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HIGHWAY RESEARCH BOARD

REPORT OF INVESTIGATION
OF
THE USE OF CALCIUM CHLORIDE AS A DUST PALLIATIVE

BY
FRED BURGGRAF

PART II
PROCEEDINGS OF THE TWELFTH ANNUAL MEETING
OF THE
HIGHWAY RESEARCH BOARD

Held at Washington, D. C.
December 1 and 2, 1932

EDITED BY
ROY W. CRUM
Director, Highway Research Board

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL
1933

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FOREWORD

The Proceedings of the Twelfth Annual Meeting have been printed in two parts

Part I contains the reports of the research committees and the technical papers presented at the meeting

Part II is devoted to the report of the Special Investigation on Dust Laying Materials and Methods on "The Use of Calcium Chloride As A Dust Palliative" This report was presented at the Highway Research Board meeting on December 1, 1932 Publication has been recommended by the Committee on Maintenance, and approved by the Publications Committee of the Board This investigation and report were made possible through the cooperation of the State Highway Departments of South Carolina, Missouri and Nebraska and the Calcium Chloride Association.

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THE USE OF CALCIUM CHLORIDE AS A DUST PALLIATIVE

By FRED BURGGRAF, *Research Engineer, Highway Research Board*

INTRODUCTION

The object of this investigation has been to secure data concerning the effects of dust alleviating treatments upon the soil (binder) and upon the preservation of the road metal, pertinent to the use of deliquescent salts and other materials as dust palliatives The work comprised auxiliary tests and studies of the effects of calcium chloride on experimental roads in South Carolina, Missouri and Nebraska

Work was started early in 1931 and preliminary observations were made upon the test sections in South Carolina and Missouri during that year A progress report was presented at the Eleventh Annual Meeting of the Highway Research Board of the National Research Council and published in the Proceedings of that meeting This is summarized briefly in this report

In 1932 another test road was added, in Nebraska, and more detailed studies were made upon all three sections

As the work progressed it largely resolved itself into an investigation of the dispersion of the calcium chloride by chemical action, rainfall, and maintenance manipulation The most important development was the observation of the effects shown by the modification of the customary maintenance methods which consisted in eliminating the usual float material from the road surface and in reducing the maintenance operations

The report also includes brief resumés of the available information on the effects of calcium chloride on roadside trees and vehicles.

RÉSUMÉ OF 1931 PROGRESS REPORT

SOUTH CAROLINA PROJECT

This project is located about five miles Southwest of Columbia, South Carolina, on Route 215 It is a typical sand-clay road carrying about 300 vehicles per day. The experimental section is six miles long, of which three were treated with two applications of calcium chloride The first application was made on July 29 and consisted of 1 25 lbs per square yard The second application was made on August 6 and consisted of 0 5 lb per square yard The project was divided into six, one mile sections The dust palliative (calcium chloride) was placed on alternate miles, in order to mitigate the influence of such major variables as topography and surface texture The calcium chloride was applied by a "Handy Sandy Distributor" which assured uniform application

TABLE I

MECHANICAL ANALYSIS OF SURFACE MATERIALS

SOUTH CAROLINA PROJECT

Sieve Classification	Particle Size Distribution of Untreated Samples of Sand-Clay Top Surface (Percentage)										
	Sample Identification										
	1	2	3	4	5	6	7	8	2-B	4-B	5-B
Retained on No 10	5	3	6	2	2	1	1	1	4	2	2
Retained on No 20	10	17	10	10	11	9	8	7	22	5	8
Passing No 20 Retained on No 60	44	34	36	33	37	28	35	33	30	36	37
Total Sand Retained on No 60	55	50	46	43	48	37	43	40	54	41	46
Passing No 60 Retained on No 100	14	8	11	13	13	14	14	13	9	14	15
Passing No 100 Retained on No 200	9	5	9	13	9	14	8	9	5	13	14
Total Sand Passing No 10, Retained on No 200	78	63	66	69	70	65	64	62	68	68	75
Total Silt	7	5	10	12	14	13	9	8	3	13	10
Total Clay	15	32	24	19	16	22	27	30	29	20	16

RATE OF EVAPORATION TESTS

To ascertain to what extent the physical properties of the soil were modified by the addition of a surface application of calcium chloride the rate of evaporation of moisture from treated and untreated samples was determined

A laboratory dried sample weighing approximately seven pounds was thoroughly mixed with a known quantity of water and the sample divided into two parts These were placed in shallow pans, having an area of approximately one square foot To the surface of one of each set of samples was added calcium chloride at the rate of 1 25 pounds per square yard These pans were weighed daily and the rate of evaporation of the original soil moisture was calculated

Figure 1 shows these data graphically, and also the maximum outside air temperature and the relative humidity at noon, during the duration of this test, as reported by the weather bureau The prevailing atmospheric conditions for accleration of evaporation in the laboratory were undoubtedly more severe than these results signify

These tests showed the variation in rate of evaporation of different samples taken from the same road The untreated soil sample Number

7-8A in Figure 1 showed a smaller moisture loss than did the three treated samples in this test, but in all parallel cases the moisture evaporated more rapidly from the untreated soil samples

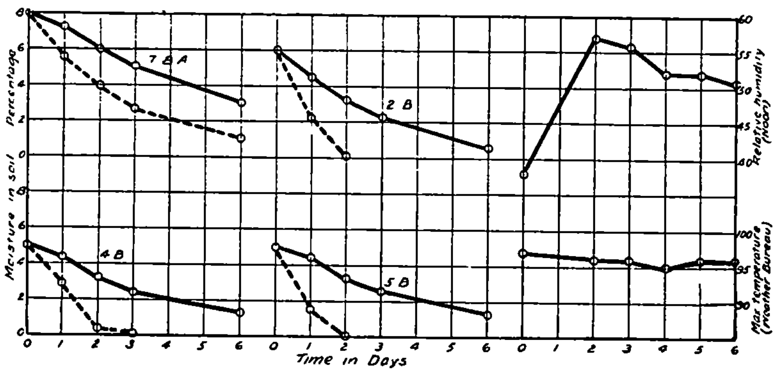


Figure 1. Relationship between the Rate of Evaporation of Moisture from Treated and Untreated Soils Under Similar Storage Conditions. Tests Made in Laboratory. (South Carolina Project.)

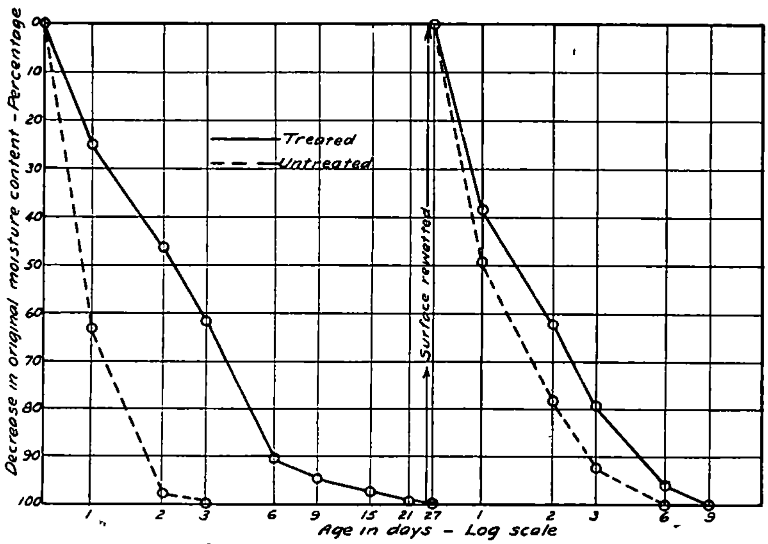


Figure 2. Relationship between the Initial and Subsequent Rates of Evaporation of Moisture from Treated and Untreated Soils. Laboratory Tests. (South Carolina Project)

Figure 2 shows graphically the relationship between the initial and subsequent rates of evaporation of moisture from treated and untreated soils The curves show that it required 27 days for the treated sample (1 25 pounds of calcium chloride per square yard) to lose all of its moisture whereas the untreated sample was dry at the end of three days

The surfaces of these samples were both wetted with an equal amount of water at the end of 27 days In this case the rate of moisture loss in in the treated sample was much greater than in the initial treatment and the difference between the treated and untreated samples was also less

MOISTURE CONTENT OF ROAD SURFACE

As a direct measure of the effectiveness of calcium chloride under field conditions, the moisture contents of samples of the surface soil from the treated and untreated roads were determined each week The relation between the moisture content in the top inch of treated and untreated road surfaces together with the amount of rainfall is shown graphically in

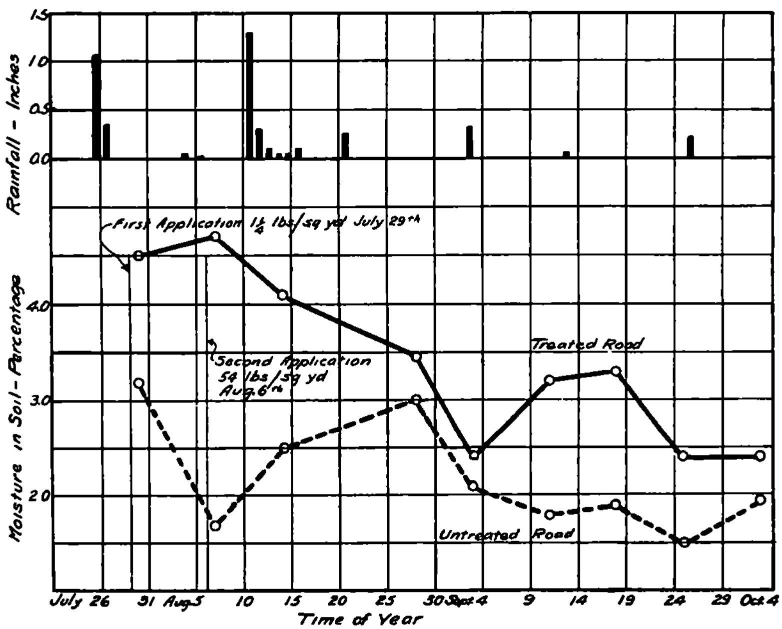


Figure 3. Relationship between the Moisture Content in Top Inch of Treated and Untreated Road Surfaces and the Amount of Rainfall. (South Carolina Project.)

Figure 3 The moisture content in the untreated road surface is always less than in the treated surface, but after prolonged dry periods these differences are quite small

The ability of the treated road to hold the moisture content for a longer period than the untreated surface after a rain is shown by the rise in the moisture curve after the rain of September 3 An analysis of the treated road curve also shows the effect of washing out the calcium chloride by the daily rains between August 11 and 16 This is manifested by the decreasing slope of the curve The extreme dryness in the vicinity of this project may be appreciated when it is noted that the total rainfall from August 22 to October 4 was only 0 81 inch

Missouri Project

This investigational road is located on Route 52 extending west from the city limits of Eldon for eight miles The first three miles are in Miller County, and are divided into two 1 5 mile sections, of which one is treated. The remainder of the project is in Morgan County and is divided into mile sections of which every other mile is treated The first treatment was made August 24 and consisted of approximately 1 25 pounds of calcium chloride per square yard, spread over a 20 foot width A second application was made on September 23 at the rate of 0 67 of a pound per square yard This is a gravel road and carries about 500 vehicles per day

MECHANICAL ANALYSIS OF SOIL SAMPLES

Table II contains the result of mechanical analyses of samples of the surface material before treatment Samples 1, 2, 3 and 4 were obtained from the compacted road surfaces and sample 5 from the excess material in the ridge along the edge of the road The dissimilarity in the texture

TABLE II

Mechanical Analysis of Surface Materials

MISSOURI PROJECT

Sieve and Screen Classification	Particle Size Distribution of Untreated Samples of Soil and Gravel (Percentage)				
	Sample Identification				
	1	2	3	4	5
Passing 2-inch Screen		100			
Passing 1½-inch Screen		99		100	
Passing 1¼-inch Screen	100	95	100	99	100
Passing 1-inch Screen	99	91	97	99	98
Passing ¾-inch Screen	95	85	91	96	87
Passing ½-inch Screen	88	78	79	90	76
Passing ¼-inch Screen	71	66	61	78	58
Passing ⅛-inch Screen	61	60	51	71	47
Passing No 10 Sieve	50	54	44	65	36
Passing No 18 Sieve	38	49	37	58	26
Passing No 35 Sieve	31	44	33	54	19
Passing No 60 Sieve	22	38	27	47	9
Passing No 140 Sieve	17	32	22	43	5
Passing No 200 Sieve	16	32	22	43	4
Silt (05- 005 mm diam)	7	17	7	25	2
Fine Clay (005- 002 mm diam)	2	4	4	5	0 4
Colloids (Less than 002 mm)	5	7	7	7	2

of the binder portion of these samples is shown by the uneven distribution of the constituents in the mechanical analyses.

MOISTURE CONTENT OF ROAD SURFACE

The relationship between the moisture content in the top inch of treated and untreated road surfaces for the month of October along with the amount of rainfall is shown graphically in Figure 4 This group of tests was started 12 days after the treated sections had received their second application of calcium chloride The results were different from those of the South Carolina project, but a comparison of the two projects shows that the minimum moisture content in the Missouri project was

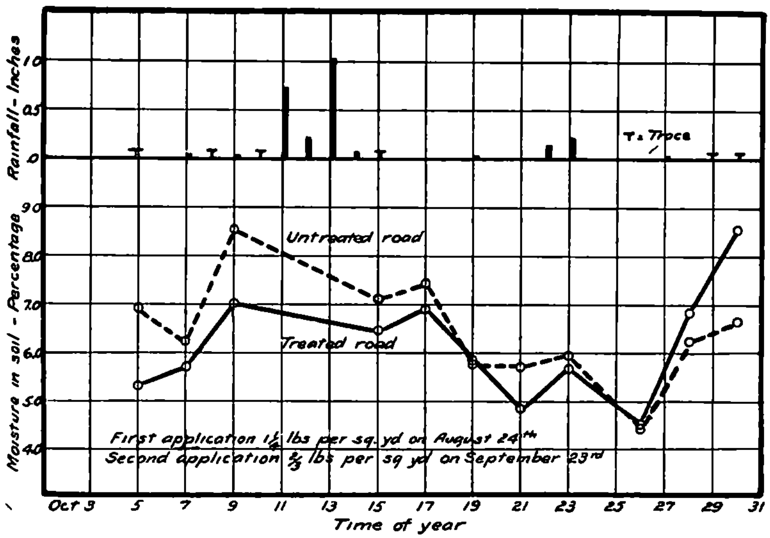


Figure 4. Relationship between the Moisture Content in Top Inch of Treated and Untreated Road Surfaces and the Amount of Rainfall. (Missouri Project.)

equal to the maximum moisture content in the South Carolina project The general conditions conducive to high evaporation losses were much less in Missouri than in South Carolina The fact that the untreated road surfaces showed a higher moisture content during practically the whole month, than the treated, for moisture contents between 5 and 8 5 per cent, may be due to the flocculation action of the calcium chloride, which caused a decrease in the surface area of the soil by coagulating the colloids The sharp rise in the moisture curve for the treated surface at the end of the month when the air temperature dropped to 40 degrees is of interest, as the rise is not related to the rainfall This increase in the moisture holding capacity of the calcium chloride treated soil may be due either to a deflocculation of the soil particles with the attendant increase in surface area or to the salt being concentrated at the surface by some migratory action influenced by low temperatures

