USE OF CALCIUM CHLORIDE IN ROAD STABILIZATION

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TOPICAL INDEX

CALCIUM CHLORIDE

Hogentogler, Jr.: Calcium chloride has been used as a treatment of unpaved road surfaces for more than twenty-five years. F. R. Newman (1913) in his report on, "The Action Of Calcium Chloride On Roads" stated: "It is fairly common practice nowadays to spread calcium chloride over the roads as a means of preventing dust."

Calcium chloride is present in solution in many mineral springs, J. F. L. Hausmann found calcium chloride in the anhydrite of Luneberg, and called it hydrophylite, water lover, in reference to its hygroscopicity or its ability to absorb and retain moisture. Calcium chloride occurs as crude brine in several manufacturing processes, but the following are its most common sources:

(1) The preparation of sodium carbonate by the ammonia-soda process, and,

(2) the production of bromine from natural brines. The commercially produced calcium chloride is obtained by the evaporation and refinement of these crude brines.

PRINCIPLES OF STABILIZATION

Elleman: Originally calcium chloride was used simply as a dust palliative, but early it was noted that the application was more effective on certain roads than on others. Comparative tests showed that the good roads, with few exceptions, had a somewhat similar gradation of materials from the top size down, and always had some fines and some binder material such as loam, clay or limestone dust mixed in with the aggregate. The aggregate might vary from two inches down to the number forty sieve, but below the top size the gradation of the material size was such that the voids in the mixture were greatly reduced. The quantity of the binder-soil present varied with the type.

Furthermore, these test results agreed with observations in the field, where it was noted that certain gravel deposits containing some dirt or clay made excellent roads. Also that roads built of clean gravel and stone frequently became better after some soil from the subgrade or shoulders had worked into them. It was also noted, that in addition to gradation and binder-soil, the presence of moisture was essential. It was from these observations and tests that stabilization was developed.

Broadly defined a stabilized road surface is one that will not flow laterally under load. Stability is obtained from two main factors, internal friction and cohesion. Internal friction gives stability under excess moisture or wet weather conditions. Cohesion due to moisture films which surround the individual particles of material in the soil mixture is the force which is effective in dry weather to bind the materials together to prevent ravelling. In order to develop this binding force the presence of moisture as well as a certain amount of fine material, known as binder-soil, the minute particles of which carry the moisture films, are necessary.

MIXTURE DESIGN SPECIFICATIONS

Downey: The correlation of mechanical analysis, plasticity indices, shrinkage limits, permeability tests and liquid limits of various road materials available in Michigan, has resulted in a surface course specification which has produced satisfactory road surfaces for Michigan materials, weather conditions and traffic. For most practical purposes, only two soil tests are absolutely essential to con trol stabilized mixtures:

(1) Mechanical analyses will furnish adequate data for the design of aggregate surface courses which will readily compact, and attain high density and stability.

(2) The plasticity index will furnish design data for obtaining maximum resistance to abrasion with effective capillary characteristics.

In the Michigan specifications, the coarse limit of grading is approached in base courses which are covered by bituminous mats. Here the plasticity index range of the material passing the No. 40 sieve in the stabilized mixture must be held between 1 and 6, and preferably toward the lower range where maximum penetration of the bituminous seal is desired. Conversely the fine limit of grading is approached in wearing courses requiring the use of calcium chloride as a stabilizer. Here the plasticity index range of the material passing the No. 40 sieve must be held between 5 and 9. This insures adequate resistance to traffic abrasion, without excessive slipperiness, and maximum retention of calcium chloride in the capillary water of the road surface during the wet weather cycle. The plasticity index should approach 7 for best road performance under average Michigan traffic and weather. In general, it appears that if the plasticity index of the soil fines is increased or decreased from approximately 7, the calcium chloride must be increased to secure maximum road performance.

In cases where the use of calcium chloride is not feasible due to low traffic density, it is desirable to carry maximum soil fines and a higher plasticity index range (8 to 12) to secure satisfactory results. The extra soil fines are necessary to compensate for the loss of fines during dry weather. This type of road has a tendency to be slippery during wet weather.

In all cases a crown of at least 2½ in. for a 20-ft. travelled roadway is necessary if a smooth surface is to be expected for all types of weather conditions.

Michigan State Highway Department Specifications for Stabilized Aggregate

Sieve Size	Percentage Passing	
	Gravel	Stone
1-in.		100
¾-in.	100	80–95
⅜-in.	65–90	60–80
No. 10	35–50	40–55
No. 40	20–35	20–35
No. 200	5–20	5–20

Gravel (Uncrushed) Modified Abrasion, not more than 20%
Gravel (Crushed) Modified Abrasion, not more than 30%
Stone, Standard Abrasion, not more than 8%
Crushed Material, not less than 25%

The fraction passing the No. 40 sieve shall have a plasticity index within the following limits, depending on the treatment which has been specified for the surface:

Type of treatment	Plasticity Index
Surface for Bituminous Treatment	1-6
Surface for Chemical Treatment.	5-9
Surface for use without Treatment	8-12

Material Soil Binder (Clay) shall primarily be fine soil particles and shall contain not more than 5 per cent organic matter. It shall not contain stone which does not conform to the gradation requirements of the coarse aggregate. The binding properties of the soil binder shall be such that it provides the required physical characteristics to the finished mixture.

The State Highway Department has made a survey of most known clay and gravel sources used by the Maintenance Division and has listed many of the approved material sources for each district. The most suitable clay binder-soil source has been recorded for each gravel source. With these data it is sometimes possible to produce satisfactory maintenance gravel, having the proper proportion of clay binder-soil. In case of new material sources or rebuilding existing surfaces, laboratory tests are made prior to approving the production of materials. In areas where binder-soils are unsatisfactory, other types of stabilization (bituminous and cement) are more feasible due to the increased cost of obtaining suitable binder-soils.

Burggraf: The following specifications on mixture design are standards of the American Association of State Highway Officials and are recommended for general use.

American Association of State Highway Officials
Standard Specifications for Materials for Stabilized Surface Course
Specification M-61-38

A. Material Covered

1. This specification covers the quality and size of sand-clay mixtures, gravel, stone or slag screenings or sand, crusher run coarse aggregate consisting of gravel, crushed stone or slag combined with soil mortar or any combination of these materials for use in the construction of a stabilized surface course. The requirements are intended to cover only materials having normal or average specific gravity, absorption and gradation characteristics. Where materials such as caliche, gypsum, limerock and water soluble salts are to be used, appropriate limits suitable to their use must be specified.

B. Types

2. The following types of surface course stabilized mixtures are specified. The engineer shall designate the type or types desired:

Type A—Sand-clay mortar.
Type B—Coarse graded aggregate.
Type C—Gravel, stone or slag screenings or sand.

C. General Requirements

3. The type or types designated shall conform to the following requirements:

Type A—The materials for this type shall be composed of natural or artificial mixtures of clay or soil binder and gravel, sand or other aggregate proportioned to meet the requirements hereinafter specified. The aggregate retained on the No. 4 sieve shall be composed of hard, durable particles and shall be free from injurious or deleterious substances.

Type B—The material for this type shall consist of natural or artificial mixtures of gravel, stone or slag and soil mortar so proportioned as to meet all the requirements hereinafter specified.

The course aggregate shall consist of clean, hard, durable particles of crushed or uncrushed gravel, stone or slag free from soft, thin, elongated or laminated pieces and vegetable or other deleterious substances. It shall be hard and durable enough to resist weathering, traffic abrasion and crushing. Shales and similar materials that break up and weather rapidly when alternately frozen and thawed or wetted and dried, shall not be used.

The soil mortar shall be that portion passing the No. 10 sieve and shall be composed of soil binder and granular material such as stone or slag screenings or sand.

Type C—The materials for this type shall be composed of gravel, stone or slag screenings or sand or mixtures thereof proportioned to meet the requirements hereinafter specified.

The material shall be composed of hard, durable particles, free from injurious or deleterious substances, uniformly graded from coarse to fine.

C. Detail Requirements

4. The type or types designated shall conform to the following requirements:

Type A

Passing	Percentage by Weight
1-inch sieve	100
No. 10 sieve	65–100

The material passing the No. 10 sieve shall meet the following requirements:

Passing	Percentage by Weight
No. 10 sieve	100
No. 20 sieve	55–90
No. 40 sieve	35–70
No. 200 sieve	8–25

The fraction passing the No. 200 sieve shall not be greater than two-thirds the fraction passing the No. 40 sieve. The fraction passing the No. 40 sieve shall have a liquid limit not greater than 35 and a plasticity index not less than 4 or more than 9.

Type B

Passing	Percentage by Weight
1-inch sieve	100
¾-inch sieve	85–100
⅜-inch sieve	65–100
No. 4 sieve	55– 85
No. 10 sieve	40– 70
No. 40 sieve	25– 45
No. 200 sieve	10– 25

The fraction passing the No. 200 sieve shall be less than two-thirds of the fraction passing the No. 40 sieve. The fraction passing the No. 40 sieve shall have a liquid limit not greater than 35 and a plasticity index not less than 4 or more than 9.

Type C

Passing	Percentage by Weight
¾-inch sieve	100
No. 4 sieve	70–100
No. 10 sieve	35– 80
No. 40 sieve	25– 50
No. 200 sieve	8– 25

The fraction passing the No. 200 sieve shall be less than two-thirds of the fraction passing the No. 40 sieve. The fraction passing the No. 40 sieve shall have a liquid limit not greater than 35 and a plasticity index not less than 4 or more than 9.

D. Moisture Content

5. The materials A, B and C herein specified shall contain sufficient moisture to insure maximum compaction.

E. Admixtures

6. Chemicals or other admixtures shall meet all the requirements of the current A.A.S.H.O. specifications. When the chemical to be used is not covered by an A.A.S.H.O. specification, a good commercial grade meeting the approval of the Engineer shall be used.

F. Methods of Testing

7. Sampling and testing shall be in accordance with the following standard methods of the A.A.S.H.O.

(a) Sampling	T- 2-35
(b) Size	T-27-38
(c) Liquid Limit	T-89-38
(d) Plasticity Index	T-91-38

(The liquid limit and plasticity index values can also be determined by the standard methods of the American Society for Testing Materials, D423-38T and D424-38T).

Standard Specifications for Materials for Stabilized Base Course Specification M-56-38

(Sections A, B, C (general requirements), *D*, E, and F are the same as those under M-61-38.)

C. Detail Requirements

4. The type or types designated shall conform to the following requirements:

Type A

Passing	Percentage by Weight
1-inch sieve	100
No. 10 sieve	65–100

The material passing the No. 10 sieve shall meet the following requirements:

Passing	Percentage by Weight
No. 10 sieve	100
No. 20 sieve	55–90
No. 40 sieve	35–70
No. 200 sieve	8–25

The fraction passing the No. 200 sieve shall not be greater than one-half the fraction passing the No. 40 sieve. The fraction passing the No. 40 sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 6.

Type B

Passing	Percentage by Weight B-1 1-in. max. size	B-2 2-in. max. size
2-inch sieve		100
1½-inch sieve		70–100
1-inch sieve	100	55– 85
¾-inch sieve	70–100	50– 80
⅜-inch sieve	50– 80	40– 70
No. 4 sieve	35– 65	30– 60
No. 10 sieve	25– 50	20– 50
No. 40 sieve	15– 30	10– 30
No. 200 sieve	5– 15	5– 15

The fraction passing the No. 200 sieve shall be less than one-half of the fraction passing the No. 40 sieve. The fraction passing the No. 40 sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 6.

Type C

Passing	Percentage by Weight
¾-inch sieve	100
No. 4 sieve	70–100
No. 10 sieve	35– 80
No. 40 sieve	25– 50
No. 200 sieve	8– 25

The fraction passing the No. 200 sieve shall be less than one-half of the fraction passing the No. 40 sieve. The fraction passing the No. 40 sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 3.

