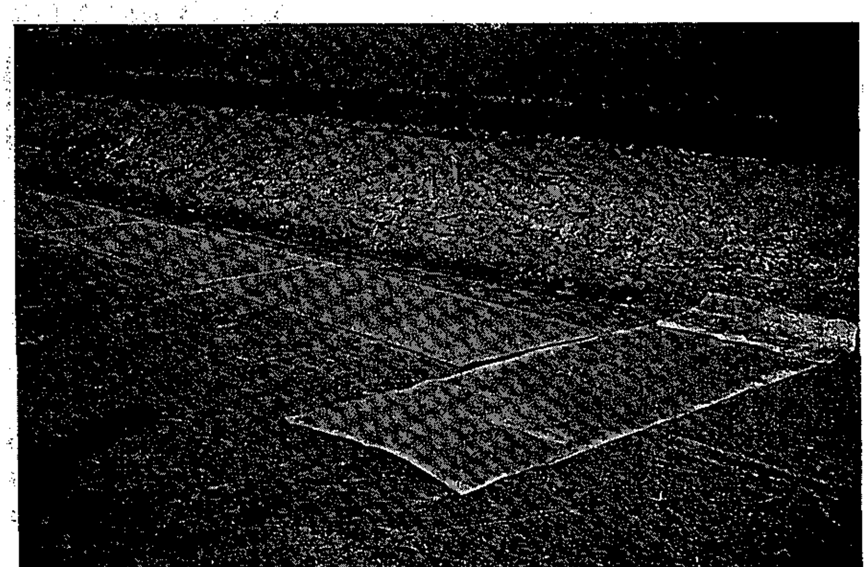


Figure 21
A 3 foot wide paper laid transversely and longitudinally to check the lime spread.

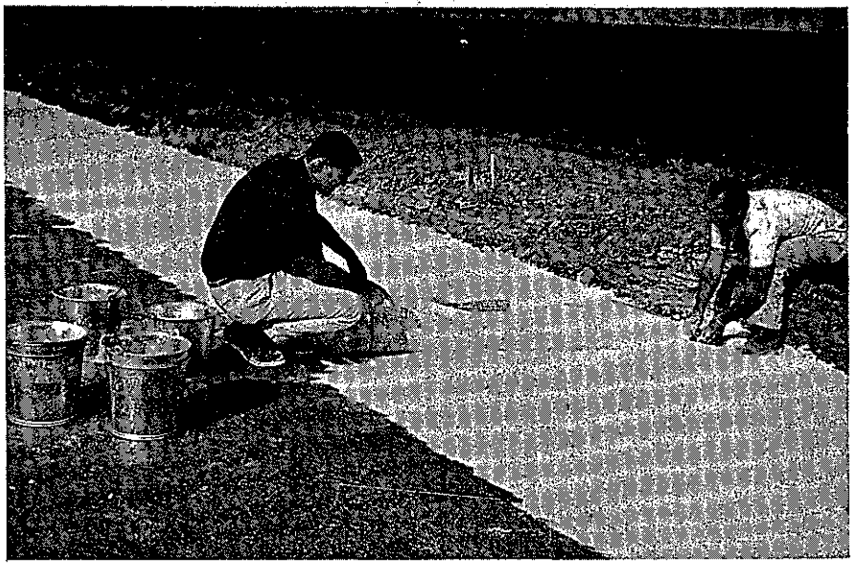


Figure 22
Measuring the spread of the lime

Figure 23
String line stretched across road between two fixed points to measure distance to undisturbed subgrade before and after mixing.

Figure 24
Trench across compacted lime treated subbase to check uniformity of mixing.