The amount of rainfall shown in Figure 4 was taken from the United States Weather Bureau records at Springfield, Missouri, which is about 70 miles from the project

DISCUSSION

MR W R COLLINGS and MR LEROY C STEWART, *Dow Chemical Company*: The opinion is expressed that the slower rate of moisture loss in the treated soils as noted in the South Carolina tests (Figure 1) was due almost wholly to the presence of the salt rather than to flocculation of the soil particles Solutions of calcium chloride have considerably lower vapor pressures than water, consequently they evaporate at a slower rate than water Flocculation of the soil particles would mean a grouping together of small particles into larger ones Such action would result in larger soil pores, that is, a more open soil Hence if flocculation did take place its tendency would have been to increase the rate of moisture loss rather than to decrease it

The lower rate of moisture loss in the treated specimens is explainable by the fact that calcium chloride solutions have lower water vapor pressure than water In the treated specimens all the water from the soil had to pass through the low vapor pressure solution at the surface in order to be evaporated This is similar to the action of calcium chloride when applied to a damp road surface following a rain The solution formed near the surface of the road retards the evaporation of the moisture which had previously entered into the road bed

When, at the end of the 27 day drying period, both the treated and untreated samples were rewetted by applying moisture to the surfaces (Figure 2), the first part of the moisture applied to the treated sample carried the salt which had been on or near the surface, down into the lower part of the soil cake, the balance of the water staying in the upper part Thus, the rate of evaporation of the beginning of the second stage of the test was almost the same for both samples, because there was little difference in vapor pressure between the water in the untreated sample and the weak calcium chloride solution at the surface of the treated sample

The vapor pressure curves in Figure 5 show the performance of calcium chloride solutions under all ordinary temperature and humidity conditions encountered in road maintenance and explain how both the solid and its solutions absorb or evaporate water in contact with air until the solution strength is adjusted to one having a vapor pressure equal to that of the water in the air

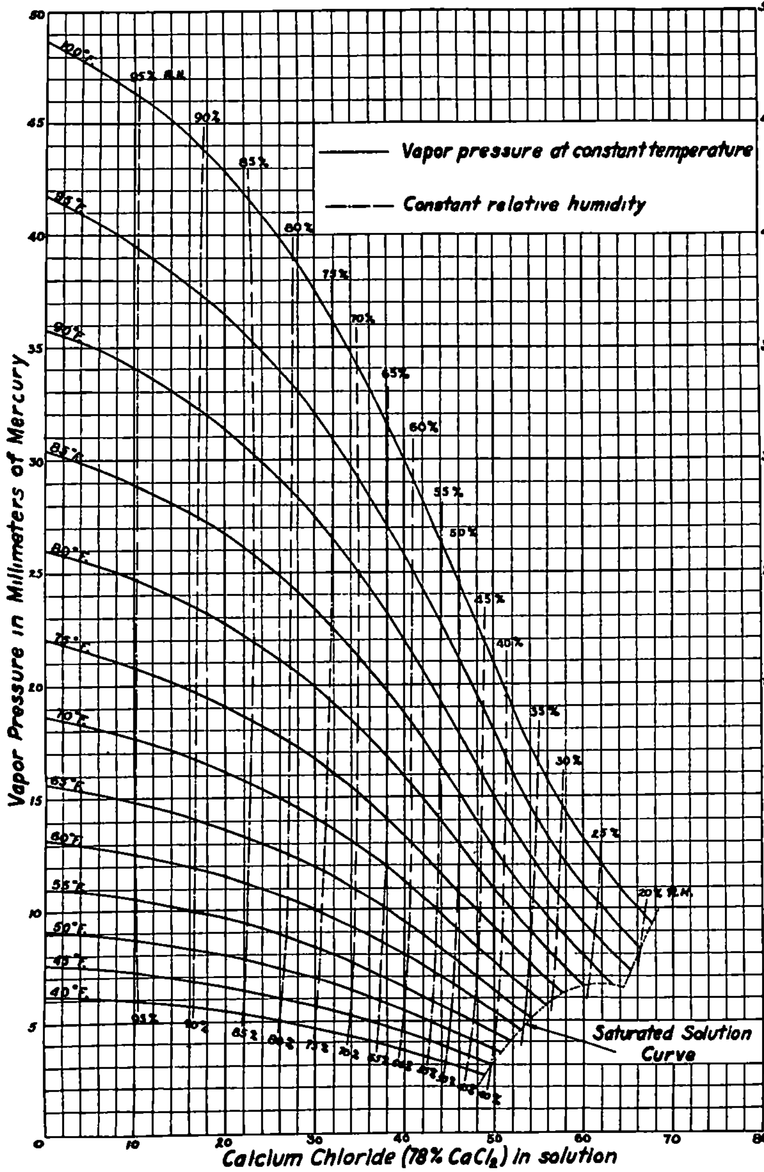


Figure 5. Vapor Pressures of Calcium Chloride Solutions (From Dow Chemical Co.)

EXPLANATIONS OF CURVES

1 VAPOR PRESSURE OF WATER is given by the intersection of temperature curves with 0% calcium chloride ordinate Thus vapor pressure of water at 85°F is 30 4 mm

2 VAPOR PRESSURES OF CALCIUM CHLORIDE SOLUTIONS of various strengths at different temperatures are shown by the heavy lines

Thus at 85°F a solution containing 20% calcium chloride (78% $CaCl_2$) has a vapor pressure of 26 8 mm and one containing 50% has a vapor pressure of 12 8 mm As noted above, water at this temperature has a vapor pressure of 30 4 mm

3 RELATIVE HUMIDITY CURVES show vapor pressures of water at each temperature and humidity represented by their intersections with temperature curves

Thus at 85°F and 50% relative humidity the vapor pressure of water in the air is 15 2 mm, i e, 50% of 30 4 mm Under these conditions of temperature and vapor pressure, calcium chloride or any of its solutions having a vapor pressure lower than 15 2 mm will absorb water sufficient to make a solution containing 46% calcium chloride (78% $CaCl_2$), which is the strength having a vapor pressure of 15 2 mm A weaker solution than 46% at this temperature and humidity will have a higher vapor pressure than 15 2 mm, hence will lose water to the air until this strength is reached

4 SATURATED SOLUTION CURVE is determined by the fact that when the humidity and temperature conditions fall to the right of it, vapor pressures are so low that calcium chloride solution will be concentrated to crystalline or solid form Such crystalline material will reabsorb moisture as soon as the humidity and temperature conditions change to those shown at the left of the saturated solution curve

REPORT OF INVESTIGATION OF USE OF CALCIUM CHLORIDE AS A DUST PALLIATIVE SEASON OF 1932

In 1932 an additional test road in Nebraska was placed under observation This section is located about 15 miles southeast of Lincoln on State Highway Number 2

The surfacing material of this road was the fine, hard clean material from the Platte River valley, known locally as "Sand-Gravel" A typical analysis is given in Table III This material compacts solidly and the resulting mat does not mix easily with the subgrade In general the subsoil conditions were good

A distinctive feature of the sand-gravel roads in Nebraska is the thinness of the surface metal On the experimental section it was approximately only 1½ inches thick

TABLE III

MECHANICAL ANALYSIS OF TYPICAL SURFACE MATERIAL

NEBRASKA PROJECT

Sieve and Screen Classification	Percentage
Passing 1½-inch Sieve	100
Passing ¾-inch Sieve	99
Passing ⅜-inch Sieve	96
Passing Number 4 Mesh Sieve	74
Passing Number 8 Mesh Sieve	57
Passing Number 14 Mesh Sieve	48
Passing Number 28 Mesh Sieve	41
Passing Number 48 Mesh Sieve	38
Passing Number 100 Mesh Sieve	36
Passing Number 200 Mesh Sieve	34
Silt	5 0
Clay	6 0

Specific Gravity 2 62
Voids 37 Per Cent
Weight per Cu Ft 103 Pounds

THE AMOUNTS OF CALCIUM CHLORIDE USED ON THE DIFFERENT PROJECTS

South Carolina—This typical sand-clay road received the first application of the second season of 1 2 pounds per square yard of calcium chloride on May 30th The second application was made on June 27th and consisted of 0 8 pounds per square yard The third and last application of 1 1 pounds per square yard was made on September 19 and 20th, 1932 The total amount for the season was 3 1 pounds per square yard

Missouri—This cherty gravel road was given its initial treatment of the second season of 0 7 pounds per square yard on June 10th The second application of 1 2 pounds per square yard was made on July 6th and the last application, made on August 11th, 1932, consisted of 1 3 pounds per square yard The total amount for this project was 3 2 pounds per square yard

Nebraska—This road was given its initial treatment of 1 3 pounds per square yard on July 9th and the second and last one consisting of one pound per square yard on September 12th, 1932

Evaporation Tests

EFFECT OF REWETTING SURFACE

Laboratory determinations of the rate of evaporation of moisture from treated and untreated samples were made on specimens in which the ratio of area exposed to total volume was similar to that of the road surface This was accomplished by placing the samples in metal containers having a depth of 8 inches and a diameter of 5 inches The samples were placed in these containers in layers conforming to the actual thicknesses of the different materials found in the surface mat and subsoil of the road To the surface of one of each set of samples calcium chloride was added at the rate of two pounds per square yard These containers were weighed daily and the rate of evaporation of the original moisture was calculated

At predetermined periods the surfaces of these samples were sprinkled with water to stimulate rain The amount of water added at each

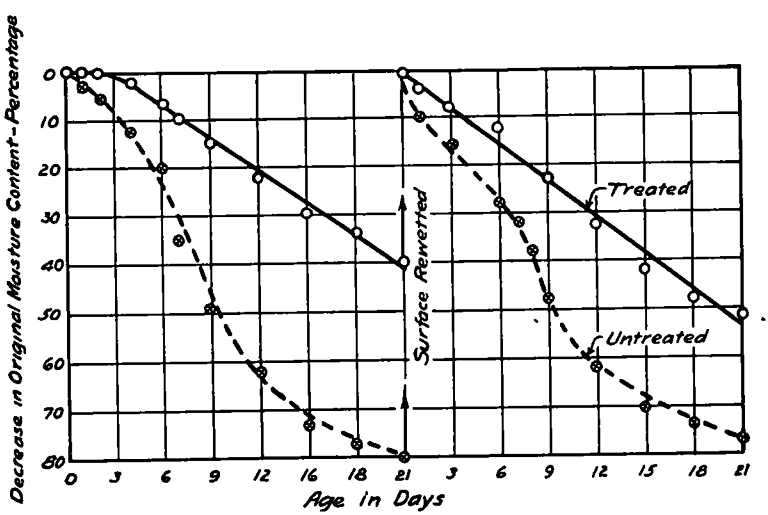


Figure 6. Relationship between the Initial and Subsequent Rates of Evaporation of Moisture from Treated and Untreated Soils. (Water Added to Surface.) (Laboratory Tests, South Carolina Project.)

rewetting was equivalent to one-half inch of precipitation The purpose of this procedure was to determine the relationship between the initial and subsequent rates of evaporation of moisture from treated and untreated soils, and from these data to deduce the extent of the decrease in effectiveness of calcium chloride treatment due to this process The principal difference between this laboratory procedure and

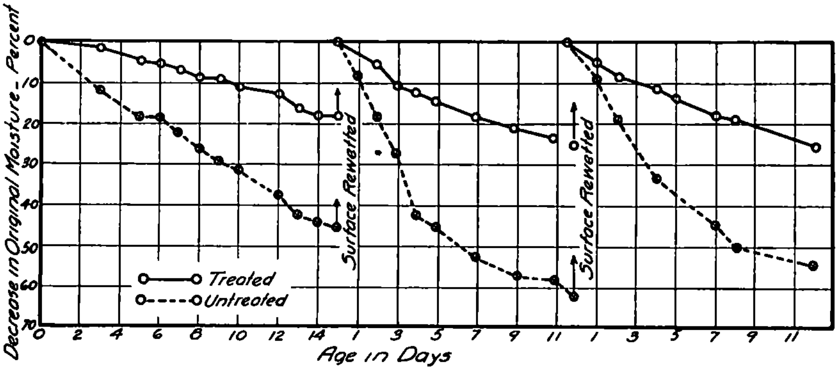


Figure 7 Relationship between the Initial and Subsequent Rates of Evaporation of Moisture from Treated and Untreated Soils. (Water added to Surface.) (Laboratory Tests, Missouri Project.)

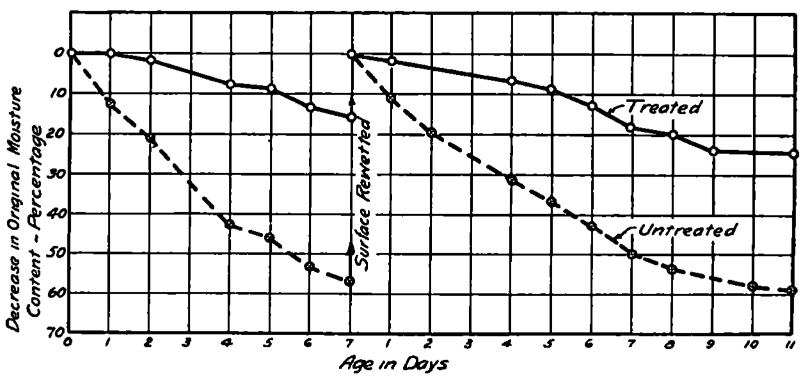


Figure 8. Relationship between the Initial and Subsequent Rates of Evaporation of Moisture from Treated and Untreated Soils (Water Added to Surface.) (Laboratory Tests, Nebraska Project.)

the conditions prevailing in the field is that all of the applied water must penetrate into the samples, whereas in the field there would be an appreciable amount of water lost due to run-off Figures **6**, **7** and **8** show the relationships between the initial and subsequent rates of evaporation of moisture from treated and untreated soils taken from each of the three experimental projects The data are in Table IV The results from the different projects for seven days after initial treatment

TABLE IV

EVAPORATION LOSSES FROM TREATED AND UNTREATED SOILS EXPRESSED AS PERCENTAGE OF ORIGINAL WEIGHT OF WATER IN THE SAMPLES (LABORATORY TESTS)