COMPUTING QUANTITIES

Burggraf: A well designed stabilized mixture of the B-1 gradation type will contain 35 to 65 per cent coarse aggregate (retained on No. 4 sieve), 15 to 30 per cent fine aggregate and 5 to 15 per cent binder-soil (passing 200-mesh sieve). In order to obtain a mixture of such composition it is necessary to combine at least two or sometimes three different materials. It is noted from the gradation limits of the B-1 specifications that the well graded stabilized mixture must contain at least 15 per cent and not more than 30 per cent of material that will pass a No. 40 sieve and that this material must not have too much cohesiveness (maximum plasticity index of 6). The plasticity in a stabilized mix is obtained from the amount of binder-soil that is added to the mix. The amount that is added depends upon the quality of the binder and the amount of material pass-

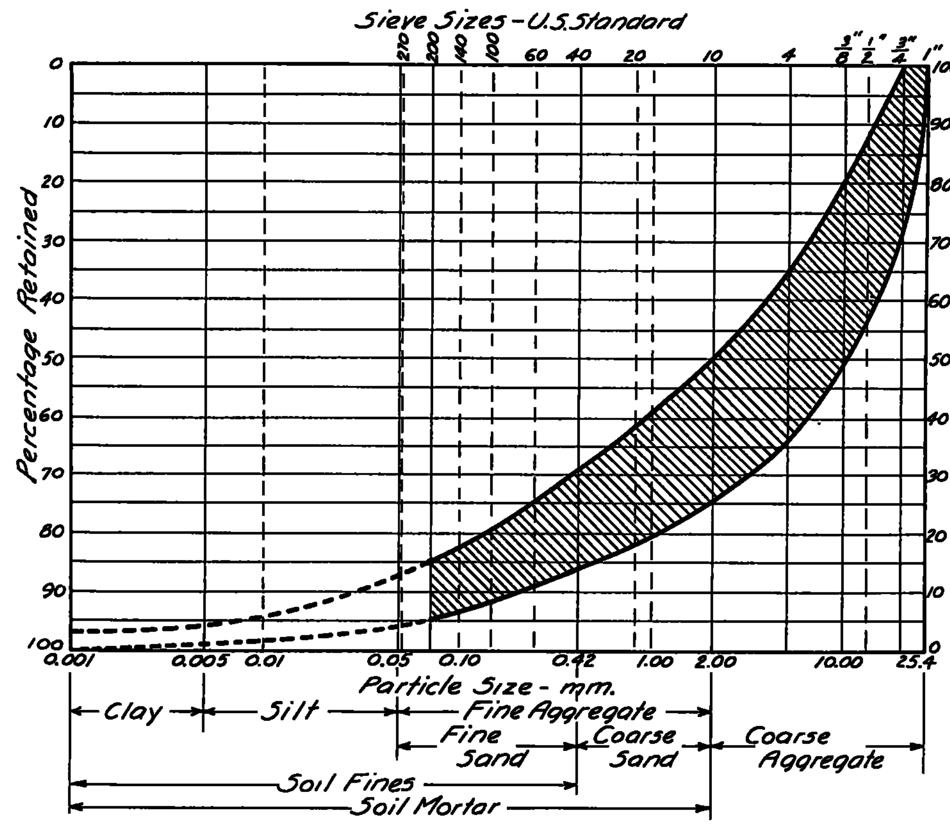

Figure 1. Stabilization Chart for 1-in. Maximum Size Aggregate for Base Course

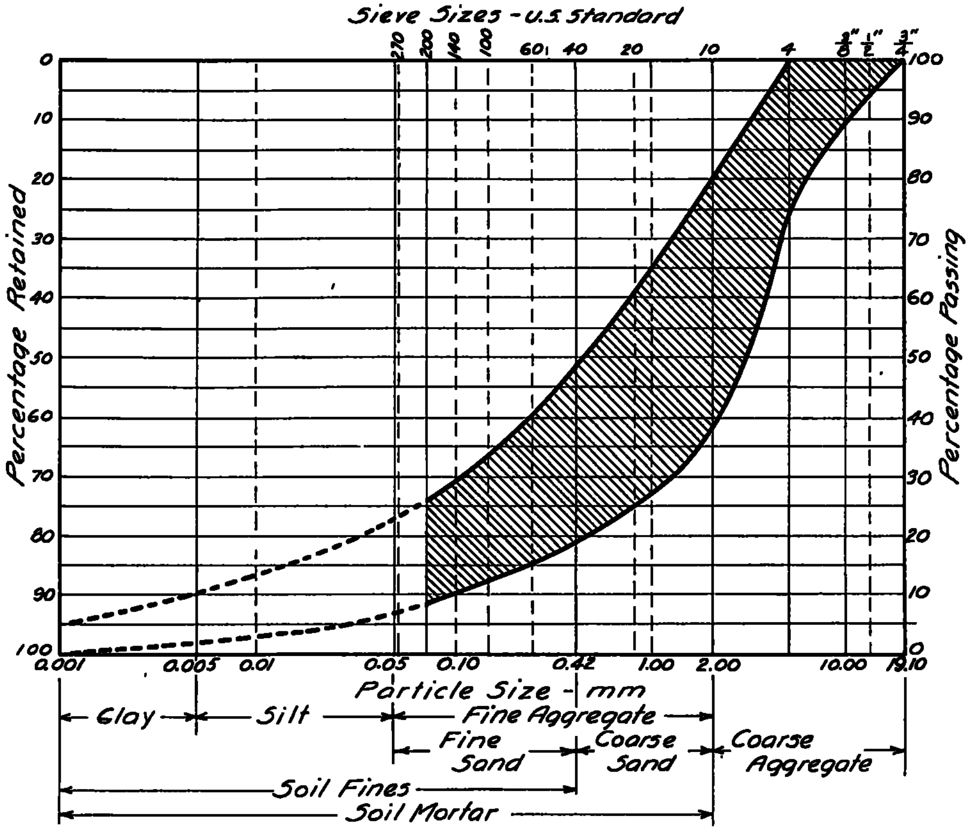

Figure 2. Stabilization Chart for Fine Aggregate Mixture

TABLE 1
Gradation Analyses and Quality Tests on Samples

Material No.	Per Cent Passing (by Weight)							
	1"	¾"	⅜"	No. 4	No. 10	No. 40	No. 200	Plas. Index
1—Coarse Aggregate	100	90	64	30	12	5	0	Non Plastic
2—Fine Aggregate	100	100	100	100	95	90	11	Non Plastic
3—Binder-Soil	100	100	100	100	99	90	86	24

TABLE 2

Material	Per Cent Passing						
	1"	¾"	⅜"	No. 4	No. 10	No. 40	No. 200
85% No. 1	85	77	54	26	18	4	0
15% No. 2	15	15	15	15	14	13	2
100%	100	92	69	41	32	17	2

ing the No. 40 sieve in the graded aggregate. The proper proportioning of materials can best be explained by the following example:

The three materials in Table 1 are to be combined.

From the data in Table 1 it can be seen that sample No. 1 will require the addition of some material such as sample No. 2 to have a well graded aggregate. A mixture of 85 per cent of sample No. 1 and 15 per cent of sample No. 2 by weight would be graded as in Table 2.

The amount of binder-soil (Material No. 3) to be added to the well graded aggregate mix to give it the desired plasticity is determined by cut and try. A mixture of the material passing the No. 40 sieve in the binder-soil and the same fraction of the well graded aggregate is made up and the plasticity index determined. If the results are not satisfactory the proportion is adjusted until the mix has a plasticity index that falls within the required limits. In this case it was found that a mixture of 35 parts by weight, of soil fines from the binder-soil, to 65 parts of soil fines from the well graded aggregate, gave a plasticity index of 6, which falls within specification limits.

TABLE 3

Material	Per Cent Passing						
	1"	¾"	½"	No. 4	No. 10	No. 40	No. 200
85% of No. 1	85	77	54	26	10	4	0
15% of No. 2	15	15	15	15	14	13	2
10% of No. 3	10	10	10	10	10	9	9
110%	110	102	79	51	34	26	11
Final Mix	100	92	71	46	30	23	10

TABLE 4

Width of Road, ft.	Sq. Yds. per Lin. Foot	Sq. Yds. per Mile	Average Thickness of Compacted Wearing Course in Inches											
			1		2		3		4		5		6	
			Wt. (T.)	Vol. (C.Y.)	Wt. (T.)	Vol. (C.Y.)	Wt. (T.)	Vol. (C.Y.)	Wt. (T.)	Vol. (C.Y.)	Wt. (T.)	Vol. (C.Y.)	Wt. (T.)	Vol. (C.Y.)
10	1.11	5867	330	163	660	326	990	489	1320	652	1650	815	1980	978
12	1.33	7040	396	196	792	391	1188	587	1584	782	1980	978	2375	1173
14	1.55	8213	462	228	924	456	1386	684	1848	912	2310	1140	2772	1369
16	1.77	9387	528	261	1056	522	1584	782	2112	1041	2640	1303	3168	1564
18	2.00	10560	594	293	1188	586	1782	880	2376	1172	2970	1466	3564	1760
20	2.22	11733	660	326	1320	652	1980	978	2640	1304	3300	1630	3961	1956

The values for weight quantities are based on a compacted stabilized wearing course weighing 2.03 tons (dry) per cu. yd.

The percentage by weight of sample No. 3 to be added to the graded aggregate may now be calculated as follows:

Let, P = percentage by weight of binder-soil to be added.

A = grams of fines from binder-soil used in trial mix.

B = grams of fines from well graded aggregate used in trial mix.

C = percentage of material passing No. 40 sieve in well graded aggregate.

D = percentage of material passing No. 40 sieve in binder-soil.

Solving for P:

$$P = \frac{A}{B} \times \frac{C}{D} = \frac{35}{65} \times \frac{17}{90} = 10.$$

If 10 per cent of Sample No. 3 is added to the graded aggregate, the final mixture will have the gradation of Table 3.

The final mix will contain 77 per cent of Material No. 1, 14 per cent of Material No. 2 and 9 per cent of Material No. 3.

Table 4 contains the quantities of combined materials for compacted stabilized roads in tons and cubic yards per mile.

PROPERTIES OF CALCIUM CHLORIDE AND HOW THEY FUNCTION IN ROAD STABILIZATION

Downey: Of first importance is the ability of calcium chloride to retard evaporation. Adequate or complete compaction of the road metals after construction is very difficult, if not impossible, under conditions of rapid evaporation of moisture from the road materials during the period when stabilizing is being carried on.

On gravel roads, this function also serves to maintain a moisture film on the "fines" in the mixture, which results in maximum cohesion of the binder-soil.

In stabilized bases, moisture promotes cohesion, but here the surface course, and the capillarity of the mixture, are extra contributing factors to the retention of moisture.

Another characteristic of calcium chloride is that it attracts additional moisture. That is, it not only retards the rate of evaporation from the road during the heat of the day, but, because of its deliquescent character, actually recaptures or replaces lost moisture at night, or under other favorable humidity conditions.

The successful performance of a stabilized surface is primarily dependent on the presence of moisture at, or very close to, the surface of the metal.

The ability of chloride to maintain moisture on the road surface prevents the loss of the surface fines as dust. This in turn prevents the unkeying of the coarse aggregates, with consequent ravelling and progressive disintegration of the whole surface.

A few years ago any paper dealing with the use of chloride in road construction or maintenance would have covered the subject entirely from the standpoint of dust control. Dust, as such, is now controlled; but that is only an important by-product of the use of chloride, not the sole objective.

The ability of calcium chloride to attract moisture varies according to the climatic conditions under which it is used. It is soluble in water and moves along with soil moisture either in the capillary or free water state.

If calcium chloride is used in a road surface with too low capillary characteristics, rains will leach the chloride through the road metal and into the subgrade. The calcium chloride will not return to the road surface during dry periods since the surface course does not have adequate capillary action to bring moisture from the subgrade to the surface. Without the calcium chloride in the road surface the road continues to dry out, and a dusty, loose floating cover will be formed by the action of traffic.

If calcium chloride is used in a road surface with too high capillary characteristics, rains will remove the calcium chloride by movement of free water across the road surface to the shoulders or drainage ditches. The calcium chloride is lost and the surface becomes dry and dusty as in the previous case. Thus both of these types of roads require excessive amounts of calcium chloride to eliminate dust and a loose cover.