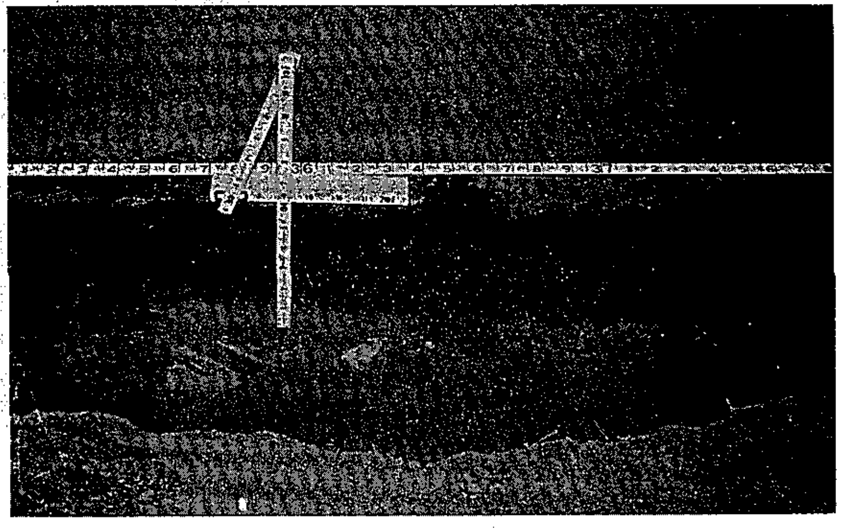


Figure 25
Poorly mixed LTS. Phenolphthalein applied to the sides of the trench results in a color change in the presence of lime.

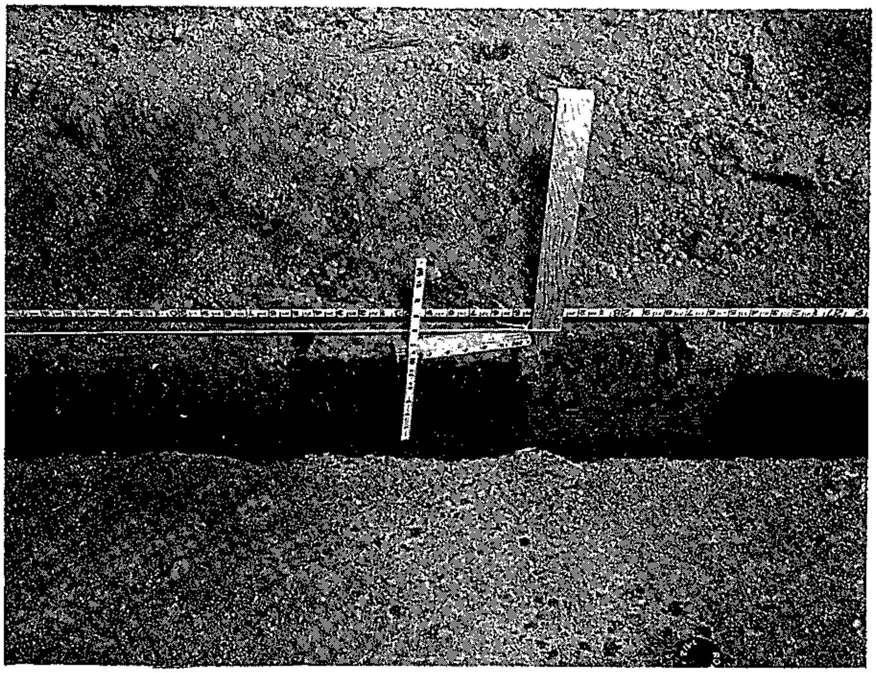


Figure 26
Well mixed LTS

Figure 27
Test samples of the mixed lime treated soil were taken by first digging a vertical sided hole to the full depth of the material and then scooping the sample from the side of the hole.