Source	Surface Condition	Number of Times Surface Rewetted	Age In Days																				
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
S Carolina	Treated	0	+1 0	+1 0		1 8		6 3	9 7		15 2			22 3			29 6			33 9			40 4
S Carolina	Untreated	0	3 2	4 7		12 0		21 1	32 5		49 5			61 7			72 6			76 6			80 0
S Carolina	Treated	1	4 2		7 7			13 1	16 0		22 6			31 5			41 6			47 8			51 8
S Carolina	Untreated	1	9 6		16 0			27 8	32 0		47 7			61 6			70 2			74 2			77 4
Missouri	Treated	0			1 4		4 5	5 5	7 2	8 6	9 5	11 2		12 9	16 4	18 3	18 3						
Missouri	Untreated	0			11 2		18 1	19 0	22 4	26 7	29 3	31 9		37 1	42 2	44 0	45 2						
Missouri	Treated	1		5 1	10 9	12 7	14 5	16 2	18 8		21 5	21 7	23 9	25 4									
Missouri	Untreated	1	8 4	18 3	27 1	42 2	45 0	47 8	52 4		57 1		58 4	62 8									
Missouri	Treated	2	5 0	8 2		11 9	14 0	15 3	18 2	19 9				25 3									
Missouri	Untreated	2	9 6	19 4		33 8	35 5	39 4	45 7	50 2				54 5									
Nebraska	Treated	0	0 0	1 4		7 9	8 9	13 2	15 7														
Nebraska	Untreated	0	12 3	21 0		42 8	46 0	53 3	56 5														
Nebraska	Treated	1	2 0			7 0	9 0	13 0	18 0	20 0	24 0		25 0										
Nebraska	Untreated	1	10 9	19 0		31 2	36 9	42 3	50 0	53 8	57 8		58 8										

and seven days after the first rewetting are compared graphically in Figure 9 This Figure shows that the average decrease in the effectiveness of the treatment after rewetting was 10 per cent The average evaporation from the treated samples is shown to be 31 per cent of that from the untreated samples before the initial wetting and 41 per cent after the rewetting

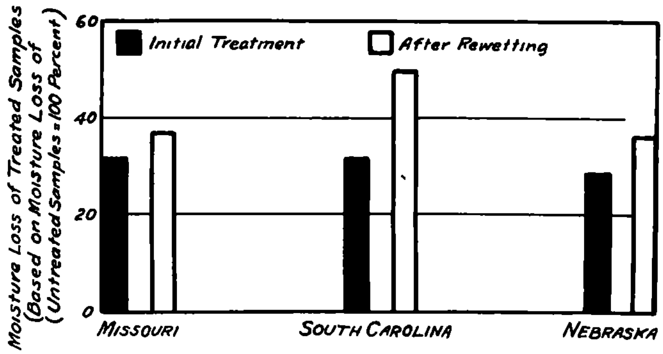


Figure 9. Relationship between the Rates of Evaporation of Moisture from Treated and Untreated Soils before and after Leaching with Water. (Comparisons Made on Data Obtained 7 Days after Initial Treatment and 7 Days after First Rewetting)

Effects of Different Methods of Applying Calcium Chloride

In Figure 10 are shown the relationships between the rates of evaporation of moisture from soils treated in different ways with the same amount of calcium chloride and from an untreated soil Treatment A consisted in placing the calcium chloride on the surface in the usual manner In treatment B the same amount of calcium chloride as used in treatment A was dissolved in the water used to bring the laboratory dried soil sample up to the moisture content of that of the sample used in treatment A The sample in treatment C had the same moisture content as that of sample A, but the surface was untreated The results of this series of tests show a decidedly lower rate of evaporation loss from the surface treated with calcium chloride than from the integrally mixed treatment The integral treatment shows a similar advantage over the untreated sample The data are in Table V

Description of Special Apparatus to Measure Evaporation

Some evaporation tests were also made volumetrically with a device especially developed for this purpose

In this apparatus, as shown in Figure 11 the amount of moisture lost by evaporation in any period is determined by the amount of water added at the supply inlet to bring the water-table in the soil back to the original elevation as registered on the meter stick by the indicator on the cork float The water was added twice daily, so that the maximum difference

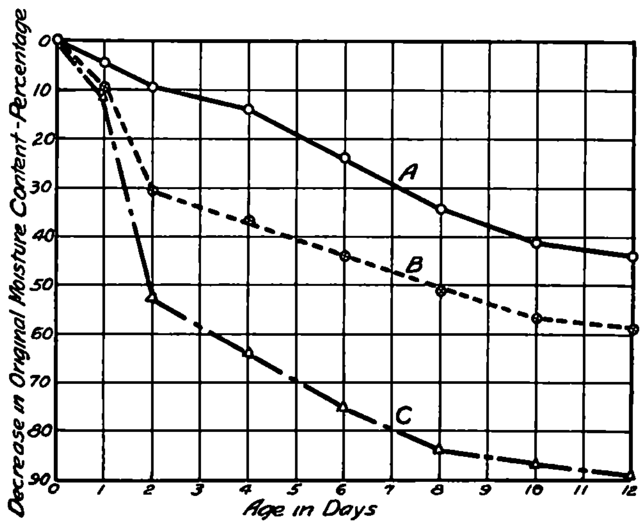


Figure 10. Relationship between the Rates of Evaporation of Moisture from Soils Treated in Different Ways with the Same Amount of Calcium Chloride and from Untreated Soils. (Laboratory Tests, Missouri Project.)

A. Ten grams of calcium chloride sprinkled on surface. Rate of 2 pounds per square yard.

B. Ten grams of calcium chloride added to water to obtain desired moisture content.

C. Untreated.

TABLE V

EVAPORATION LOSSES FROM SIMILAR SOILS TREATED IN DIFFERENT WAYS WITH THE SAME AMOUNT OF CALCIUM CHLORIDE AND FROM UNTREATED SOILS (LABORATORY TEST MISSOURI PROJECT)

(PERCENTAGE OF ORIGINAL WEIGHT OF WATER IN THE SAMPLES)

Treatment	Age In Days						
	1	2	4	6	8	10	12
A	4 2	9 4	13 5	24 5	34 4	41 1	43 8
B	9 4	30 2	36 5	43 8	51 0	56 3	58 4
C	9 4	52 1	63 6	75 0	83 4	86 4	88 6

A—Ten grams of calcium chloride sprinkled on surface (equivalent to two pounds per square yard)

B—Ten grams of calcium chloride added to water to obtain the same moisture content as A and C

C—Untreated Contains same moisture content as A and B

in the water-table elevation was approximately one inch The depth from the surface of the soil to the water-table was held at 15 inches

The test soil, which was 12 inches in depth was taken directly from the road and placed in the steel pipe in such a manner that the original arrangement was not changed. This material was packed into the

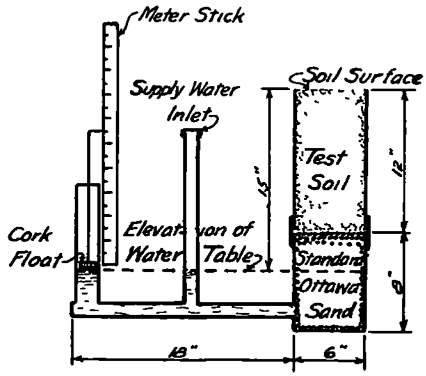


Figure 11. Diagrammatic Sketch of Apparatus for Measurement of evaporation from soils.

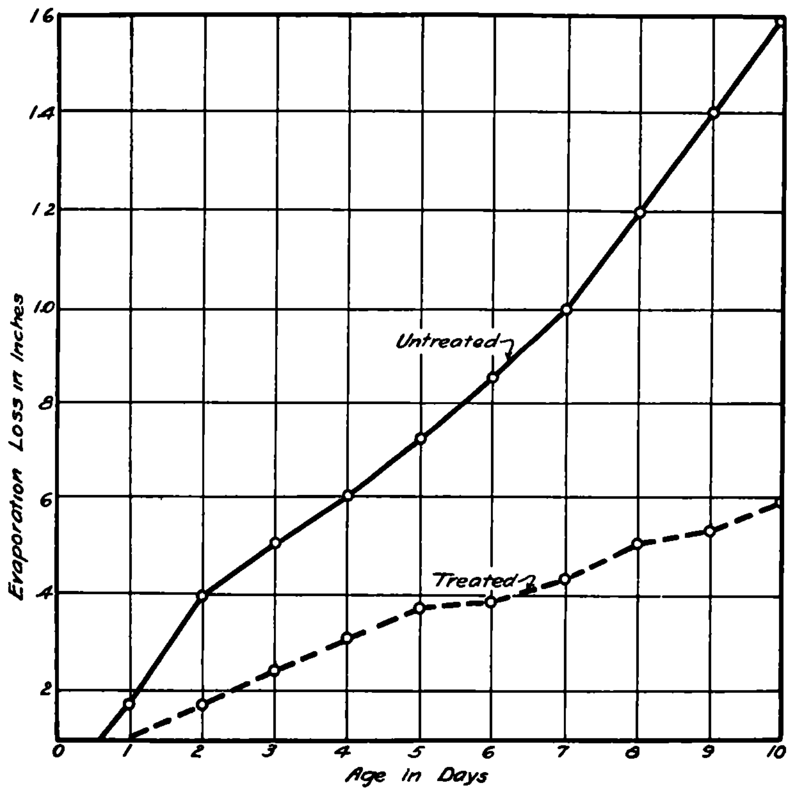


Figure 12. Relation of Evaporation Losses from Treated and Untreated Soils. (South Carolina Project.) (Data from Evaporation Apparatus.)

cylinder by tamping in three inch layers The sub-stratum of Standard Ottawa sand was moistened and tamped into the lower cylinder A layer of cheese cloth was placed on top of the Standard Ottawa sand before the upper test soil cylinder was screwed on to the lower cylinder There was intimate contact between the materials in the two cylinders, as the height of that in the lower cylinder was such that the contact would be obtained before the upper cylinder could be threaded to refusal To insure no moisture loss the outside of this loose connection was heavily coated with paraffin The apparatus was constructed of the two short sections of steel pipe six inches in diameter and short pieces of $\frac{3}{4}$ and $1\frac{1}{2}$ inch iron pipe The diagrammatic sketch in Figure 11 gives other dimensions

TABLE VI

EVAPORATION LOSSES FROM TREATED AND UNTREATED SOILS AND THE PREVAILING WEATHER CONDITIONS (SOUTH CAROLINA PROJECT) (DATA FROM EVAPORATION APPARATUS)

Number of Days	Untreated					Treated (2 lbs Calcium Chloride per sq yd)				
	Date	Maximum Temperature	Relative Humidity (Noon)	Precipitation (Inches)	Evaporation Loss (Inches)	Date	Maximum Temperature	Relative Humidity (Noon)	Precipitation (Inches)	Evaporation Loss (Inches)
1	May 18	79	53	0 03	0 17	May 31	82	33	0 00	0 09
2	May 19	66	72	0 08	0 22	June 1	83	40	0 00	0 08
3	May 20	69	89	0 14	0 11	June 2	82	39	0 00	0 07
4	May 21	80	66	0 08	0 10	June 3	81	48	0 00	0 07
5	May 22	78	59	0 31	0 12	June 4	83	42	0 00	0 06
6	May 23	73	46	0 02	0 13	June 5	86	66	0 03	0 01
7	May 24	83	36	0 00	0 14	June 6	91	50	0 00	0 05
8	May 25	85	38	0 00	0 20	June 7	96	42	0 00	0 07
9	May 26	87	56	0 00	0 21	June 8	89	58	0 36	0 03
10	May 27	88	52	0 00	0 22	June 9	86	57	0 07	0 06
Totals and Averages		79	57	0 66	1 62		86	48	0 46	0 59

In Figure 12 are shown the relations between the rates of evaporation loss from treated and untreated soils as determined by this apparatus These tests were not made simultaneously as only one apparatus was constructed, but from the data in Table VI it will be noted that the climatological conditions were more favorable for evaporation during the test of the treated samples. In both cases the surface of the soil was protected from rainfall

From a comparison of the results from this apparatus and those of the weighing method, it is believed that this method gives as dependable results as the weighing method and is less cumbersome An automatic control to maintain the water-table at a constant elevation would be a desirable improvement in this device

Relation between Vapor Pressure and Evaporation

Vapor pressure is defined by the physical chemist as the "tendency shown by a substance to pass from the liquid or solid into the gaseous state" This phenomenon is of great importance in understanding the effect of calcium chloride on the evaporation of water from soil For similar humidity and temperature the vapor pressure of a calcium chloride solution is always lower than that of water, which means a slower rate of evaporation Vapor pressure may be considered as being a property of the free energy at the surface of the moisture film that surrounds each particle of the soil With an increase in the concentration of the calcium chloride solution the vapor pressure is decreased with a corresponding decrease in moisture loss due to evaporation It is chiefly the lower vapor pressure of the calcium chloride solution on the surface of the treated soil samples that retards the evaporation of the moisture from the soil This layer of solution on the surface of the soil may be conceived of as an effective semi-permeable blanket through which the moisture from the soil has difficulty in reaching the surface where evaporation takes place

Effect of Hygroscopic Property of Calcium Chloride on Evaporation

The differences observed in the rate of evaporation between the treated and untreated samples were not entirely due to the difference in the vapor pressures of the calcium chloride solution and of the soil moisture in the untreated samples The hygroscopic property of the calcium chloride is also partially responsible Figure 13 depicts the relations between the rates of evaporation of moisture from treated and untreated soils and relative humidity These data show that during the night when the relative humidity increases the calcium chloride solution absorbs moisture from the air and there is a gain in weight of the soil sample Under like conditions the untreated soil continues to lose weight, but less rapidly

Moisture Content of Road Surface

As a direct measure of the effectiveness of calcium chloride under field conditions, the moisture contents of samples from different depths of the treated and untreated roads were determined at stated intervals The results from two of the experimental projects are shown in Figures 14 to 17 and Tables VII and VIII inclusive These data show that the moisture content in the untreated roads is less than in the treated roads

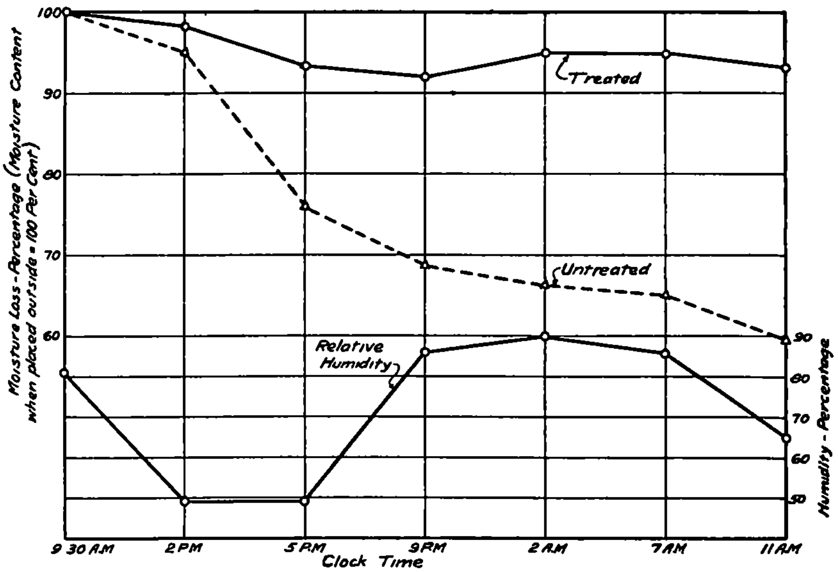


Figure 13. Relationship between the Rates of Evaporation of Moisture from Treated and Untreated Soils and the Effect of Relative Humidity on the Hygroscopic Property of the Calcium Chloride Treated Soil. (South Carolina Project.)