Proper balance between the moisture movements indicated by the two extreme cases results in a favorable moisture movement capable of retaining the calcium chloride in the road surface where it can function economically as a stabilizing agent. The ideal surface course is an aggregate mixture which has a uniform gradation from coarse to fine and has sufficient binder-soil to produce effective pore diameters in the compacted aggregate mixture. These pore spaces or voids act as a reservoir for holding the calcium chloride in the capillary soil moisture phase during periods of rains. The capillary moisture will then move to the surface during the drying period and deposit the calcium chloride in the surface layer. If the surface course did not have to resist the abrasive action of traffic, the most efficient soil-binder would be silt, which has excellent capillary characteristics, but possesses little, if any, cohesive properties. However, to resist traffic abrasion, cohesion as furnished by soil colloids is necessary. The most effective binder-soil is a mixture of clay, silt and fine sand.

Elleman: It has been definitely established that moisture films exert a tremendous bonding action, and that this action is increased as the thickness of the films is decreased. In a stabilized road calcium chloride solution exists as films surrounding each particle of material. In the fines or binder-soil there is an enormous number of moisture films. Under the action of traffic or by mechanical means, these particles are squeezed closely together and are separated only by the extremely thin films of the calcium chloride solution. The great surface area of the fines acts as a storage space for the film moisture. The amount of moisture held in the surface of the road is dependent upon the humidity because an equilibrium between it and the moisture retaining power of the calcium chloride is set up.

It is evident that there are three main links in the stabilization chain: graded aggregate, fines and moisture, and as in any chain, each link is equally important.

The aggregate gives structural strength during wet weather and the gradation reduces the voids.

The fines further reduce the voids and serve to hold the moisture, and in conjunction with the moisture serve to seal the road and prevent the entrance of excess water.

The enormous bonding action of the moisture films is utilized in a stabilized road first to maintain the original gradation of the surfacing materials by preventing the loss of fines in the form of dust, and second to improve the riding surface by reducing the formation of the wash-boards which form on unbonded surfaces.

Moisture Attraction

Hogentogler, Jr.: Flake calcium chloride, which is the form most widely used in highway work, possesses both deliquescent and hygroscopic properties. Del-

TABLE 5

DELIQUESCENCE

(Lowest Relative Humidity and Temperature at Which Calcium Chloride Will Dissolve)

Relative Humidity	Temp., Deg. F.
20	100
30	74
40	44
43	32

HYGROSCOPICITY

(Pounds of Water Taken Up by One Pound of Flake Calcium Chloride at Different Humidities)

Relative Humidity	Temp., Deg. F.	Lbs. of Water Taken Up by 1 Lb. $CaCl_2$
36	77	1.0
60	77	1.6
70	77	2.0
80	77	2.8
85	77	3.5
90	77	5.0
95	77	8.4

iquescence is the process of dissolving and becoming liquid by attracting and absorbing moisture from the air. Hygroscopicity is the process of readily absorbing and retaining moisture. These properties of calcium chloride are closely related to the relative humidity and the temperature of the air. Table 5 contains a summary of these properties and their relationship to humidity and temperature.

The yearly average absorption ratio of calcium chloride to moisture absorbed in various sections of the United States is shown graphically in Figure 3, as computed from U. S. Weather Bureau reports, and reveals that under average weather conditions calcium chloride takes

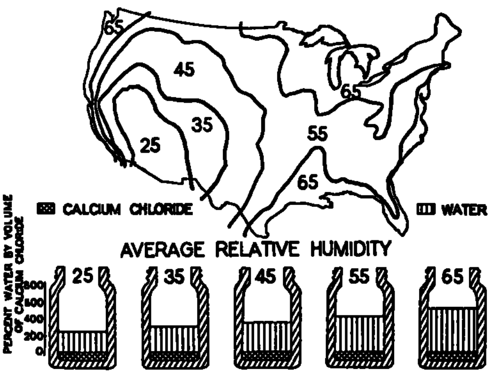

Figure 3. Moisture Attraction Yearly Average for U. S.

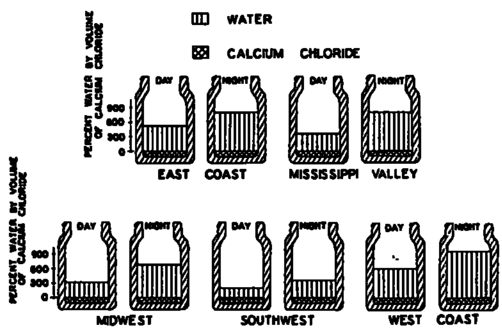

Figure 4. Average Moisture Attraction for July (Note Reserve Attracted at Night)

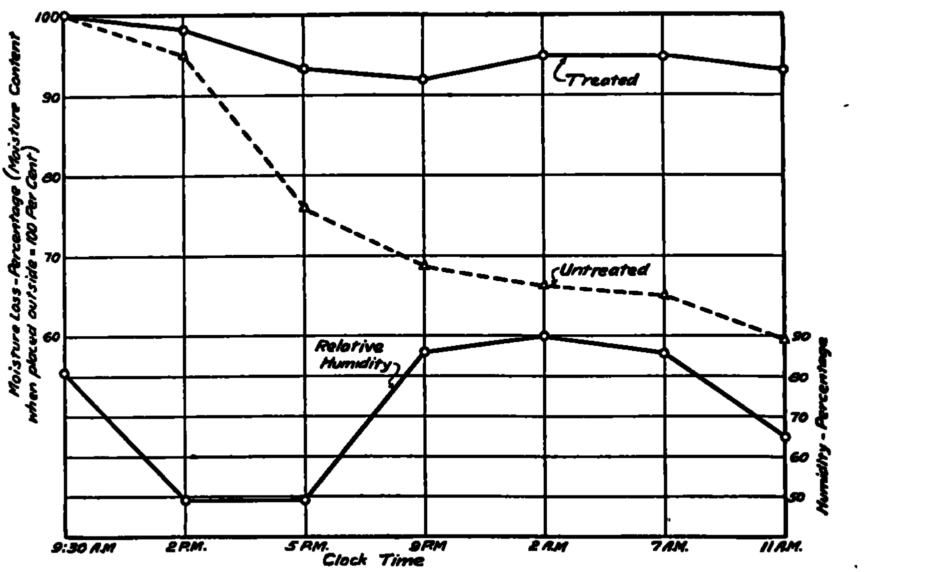

Figure 5. Relationship Between the Rates of Evaporation of Moisture from Treated and Untreated Soils and the Effect of the Relative Humidity on the Hygroscopic Property of the Calcium Chloride Treated Soil (South Carolina Project). Data from Proceedings of Highway Research Board, Vol. 12, Part II, 1932.

up from 2 to 5 times its weight in moisture.

Another interesting factor is the difference in moisture attraction during

Figure 6. This Picture Shows a Flake of Calcium Chloride about Ten Times Its Natural Size.

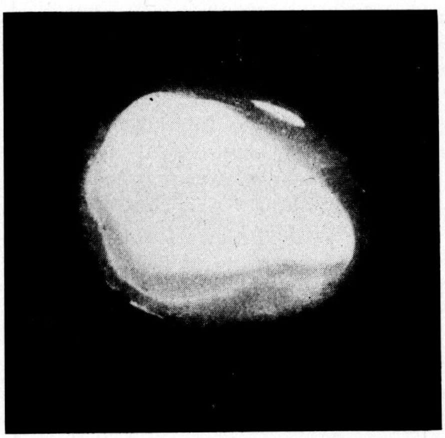

Figure 7. The Same Flake as in Figure 6, 24 Minutes after Exposure to the Air at a Normal Summer Temperature of 77° and a Relative Humidity of 78. At This Temperature and Humidity, a Pound of Flake Calcium Chloride Will Take up about $2\frac{3}{4}$ lb. of water.

the day and at night. This is illustrated in Figure 4.

Therefore, when used as a road binder, calcium chloride takes up from 4 to 10 times its weight in moisture during the night and retains from one-half to two-thirds of it throughout the heat of the

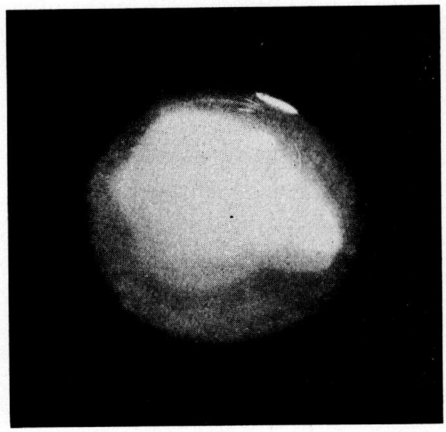

Figure 8. The same Flake as in Figure 6, 48 Minutes after Exposure at the Same Temperature and Humidity as in Figure 7.

Figure 9. The Same Flake as in Figure 6, Three Hours after Exposure to Same Air Conditions as in Figure 7. It has completely dissolved itself in the moisture it attracted.

day. The effect is similar to a light rainfall each night as contrasted with untreated roads which do not recover moisture and often completely dry out between rains. This is verified by data reported by the Highway Research Board,[1] as given in Figure 5.

It should be emphasized that the attraction of moisture from the air is, by far, a more important property than just a decrease in the loss of moisture supplied by rains, dew or exceptionally humid weather, because the attraction of moisture from the air is a continuous process, whereas the retarding of the loss of moisture supplied by rains, only postpones for a short time, the ultimate drying out of a road surface.

Burggraf: The moisture absorbing action of calcium chloride is a powerful natural force. The pictures (Figs. 6, 7, 8, 9) of flakes of calcium chloride show how it dissolves itself in the moisture it draws through these natural forces.

Vapor Pressure

Burggraf: 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.

A practical verification that the lower vapor pressure of calcium chloride solutions greatly conserves the moisture content in the road is shown graphically in Figure 10. This conservation of the moisture content in the road surface averts the formation of dust, which means the prevention of wear or a saving of road material.

Hogentogler, Jr.: The vapor pressure curves in Figure 11 show the performance of calcium chloride solutions under all

[1] Report of Investigation of the Use of Calcium Chloride as a Dust Palliative, *Proceedings*, Highway Research Board, Vol. 12, Part 2, p. 24 (1932).

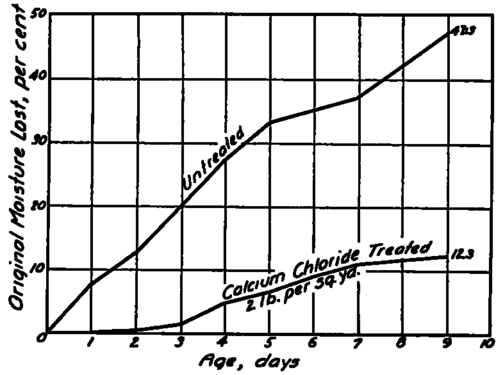

Figure 10. Relation of Evaporation Losses from Treated and Untreated Soil Aggregate Road Mixtures. (Composite Date on Laboratory Tests from Three States, Highway Research Board Proceedings, Vol. 12, Part II, 1932.)

Figure 11. Vapor Pressures of Calcium Chloride Solutions.