Figure 28

COMPARISON OF SPREADER EFFICIENCIES

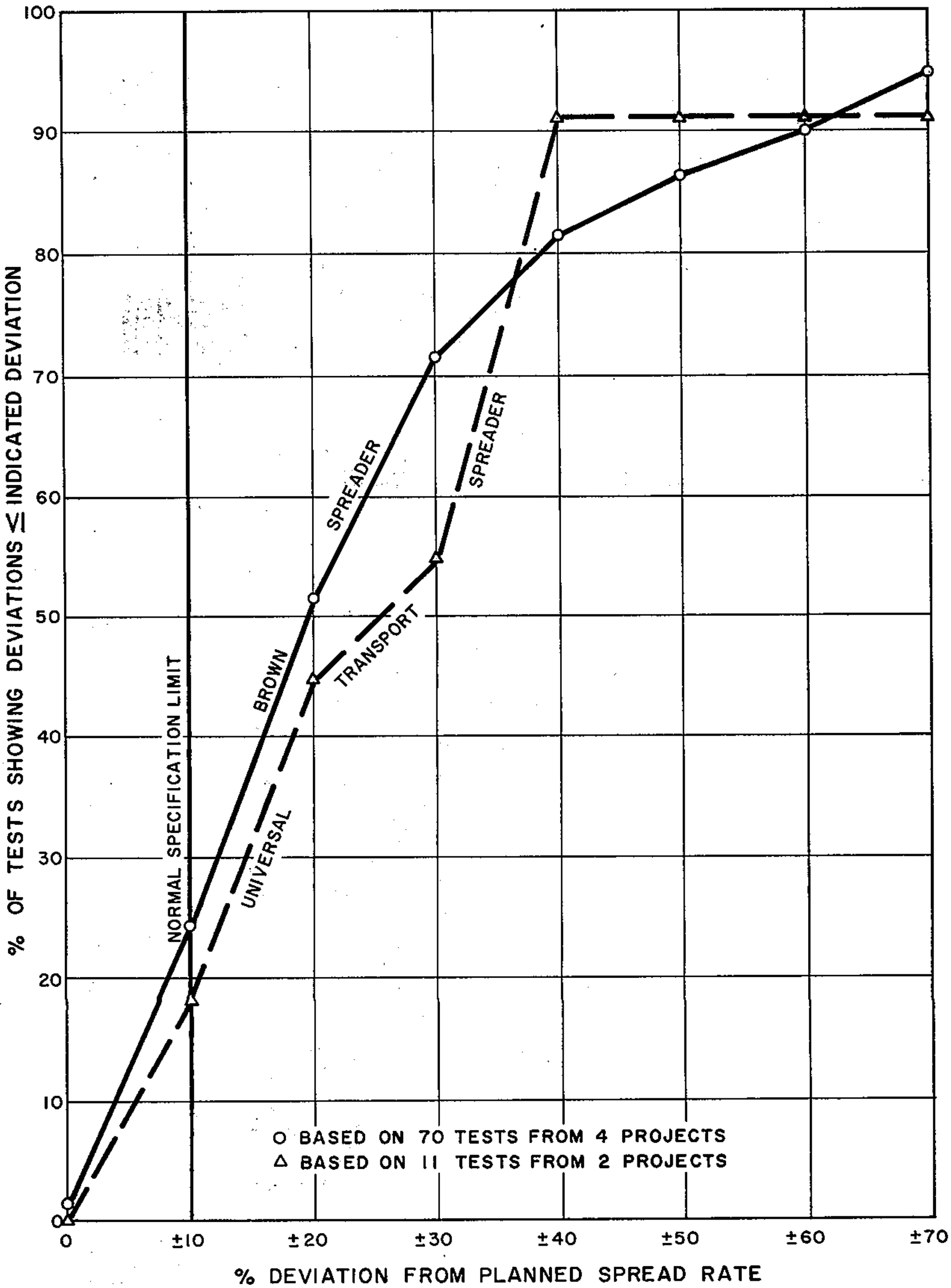


Figure 29

COMPARISON OF PUGMILL MIXER EFFICIENCIES