The greatest moisture difference between the treated and untreated roads appears to occur during prolonged dry intervals The results from the Nebraska project, Figure 16, show the rapid drying out that is characteristic of this material Figure 15 shows the relations between

TABLE VII

MOISTURE CONTENT OF TREATED AND UNTREATED ROAD SAMPLES (SOUTH CAROLINA PROJECT)

Time (Month)	Surface Condition	Moisture Content at Different Depths (Inches from Surface)						Number of Tests Included in Average
		1	2	3	4	5	Average	
June	Treated	5 6	6 1	6 9	8 3	6 0	6 8	20
June	Untreated	4 6	5 4	6 4	6 1	4 9	5 6	20
July	Treated	2 2	5 7	7 9	7 4	5 6	5 8	20
July	Untreated	2 5	5 8	6 5	6 1	5 7	5 3	20
August	Treated	4 6	5 7	6 4	5 8	4 8	5 6	25
August	Untreated	2 1	3 8	5 0	4 6	5 4	3 9	25
September	Treated	2 7	7 2	6 8	5 3	5 1	5 5	20
September	Untreated	3 6	5 1	6 0	6 5	5 8	5 3	20
October	Treated	3 6	5 1	5 1	5 9	5 4	4 9	10
October	Untreated	3 2	3 2	3 3	5 3	5 2	3 8	10
Weighted Average	Treated	3 8	6 0	6 8	6 6	5 4	5 7	
	Untreated	3 1	4 8	5 6	5 7	5 5	4 9	

TABLE VIII

MOISTURE CONTENT OF TREATED AND UNTREATED ROAD SAMPLES (NEBRASKA PROJECT)

Time	Surface Condition	Moisture Content at Different Depths (Inches from Surface)				
		1	2	3	4	5
7-11-32	Treated	3 3	5 6	11 4		11 9
7-11-32	Untreated	1 0	12 1	12 0	12 0	
7-13-32	Treated	3 3	5 9	13 7	11 7	12 1
7-13-32	Untreated	0 9	6 1	11 3	11 4	12 1
7-15-32	Treated	1 8	3 7	9 6	11 3	11 2
7-15-32	Untreated	0 8	4 7	8 7	10 0	9 8
7-18-32	Treated	1 7	3 2	9 6	9 6	11 1
7-18-32	Untreated	0 8	3 7	9 8	10 8	11 8
7-20-32	Treated	2 0	3 1	9 0	11 1	13 0
7-20-32	Untreated	0 8	4 3	8 5	11 1	12 6
7-22-32	Treated	2 0	3 1	10 2	12 5	11 7
7-22-32	Untreated	0 8	6 5	10 2	10 8	12 1
7-23-32	Treated	5 3	4 7	9 1	9 8	9 8
7-23-32	Untreated	4 7	5 5	8 1	7 8	9 6
7-26-32	Treated	2 0	2 8		8 8	11 1
7-26-32	Untreated	1 7	5 1	10 5	10 3	9 9
7-28-32	Treated	2 6	4 5	10 3	13 4	13 0
7-28-32	Untreated	1 5	9 4	12 7	15 7	16 0
8- 1-32	Treated	4 3	5 0	11 4	12 4	12 2
8- 1-32	Untreated	3 7	5 2	11 5	12 0	11 4
8- 3-32	Treated	2 6	4 5	8 4	14 1	14 3
8- 3-32	Untreated	1 5	5 3	13 1	13 3	12 8
8- 5-32	Treated	1 1	3 8	8 2	15 4	13 2
8- 5-32	Untreated	0 6	3 8	13 1	13 0	13 5
Average	Treated	2 7	4 2	10 1	11 8	12 1
	Untreated	1 6	4 9	10 8	11 5	12 1

moisture content of treated and untreated road samples taken at different depths from the surface of the South Carolina project These results show that the treated road moisture content is higher as far down as the fourth inch In Figure 17 we have similar data for the Nebraska project, in which case there is very little difference below the top inch

When we consider the thinness of the mat surface and the dense clay subsoil under this road, these results appear reasonable The metero-logical data for the South Carolina and the Nebrasks projects are shown in Figures 18 and 19 respectively

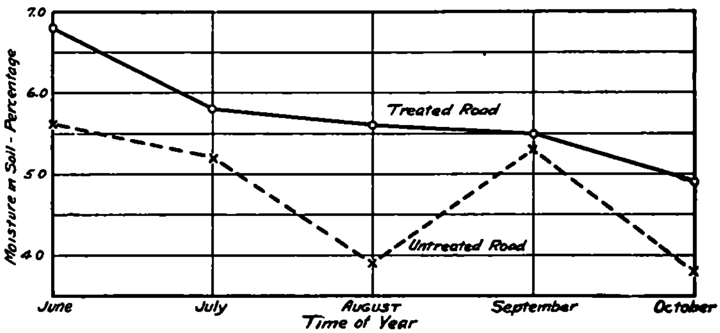


Figure 14. Relationship between the Moisture Content of Treated and Untreated Road Surfaces. (South Carolina Project)

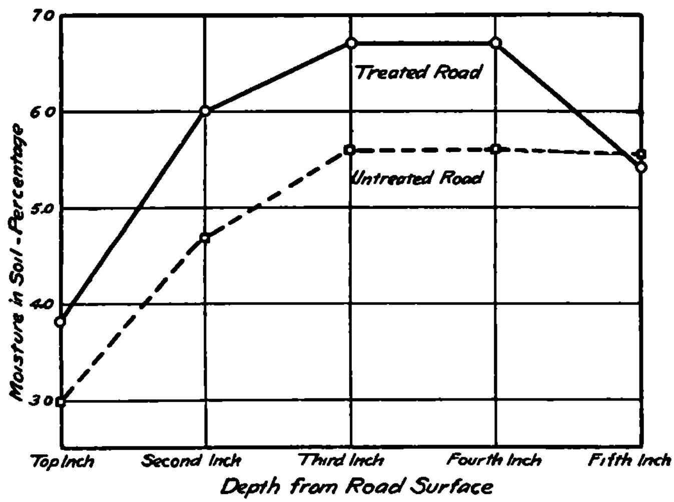


Figure 15. Relationship between Moisture Content of Treated and Untreated Road Samples Taken at Different Depths from Surface. (South Carolina Project.)

Factors that Influence the Retention of Calcium Chloride in a Road Surface

BASE-EXCHANGE

The loss of calcium chloride due to chemical reaction with the soil, or base-exchange, is dependent on the chemical composition and the degree of acidity of the soil The fact is well established that an exchange of bases takes place when a soil is treated with calcium chloride

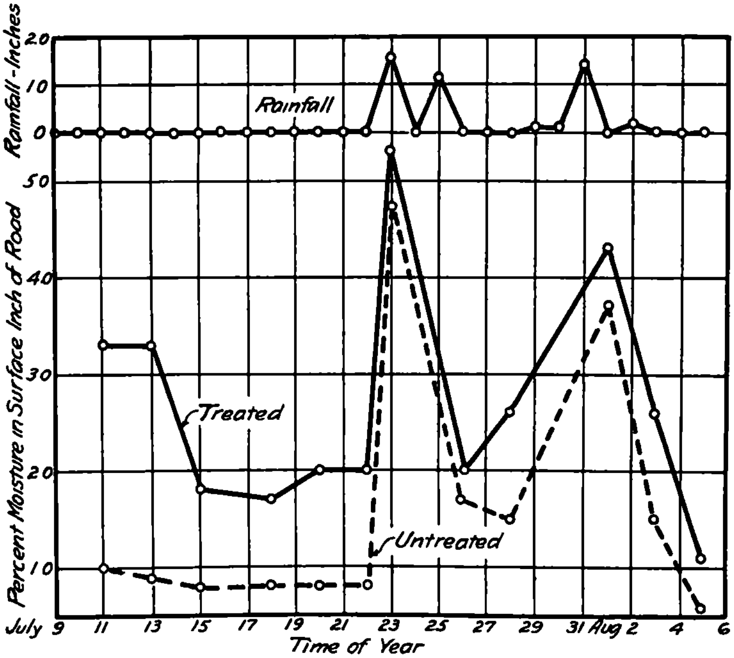


Figure 16. Relationship between the Moisture Content in Top Inch of Treated and Untreated Road Surfaces and the amount of Rainfall. (Nebraska Project.)

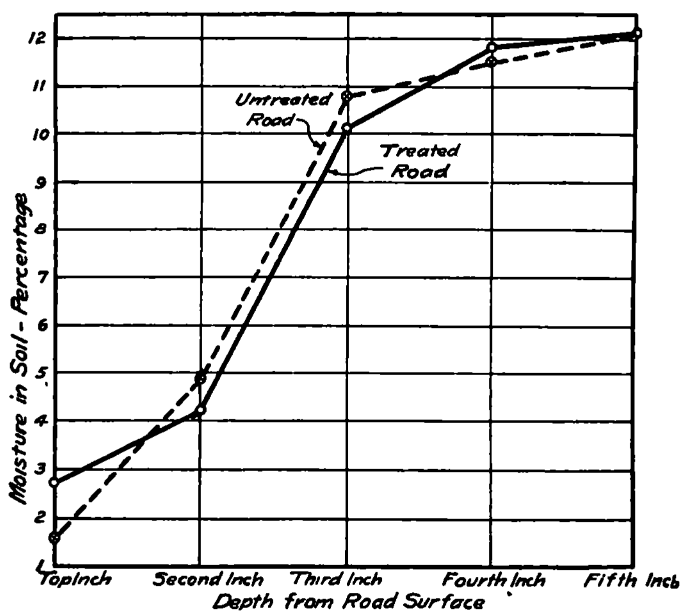


Figure 17. Relationship between Moisture Content of Treated and Untreated Road Samples Taken at Different Depths from Surface. (Nebraska Project.)

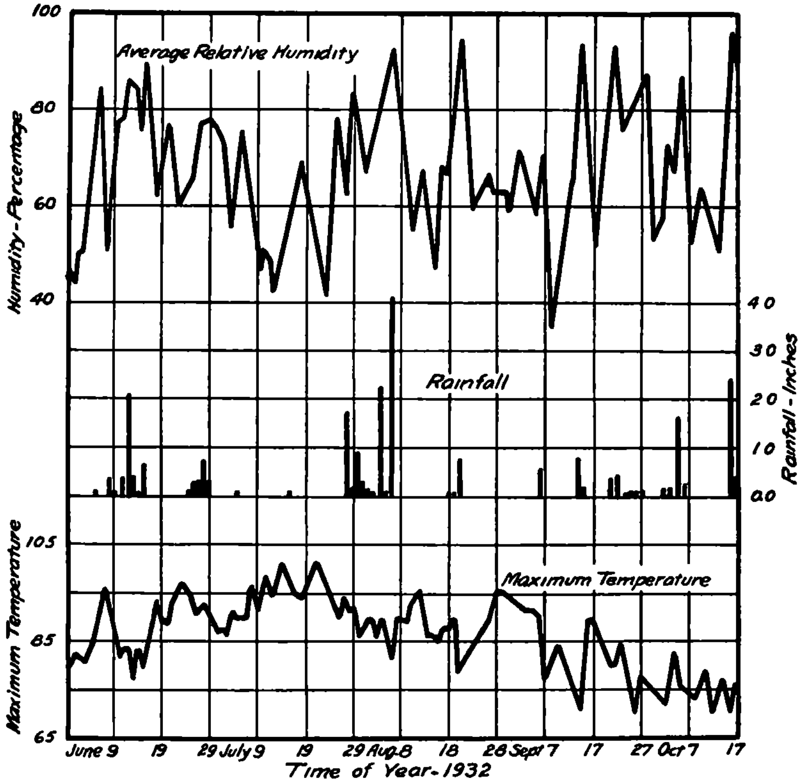


Figure 18. Comparative Meteorological Data. (South Carolina Project.)

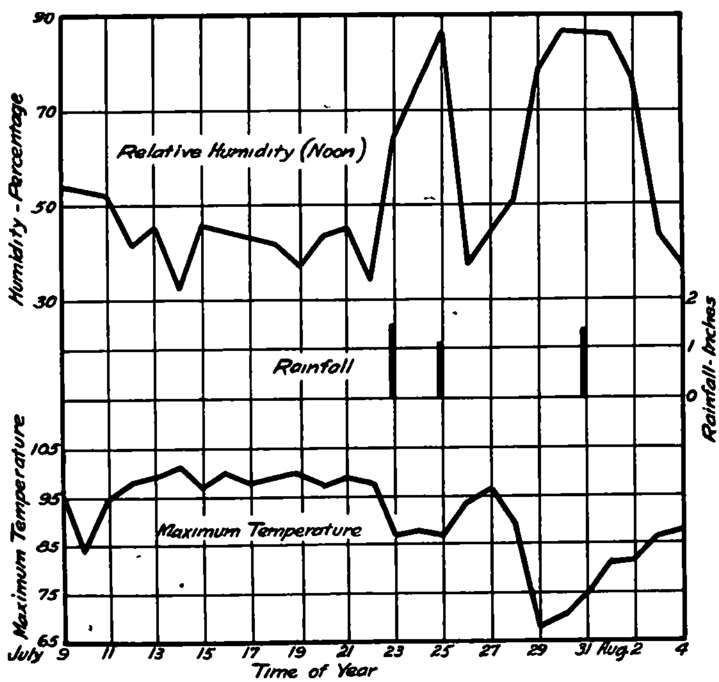


Figure 19. Comparative Meteorological Data. (Nebraska Project.)

solution That is, part of the calcium is absorbed by the soil and is replaced by an equal amount of some other base from the soil This exchange of bases is probably not carried to completion by a single treatment This chemical exchange is the least influential one of the three dispersion factors in reducing the amount of calcium chloride, but it is mentioned because in some soils it may influence the structural texture in such a manner as to make its effect of some importance It does offer the best method for determining the effects of calcium chloride on different soils At present it appears that this action is usually offset by certain inherent structural characteristics of the soil, which play a more important rôle in the retention of the salt

RAINFALL

The amount of calcium chloride lost due to the washing out and leaching down effects of rain is worthy of consideration Several factors must be considered as contributing agencies in this action Chief among them are: (a) type of rain, (b) time of rain in relation to chemical application, (c) water permeability of the soil and (d) composition of the soil The laboratory study consisted in placing two identical samples of the road material in metal containers and applying calcium chloride to the surfaces; then after a stated interval of time, water was sprinkled on the surface of one sample and the same amount of water was added to the subsoil of the other In the one case we have the leaching down effect of the calcium chloride solution against the rise of capillary water and in the other the added water acts as excess capillary water and tends to hold the initially applied calcium chloride at or near the surface. Chemical determinations for calcium chloride content at different depths from the surface were made on these samples and the results are shown in Figure 20