Explanation of Curves: 1. Vapor Pressure of Water is given by the intersection of temperature curves with 0 per cent 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 per cent calcium chloride (78 per cent $CaCl_2$)has a vapor pressure of 26.8 mm., and one containing 50 per cent 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 per cent relative humidity the vapor pressure of water in the air is 15.2 mm., i.e., 50 per cent 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 per cent calcium chloride (78 per cent $CaCl_2$), which is the strength having a vapor pressure of 15.2 mm. A weaker solution than 46 per cent at this temperature and humidity will have a

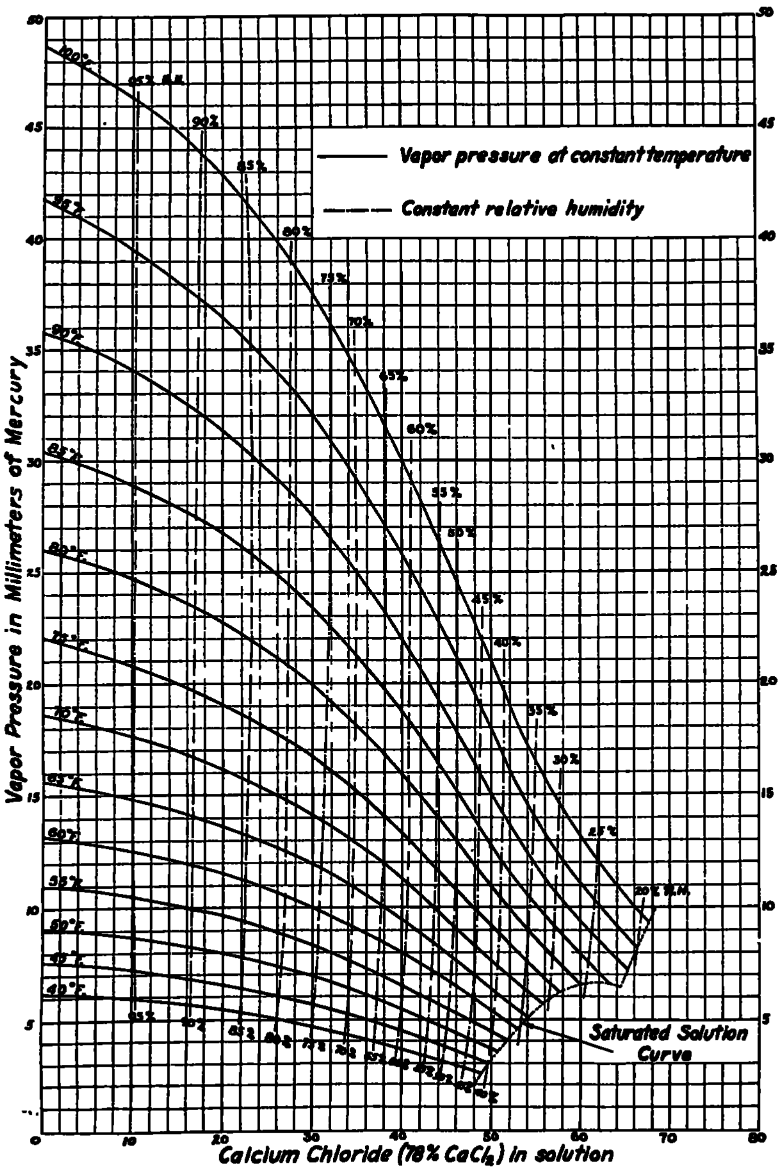

Figure 11

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.

ordinary temperature and humidity conditions encountered in road construction or 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. This figure is very valuable as it shows plainly the inter-relationship of the various factors and explains the mechanics of this important property.

Table 6 shows the vapor pressure relationship at certain temperatures, between plain water and concentrated solutions of calcium chloride.

TABLE 6

Temperature, Deg. F.	Vapor Pressure	
	Plain Water	Concentrated Calcium Chloride
41	6.54	2.74
50	9.21	3.71
59	12.79	4.76
68	17.54	6.06
77	23.76	6.97
84	30.04	7.30
104	54.32	10.53

These values become highly significant when we realize that the rate of evaporation is proportional to the vapor pressure, and that evaporation from calcium chloride solutions is, as shown, materially lower than from plain water.

Surface Tension of Water

Hogentogler, Jr.: Each molecule (or minute part) of liquid within the body of a liquid is powerfully attracted to the particles surrounding it. These forces, however, acting in all directions on the inner molecules balance each other and hold them tightly in suspension. But the molecules in the surface layer of the liquid are not subjected to such forces from above, and as a result cling to the body of the liquid to form a tightly stretched, but elastic, "skin" over the liquid. This is evidenced when, for instance, a needle carefully placed on the surface of water is supported and prevented from sinking through the liquid by the surface tension.

Too, when liquids are freed from external forces (such as gravitation) and form into drops, the forces of attraction among the particles promptly arrange them in the closest possible proximity which normally will form a true sphere. These phenomena of forces tending to reduce the surface of liquids to the smallest area possible are identified as "surface tension" which may also be conceived as the field of force existing at the boundary of a liquid with the vapor around it. Various liquids and solutions differ in surface tension. Figure 12 shows the increase of surface tension of water by the addition of calcium chloride.

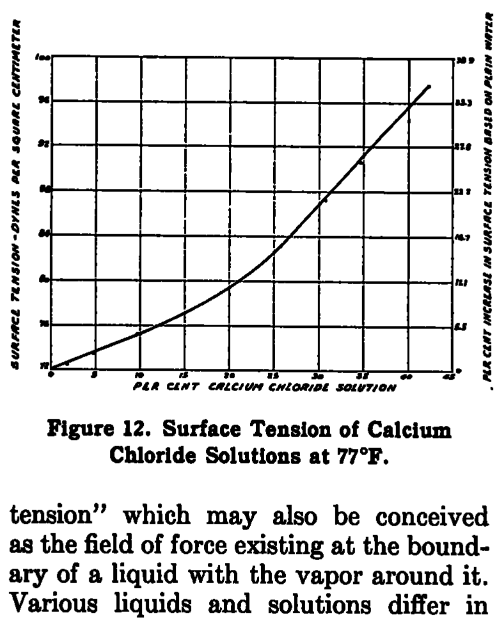

Figure 12. Surface Tension of Calcium Chloride Solutions at 77°F.

This property of calcium chloride solutions is not only effective in lowering the evaporation from treated roads but the resultant moisture films are stronger than those of plain water.

Freezing Point of Water

Hogentogler, Jr.: Calcium chloride lowers the freezing point of water as shown in Table 7, which reduces the number of freezing and thawing cycles and prevents the loss of stability of soil mixtures.

The results in the first progress report on the investigation of frost action in stabilized soil mixtures being carried on as part of the research program of the Joint Highway Research Project at Purdue University, show definitely that the admixture of calcium chloride greatly reduces the damaging effects of frost action.[2]

TABLE 7
EFFECT OF CALCIUM CHLORIDE ON FREEZING OF WATER

Chemical, % of Weight of Water	Freezing Point, Deg. F.
5	28
10	23
15	21
20	10
25	−2
30	−18
35	−30
40	−46
45	−55
50	−60

Binding Properties

Hogentogler, Jr.: One of the prime requisites for the efficient service behavior of stabilized roads is that they possess a certain degree of cohesion, which is supplied by the binder-soil fraction in the presence of sufficient moisture.

An excellent review of the importance and value of moisture in film phase is given in the Proceeding of the Royal Society of London (1927). The following statement is taken from that article:

"It is well known that two clean glass plates with flat surfaces adhere to one another when brought into intimate contact. . . . Such adherence is clearly due to molecular cohesion. . . . This adherence can be further improved by interposing a trace of liquid between the surfaces. . . . If the film is not too thick every liquid molecule is under the influence of the solid molecules. The film has lost its property of fluidity and is in a condition which may be described as quasi-solid. A direct pull of 213 pounds per square inch was found necessary to separate two block gauges adhered together with a lubricant."

The phenomenon of the binding power of moisture is obvious in the stabilizing effect of ebbing tide waters on the loose sands at Daytona Beach and elsewhere. Here, heavy racing cars, exerting enormous tractive powers and attaining tremendous speeds, find stable footing in moisture-bound sand which when dry would not support the weight of a man.

The fact that calcium chloride increases the surface tension, viscosity and lubricating properties of water is probably an important factor in the explanation of why soils to which calcium chloride has been added attain greater density under shrinkage or artificial compacting forces than similar untreated soils.

In some shrinkage tests on oven-dried samples it was found that the weight of a soil containing just ½ per cent of calcium chloride was 112 lb. per cu. ft., while the same soil without any admixture had a weight of but 103 lb. A commonly accepted theory as to why soils become more dense as they dry out is that the moisture films, acting like thin rubber membranes, gradually become thinner and more taut and pull the soil particles closer together. This process continues until the resistance to further consolidation is just balanced by the tensile strength of water. Therefore, in view of the fact that calcium choride increases the surface tension of water, it is probable that the tensile strength of water is also increased and the soil containing calcium chloride attains greater density because the moisture films have been strengthened.

Research has also established that calcium chloride admixture produces thinner moisture films than plain water.

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[2] H. F. Winn, "Frost Action in Stabilized Soil Mixtures," *Proceedings*, Highway Research Board, Vol. 18, Part I, p. 264.

Effect on Density

Hogentogler, Jr.: In a series of compaction tests it was found that under the same compactive effort the weight of the plain and calcium chloride treated soils was 97 and 108 pounds per cubic foot, respectively. The extent of this difference in density is clearly shown in Figure 13. This increase of 11 per cent in weight is vitally significant, when it is realized that the mass equivalent of the added weight exists as voids, in the untreated soil, which are open to excess water penetration and may cause failure under wetting.

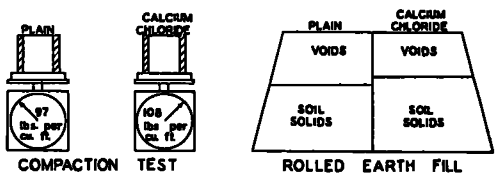

Figure 13. Calcium Increases Density. (Same Compactive Force.)

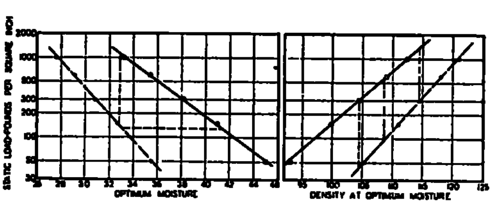

Figure 14. Control Curves A and B

The control curves, Figure 14, serve to explain these phenomena. The full lines were furnished by tests of one kind of soil, A, and the broken lines by tests of the same soil treated with calcium chloride, B. The curves at the left show that at the same pressure, 135 lb. per sq. in., the optimum moisture content of soil A is 41.2 per cent as compared with only 33 per cent for soil B; also that to have the same optimum moisture content of 33 per cent, soil A requires a pressure of 1,100 lb. per sq. in., and soil B a pressure of only 135 lb. per sq. in.

The curves to the right, Figure 14, show that to attain the same density of 104.4 lb. per cu. ft., a pressure of 300 lb. per sq. in. is required for sample A as compared with 42 lb. per sq. in. for sample B; and that the same pressure of 300 lb. per sq. in. on soil A attains a density of 104.4 lb. per cu. ft. as compared with 114.5 lb. per cu. ft. on soil B. The extent of this difference in compactive effort is clearly shown in Figure 15.

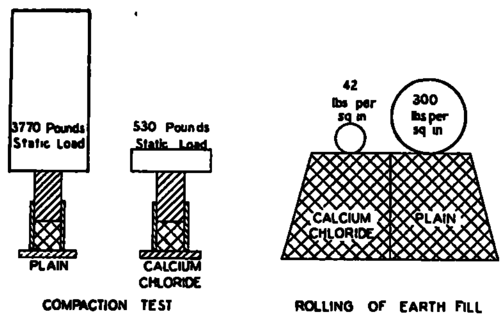

Figure 15. Calcium Chloride Decreases Compactive Effort. (Same Density.)

An admixture of calcium chloride also assures better compaction as it sustains the moisture content over a longer period. In the May 1936 issue of Public Roads, a summary of the importance of conserving the moisture is given. It states:

"The value of this ability to conserve moisture is most apparent during compaction of the stabilized mat in which the salt has been incorporated. The plasticity of the clay component is maintained over a longer time, plus prolonging the period during which compaction is taking place and permitting compression of the aggregate into a denser mass, with thinner and consequently stronger and more lasting binding films than would otherwise be obtained."

Burggraf: The moisture content necessary to give the greatest density to which an acceptable stabilized mixture may be compacted by a specific method is the most important factor in obtaining a suitable road. The moisture content to obtain this required consolidation with the usual equipment is approximately eight per cent by weight. The extent to which the voids in the stabilized mixture are reduced by compaction determines the degree of softening that will take place from water saturation.