CEMENT TREATMENT OF AGGREGATES

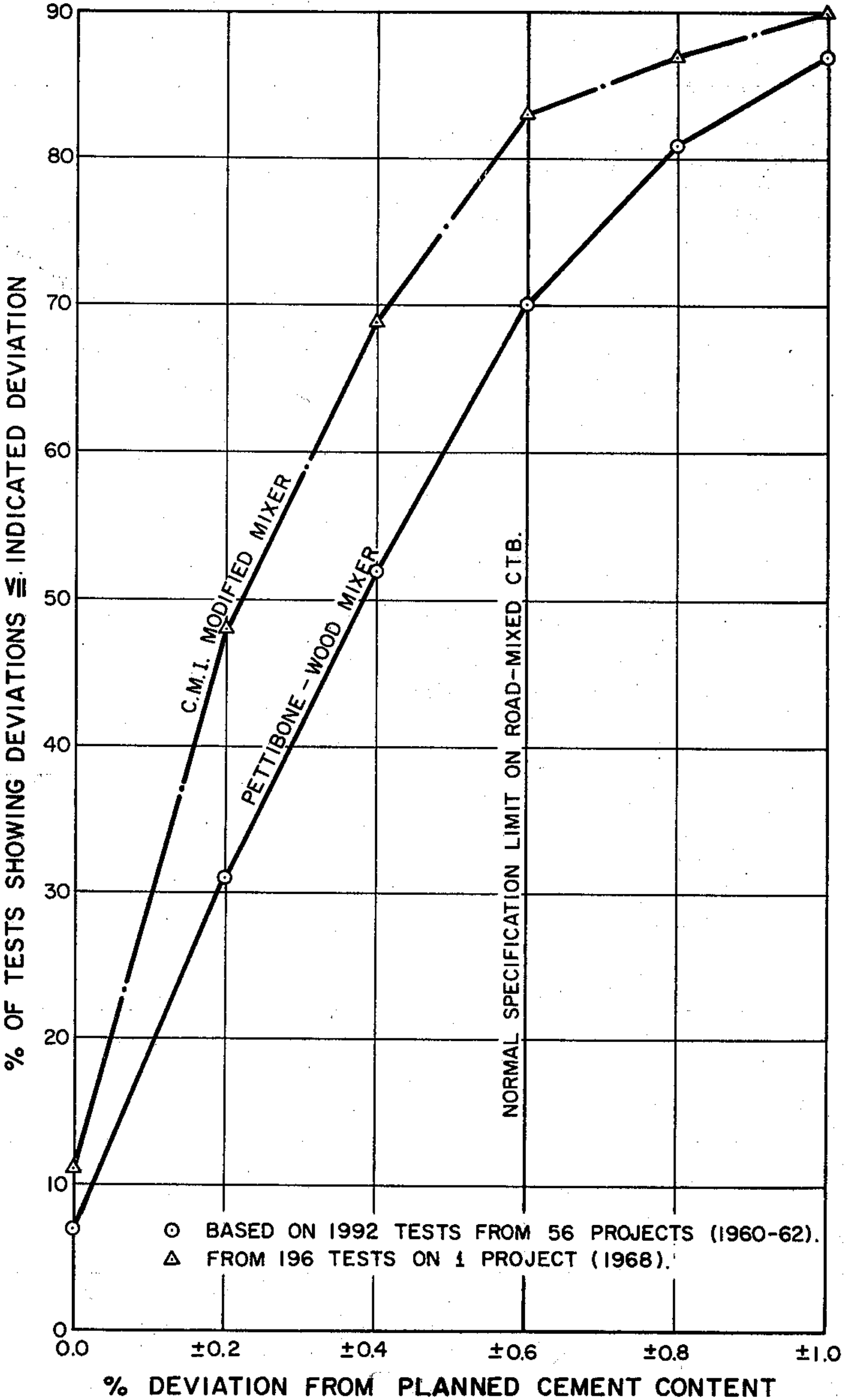
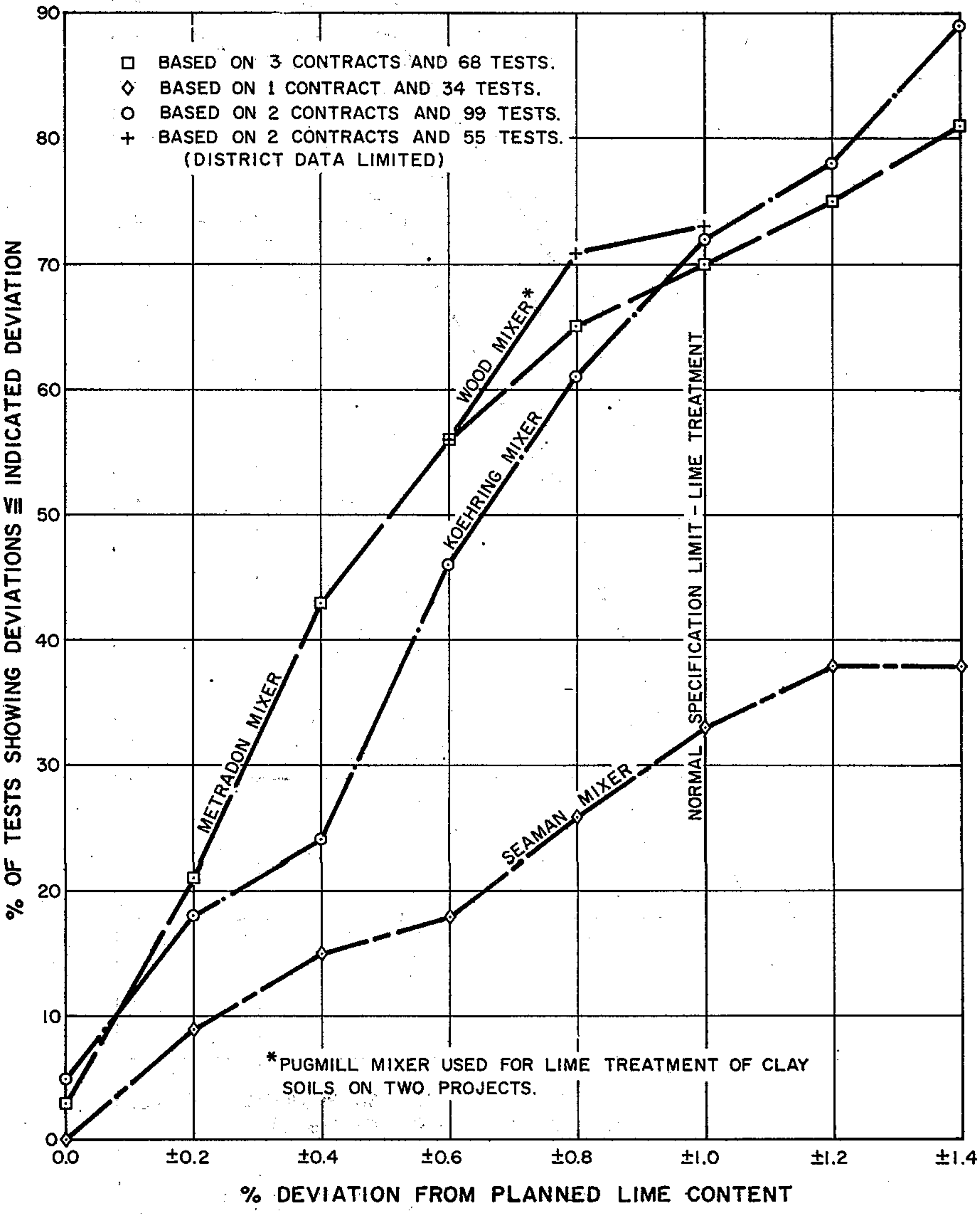