The calcium chloride content in the second inch of the sample to which water was added on the surface was found to be 75 per cent of that in the first inch and in the sample to which the water was added through the subsoil, the calcium chloride content was found to be only 28 per cent of that in the first inch This shows that an appreciable amount of the soluble salt leaches down into the subsoil The small variations in the calcium chloride content at depths more than two inches below the surface show that there is a limiting depth for the leaching action in this soil The positive movement of the soluble salt upward due to surface evaporation after having been leached down into the lower layers, is shown graphically in Figure 21 These results are from tests on two samples in which the depth of material was a variable. In sample A, Figure 21, the calcium chloride content in the surface inch was approximately one per cent after being leached three times with water The calcium chloride content rose to approximately two per cent after being dried for 16 hours at 100°C In sample B, which had a greater depth of surface metal than sample A we note that the calcium chloride content rose from approximately one per cent in the

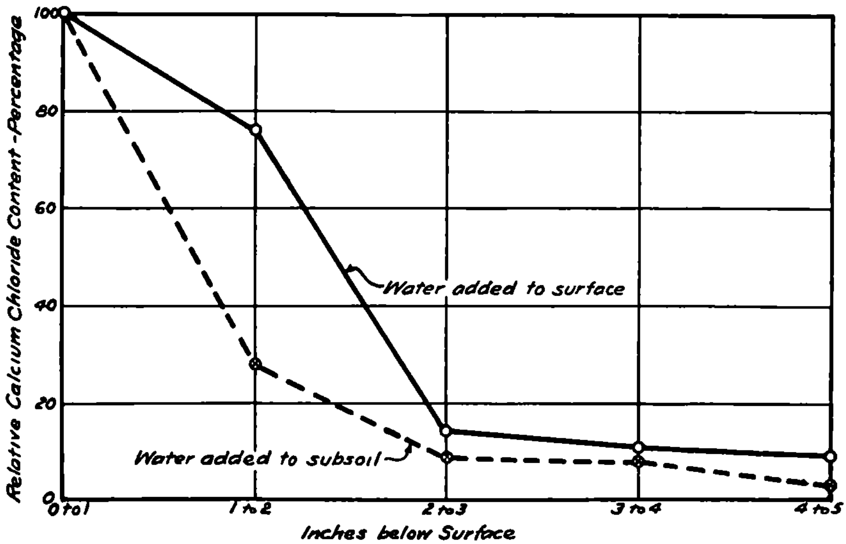


Figure 20. Relative Movement of Calcium Chloride into Soils Due in One Case to Adding Water to the Surface of the Sample and in the Other to Adding an Equivalent Amount of Water through the Subsoil. (Missouri Project.)

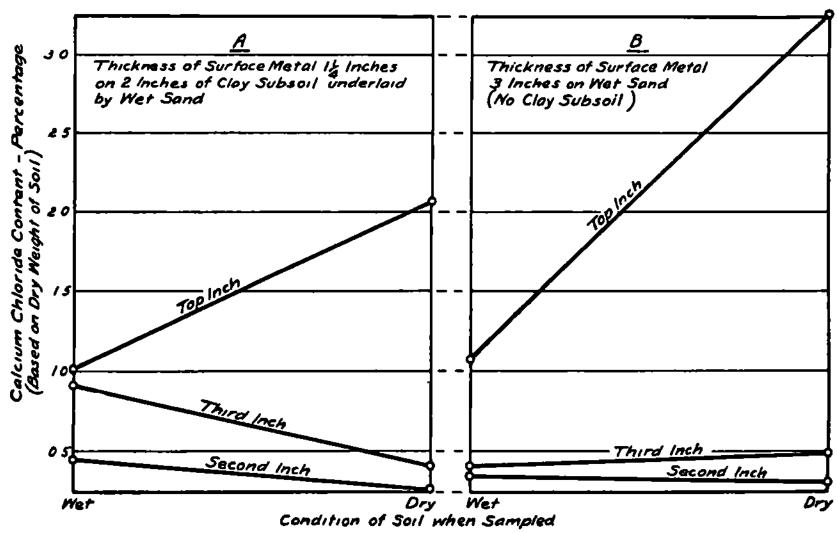


Figure 21. Movement of Calcium Chloride in Different Samples of Road Material after Leaching with Water and then Drying the Samples. (Laboratory Tests, Nebraska Project)

wet state to 3 5 per cent in the dry state The lower layers were not affected to any marked degree, although there was a slight tendency for the calcium chloride content to decrease with the change from the wet to dry state These data are in Table IX

TABLE IX

CHEMICAL ANALYSES OF CALCIUM CHLORIDE CONTENT AT DIFFERENT LAYERS IN THE SOIL PROFILE AFTER LEACHING WITH WATER AND THEN RE-ANALYZING THE SOIL AT THESE SAME ELEVATIONS AFTER DRYING THE SAMPLES (LABORATORY TEST, NEBRASKA PROJECT)

Identification	Location of Sample (Inches Below Surface)	Conditon of Sample at Test	Percentage of Calcium Chloride (Based on Dry (Weight)	Percentage of Water in Sample
PAW	1	Wet	1 02	7 3
PAW	2	Wet	0 45	18 4
PAW	3	Wet	0 92	22 1
PAD	1	Dry	2 06	3 7
PAD	2	Dry	0 26	1 6
PAD	3	Dry	0 40	5 6
PCW	1	Wet	1 07	6 4
PCW	2	Wet	0 33	6 7
PCW	3	Wet	0 41	6 7
PCD	1	Dry	3 27	5 5
PCD	2	Dry	0 31	1 6
PCD	3	Dry	0 49	1 5

Figures 22 and 23 demonstrate conclusively the leaching of the calcium chloride from the surface into the lower layers This leached soluble salt will be carried toward the surface as the capillary water moves upward due to surface evaporation and the concentration of the solution in the upper layer will be increased The extent of this upward movement will depend upon the penetration of the surface water after rewetting, the duration and the intensity of the drying period and probably the composition of the soil Tables X and XI contain the chemical analyses of the soil samples from the South Carolina and Missouri projects

Figure 24 shows the loss of calcium chloride from the different experimental projects due to all causes These results are the differences between the average calcium chloride content in the road base at the various depths immediately after treatment with calcium chloride and the content after different intervals of time had elapsed Referring to the Nebraska data in this figure, attention is called to the much lower loss of calcium chloride content after the second treatment (B) The loss represented by (A) is that determined after the initial treatment of

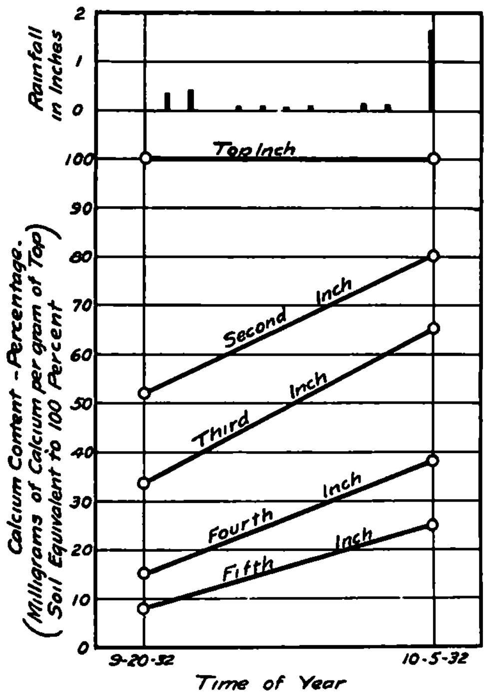


Figure 22. Extent of Leaching of Calcium Chloride into the Road Surface and Its Relation to Rainfall.

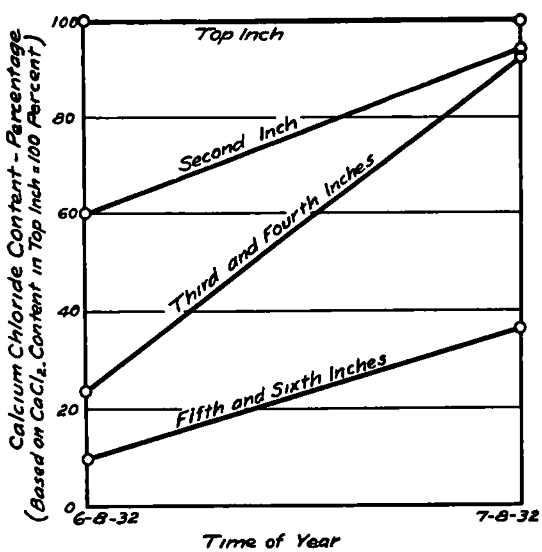


Figure 23. Extent of Leaching of Calcium Chloride into Road Surface. (Missouri Project.)

TABLE X

CHEMICAL ANALYSES OF SOIL SAMPLES TAKEN FROM DIFFERENT DEPTHS OF TREATED ROAD (SOUTH CAROLINA PROJECT)

Location of Sample (Inches Below Surface)	Milligrams of Calcium Per Gram of Soil		Percentage Average of A and B	Date
	Sample A	Sample B		
0–1	2 10 (100)*	9 72 (100)*	100	9–20–32
1–2	1 20 (57)	4 57 (47)	52	9–20–32
2–3	0 88 (42)	2 45 (25)	34	9–20–32
3–4	0 39 (19)	1 13 (12)	15	9–20–32
4–5	0 20 (9)	0 59 (6)	8	9–20–32
Average	0 95	3 69		9–20–32
0–1	0 61 (100)	4 40 (100)	100	10– 5–32
1 2	0 57 (94)	2 85 (65)	80	10– 5–32
2–3	0 49 (81)	2 12 (48)	65	10– 5–32
3–4	0 27 (44)	1 47 (33)	38	10– 5–32
4–5	0 18 (29)	0 90 (21)	25	10– 5–32
Average	0 42	2 35		10– 5–32

* Figures in parenthesis are the Calcium content expressed as a percentage of the Calcium content in the top inch

TABLE XI

CHEMICAL ANALYSES OF SOIL SAMPLES TAKEN FROM DIFFERENT DEPTHS OF TREATED ROAD (MISSOURI PROJECT)

Location of Sample (Inches Below Surface)	Milligrams of Calcium Chloride Per Gram of Soil		Percentage Average of $\frac{Ca}{2}$ and Cl	Date
	$\frac{Ca}{2}$	Cl		
0–1	0 078 (100)*	0 080 (100)*	100	6–8–32
1–2	0 046 (59)	0 049 (61 3)	60 0	6–8–32
2–3	0 027 } (22 4)	0 029 } (24 5)	23 5	6–8–32
3–4	0 008 }	0 010 }		6–8–32
4–5	0 013 } (12 8)	0 006 } (6 8)	9 8	6–8–32
5–6	0 007 }	0 005 }		6–8–32
Average	0 030	0 030		6–8–32
0–1	0 022 (100)	0 032 (100)	100	7–8–32
1–2	0 022 (100)	0 028 (87 6)	94 0	7–8–32
2–3	0 025 } (102 3)	0 028 } (84 0)	93 0	7–8–32
3–4	0 020 }	0 026 }		7–8–32
4–5	0 010 } (34 2)	0 013 } (37 0)	36 0	7–8–32
5–6	0 005 }	0 011 }		7–8–32
Average	0 021	0 023		7–8–32

* Figures in parenthesis are the Calcium or Chloride content expressed as a percentage of the Calcium or Chloride content in the top inch

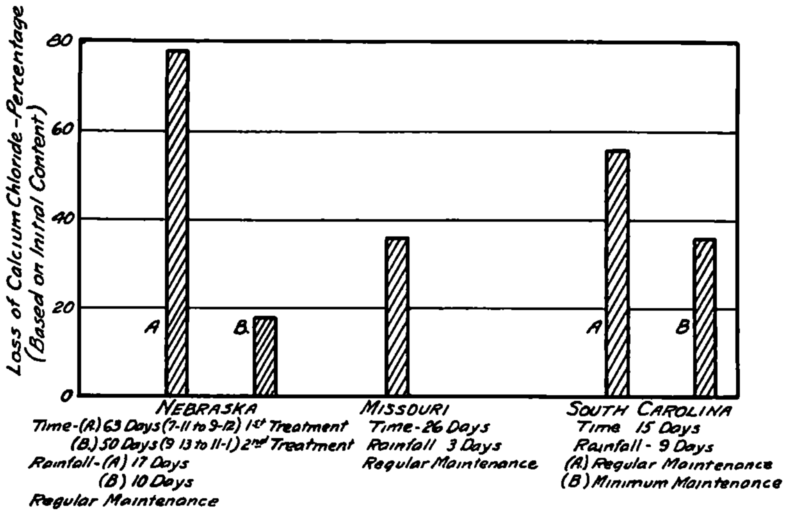


Figure 24. Loss of Calcium Chloride Content from the Different Experimental Projects Due to the Combined Action of Rainfall and Maintenance Manipulation

TABLE XII

CHEMICAL ANALYSES OF SOIL SAMPLES TAKEN FROM DIFFERENT DEPTHS OF TREATED ROAD (NEBRASKA PROJECT)

Location of Sample (Inches Below Surface)	Percentage of Calcium Chloride (Based on Dry Weight)	Date
0–1	1 70	7–11–32
1–2	1 73	7–11–32
2–3	0 69	7–11–32
3–4	0 07	7–11–32
4–5	0 04	7–11–32
Average	0 85	7–11–32
0–1	0 11	9–12–32
1–2	0 24	9–12–32
2–3	0 21	9–12–32
3–4	0 19	9–12–32
4–5	0 17	9–12–32
Average	0 18	9–12–32
0–1	1 31	9–13–32
1–2	0 32	9–13–32
2–3	0 21	9–13–32
3–4	0 13	9–13–32
4–5	0 24	9–13–32
Average	0 44	9–13–32
0–1	0 38	11– 1–32
1–2	0 27	11– 1–32
2–3	0 51	11– 1–32
3–4	0 36	11– 1–32
4–5	0 17	11– 1–32
Average	0 36	11– 1–32

the road surface On the South Carolina project we have the only direct quantitative comparison between the loss of calcium chloride under regular and restricted maintenance Undoubtedly the total number of days on which it rained minimized this effect This graph is drawn from the data in Tables X, XII and XIII

TABLE XIII

CHEMICAL ANALYSES OF SOIL SAMPLES TAKEN FROM DIFFERENT LOCATIONS ON THE SURFACE OF A TREATED ROAD (MISSOURI PROJECT)

Date	Milligrams of Calcium per Gram of Soil					Average
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	
8-18-32	2 02	1 43	2 40	2 45	2 58	2 18
9-13-32	1 48	1 10	1 45	1 22	1 72	1 39

MAINTENANCE MANIPULATION

Prevailing maintenance methods on traffic bound roads require that a loose surface layer from ½ to ¾ inches thick be present at all times The purpose of this loose surface material is to retard the formation of pot holes and corrugations and to aid in resistance to erosion This is accomplished by blading or dragging the loose material back and forth or along the surface of the road These maintenance methods are employed on both untreated gravel roads and on those on which calcium chloride is applied for a dust palliative This procedure is well adapted to untreated surfaces where the top layer loses moisture rapidly thus lowering stability to the point where raveling and other surface defects occur These are corrected to various extents, depending upon the nature of the float material, by the blading or dragging These operations do not eliminate the dust and even may, if cohesionless float material is used, increaese it by the grinding action of traffic There is a definite moisture range in the surface of a bonded gravel road, within which the road gives very satisfactory service—not too wet to cause permanent plastic deformation or rutting and not too dry to destroy the cohesion of the surface particles resulting in loose material which causes corrugations and dust