The importance of compaction during the construction of these roads and the valuable aid of integral calcium chloride in obtaining an increased density by facilitating compaction, were quantitatively determined during the 1938 construction season. A series of tests were made on a plant-mix stabilization job by determining after different passes of a multiple wheel roller, the density of

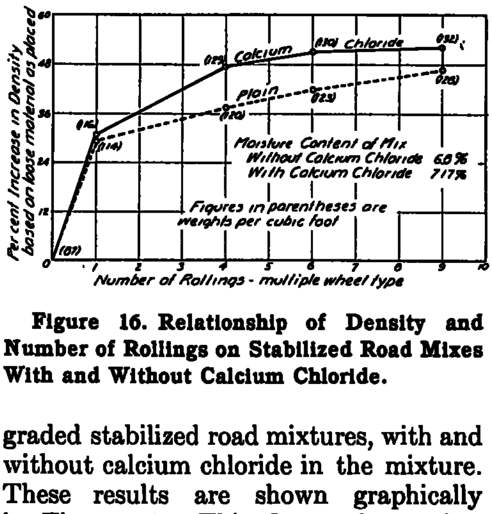

Figure 16. Relationship of Density and Number of Rollings on Stabilized Road Mixes With and Without Calcium Chloride.

graded stabilized road mixtures, with and without calcium chloride in the mixture. These results are shown graphically in Figure 16. This figure shows that the densities of the materials as placed on the grade from the spreader box were 87 lb. per cu. ft. After one pass of the multiple wheel roller, the calcium chloride mix had attained a density equivalent to 116 lb. per cu. ft., to 114 lb. for the plain mix. The difference at the end of four passes of the roller was 9 lb. per cu. ft., in favor of the mix containing the 4.5 per cent solution of calcium chloride. The results further show that the degree of compaction attained at the end of four rollings of the mixture containing the calcium chloride is slightly greater (129 lb. per cu. ft.) than that of the plain water mixture after nine rollings (128 lb. per cu. ft.).

CALCIUM CHLORIDE STABILIZATION TYPES

Burggraf: It has been found convenient to classify calcium chloride stabilized roads into: (1) Surface Consolidation, and (2) Stabilization.

Surface Consolidation means improving the surface of a road as a maintenance function, by utilizing shoulder or easily obtained soil material for the purpose of binding up, consolidating and smoothing the resultant surface, with the aid of moisture and compaction, in order that the calcium chloride treatments will function longer and more effectively.

Stabilization includes the construction of a dense wearing course or base composed of a designed and controlled mixture of graded aggregate, binder-soil and calcium chloride used either integrally or on the surface, or both.

SURFACE CONSOLIDATION BY MAINTENANCE METHODS

Elleman: An untreated gravel or crushed stone road surface becomes dusty in dry weather and develops an appreciable amount of loose aggregate. It has been common maintenance practice to windrow this loose stone to the side of the road, to be bladed back again during wet weather. While this practice is admittedly better than the "mulch" method of leaving loose material under the wheels of traffic, it is illogical, in that the windrowed material is giving no service to traffic but on the contrary constitutes a hazard to emergency use of the shoulder and obstructs the flow of storm water.

According to The Iowa State Highway Department[3] the "mulch" method of maintenance is objectionable; because the mulch acts as an abrasive and causes

[3] *The Earth Mover*, May 1938. W. H. Root, Maintenance Engineer.

raveling; because it promotes loss of material; because it may cause skidding; because it may cause snow drifts and because these roads are practically always dusty.

The consolidation of loose aggregate on road surfaces is a maintenance operation and may be accomplished satisfactorily by the so-called "trial and error" method. This consists of mixing a trial amount of pulverized clay or clay combination soil with the loose aggregate. The trial amount is usually about 10 per cent of the volume to be consolidated. Water is added and the mixture is shaped and compacted under traffic. The dry mixture may be windrowed to be bladed into the road during the next rain. If the local soil from the shoulder is of a cohesive nature, it is frequently used and bladed into the loose aggregate as binder material. The preservation of moisture in the mixture is very essential and may be accomplished by surface application of calcium chloride.

If the road surface shows a tendency to muddiness in wet weather, an excess of binder-soil is indicated, and this is corrected by a light application of coarse sand, fine gravel, crushed stone or slag. The behavior of the road under traffic in both wet and dry weather thus becomes the practical means of establishing a balance between aggregate and binder-soil.

Experience with local soils and aggregates soon enables the superintendent to reduce any necessary corrections to a minor amount; an alert maintenance organization can correct an unsatisfactory condition promptly, before it becomes an object of public criticism. This method provides an intermediate stage of improvement which produces a serviceable road at low cost.

Many miles of existing roads need only the addition of moisture to make them stable in all kinds of weather, the year around. Some of these roads were constructed of naturally graded gravel which contained binder-soil, or of graded limestone. Others became compacted as the result of binder-soil from the subgrade or shoulders working into them through traffic or maintenance.

In this type of construction, a rough method of testing materials without laboratory equipment is described by Hogentogler and Willis in May, 1936 Public Roads, as follows:

"A sample of well-graded sand and binder-soil may assist in the selection of soil mixtures that have the desired properties.

"If a sample of well-graded material is wetted and squeezed in the hand, the following characteristics will be noted: (a) The soil is extremely gritty; (b) it can be formed into definite shapes that retain their forms even when dried; (c) if the clay alone adheres to the hands, it will only be enough to discolor them slightly; (d) if more than enough soil to discolor the hands adheres to them, it will consist of both sand and clay instead of clay alone; and (e) when the wetted sample is patted in the palm of the hand, it will compact into a dense cake that cannot be penetrated readily with a blunt stick the size of a lead pencil. These characteristics indicate well-graded material. The grittiness of the sample indicates the presence of sufficient granular material. Development of some strength on drying indicates a sufficient amount of binder-soil. Resistance to the penetration of the pencil or stick, even when the sample is thoroughly wetted, indicates a desirable interlocking of the grains and the presence of a sufficient amount of capillary force.

"Too much sand would cause the sample to fall apart when dried. Too much clay would leave the hand muddy after the wet sample was squeezed and would cause the wet sample after being patted, to offer little resistance to the penetration of the stick."

Wilford: In our County of Victoria, by far the greatest mileage of road to be maintained, consists of gravel surfaces. It therefore is expedient that some action be taken, consistent with a limited budget, which will serve to improve their smoothness, safety and comfort for road users, and at the same time will serve to develop a stable well compacted base for a foundation for some more permanent surface in the future. This to my mind, constitutes the field of use of calcium chloride as applied to "Low Cost Roads."

Local Conditions: The gravel materials for the greater part of our mileage were obtained from local deposits. In practically all cases the fines were all retained in the aggregates used, the material being simply run through a crushing and screening plant, to reduce the coarse aggregate sizes within suitable limits. We have found that many of our gravel deposits will, under moderate traffic, produce good firm surfaces and except in continued spells of dry weather under heavy traffic, they can be fairly easily maintained as a stable surface with very little surplus loose float. Our problem then resolved itself mainly into one of finding some means of keeping the gravel surfaces moist and for this purpose we have for the last two years been using calcium chloride with very encouraging results.

Procedure: In general the work has been carried out as part of our maintenance resurfacing program on roads already graded and metalled with either crushed stone or crushed gravel.

In some cases where the existing road surface already appeared to be well compacted, and had retained a reasonable crown, an effort was made to obtain stabilization by a dust laying treatment of calcium chloride. In other cases shoulder material, if it appeared to provide the desired binding qualities, was graded on to the metalled surface, mixed with the road metal present, reshaped and a calcium chloride treatment given. In other cases it was found necessary to haul clay or other binder material for additional mixing with the road metal before treatment with calcium chloride.

I shall outline briefly the equipment and methods employed on our County Road No. 8, westerly from Bobcaygeon. This road carries an average daily traffic of about 500 vehicles, and connecting as it does the Villages of Fenelon Falls and Bobcaygeon, both of which offer many attractions to tourists, is at times subjected to considerably higher peak traffic loads. It was found to be impossible during dry periods under summer traffic to prevent by frequent draggings, the formation of severe chatter bumps on this road surface. The dust nuisance was also a serious menace to the comfort and safety of those using and living along this road.

The equipment in addition to trucks for hauling materials comprised a steam roller with attached scarifier, a large horse drawn grader of somewhat ancient vintage, one set of disc harrows and one set of ordinary farm harrows.

The road was scarified to a depth of about three inches over an 18-ft. width and while the original intention was to scarify, add and mix the clay binder, and reshape the complete length of 2.6 miles before applying calcium chloride, it soon became apparent that traffic would remove a large portion of the binding material in the form of dust from the completed portions while work was proceeding elsewhere. It was thought best therefore to add the necessary binder material to the portion of road already scarified, follow this with a thorough mixing of loosened road metal and binder using the two sets of harrows, after which the material was further mixed and shaped by the grader to give an approximate crown of four inches. When a half mile or so had thus been completed, this portion of road was thoroughly compacted under the roller, care being taken to preserve the crown. Calcium chloride was applied in the late afternoon or early evening on the portion completed each day. The most uniform application was obtained with a sand spreader drawn behind a truck.

At points where the shoulder was high,

and appeared to contain suitable binding material, the sods on the shoulders were turned back and binder was graded in; but in the main, the binder material was obtained from local deposits adjacent to the work.

The 1936 and 1937 procedure consisted of an application of calcium chloride during the third week of May on the surface treated in the previous year. One ton less calcium chloride was used on the 13 miles treated than had been used in the original application the first year. Maintenance for the balance of the year consisted mainly of occasional dragging or light honing following rains, and the patching of any holes that developed, with material similar to that in the stabilized surface, treated with calcium chloride.

We now have 34½ miles of road treated with calcium chloride, of which 14 have had the material applied simply as a dust layer. The other 20½ miles have been treated by the slightly more elaborate methods just discussed.

Knight: When we talk of "Consolidation" we mean a maintenance method in which binder-soil, obtained by cutting down the road shoulders is incorporated with loose stone on the road surface to produce a stable mixture which is shaped to an adequate crown and treated with calcium chloride. In areas where the shoulders do not contain binder-soil this material should be imported.

The economy of using high powered modern machinery in road work has been demonstrated, but since the entire population of Canada is about equal to that of New York State a lot of our work will have to be done with light or improvised equipment. However, in spite of the handicap of low population density we have built many hundreds of miles of excellent consolidated roads very cheaply.

In this construction laboratory work is to a great extent replaced by visual control and trial and error methods.

Three materials are necessary for these consolidated surfaces, aggregate, binder and calcium chloride. If the work is to be done cheaply aggregate and binder must be of local origin, so the specifications cannot be rigid.

The aggregate should be as hard, durable and well graded, as is available locally. The only point where the judgment of the foreman can be exercised is in the gradation. In many cases he may be able to improve the consolidating qualities of his gravel by mixing material from several pits, or from different parts of the same pit. In one case two pits were available at approximately the same hauling distance. The gravel from one was fragmentary in character, clean and of very uniform size. The other pit contained fine stone and loam, which was not much more than dirty, coarse sand. Roads built from either of these pits were unstable, but a road where alternate loads from each pit were mixed by grading gave a perfect example of stability.

The greatest field for education exists with respect to the binder. Experience has proved that we must show the operator why we need binder, how to recognize it, and how to use it.

Figures 17 and 18 show why binder is needed. Figure 17 shows stone plus 10 mesh, coarse sand plus 40, fine sand minus 40, and a mixture of these materials. If some of the sand is very fine, this mixture will appear to be stable.

Figure 18 shows the error of this assumption. With a special camera and powerful spotlights these sands were magnified to sizes comparable with the stone. On examination of the ¾-in. stone it is easy to show an operator that there are many holes or voids in the pile. He will recognize that these holes are full of air and that air is an unstable road material. The coarse sand when magnified very closely resembles the stone showing about the same proportion of voids. The fine sand shows an even

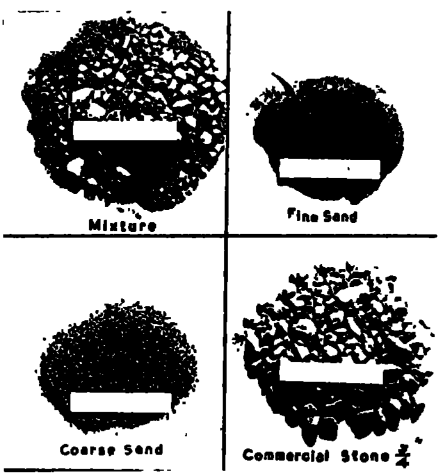

Figure 17. A Mixture of Fine Sand, Coarse Sand and ¾-in. Stone.