Figure 30

COMPARISON OF ROTARY MIXER EFFICIENCIES

LIME TREATMENT OF CLAY SOILS



APPENDIX

Project "A" Test Data

CONTRACT 03-061754 ROAD 03-Sac-5 Post Mile 29.8/34.6

PLANNED DEPTH AND TYPE MATERIAL: 0.50' Lime Treated Subbase

PLANNED TREATMENT PERCENTAGE: 2.0% originally, but later increased to 4.0%

BRAND SPREADER: Brown

BRAND MIXER: Metradon

Spread Rate - Transverse Direction

Station	Distance from Outer Edge of Spreader — Measured Spread (lbs/ft^2)				Planned Spread (lbs/ft^2)
	0-1.75'	1.75-3.50'	3.50-5.25'	5.25-7.00'	
468+75	0.44	1.21	1.43	1.75	1.10
465+80	0.82	0.88	0.82	0.62	1.10
415+75	2.04	5.84	2.91	2.70	2.20
437+30	2.31	2.74	2.31	5.84	2.20
416+65	0.88	1.04	0.94	1.04	1.10

Spread Rate - Longitudinal Direction

Station	Distance from Beginning of Test Site — Measured Spread (lbs/ft^2)							Planned Spread (lbs/ft^2)
	0-3'	3-6'	6-9'	9-12'	12-15'	15-18'	18-21'	
402+50 to 402+71	1.37	1.21	1.16	1.37	1.21	1.10	1.32	1.10
416+67 to 416+88	0.82	0.94	0.94	0.88	0.82	0.94	0.94	1.10

Depth of Mixing

Station	Distance from Left Edge of Mixer — Actual Depth of Mixing			Planned Depth
	1.0'	3.5'	6.0'	
431+50	0.48	0.53	0.56	0.50
490+00	0.58	0.55	0.59	"
489+00	0.48	0.47	0.48	"
488+00	0.49	0.55	0.53	"
487+00	0.43	0.40	0.37	"
490+00	0.57	0.49	0.53	"
489+00	0.45	0.47	0.53	"
488+00	0.62	0.62	0.60	"
432+00	0.39	0.46	0.48	"
431+00	0.43	0.43	0.43	"
430+00	0.48	0.51	0.49	"