Treatment with calcium chloride has been used for many years as a simple artificial method of maintaining a beneficial moisture content in the road surface But the success of such treatment has been variable

From observations made on the Missouri project during the early part of the summer it was noticed that the interval of time during which the calcium chloride treatment was effective was less on that part of the project on which a greater amount of surface "float material," was being carried The Nebraska project which was started shortly after this offered a good opportunity to test out the relative effects of different amounts of maintenance manipulation on surfaces with and without "float material" On one mile of the project, after the calcium chloride was applied, the maintenance manipulation was practically discontinued and the compaction of the damp road surface by traffic soon removed the usual loose float material layer After five weeks this section still retained practically the initial effectiveness of the calcium chloride, whereas the other three treated miles, which carried a loose surface layer and were manipulated daily by maintenance machinery showed considerable loss in effectiveness The one mile of treated "Bare-surface" was entirely free from corrugations and presented a durable, dustless and smooth surface

There appear to be two reasons for these results *First, the true "mulch" action of calcium chloride* When calcium chloride dissolves on a road it forms a continuous layer of solution on the upper part of the surface This calcium chloride solution has a considerably lower vapor pressure than water, and therefore retards the evaporation of the water near the surface, thus tending to maintain the amount of moisture above the detrimental minimum content. This action is aided also by the hydroscopic property of the salt which permits it to take up moisture from the air during periods of higher humidity *Second, the absence of loose surface float material and the harmful effects of maintenance manipulation.* The presence of unbonded float material acts as a grinding medium on the road surface under the action of traffic This produces more fine material which soon dries out due to air agitation by the vehicles and becomes dust Furthermore this unbonded float material offers little resistance to the flow of rain water and a large amount of the calcium chloride is washed away. These processes naturally reduce the thickness of the "mulch" or protective layer of calcium chloride solution which means faster evaporation of the surface moisture The grinding action of the maintenance machinery is equally as harmful as the presence of the loose float material, since it disturbs the entire road surface

On the Nebraska project the amount of maintenance on the "Bare-surface" treated mile was 80 per cent less than on the sections maintained with a loose float layer The "Bare-surface" treated road showed practically no dust after five weeks treatment during July and early August, and did not develop any corrugations during this period The elimination of maintenance manipulation and the usual float material from the surface was also tried on one mile each of the Missouri and South Carolina projects, but due to the lateness of the season there is very little definite information on them, except that shown in Figure 24 for the South Carolina project.

A recent report of the Nebraska project indicates that later the condition of the treated "Bare-surfaced" mile became not so good as that of the untreated surface manipulated sections This may mean that there is a limiting period during which this minimum maintenance can be used successfully The fact that the "Bare-surface" treated section in Nebraska showed marked improvement over the other treated sections during the months of July, August, September and October is ample proof of its value The influence of climate on the moisture content of soils must be considered in connection with this behavior The moisture holding capacity of a soil increases as its temperature is lowered, and this affects the drainage and the structural stability of the soil For this reason it may be advisable in the Fall of the year to discontinue the use of the "Bare-surface" method and blade in and build up a metal mat for the Winter and Spring traffic The thinness of the metal mat in Nebraska renders it especially susceptible to break-ups if the moisture content in the subsoil increases to such an extent as to impair its stability Further observations on these roads during the coming months will furnish valuable additional information But whatever the behavior during this period may be it can not detract from the excellent service this type of treated road has given during the Summer months, with its economical and convenient elements of (1) decreased maintenance operations, (2) use of less calcium chloride, and, (3) the effective elimination of the dust nuisance

THE RÔLE OF CALCIUM CHLORIDE IN SOIL STABILIZATION

Soil stability depends upon a balanced combination of internal friction and cohesion Internal friction is supplied by the granular surfacing materials, such as gravels, crushed rock and silt Cohesion is furnished by two pressures acting between the clay particles The one called "true cohesion" is due to the attraction between the molecules at the points of contact of the grains The other, "apparent cohesion" is due to the surface tension of the water in the voids A better name for this type of cohesion probably would be "moisture film cohesion" It can be best visualized by likening the water menisci at the entrance of the surface voids to a rubber membrane stretched tightly around the samples and pressing the grains together

Calcium chloride due to its deliquescent and hygroscopic properties furnishes this "moisture film" to the road surface particles, thus providing additional cohesion to resist the shearing action of traffic The effectiveness and lasting qualities of the calcium chloride "moisture film" are much greater than those of the ordinary water "moisture film" because of its lower vapor pressure, which means a much slower evaporation rate

These cohesion phenomena are usually associated with clay, because their effects are most pronounced in fine grained material; but they can occur to a certain degree in any type of soil For example, a moistened sand can be moulded into a cylinder, because the surface tension of the water produces some "apparent" or "moisture film" cohesion If the cylinder is immersed in water the surface tension disappears and the cylinder disintegrates Another example is the stability furnished by beach sands for automobile racing when wet as compared with the instability of the same sands when dry True cohesion also exists in a mass of sand but this is small since there are a relatively small number of points of contact per unit area Moisture film cohesion being a function of grain size, grain shape, structure and density is also subject to wide differences brought about by changing moisture conditions If the moisture film between the particles is not too thick, the resistance of the film to shear is relatively great, due to the strong cohesive forces At the optimum thickness of the moisture film the liquid molecules can be visualized as being under the influence of the molecules of the solid and the film has lost its property of fluidity and is in a condition which has some resemblance to that of a solid If the moisture content is raised to the point where the film thickness increases beyond the field of influence of the molecules of the solid surface, the moisture film then regains normal fluidity and offers very little resistance to shearing stresses

A typical case of the value of "moisture film cohesion" in aiding road surface stabilization is shown in the Nebraska experimental project Table XIV gives the mechanical analyses and physical characteristics of the soils from the three projects From this table it will be seen that the clay content of the Nebraska project is only 14 per cent or approximately one-half of that of the other two projects, yet from the standpoint of service behavior this road was probably the best The 14 per cent clay content of the sample submitted is about normal for these roads In a 1928 report by C M Duff, Testing Engineer of the Nebraska Highway Department a value of 12 8 per cent is given for the clay content of 76 different projects Figure 25 shows a close-up view of the treated surface on this project The presence of the calcium chloride on the road surface caused the translocation of a sufficient amount of moisture by accelerating the capillary rise from the lower soil to the surface to assure moisture film cohesion This together with the internal friction and true cohesion produced a combination for ideal stability A contributing factor, that probably facilitated the capillary movement of the moisture under the influence of the calcium chloride, was the presence of a sub-stratum of stable clay two inches below the road surface which had an average moisture content of approximately 10 per cent

The history of the development of crushed rock and gravel roads is the story of soil stabilization more and more economically attained by improvements in construction, maintenance methods and materials

TABLE XIV

Mechanical Analysis

These tests were made by the Soil Laboratory of the Bureau of Public Roads

Soil Classification	State	Particles Larger than 2.0 mm.	Particles Smaller than 2 mm. (Per Cent by Weight)						
			Coarse Sand 2.0 to 0.25 mm.	Fine Sand 0.25 to 0.05 mm.	Silt 0.05 to 0.005 mm.	Clay Smaller than 0.005 mm.	Colloids Smaller than 0.001 mm.	Passing No. 40 Sieve	Subgrade Group (Binder Portion)
Sandy Clay Loam....	S. C.	0	36	26	10	28	22	79	A-2
Clay Loam..........	Mo.	42	35	14	26	25	17	77	A-4& A-6*
Sandy Loam.........	Neb.	66	60	13	13	14	6	53	A-2

Physical Characteristics of Material Passing No. 40 Sieve

State	Liquid Limit	Plasticity Index	Shrinkage		Moisture Equivalent		Hygroscopic Moisture
			Limit	Ratio	Centrifuge	Field	
South Carolina.....	25	13	12	1.9	20	16	1.0
Missouri...........	29	14	13	1.9	24	24	2.2
Nebraska...........	27	12	15	1.9	24	20	1.0

* This is a border line soil having some of the physical characteristics of the A-4 subgrade group and a volumetric change of 20.9 per cent indicative of an A-6 subgrade soil.

Figure 25. Close-up View of the Sand-Gravel Road Surface Treated with Calcium Chloride. Note the Abscence of Loose "Float" Material. (Nebraska Project.)

In the past the highway engineer acquired by trial and experimentation any knowledge that may have aided him in attaining a suitable road under prevailing local conditions Today in the light of what we know about the characteristics of soils, such knowledge may be deduced from soil mechanics. It will be seen, therefore, that the process of stabilization is not a haphazard operation that calls for no skill or forethought Only by close attention to technical and practical considerations will this type of road be placed on its true and useful plane to the satisfaction of both engineers and road users The scope of this investigation does not permit a detailed discussion of the entire field of soil stabilization, but it is hoped that this contribution will be of value in enlarging the general knowledge of the part that "moisture film cohesion" plays in this important and interesting problem

Summary of Facts

1 The better retention of calcium chloride in a compacted and undisturbed surface than in a loose and frequently maintained surface results in an appreciably increased period of effectiveness

2 The absence of unbonded surface material on calcium chloride treated roads materially reduces the maintenance operations needed

3 Calcium chloride furnishes to the finer road surface particles "moisture film cohesion" which is an important factor in soil stabilization and greatly aids in resisting the shearing forces of traffic

4 Calcium chloride placed on the surface of soil samples retards the evaporation of soil moisture The primary reason for this decrease in rate of evaporation is the low vapor pressure of the calcium chloride solution This solution layer at the surface acts as a "mulch", which retards the passage of the soil moisture The hygroscopic property of calcium chloride also plays a rôle in slowing up the evaporation of soil moisture This is due to the absorption of moisture from the air during periods of high humidity

5 Due to the combined properties of lower vapor pressure and hygroscopisity, the "moisture film cohesion" furnished by the calcium chloride is more stable than that furnished by plain water

6 The loss of calcium chloride by chemical base-exchange with soil is probably not very large in comparison with losses from other sources

7 The leaching of the calcium chloride by rain into the lower layers of the road surface decreases the effectiveness of the initial application

8 Chemical analyses of both laboratory and field samples show that the calcium chloride content increases in the lower layers under the leaching action of water

9 Laboratory tests show that there is a positive movement of the salt from the lower layers of the soil toward the surface under drying conditions

10 The application of calcium chloride on the surface is far more effective in preventing evaporation of soil moisture than is the mixing of a similar amount with the soil

11 The greatest difference in surface moisture content between the treated and untreated field projects was observed during periods of low rainfall and high temperatures The treated section under these conditions had the higher moisture content

Indications

There is some indication that the season when the "Bare-surface" type of road should be used is limited The building up of the moisture holding capacity of soil during the late fall months due to lower temperature probably requires the resumption of more frequent maintenance to insure smooth riding surfaces But the good service rendered by this type of surface during the summer, along with the dual economical advantages of (a) less maintenance, and (b) less calcium chloride, makes it worthy of consideration in the low cost road program

Recommendation by Committee on Highway Maintenance

The Committee recommends, after a review of this report, that further comparisons be made between projects on which the combined factors of less "float" material and reduced maintenance exists and others on which the usual maintenance and loose surface material prevail: that these tests be made in states in which the calcium chloride method of treatment is used or is feasible: and that the results of these comparisons be submitted to this Committee to be used as a basis for determining correct methods for obtaining the best results with this type of dust palliative

Committee on Highway Maintenance
Highway Research Board
B C Tiney, *Chairman*
H K Bishop
J S Crandell
T H Dennis
B E Gray
A H Hinkle
C P Owens
W. H Root

THE CORROSIVE ACTION OF CALCIUM CHLORIDE ON VEHICLES

An attempt was made to obtain maintenance cost data from which the effect of calcium chloride on the under side of the vehicle could be ascertained. Unfortunately no groups of trucks or buses could be found that were operated exclusively for any length of time over both of these types of roads.

The following statements from a report "Calcium Chloride Testing of Electroplated Deposits" by H. C. Mougey, Transactions, American Electro-Chemical Society, Volume 58, 1930, Page 93, give some valuable information on this problem.

"Our records indicate that the use of either sodium or calcium chloride to melt ice in winter is accompanied with much more danger of producing corrosion than is the use of calcium chloride on dusty roads in summer. This is probably due to the salt and melted ice mixture producing a more concentrated salt solution on the plated parts than is the case with calcium chloride treated dust. Since winter conditions are so much more severe than summer conditions, our attention should be directed to winter conditions. If these troubles are solved, the summer troubles will automatically take care of themselves. ... Our records indicate that calcium chloride is much more corrosive to plated parts than is sodium chloride, although in the case of black enameled sheet metal parts, sodium chloride is much more corrosive than calcium chloride."

In the same Transactions, page 89, from a paper by R. J. Wirshing on "Heat Treatment of Chromium Deposits To Increase Their Resistance To Corrosion," we have the following abstract:

"Copper panels chromium *plated* at low current densities and high bath temperatures were more resistant to calcium chloride corrosion than panels plated at higher current densities and/or lower temperatures. Greater corrosion resistance is attributed to the lower hydrogen content of the plate. *Upon removing most of the hydrogen through heat, a sevenfold improvement in corrosion resistance was noted.*"

There appears to have been very little complaint from vehicle owners on the score of corrosion due to calcium chloride.

The meager published data on this subject and the results of this investigation indicate that the possibility of damaging amounts of calcium chloride solution coming in contact with the metal of the vehicles is rather slight. Under dry weather conditions, especially when the road is subjected to minimum maintenance manipulation, the presence of dust is greatly decreased by the calcium chloride treatment.

A much worse condition prevails during a rain when dirt and water splash upon the vehicle. But under these conditions the experiments reported herein show that the calcium chloride penetrates deeper into the road and that there is a diminished amount of it present in the surface water which can be splashed.