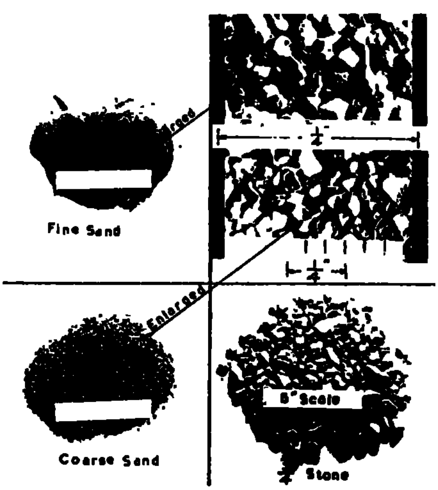

Figure 18. Same Materials as in Figure 17, Showing by Magnification the Voids in the Sand.

greater percentage of voids, due to the greater uniformity of size of the particles. After showing this picture to a non-technical man, it is not hard to persuade him that fine sand is not a binder and that something finer is needed.

Present day specifications show a steady downward trend in the plasticity index requirements in binders. Experience has proved that with careful gradation binders with very low plasticity indices are successful. This allows us to class most surface soils as binder soil. Maintenance experience has shown that surface soils are more friable than pit clays and so are more easily incorporated in the road surface. These surface soils, to a great extent, form the shoulders of our secondary roads and so the cheapest source of binder available is the dirt from the shoulders and from the cleaning out of the ditches. Shoulder soils which have no binding properties are usually of such a light, sandy texture that they are easily recognized and the trained operator knows that in such cases he must import a binder.

There is another type of binder, not so easily recognized, which includes the non-plastic stone dusts. Good results have been obtained with limestones, calcites, iron ores and volcanic silicas. Also, there is the class of aggregate which, under traffic produces plastic binders, which include the shales and schists. We believe that in standard laboratory tests, pit gravels should be tested for plasticity, after having been in the rattler. This would indicate the aggregates which are liable to change in characteristics after being exposed to traffic. We have had experience with gravels which showed a low plasticity index in the pits, but developed very soft, slippery surfaces under traffic. Also other gravels produced a large amount of sand which reduced their plastic properties.

The minimum treatment with calcium chloride should be 1 lb. per sq. yd., which should be applied late in the afternoon or early in the evening in order to take advantage of the higher relative humidity which exists at sunset when the air is near the dew point.

Figure 19 shows a typical gravel road which is in shape for consolidation. The loose float produces clouds of dust and is in itself a serious traffic hazard. Figure 20 illustrates poor surface drainage which leads to the formation of mud holes.

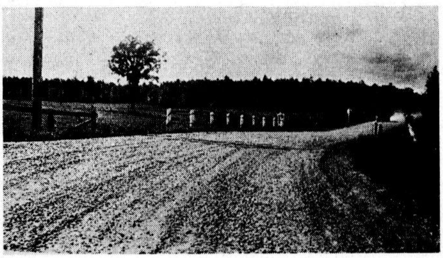

Figure 19. Needing Consolidation

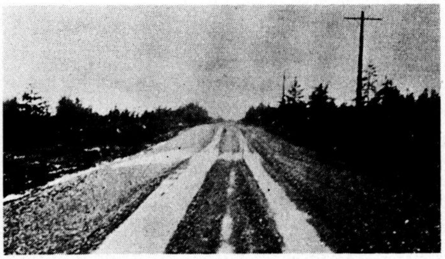

Figure 20. Poor Surface Drainage

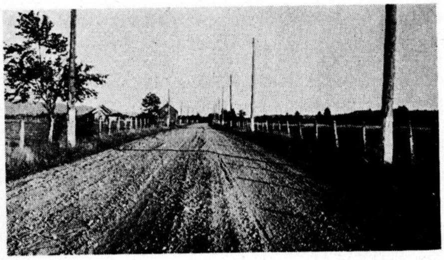

Figure 21. An Ideal Subject for Consolidation

Figure 21 shows a better road but one still far from good. It is an ideal subject for "Consolidation."

High shoulders and loose float are the two principal causes of trouble on our roads. If the shoulders are cut down and this material is mixed with the loose stone the result is a stable surface and improved drainage. Figure 22 shows what a road looks like when it has been consolidated.

The method we use when a road is to be consolidated is as follows. An examination of the whole road is made to locate weak spots because it is seldom that a road is uniform over its whole length. Where there are evidences of soft spots in

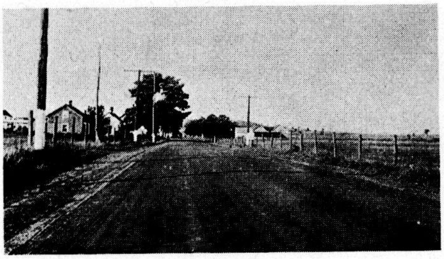

Figure 22. A Consolidated Surface

Figure 23. Binder-Soil Delivered on Roadway, Preliminary to Drying and Pulverizing

wet weather, stone is added. Where shoulders do not contain binder soil, this is imported. In extreme cases this binder soil should be mixed to sufficient depth to support the traffic, then the maintainer is put on the road. The outer end of the blade is set well down and forward to cut in binder soil. It will generally be found that this material contains much gravel as well as binder. The blade should be set so as to produce the maximum rolling effect in order to improve the mixing. The operator will soon learn how much shoulder material he will need to balance the loose stone on the road. It is essential that he be trained to know the basic principles of stability with all the confusing technical terms eliminated. An operator who is able to recognize the materials he requires when he sees them is an invaluable asset to any road organization.

If the basic principles of stabilization are studied and applied to ordinary maintenance, the result will be consolidated surfaces which closely approximate stabilized roads at costs very little in excess of normal maintenance.

CONSTRUCTION OF DESIGNED STABILIZED ROADS.

Briggs: Calcium chloride was used for the first time in Nebraska in graded mix stabilized soil base courses on two projects during 1938. One was in the east central portion of the State and the other in the extreme western portion. The annual rainfall in the vicinity of the eastern project is about 27 inches, whereas it is but 17 inches in the locality of the second project.

Calcium chloride was used experimentally on these projects to obtain information on the following points:

1. Whether or not it will insure constancy of moisture content and moisture film thickness in the stabilized soil mixture and thus supplement the cementing strength of the soil binder.
2. Whether or not it will retard evaporation of water during construction and thus facilitate laying the base course by keeping it plastic for a little longer time.
3. Whether or not, by retarding evaporation, it will reduce the quantity of water required for laying the mixture.

In hot, dry weather, considerable difficulty has been experienced in Nebraska in laying clay-gravel stabilized soil mixtures because the consistency of the mixture changes rapidly as a result of evaporation of water during the manipulation process. Retarding this evaporation was considered one possibility for making the stabilized base course easier to lay, thus permitting smoother riding surfaces to be attained.

An idea of the quantity of water which it has been necessary to add to a stabilized soil base course in Nebraska to compensate for evaporation loss and to insure thorough wetting of all of the mixture can be obtained from Table 8.

TABLE 8

COMPARISON OF THEORETICAL AND ACTUAL QUANTITY OF WATER REQUIRED FOR STABILIZED SOIL BASE COURSE

Project No.	Theoretical Quantity of Water Required		Actual Quantity of Water Required	
	% by Wt.	Gallons	% by Wt.	Gallons
1	6.9	409,200	26.4	1,564,000
2	7.3	256,700	13.4	473,000
3	7.7	589,600	12.5	955,000
4	8.1	619,800	20.3	1,552,000
5	7 7	537,500	21.8	1,526,000

The theoretical water required was determined by the Proctor compaction test for maximum density for each of the mixtures. It was thought that a substantial portion of the cost of the calcium chloride might be offset by the saving in water used.

The characteristics of the graded mixtures on these two projects are given in Table 9.

The calcium chloride was applied with a drill type spreader. As soon as the materials making up the graded mixture were partially dry mixed, approximately one-third of the windrow was spread nine or ten feet wide on the road-bed. One-third of the total application of the chemical was added to this material. This procedure was repeated until the required quantity of calcium chloride had been applied. Dry mixing of the materials was then resumed and continued until uniform mixture was obtained. The total quantity of calcium chloride was ½ lb. per sq. yd. per in. of depth of the base course.

Since these projects have been finished but a short time, the effect of the calcium chloride upon the durability of base courses has not been determined. However, the chemical did assist materially in the construction operations. It was easier to obtain a uniform distribution of moisture throughout the stabilized soil mixture than it was on others on which the chemical was not used. By retarding evaporation during the operations of spreading and compacting the mixture, it was possible to obtain smoother riding surfaces than is usually the case with this type of construction.

TABLE 9

CHARACTERISTICS OF GRADED BASE MIXTURES

	Project No. 86	Project No. 130-A
Passing No. 10 sieve %	61	55
Passing No. 40 sieve %	36	25
Passing No. 200 sieve %	17	18
Silt %	7	8
Clay %	7	6
Liquid Limit	19	22
Plasticity Index	5	5
Density-lb. per cu. ft.	138	138

A small quantity of calcium chloride was used effectively on Project No. 86 for stabilizing a portion of the subgrade that was so sandy that it was too friable when dry. After several attempts to keep it moist by sprinkling, calcium chloride was mixed with the top three inches, which maintained the moisture content of the subgrade high enough to keep it satisfactorily bound.

Road Mixing

Burggraf: This designation describes the mechanical mixing of the various constituents directly on the subgrade or road base, as contrasted with material mixed in plants.

Preparation of Binder-Soil: If the binder-soil is being obtained from the roadway, shoulders, or slopes, or from a shallow pit of considerable area, it is advantageous to remove the soil by blading it off in thin cuttings, which pulverize easily when dried. All of the binder-soil should pass a 1-in. sieve and at least 80 per cent should pass a No. 4 sieve.

During periods of slow drying or in the use of wet and heavy binder-soil, the subdivision of this material may be greatly facilitated by placing a small amount of the graded aggregate over the binder-soil and disking. This operation not only reduces the size of the binder-soil, but also permits the incorporation of a considerable amount of the graded aggregate which will cause more rapid drying and less crushing effort, if the materials are to be dry mixed. It is sometimes desirable and practicable to continue the mixing of aggregate with wet binder-soil until the latter becomes thoroughly reduced, and uniformly distributed throughout the aggregate. The cutting and abrading action of the sharp aggregate permits entrance of water into the binder-soil and promotes its further disintegration by slaking.

Mixing and Finishing: Enough of the graded aggregates and binder-soil to give the desired depth of compacted wearing course, should be thoroughly mixed by alternately spreading and windrowing the materials, or by multiple blade maintainers, or by other suitable methods. This mixture should then be bladed into a uniform windrow on each shoulder of the road, to be redistributed as specified.

In blade-mixing the various ingredients composing a stabilized wearing course, it is highly important that no appreciable amount of extra soil be picked up from the subgrade or shoulders. Carelessness in this respect may result in an excessive soil-fine content which is especially undesirable in wet weather.

The blading of the wearing course to a smooth finished formation requires that some thin cuttings be made, often resulting in segregation of the coarser aggregate. To avoid leaving loose stone on the surface, it is advisable to start the finish blading on one side of the road and carry it across the road, by successive trips, leaving any accumulated loose stone on the opposite shoulder. Proper moisture content is essential in this operation.

Application of Water: The construction of stabilized courses by the road-mix method during periods of prolonged dry weather may add unduly to the cost of the work by reason of the amount of water required to provide the optimum moisture content. This cost may be greatly reduced, where traffic conditions permit, by dry-mixing the aggregate, binder-soil, and flake calcium chloride, and windrowing the mixture to the side of the road, awaiting a rain before spreading.

Rolling: It is important that the stabilized mixture be thoroughly compacted, at the optimum moisture content, to develop density. In some localities where the traffic is heavy and well distributed over the width of the road, compaction may be secured without rolling. In other localities where rolling is necessary, the truck-wheel type of roller is preferable to the solid type because it compacts the mixture from the bottom upward, with an effective kneading action.