Percent Lime as Measured by the Titration Test

After 1 Pass of the Rotary Mixer

Station	Depth	Distance from Right Edge of Mixer (Ft.) 3.5	7.0	11.3	14.0
488+00	0"-3"	6.4	3.2	6.2	5.7
488+00	3"-6"	9.0	6.1	4.4	6.9
489+00	0"-3"	3.7	4.5	10.1	4.4
489+00	3"-6"	2.7	5.7	6.8	6.0
490+00	0"-3"	7.6	5.9	9.3	7.9
490+00	3"-6"	2.0	1.8	5.5	6.0

Percent Lime as Measured by the Titration Test

After 1 Pass of the Rotary Mixer
and 6 Passes of Blade Mixing

Station	Depth	Distance from Right Edge of Mixer (Ft.) 3.5	7.0	11.3	14.0
488+00	0"-3"	5.5	4.9	4.3	5.0
488+00	3"-6"	6.3	6.0	4.9	4.8
489+00	0"-3"	3.9	4.5	3.3	4.2
489+00	3"-6"	4.9	5.5	3.4	2.4
490+00	0"-3"	3.8	4.6	3.2	5.2
490+00	3"-6"	4.9	3.8	0.5	5.0

Percent Moisture

After 1 Pass of the Rotary Mixer

Station	Depth	Distance from Right Edge of Mixer (Ft.) 3.5	7.0	11.3	14.0
488+00	0"-3"	25.9	28.9	27.2	22.4
488+00	3"-6"	23.3	27.4	22.9	20.3
489+00	0"-3"	20.8	23.5	30.3	19.4
489+00	3"-6"	20.1	16.4	20.1	19.4
490+00	0"-3"	18.1	24.4	20.4	18.8
490+00	3"-6"	19.3	18.3	15.2	15.9

Percent Moisture

After 1 Pass of the Rotary Mixer and 6 Passes of Blade Mixing

Station	Depth	Distance from Right Edge of Mixer (Ft.) 3.5	7.0	11.3	14.0
488+00	0"-3"	22.8	20.6	22.0	22.2
488+00	3"-6"	21.4	24.6	20.9	21.2
489+00	0"-3"	20.5	21.1	20.8	21.1
489+00	3"-6"	21.9	23.7	20.9	20.5
490+00	0"-3"	21.4	19.2	19.7	20.6
490+00	3"-6"	21.9	18.7	17.2	13.0

Project "B" Test Data

CONTRACT 03-100944 ROAD 03-Sac-5 Post Mile 24.8/30.7

PLANNED DEPTH AND TYPE MATERIAL: 0.50' Lime Treated Subbase

PLANNED TREATMENT PERCENTAGE: 4.0%

BRAND SPREADER: Universal Transport

BRAND MIXER: Koehring

Spread Rate - Transverse Direction

Station	Distance from Outer Edge of Spreader 1.0-3.0'	3.0-5.0'	5.0-7.0'	Planned Spread (lbs/ft^2)
	Measured Spread (lbs/ft^2)			
255+00	3.23	2.76	2.96	2.20
255+00	3.35	3.16	2.57	"

Depth of Mixing

Station	Distance from Right Edge of Mixer 1'	3'	5'	7'	Planned Depth
	Measured Depth of Mixing				
139+00		0.51	0.50	0.51	0.50
140+00	0.52	0.49	0.51	0.47	"
140+00	0.60	0.55	0.52	0.52	"
141+00	0.59	0.47	0.40	0.36	"
141+00	0.55	0.50	0.50	0.46	"

Percent Lime as Measured by the Titration Test
(transverse direction)

Station	Distance from Right Edge of Mixer 1'	3'	5'	7'	Planned Lime (%)
	Measured Percent of Lime				
132+00	2.7	2.7	4.6		4.0
134+50	2.7	2.7	3.2	4.3	"
134+85	2.7	3.0	3.5	3.6	"
135+00	3.0	3.7	4.0	3.4	"
135+05	2.2	3.2	3.0	2.7	"
136+15	4.0	3.9	3.6	4.0	"
137+00	2.7	3.6	3.8		"
139+00	2.6	2.6	3.2	3.2	"
140+00	3.5	3.4	2.9	2.4	"
141+00	2.7	3.6	3.8		"

Percent Lime as Measured by the Titration Test
(vertical direction)

Station	Depth in Feet (before compaction) 0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	Planned Lime (%)
	Measured Percent of Lime				
135+05	3.2	3.4	3.6	4.0	4.0
137+00		3.7(0.0-0.4)		3.6(0.4-0.8)	"
139+00	3.2	3.1	3.1	3.2	"