THE EFFECT OF CALCIUM CHLORIDE ON ROADSIDE TREES

The following excerpts are taken from a report on this subject by Phelps Vogelsang, Forester, of the Michigan State Highway Department and reported in AMERICAN HIGHWAYS Volume XI, April, 1932, No 2

"We do not know at present whether the chloride in the dust draws the moisture out of the leaves or whether its presence has merely a toxic effect It is also probable that the coating of dust with the chloride covers the stoma or leaf pores, thereby wilting the needles We have no quantitative tests that will show the amount of chloride present in dust necessary to cause injury

"It has been a general opinion that most of the chloride injury is a result of absorption of the salt in solution through the root system In keeping a constant check on many thousands of trees in the field that appear to have been affected by chloride I know of only a very few trees that appear to be injured by absorption

"It is a fact that calcium chloride will kill a tree providing enough of the salt is absorbed through the root system In order to determine the amount of chloride necessary to injure a tree we prepared a quantitative test in the laboratory We might draw from these tests that it takes nearly a pound of chloride per cubic foot of soil to kill an evergreen tree These results are not applicable to field work as the plants were small, they had shallow root systems, and there was no runoff to carry the chloride away from the roots They do show, however, that it takes quite a quantity of chloride to kill even a small tree

"In a number of tests conducted in the field, 32 different species of trees of varying sizes were treated with four different common salts that are being used as dust layers It was shown that magnesium chloride and sodium chloride were far more toxic than calcium chloride It also showed, in a general way, that the evergreens were less tolerant to the salt than the hardwoods I have been informed that calcium chloride applied to the road surface will not penetrate to more than a fourth-inch depth This may also be an explanation as to why evergreens and smaller trees are more susceptible to injury than hardwoods and larger trees the former having a shallow root system

"In the past few years the writer has followed up numerous complaints from private property owners relative to calcium chloride injury to trees and shrubs In a large percentage of these cases deciduous trees such as sugar maple, elm, oak, etc , were the object of complaint In no case was I able to confine the blame entirely to calcium chloride injury Many diseases and injuries such as maple leaf scorch, oak anthracnose, gas injury and general lack of moisture and care are usually confused and mistaken for salt injury Such cases were especially prevalent during the summer of 1930 and '31 and were noticed along untreated roads as well as treated ones There is always a more rapid evaporation from a gravel surfaced road than from ordinary ground surface This is due to the porous structure as well as the constant disturbance by traffic This condition alone is sufficient to cause injury during dry seasons to trees growing close to the metal and especially when certain of the roots have been cut off in road construction Several thousand trees died along our highways during the summer of 1930 and '31 These trees had been injured previously during road construction, but were able to survive the normal seasons until the drought came

"We have not noticed any case where calcium chloride has caused injury to grass or deciduous shrubs growing along the edge of the gravel highways In support of this observation let me quote the experience of the State Department of Agriculture which experimented with calcium chloride to kill weeds and shrubs while on barberry eradication work It found that calcium was not satisfactory as a killer of this shrub and that sodium chloride was a far better agent

"In our many observations and experiments it is evident that calcium chloride is the least toxic of any of the salts now commonly used It has been brought to our attention that various oils may be used that will have the necessary dust laying qualities and still be less injurious to foliage

"In observing the effects of oil used as a dust layer on foliage we find much the same results as when chloride is used The oil rises very readily with dust when the surface has become worn This dust when settled on the leaves is very sticky and seems to clog the pores, thus producing wilt We have observed that this dust is so adhesive that a heavy rain will not remove it from the leaf surface Road oils when sprayed on foliage also appear to be very toxic

"It is very noticeable that trees growing along gravel roads which are kept practically dustless during the entire growing season, do not show as much injury as those growing along roads that carry an excess of loose cover, and even though chloride is used, are not entirely dustless during the dry season It is clearly evident that proper road maintenance and removal of surplus loose gravel will reduce dust and make the chloride more effective, thereby reducing tree injury If this procedure is practiced it is possible that less chloride can be used and still keep the road dustless Some of our roads are carrying so much loose gravel that even though large amounts of chloride are used the road is not dustless Such a condition is bound to produce greater injury to the adjacent trees I also believe that small amounts of chloride applied more often will reduce tree injury in that it lowers the chance of large amounts of chloride going into solution with the runoff water A study and an adjustment of the chloride requirements for various sections of road should be sufficient to reduce tree injury to a negligible quantity"

DISCUSSION

Messrs L C Stewart and W R Collings, *The Dow Chemical Company*: Some very interesting and valuable information has been presented much of which is corroborated by our studies and work on the same subject We were particularly interested to note the intimation that the condition of the road surface affected the behavior of the calcium chloride applied to the roads under observation Our work has included a study of the fundamental properties of soil materials and their relationship to gravel road stability and calcium chloride behavior It differs from that just reported in that we have designed road surfaces for maximum stability before applying the calcium chloride whereas Burggraf's investigations involved the treatment of existing surfaces

The performance and service of gravel roads depend largely on the properties of the finer constituents The tests developed by the U S

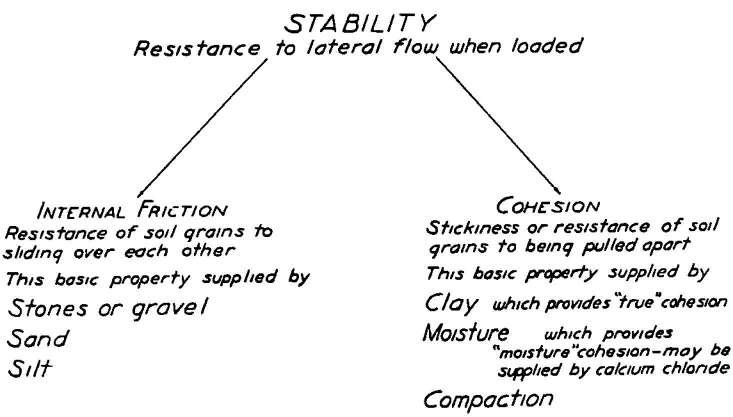


Figure 1. Basic Soil Properties Required to Obtain Stability in Gravel Roads.

Bureau of Public Roads for measuring properties of subgrade soils furnish very significant information when applied to the finer constituents of road gravels These tests have made it possible to specify how a natural gravel should be modified, by the addition of constituents which may happen to be lacking, so as to produce a combination possessing maximum wet- and dry-weather stability In other words, by this means the fine constituents are adjusted to give the most stable filler obtainable for the gravel

Stability of soil is defined as resistance to lateral flow when loaded Figure 1 shows how stability requires the presence of two of the basic soils properties, internal friction and cohesion Internal friction, which is the resistance of soil grains to sliding over each other, is furnished by sharp stones and gravel, sand and silt Cohesion, which is the stickiness or resistance to being pulled apart, is furnished particularly by clay and is supplemented or improved by moisture and compaction That portion of the cohesion supplied by clay is usually called true cohesion We define that part added by small amounts of moisture as moisture cohesion Calcium chloride supplies moisture cohesion

Figure 2 shows the various soil constituents found in subgrades and gravels as classified according to size by the U S Bureau of Public Roads The relative sizes of fine sand, silt and clay particles are shown in the magnified illustrations in the right-hand column For full discussions of soil properties the reader is referred to publications of the U S Bureau of Public Roads *

The functions of the various soil constituents are shown graphically in Figure 3 It will be noted that there is a maximum amount of clay, which it is permissible to use in the finer portion of a gravel, in order to

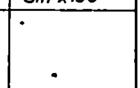
Name	Particle size dia in inches	Screen size Passes	Retained	Remarks	
Gravel or coarse materials	over 08		10 mesh	Alone or in mixtures these constituents furnish High Internal Friction Little or no Capillarity No Cohesion No Compressibility or Elasticity, hence are non-expansive	 Fine sand x 150
Coarse sand	01 to 08	10 mesh	60 mesh		
Fine sand	002 to 01	60 mesh	270 mesh		
Silt	0002 to 002	Supplies Internal Friction to stable mixtures. Alone it has { Some Internal Friction, Rapid detrimental Capillarity, No Cohesion, Compressibility, hence is expansive }			 Silt x 150
Clay	Under 0002	Supplies Cohesion to stable mixtures. Alone it has { No Internal Friction, Slow Capillarity, High Cohesion, Compressibility, hence is expansive }			 Clay x 150
Colloidal or gluey material	Under 00004	The smaller particles included in the clay constituent			
Mica flakes	Elastic and undesirable				
Peat	Elastic, highly capillary and undesirable				
Diatoms	Skeletons of microscopic organisms. Non cohesive and undesirable				

Fig 2 Representative Soil Constituents as Classified by the U. S. Bureau of Public Roads.

obtain maximum cohesion without encountering detrimental effects in other directions Excessive amounts of clay, upon becoming wet, lubricate the sand particles and cause wet-weather instability The Bureau of Public Roads soil tests, make it possible to determine the correct amount of clay which should be present in gravel to obtain the benefits and avoid the undesirable features

The effects of the composition of the fine constituents of gravel upon stability were demonstrated by some tests made on an indoor test road This test road was so arranged that it could be artificially subjected to rain or to drying conditions

* Public Roads, June, July, September and October, 1931 or Reports on Subgrade Soil Studies of Bureau of Public Roads

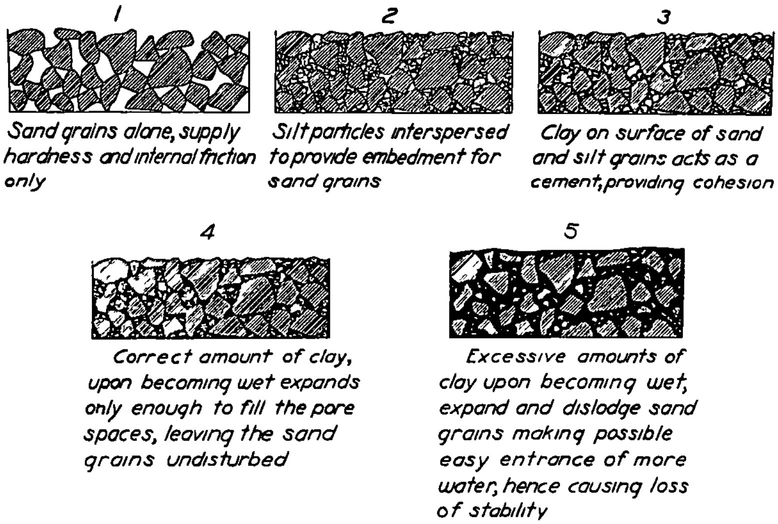


Figure 3 Functions of Constituents in Sand-Clay Mixtures.

The sections of the test road were first covered with the sand clay mixtures given in Table I Then a one inch layer of high quality natural gravel was spread on the left hand one half, leaving the right half with the sand clay surface Calcium chloride was distributed over the gravel surfaced left half at the rate of one-half pound per square yard the day before the picture (Figure 5) was taken Figures 4 and 5 show the five-section test road with the rain-maker at the left and the hot air ducts at

TABLE I

Composition and Properties of Sand-Clay Mixes

Section	Mechanical Analyses*—Percentage by Weight				
	A	B	C	D	E
Coarse Sand (2 0–0 25 mm)	37	34	38	34	34
Fine Sand (0 25–0 05 mm)	47	39	40	53	59
Silt (0 05–0 005 mm)	1	7	6	2	3
Clay (Below 0 005 mm)	15	20	16	11	4
	Physical Properties*—Moisture Percentage by Weight				
Liquid Limit	16	15	15	16	17
Plastic Limit	15	11	14	None	None
Plasticity Index	1	4	1	None	None
Shrinkage Limit	15	12	15	15	17
Field Moisture	12	10	12	12	19

* For interpretation see Public Roads, June, July, September and October, 1931, or Reports on Subgrade Soil Studies of Bureau of Public Roads.

the right. The road slopes downward from the cement curb side at the left to the steel plate side at the right. The latter is perforated at different levels and provision is made to collect, separately, the water

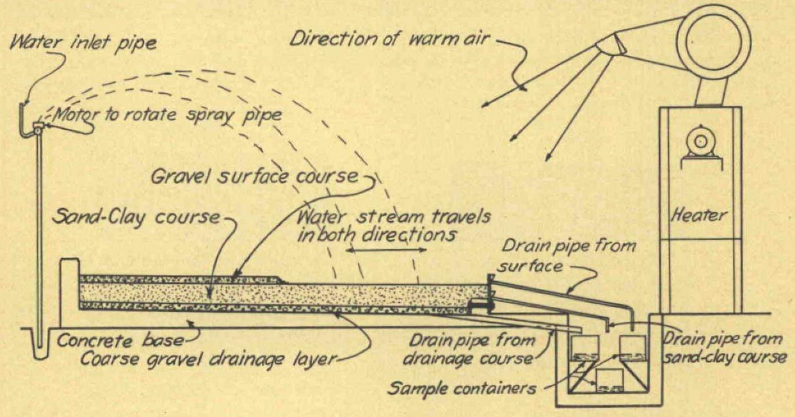


Figure 4. Cross Section of Indoor Test Road. (From Dow Chemical Co.)

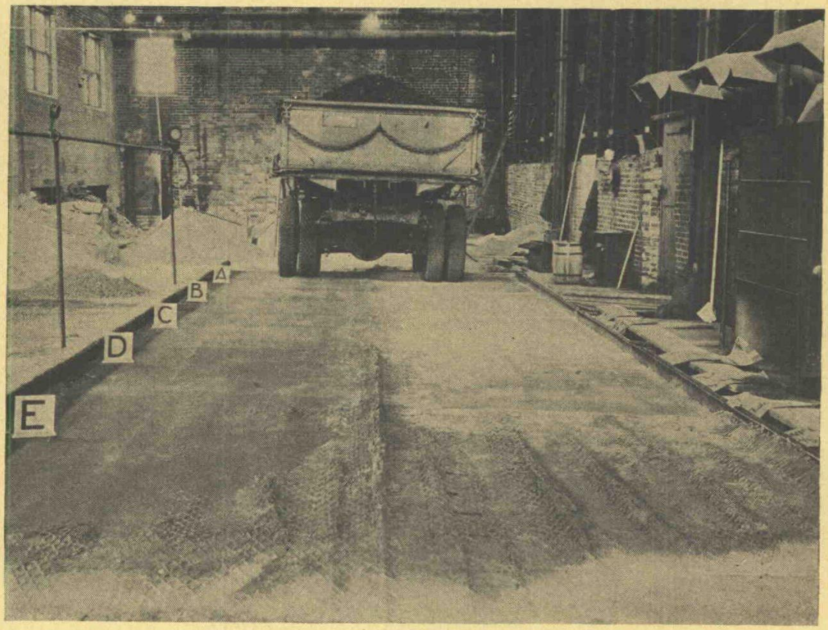


Figure 5. Method of Compacting Indoor Test Road.

which tends to flow from each level of each section. The water thus obtained may be measured and analyzed in the case of calcium chloride studies. The loaded truck shown in the picture is the one used for compacting the various soil mixtures in place.

Previous to the calcium chloride application the road had the appearance exhibited in Figure 6. In this latter picture it will be noted that the gravel could not be compacted on Section "E" which had the lowest clay content. The calcium chloride, however, provided enough moisture cohesion to assist in compacting to the extent shown in Figure 5.