Figure 24. Mixing with Motor Grader

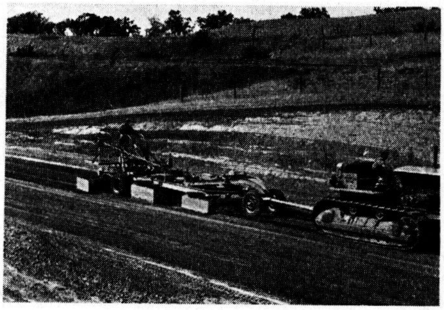

Figure 26. Mixing with Retread Paver

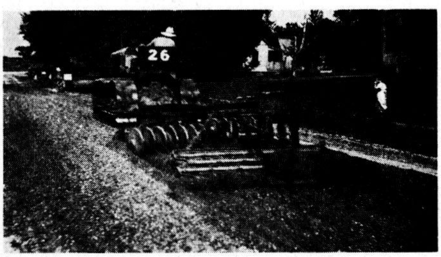

Figure 25. Mixing with Disc-harrow and Spike-tooth Drag

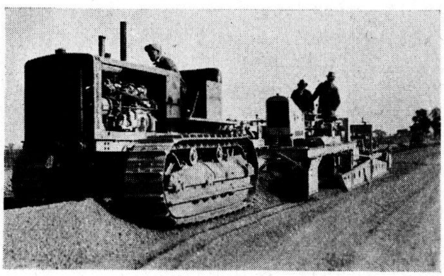

Figure 27. Combining Principles of Blade-mixing and Pug-mill

Plant Mixing

Burggraf: Plant Mixing includes either a central mixing plant or a portable plant, operating along the road. The advantages of plant-mixing over road-mixing are as follows:

To the highway official and contractor:

(1) A more uniform mixture than is obtained by blade-mixing on the road.

(2) Less delay on account of unfavorable weather conditions. (Prolonged rainy periods delay the efficient handling of clay in road-mixing.)

(3) Less interruption of traffic.

(4) Greater convenience and less cost of supplying the necessary water for the mixture.

(5) The elimination, in municipal work, of much of the difficulty of blading over manholes and crosswalks; also of the inefficiency of equipment operation in blade-mixing on short projects.

(6) Less equipment required on the road.

(7) Greater ease of laboratory control of the mixture.

To the aggregates producer:

(1) Possible utilization of soil strippings which are otherwise waste material.

(2) Utilization of fine aggregate, or certain sizes of coarse aggregate, which may have accumulated in the production of materials for other purposes.

The plant machinery necessary in the production of stabilized mixtures (in addition to the usual screening and crushing equipment for producing graded aggregates) varies according to the nature of the materials used and the method of processing adopted. The operation consists essentially of pulverizing the binder-soil and proportioning and feeding the graded aggregate, binder-soil, calcium chloride and water into a mixer, where they are combined uniformly and delivered into trucks or storage bins.

In the process most commonly used, the binder-soil is dumped into a hopper from which it feeds by gravity to a screw-conveyor which delivers it at a uniform rate to a disintegrator, either directly or by means of an intermediate belt conveyor.

The disintegrator unit consists of two pairs of rolls, the upper pair having one larger-diameter smooth-faced roll operated at slow speed and one smaller-diameter roll with longitudinal knives set in its face, operated at higher speed. The lower pair, or crusher-rolls, are both of the same diameter and are smooth-faced. This unit may be used with binder-soil containing up to about 20 per cent of moisture and while the most thorough pulverizing is accomplished with dry material, artificial drying has not been found necessary.

Graded aggregate and flake calcium chloride are delivered from storage hoppers by controlled feeds, along with the pulverized binder-soil into a mixer, usually of the pug-mill type. A pipe line provides the water necessary to bring the moisture content of the mixture up to about five to eight per cent.

The pug-mill contains a longitudinal shaft to which replaceable blades are attached at such angle as to mix the materials continuously and convey them through the mill to an outlet, where the finished mixture is taken by belt or bucket conveyor to storage bins, or dropped into a pit from which it is loaded by clamshell into trucks.

Alternate equipment and methods may be mentioned as follows:

In some locations the soil overburden on pits and quarries consists of a suitable sand-clay which when passed through a vibrating screen to remove the sod and stone, becomes sufficiently pulverized.

A plate-feeder might be substituted for the screw-feeder, for use with some types of binder-soil.

In some plants the aggregate and

binder-soil are proportioned and partially mixed by handling several times with a clam-shell or power-shovel.

Batching equipment designed for concrete aggregates, and a concrete mixer may be used for porportioning and mixing.

A method of processing wet binder-soil is being used successfully, which eliminates the screw-feeder. The binder-soil is passed from a hopper into an enclosed pug-mill, with sufficient water to form a thick paste. This paste is extruded, at a controlled rate, and passes,

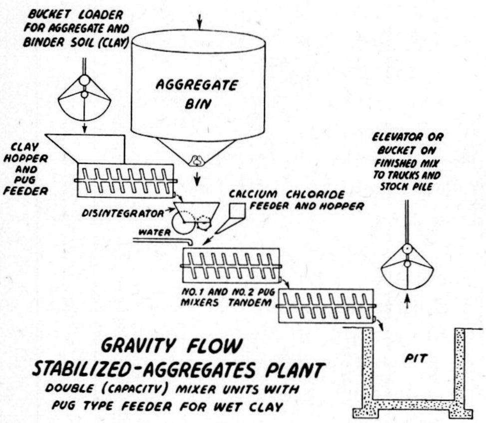

Figure 28. Typical Gravity-Flow Wet-Mix Plant

along with the flow of graded aggregate, between a pair of rollers set about one and one half inches apart. The combined binder-soil and aggregate then pass through two pug-mills, where calcium chloride and any necessary water are added. In this process the binder-soil is thoroughly disintegrated and a uniform mix is obtained. (See Figure 28.)

Portable stabilizer plant units, embodying the above described features, are now being manufactured, to work in conjunction with any production of aggregates. (See Figure 29.)

Mixing may also be done with a portable mixer, which moves along the roadway picking up the aggregates and binder-soil from a windrow, mixing them with water and calcium chloride in a pug-mill and depositing the finished mixture in a windrow or spreading it into place.

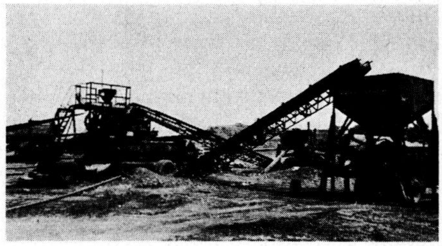

Figure 29. Portable Stabilizer Plant

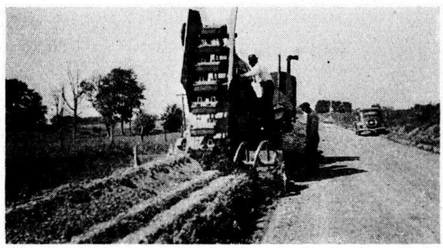

Figure 30. Mixing with Traveling Plant, Front View

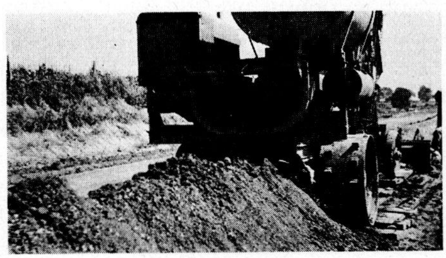

Figure 31. Mixing with Traveling Plant, Rear View

This equipment requires that the binder-soil be previously pulverized (at least partially) on the roadway and is therefore more subject to wet-weather delays than the stationary central plant. (See Figures 30 and 31.)

Methods of Using and Amount of Calcium Chloride

Downey: If the stabilizing is being done by the "mixed in place" method, the desired proportion of flake chloride is added to the combined aggregate in windrows on the road and thoroughly mixed dry by blading the aggregate across the road surface until the chloride is evenly incorporated. The road surface is then moistened until enough water has been added to the aggregate to obtain the necessary workability. The whole is then laid onto the roadway and bladed and rolled until a smooth even riding surface is obtained and compaction is well into its final stage. Generally traffic completes the compaction.

In the plant mix, as in the mixed in place method, flake calcium chloride and water in the desired quantities are added to the combined aggregate. The whole is then mixed until the chloride is thoroughly and evenly incorporated and a state of workability is attained.

Pulverized calcium chloride has been used to some extent in plant mixing. Some advantage is claimed for the pulverized form because of its more rapid solubility.

Application of pre-stabilized aggregate to the road is similar to the mixed in place method. In both cases thorough mixing is essential and blading and rolling should be continued into the final stage of compaction.

Surface treatments with flake calcium chloride are probably familiar to more road engineers than the two methods already discussed. It is also true that more road money has been uneconomically and wastefully spent in this way than in almost any other.

In Michigan, we find it economical to apply flake chloride as a surface treatment or dust palliative, in conjunction with the use of water tanks, and then only to thoroughly compacted clean surfaces. The days of loose, floating cover on gravel roads in Michigan are definitely past.

Chloride in solution, either as a natural or manufactured brine offers some advantages over flake chloride. On the other hand, the bulky brine solution carries the handicap of costly transportation to plant site or roadside where water might be easily and cheaply available.

Michigan oil fields and some of our salt and chemical plants offer chloride brines of various concentrations and conditions of suitability for stabilization work. The Highway Department has availed itself of these sources to some extent and has had satisfactory results in varying degrees.

Workability, which is very important in stabilization, is vitally affected by the strength or weakness of the brine used. Similarly, the success of surface treatments made with brine is dependent on the presence of water in proper proportions.

Burggraf: When calcium chloride is used as an admixture in road mixed material, the following procedure should be followed prior to the mixing operations. The graded aggregates and binder-soil should be spread loosely, individually or in combination, over the prepared base. Flake calcium chloride should then be spread uniformly over these materials at the rate of 0.5 lb. per sq. yd. per inch of thickness. In no case should the amount of calcium chloride exceed 2 lb. per sq. yd., which limits the maximum thickness to be so treated to 4 in. If a compacted stabilized wearing course of greater thickness than 4 in. is specified, the calcium chloride should be incorporated only in the upper layer.

In plant mixing the finished material should contain 5 to 8 per cent by weight of moisture and at least 10 lb. of calcium chloride per ton of mixture.

After being maintained for five to ten

days the compacted road should be given a surface application of flake calcium chloride of at least 0.6 lb. per sq. yd.

If calcium chloride was not used as an admixture, the road after its initial compaction and shaping should be given a surface application of flake calcium chloride of 1.0 to 1.5 lb. per sq. yd.

In either case the surface application of calcium chloride should be made during periods of high humidity, as during the night or early morning hours, or when the surface is in a damp condition from sprinkling or from natural causes.

Compaction and Seasoning

Burggraf: On page 224 I presented some data showing the importance of compaction during the construction of these roads and the aid of calcium chloride admixture in obtaining an increased density by facilitating compaction. During this same investigation, which was made on a construction project, additional data were obtained which reveal the interesting relationships of roller and shrinkage compaction to structural stability. In this part of the investigation results were obtained by determining both the density and structural stability of a graded stabilized road mix at different intervals starting when the material was deposited on the grade from the spreader-box. Figure 32 shows that 85 per cent of the resultant density was obtained during the compaction period by a multiple wheel roller and the remaining 15 per cent was due to the shrinkage compaction or the seasoning of the road. On the other hand, the roller compaction only accounted for 10 per cent of the structural stability, the remaining 90 per cent of the stability being obtained during the shrinkage compaction or seasoning period. These results show definitely the importance of permitting these roads to season properly and also indicate that a minimum density and moisture content in the mixture is necessary before this seasoning can function effectively. The results also show that calcium chloride used in the mix assures a high structural stability as it controls the rate of drying during both the compaction and seasoning period.

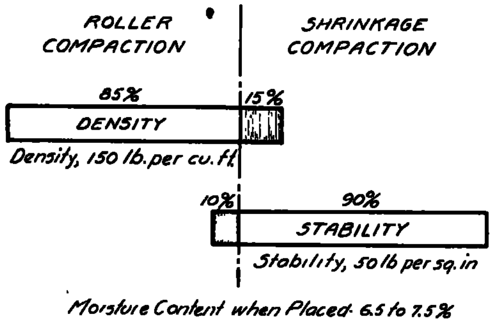

Figure 32. Average Relative Effects of Roller and Shrinkage Compaction on the Density and Structural Stability of Calcium Chloride Stabilized Roads.