Project "C" Test Data

CONTRACT 03-100964 ROAD 03-Sac-5 Post Mile 29.3/34.3

PLANNED DEPTH AND TYPE MATERIAL: 0.50' Lime Treated Subbase

PLANNED TREATMENT PERCENTAGE: 3.5%

BRAND SPREADER: Universal Transport

BRAND MIXER: Koehring

Spread Rate
(Samples taken on 3' wide paper)

Station	Distance from Edge of Spreader 1'	3'	5'	7'	Planned Spread (lbs/ft²)
	Measured Spread (lbs/ft²)				
367+24		2.27			1.92
367+30	*	2.05	2.61	0.37	"
367+36		2.68			"

*Sample could not be recovered.

Percent Lime as Measured by the Titration Test

Station	Depth (before compaction)	Distance from Outer Edge of Mixer 1'	3'	4'	5'	7'	Planned Lime (%)
		Measured Lime Content (%)					
314+70	0.0-0.8'			4.0			3.5
314+75	0.0-0.2'	4.1	3.4		3.1	2.2	"
"	0.2-0.4'	4.3	3.4		3.0	2.4	"
"	0.4-0.6'	3.9	3.3		3.2	2.3	"
"	0.6-0.8'	4.2	3.4		3.6	2.5	"
"	0.0-0.8'*	4.12	3.37		3.22	2.35	"
314+80	0.0-0.8'			3.7			"
332+20	0.0-0.8'			2.8			"
332+25	0.0-0.2'	2.6	2.9		2.5	2.0	"
"	0.2-0.4'	2.7	3.1		2.4	2.0	"
"	0.4-0.6'	2.6	3.0		2.3	2.0	"
"	0.6-0.8'	2.7	3.2		2.7	2.0	"
"	0.0-0.8'*	2.65	3.05		2.47	2.0	"
332+30	0.0-0.8'			3.2			"
367+25	0.0-0.8'			3.4			"
367+30	0.0-0.2'	1.8	3.2		3.2	2.6	"
"	0.2-0.4'	2.0	3.0		3.3	2.7	"
"	0.4-0.6'	1.8	3.4		3.5	2.6	"
"	0.6-0.8'	1.9	3.6		3.3	2.5	"
"	0.0-0.8'*	1.87	3.3		3.32	2.6	"
367+35	0.0-0.8'			3.3			"

*Averaged values of measurements at different depths.

Project "D" Test Data

CONTRACT 02-100764 ROAD 02-Tri-1089

PLANNED DEPTH AND TYPE MATERIAL: 0.50' Cement Treated Base

PLANNED TREATMENT PERCENTAGE: 2.25%

BRAND SPREADER: Brown

BRAND MIXER: Metradon

Spread Rate - Transverse Direction

Station	Distance from Left Edge of Spreader 1'	3'	5'	6'	Planned Spread (lbs/ft^2)
	Measured Spread (lbs/ft^2)				
131+75	0.09	2.16		1.35	1.52
133+50	0.47	3.98	2.36		"

Percent Cement as Measured by the Titration Test

Station	Distance from Left Edge of Mixer 1'	3'	4'	5'	6'	Planned Cement (%)
	Measured Cement Content (%)					
131+75	0.4	3.2			2.0	2.25
133+50	0.7	5.9		3.5		"
133+75			2.0			"
134+50			3.3			"

Project "E" Test Data

CONTRACT 03-101924 ROAD 03-Yol-1196-CR

PLANNED DEPTH AND TYPE MATERIAL: 0.50' Lime Treated Subgrade

PLANNED TREATMENT PERCENTAGE: 4.5%

BRAND SPREADER: Brown

BRAND MIXER: Seaman

Spread Rate

Station	Distance from Centerline of Road — Measured Spread (lbs/ft^2): 8' Rt	10' Rt	12' Rt	Planned Spread (lbs/ft^2)
127+33	0.99	3.36	3.08	2.38
128+75		3.90		"
128+50		3.36		"
128+75	2.59	3.90	2.04	"