After the road was prepared as shown in Figure 5, artificial rain was allowed to fall on it at the rate of four-tenths of an inch per hour. During the time of the rainfall a single-tire truck loaded with sand was operated back and forth at the rate of approximately one complete trip per minute. The appearance of the road at the end of 50 minutes of

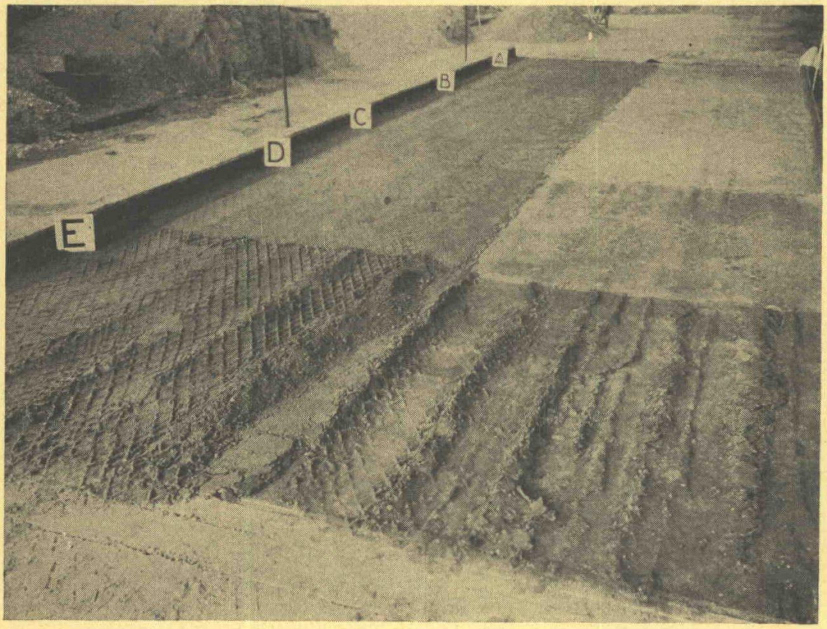


Figure 6. Gravel Cover on one-half of Indoor Test Road.

such traffic during the rain is shown in Figure 7. In this picture it will be noted that Section "E" was very much softened by the rain and traffic. Section "D" stood up fairly well as did the other sections. At the end of the 50-minute period, planks were placed on Section "E" so that the tests might be continued.

At the end of 5 hours continuous rainfall and traffic the test road had the appearance exhibited in Figure 8. In this picture, Section "E" may be said to have failed entirely, and Section "D" was in bad condition. Sections "A," "B" and "C" were all in relatively good condition.

The road was subjected to a current of dry, warm air during the night following the test, and at the end of some 16 hours of such treatment it

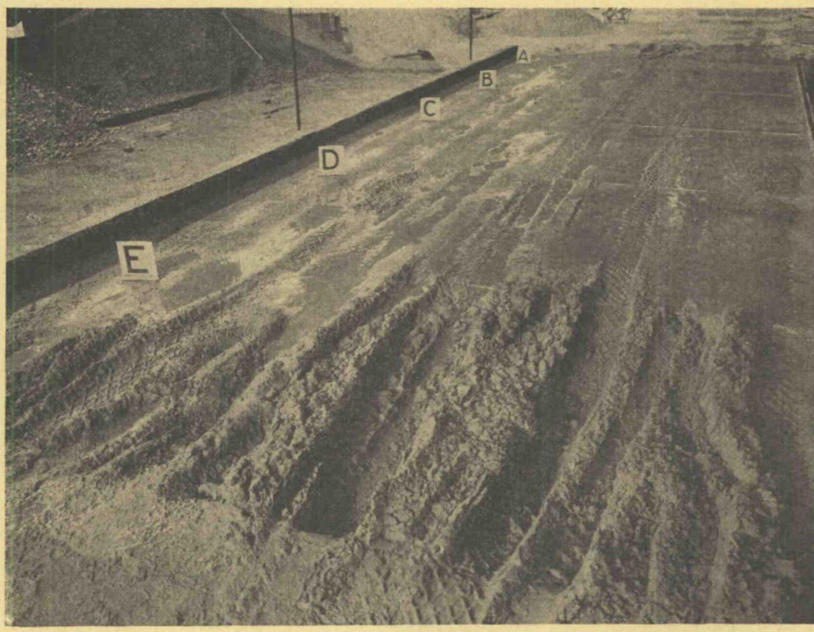


Figure 7. Fifty Minutes of Wet Traffic Test on Indoor Test Road.

Figure 8. Five Hours of Wet Traffic Test on Indoor Test Road.

had dried out quite appreciably. A light Ford dump truck was then driven back and forth over the road to smooth it up somewhat, and the appearance after this treatment is shown in Figure 9. In this latter view it will be noted that Sections "A," "B" and "C" were in excellent condition. These sections contained from 15 to 20 per cent natural local clay, whereas Section "D" which contained 10 per cent of the clay was rutted somewhat, and Section "E" which was in very bad shape contained only five per cent of the clay.

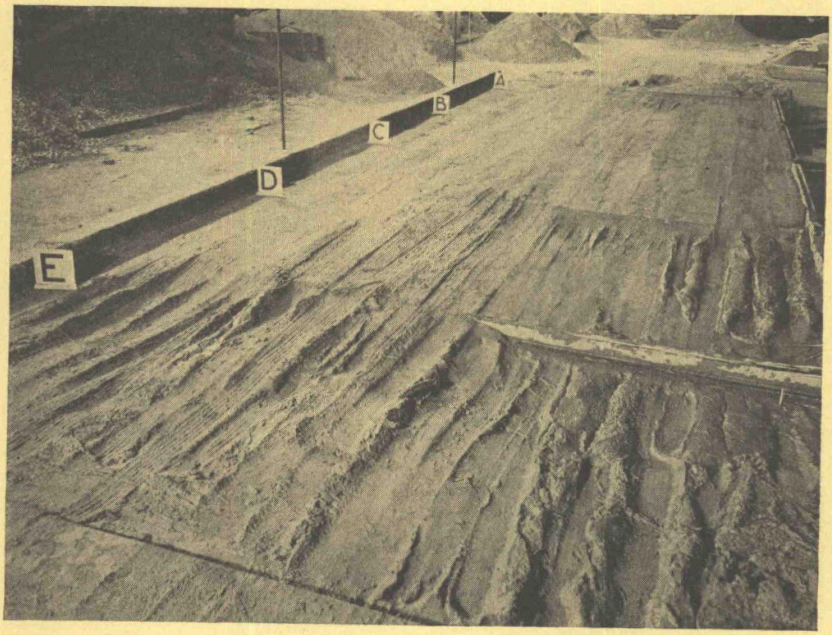


Figure 9. Indoor Test Road Partially Dried after Five Hour Wet Traffic Test.

After the test road was put into the condition shown in Figure 9, the sand-clay mixes were removed down to the drainage layer of coarse sand on which they rested. Figure 10 shows the appearance of this coarse sand and it will be noted that Section "E" was the only one in which water had penetrated through the four inches of sand-clay base into the coarse sand. The higher clay content of the other sections had helped seal them sufficiently so that the water would shed off the surface rather than flow down into the drainage layer. This series of photographs shows the difference in stability and permeability to water which occurs with reasonably small differences in clay content in sand-clay mixtures.

In coöperation with the Maintenance Division of the Michigan State Highway Department, the gravel on a state trunk line was stabilized in order to observe its service under traffic when treated with calcium chloride. The original project consisted of two miles of the road, but the results were so satisfactory that an additional ten miles were undertaken and completed at a later date. Briefly, the treatment consisted of determining by physical tests the amount of clay required to produce maximum stability of road without introducing an excess which might cause instability in wet weather.

The gravel was scarified to a depth of three inches and incorporated with the clay by thorough mixing, after which the road was shaped with grader and truck-blade and surface-treated with calcium chloride. This process produced a firm, dustless road, free from loose material, during

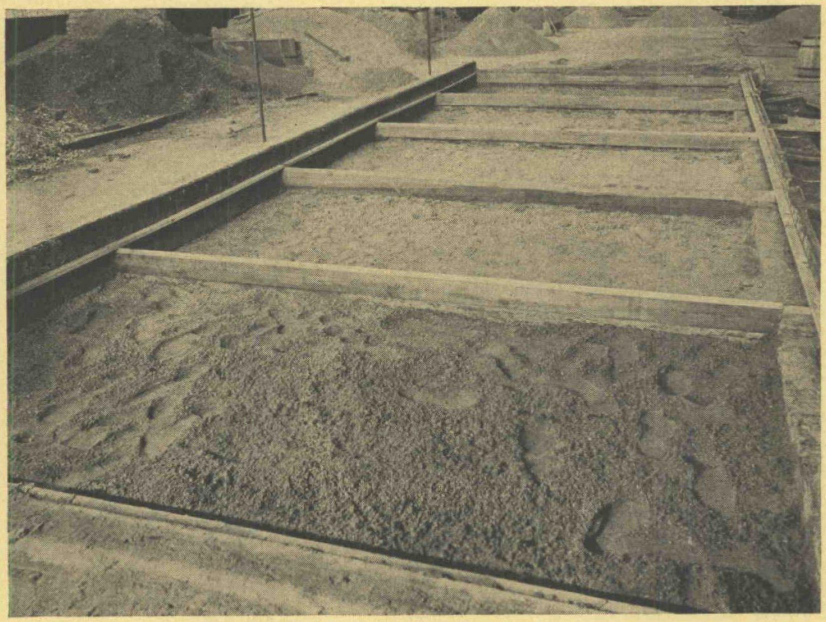


Figure 10. Indoor Test Road with Sand-Clay Bases Removed.

the summer and early fall. In wet weather the road did not pit so much as did the untreated portions.

Maintenance was only necessary immediately after periods of wet weather. This result was in accordance both with theories and observations of calcium chloride behavior in stabilized roads. These are graphically brought out in Figure 11. Following prolonged dry periods the calcium chloride will be found close to the surface of the road. Figure 11 (1). When rain begins, the surface of the road admits a certain amount of water. The first portion which is absorbed by the road serves to carry the solution of calcium chloride down below the surface. Figure 11 (2). When the surface material becomes saturated with water or the pores become closed in part by expansion of the clay constituent, subsequent rainfall is shed off into the side ditches No great quantity of water is permitted to enter the surface, so no rain water carrying calcium chloride in solution passes into the subgrade even though the latter be porous or sandy nature Figure 11 (3) shows the calcium chloride well down below the surface of the road after rainfall has ceased

The drying action of the stabilized gravel road is shown in Figure 11 (4) As the moisture in the top layer of the road material dries, it is replaced by the water containing calcium chloride This solution, having been stored below during the rain, is brought to the top by the capillarity or wick-like action of the soil material between the stones

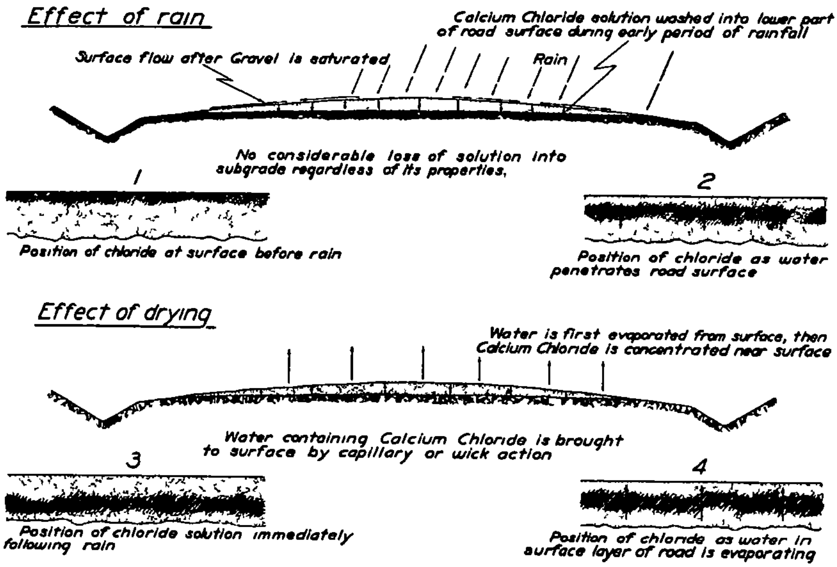


Figure 11. Behavior of Calcium Chloride in Sand Clay Gravel (From Dow Chemical Co)

It is then evaporated to a calcium chloride strength at which it will no longer lose water to the air under the existing humidity conditions The solution remains at the road surface during the subsequent dry weather and promotes dustlessness and stability by providing moisture cohesion This is the situation previously shown in Figure 11 (1)

With this condition prevailing it is desirable to eliminate machine maintenance to the greatest degree consistent with keeping the surface smooth Cutting the surface of the road when the calcium chloride is concentrated near the top results in the removal of this moisture-retaining material from some places and its concentration in others The resulting dry spots ravel more easily than the rest of the road, due to lack of moisture cohesion Some of the damp material loosened by the dry weather maintenance may be thrown off the road by traffic before it becomes packed down. This is a loss of dustless binding material rich in calcium chloride.

The fact that the calcium chloride is at the surface of a road in dry weather is also the reason for avoiding the presence of loose cover or

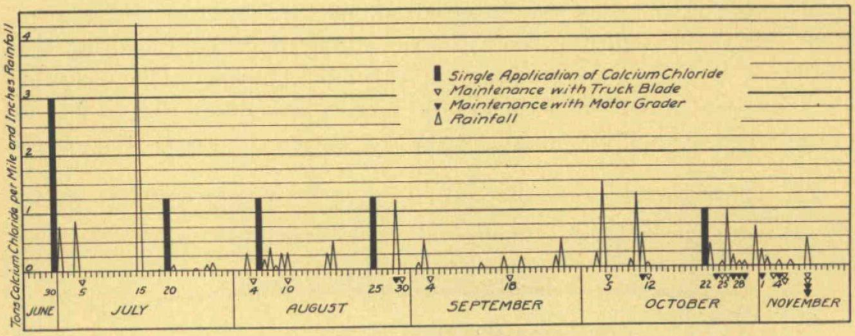


Figure 12. Maintenance and Rainfall Record on Stabilized Gravel Road.

Figure 13. Junction of Test Road with Part Maintained in Regular Manner.

stones on the surface. The movement of traffic over such loose material under these conditions causes them to abrade and punch holes in the surface, thus resulting in disturbance and losses of calcium chloride similar to those which may be caused by dry weather maintenance.

After rainfall has ceased, the calcium chloride is located well below the surface of the road as in Figure 11 (3). This is the best time for maintenance. Cutting and shifting about of the top inch of the road does not deplete some portions of the surface of this calcium chloride and build up higher concentrations in others

The maintenance record of the Michigan test road described above is shown in Figure 12 It will be noted that the applications of calcium chloride were relatively light as compared with the usual procedure These were completely effective because the modified gravel appeared much more sensitive to small amounts of calcium chloride than unstabilized gravel Tests showed that by continuously maintaining a calcium chloride content of about three tons per mile, 16 feet wide, the road was absolutely dustless in dry weather Figure 13 shows the junction of the test section with the part of the road maintained in the regular manner

The foregoing discussion has been condensed because of limited space Only the highlights have been presented but they indicate the close relationship between behavior of calcium chloride and properties of the road on which it is used The maintenace record which is presented is in agreement with Mr Burggraf's observations and conclusions

MR C N CONNER, *American Road Builders' Association* Several years ago I had occasion to inspect the calcium chloride treated roads in Michigan and Vermont and I was impressed at that time by the difference of opinion among engineers as to whether or not a surface mulch should be used on them The opinions differed considerably even in Michigan In some of the districts the engineers thought that the clay content was quite important They found that where there was considerable clay, and no surface mulch was used, the roads pot-holed quickly, and that the surface mulch prevented pot-holing

Another thing is that the surface mulch prevents the calcium chloride treated roads from becoming slippery In Vermont roads were slippery where calcium chloride is not used at all, particularly when rain had fallen

MR STEWART I might add that any slipperiness of stabilized gravel roads is prevented by use of the physical tests which maintain a correct balance between the clay and sand

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