Percent Lime as Measured by the Titration Test

Station	Depth	Distance from Centerline of Road — Measured Lime Content (%): 8' Rt	10' Rt	12' Rt	Planned Lime (%)
127+33	0-6"	1.8	6.1	5.6	4.5
127+50	0-2"	4.2	8.0	2.5	"
"	2-4"	3.9	8.7	2.3	"
128+00	0-2"	5.5	5.3	2.3	"
"	2-4"	6.4	6.0	2.6	"
128+50			6.1		"
128+75		4.7	7.1	3.7	"

Percent Lime as Measured by the Titration Test

Station	Distance from Centerline of Road — Measured Lime Content (%): 8'Lt	6'Lt	℄	6'Rt	8'Rt	Planned Lime (%)
129+50	4.1		2.6		2.1	4.5
130+00		2.5	2.4	4.6		"
131+00		2.8	2.1	2.3		"
131+50	3.5		1.7		2.9	"
132+00	3.7		2.4		4.4	"

Project "F" Test Data

CONTRACT 10-083804 ROAD 10-SJ-5

PLANNED DEPTH AND TYPE MATERIAL: 0.67' Cement Treated Base

PLANNED TREATMENT PERCENTAGE: 3.5"

BRAND SPREADER: Brown

BRAND MIXER: Metradon

Spread Rate - Transverse Direction

Station	Distance from Left Edge of Spreader 0-1'	1-2'	2-3'	3-4'	4-5'	5-6'	Planned Spread (lbs/ft²)
	Measured Spread (lbs/ft²)						
654+85	1.96		1.98		1.89		1.73
655+95(top 6")	1.83		1.71		1.48		"
655+95(bottom 6")	2.27		1.68		2.15		"
657+10	1.95	0.87	1.97	1.46	1.96	1.52	"

Spread Rate - Longitudinal Direction

	Station 654+38 to 654+41	654+41 to 654+44	654+44 to 654+47	654+47 to 654+50	654+50 to 654+53	654+53 to654+56
Measured Spread (lbs/ft²)	1.57	1.77	1.74	1.71	1.82	1.97
Planned Spread	1.73	1.73	1.73	1.73	1.73	1.73

Percent Cement as Measured by the Titration Test

Station	Distance from Centerline of Road 13'	15'	17'	19'	21'	23'	Planned Cement (%)
	Measured Cement Content (%)						
665+65 LL*				5.6	4.0	3.6	3.5
665+90 LL				7.0	6.6	6.5	"
665+90 UL			5.8	2.8	6.1		"
665+95 UL			2.2	1.8	1.8		"
666+65 UL			4.0	2.2	5.3		"
667+60 LL	3.7	3.7	4.2				"

*LL = Lower Lift UL = Upper Lift

Project "G" Test Data

CONTRACT 08-049114   ROAD 08-SBd-15/31/138

PLANNED DEPTH AND TYPE MATERIAL: 0.35' and 0.50' CTB

PLANNED TREATMENT PERCENTAGE: 3.5%

BRAND SPREADER: None

BRAND MIXER: Construction Machinery Incorporated Modified Autograder

Titration Tests

No. of Tests (Accumulative)	% of Tests	Deviation from planned cement content (% Cement)
21	10.6	0
96	48.5	±0.2
137	69.2	∓0.4
165	83.3	∓0.6
173	87.4	∓0.8
178	89.9	∓1.0
184	92.9	∓1.2
191	96.5	∓1.4
193	97.5	∓1.6
195	98.5	∓1.8
198	100	∓3.4

No depth measurements or other tests were performed.

Data Collected by District 03
Materials Department Personnel

AREA	PLANNED % LIME	MIXER	TOTAL TESTS	Number and (Percent) Within ±0.6	±0.8	±1.0
BUT Hwy 99	3.0	Woods	37	17 (46%)	21 (57%)	22 (59%)
CHICO Skyway	4.0	Seaman-Rotill	10	3 (30%)	5 (50%)	8 (80%)
ED-50 Harms Pit	4.5	Woods	18	14 (78%)	18 (100%)	
SAC-5 Porter	4.0	Metradon	12	3 (25%)	6 (50%)	7 (58%)
SIE-1345 Alleghany	4.0	Metradon	68	27 (40%)	32 (47%)	42 (62%)
YOL-1196 Davis	4.5	Woods & Seaman	14	3 (21%)	4 (28%)	5 (36%)
YOL-1196 Davis	4.0	Woods & Seaman	66	29 (44%)	33 (50%)	37 (56%)

Note: Some of the information in this tabulation is used in Figure 2.