Crown

Burggraf: The results of crown measurements on several stabilized projects in four States showed that on sections having a good surface the average crown was 0.50 in. per ft. of width, and for potholed or rutted sections the crown was only 0.24 in. per ft. of width. Figures 33 and 34 show, respectively, the correlation of poor and good surface conditions with crown.

The typical parabolic or circular arc type of crown was intended for rigid wearing surfaces on municipal streets to increase the gutter capacity for accelerating the removal of storm water. This type of crown was also adopted for the construction of rural highways, although the shoulders adjacent to the roadway were always designed with a greater slope to carry the storm water into the ditches.

This type of crown does not appear logical on even the rigid wearing surfaces of rural highways, as it has a tendency to inconvenience traffic by concentrating three-fourths of the total

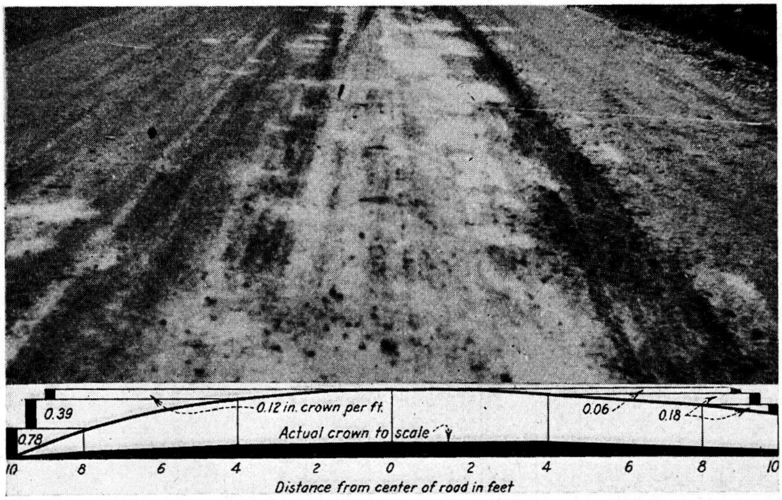

Figure 33. Stabilized Road in Poor Condition Due to Flat Crown. Peg in Center of Road Indicates Location of Cross Sectional Readings

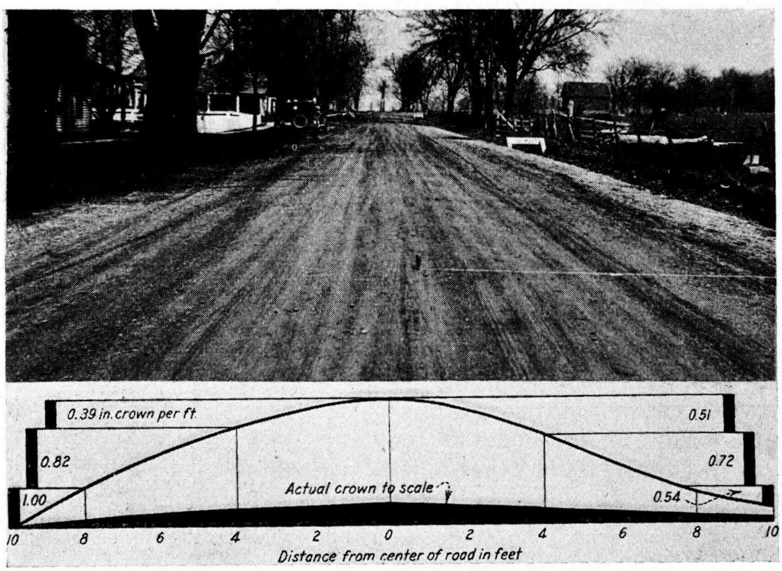

Figure 34. Stabilized Road with Proper Crown

cross-slope in the outer half of each side of the roadway.

The circular arc or parabola type of crown should never be used for the semi-rigid wearing surfaces or other low-cost types, because it gives an area in the center of the road that is too flat for adequate surface drainage. The most suitable type for these surfaces is composed of straight lines, dropping both ways from the center. As this would produce an impracticable ridge longitudinally along the center of the road, the type of crown shown in Figure 35 is recommended for stabilized roads. This is a modified "A" type, which has practically an even cross-fall to either side, with the center slightly rounded. The upper part of Figure 35 shows the differences in the amount of crown for the recommended and the circular arc type over similar cross-sectional widths. This comparison is interesting as it shows that the amount of crown for sections A and B, which constitute the outside half of each side of the road, are much less in the recommended than in the circular arc type. for the recommended type these would be 27, 27, 27 and 19 per cent. These results plainly show the superiority of the recommended type over the circular arc.

Experience has shown that the magnitude of crown is not so important on stabilized roads on grades as on level sections. If the surface of the road is rolling it naturally drains well, but if it is level the cross-slope must be adequate or the sluggish drainage will cause surface defects. Due to the hard and compacted surfaces of stabilized roads, they do not scour easily, so are capable of carrying the longitudinal flow of storm water for short distances, down the grade before discharging it into the ditches.

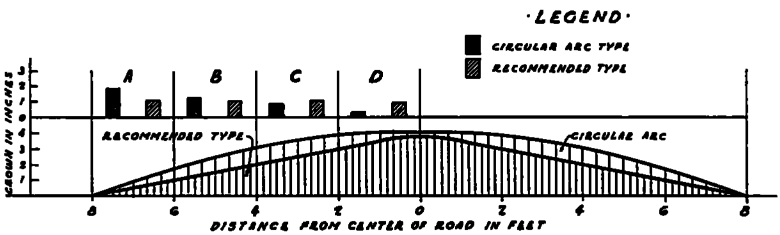

Figure 35. Comparison of the Recommended Crown Section for Stabilized Roads With the Typical Circular Arc Type. The Upper Part of the Figure Gives a Graphical View of the Amount of Crown for Each Type Over Similar Cross-Sectional Widths.

The amount of crown is similar, for both types for section C, which is the area between the inside quarter and the half width of each side of the road. For section D, which is the area one-fourth of the distance each side of the center, the amount of crown for the recommended type is greater than that of the circular arc. This assures much better drainage for the recommended type over this area, which is practically flat for the circular arc type.

If the total crown is taken as 100 per cent, the amount of crown for sections A, B, C and D for the circular arc type would be 44, 31, 19 and 6 per cent, and

The amount of crown recommended during construction, to obtain adequate surface drainage on stabilized roads, is $\frac{1}{2}$ in. per ft. of width. This will be reduced some during the compaction stage and early maintenance period, but should never be less than $\frac{3}{8}$ in. in the final compacted road. During this period of compaction it is important to keep the crowned surface even and smooth, as any uneveness in the road surface of sufficient magnitude to interfere with effective drainage will cause "water pits" and subsequent rutting.

For the determination of the crown height, considering the width and headfall of the roadway, the following formula is recommended for stabilized roads:

$$C = \frac{W(100 - 4L)}{4800}$$

Where C equals crown in inches.
W equals total width of road in inches.
L equals longitudinal gradient in per cent.

This formula gives a crown of ½ in. per lin. ft. on level sections and 0.4 in. per lin. ft. on a 5 per cent grade. For ordinary purposes, the longitudinal gradient factor may be disregarded, as the method of obtaining and maintaining crown in stabilized roads does not warrant such refinement. The shape of the crown should conform to the recommended modified "A" type.

It is also recommended that a checking templet be used to obtain the type and amount of crown during the construction of stabilized roads. This templet can be easily and economically constructed and will be an invaluable aid in obtaining the desired crown. The templet can also be used for a rough check of the subgrade or base, which should conform to a shape somewhat similar to that of the finished stabilized wearing surface.

Knight: Care should be taken in the construction and maintenance of surface consolidated roads to build and preserve crown. If the crown is not at least ½ inch per foot, trouble can be expected from pitting. We prefer the A-type cross-section.

CONSTRUCTION COSTS

Affective Factors

Burggraf: The cost of this type of surfacing varies widely. The main factors are: (1) delivered fine and coarse aggregates, (2) prepared binder-soil, (3) water applied, (4) mixing, (5) spreading, (6) compaction and (7) calcium chloride. The cost of the delivered aggregates is by far the greatest item. This item also is the cause of the wide variations in contract prices as the use of local aggregates involving no rail haul effects a great saving compared to materials shipped in by rail. Unless the cost of each item, especially that of the delivered aggregates, is known, the comparison of costs is meaningless.

Costs of Surface Consolidation

Knight: The cost of this work in Canada varies from 250 to 500 dollars per mile, but the average last year was approximately $270 per mile including calcium chloride, labour, and a small amount of binder soil or stone added to improve weak spots which are present in practically all roads.

Wilford: On one project 2.6 miles long 291 cu. yd. of clay loam binder were used at the rate of 112 cu. yd. per mile, and 11½ tons of calcium chloride at 0.84 lb. per sq. yd. applied over an approximate 18 ft. width, were used.

The total cost including all labor and material and rental of the roller used, was $785, or $302 per mile of metalled surface 18 ft. wide.

On the total mileage improved in Victoria County, including all items such as calcium chloride and its application, operation of machinery, addition of binder and all other labor, but with no allowance for machinery rental or other overhead items, the costs varied from about $50 per mile in one case of a narrow road given a simple dust laying treatment to $302 per mile previously mentioned. In 1936 with our somewhat simplified procedure the highest per mile cost for the initial treatment was $250 with the average being somewhat less.

In attempting to attain a mathematical gauge of the effect on the municipal pocket-book of a policy of maintaining gravel roads using calcium chloride as against the opposite policy of maintaining them without the use of dust laying agents, I have made certain calculations from our cost records.

During 1935 and 1936, when we first made use of calcium chloride on a portion of our mileage the average cost per mile per year based on total expenditure over total gravel road mileage, was:

Dragging...	$33.21 per mile per year
Resurfacing (includes cost of calcium chloride)........	$132.60 per mile per year

Whereas for 1933 and 1934, the last two years that our road system was maintained using practically no dust layer, the corresponding figures were:

Dragging.....	$40.47 per mile per year
Resurfacing......	$156.97 per mile per year

It is easy to understand the reduction in dragging cost of about $7.00 per mile per year as we have found that much less dragging is required after treatment. The use of good mechanical equipment for a large part of our dragging work during 1936 also accounts for saving in dragging cost.

Whether the indicated saving in resurfacing cost per mile per year of $24.00 is all properly attributable to the use of calcium chloride, I am not prepared to say, but aside from any improvement due to construction expenditures, our system of gravel roads at the end of 1936 was at least in as good condition as it was at the end of 1934, and the treated portions were definitely better.

The downward trend in dragging and resurfacing costs, as indicated for 1935 and 1936, is apparently continuing with the extension of our policy in 1937. Cost records to the end of July 1937 adjusted by proportion to apply to a twelve month period, indicates that the per mile per year cost for 1937 will be $27.46 for dragging and $114.04 for resurfacing, showing a further substantial reduction in cost.

Designed Stabilization Costs

Burggraf: From records of designed stabilization work in Indiana, Illinois, Michigan and Minnesota, construction costs show remarkable uniformity, when the cost of aggregates is considered separately.

For example the average costs for stabilization, exclusive of the aggregate, but including addition, preparation and admixing of binder-soil, water and calcium chloride varied but a few cents

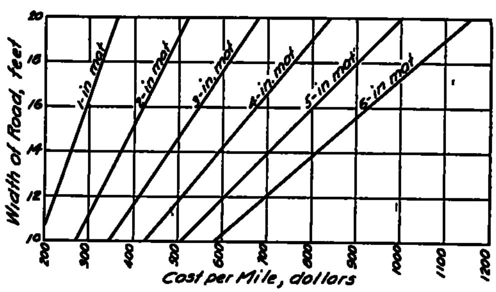

Figure 36. Cost of Stabilization Process per Mile. (Does not include cost of new aggregates.) Items included are (1) Prepared Binder-Soil, (2) Water Applied, (3) Mixing, (4) Spreading, (5) Compaction and (6) Calcium Chloride (1½ lb. per square yard). Based on cost of 25¢ per ton for compacted (145 lb. per cu. ft.) stabilized mixture in place plus cost of calcium chloride (at $23 per ton) applied at the rate of 1½ lb. per sq. yd. Twenty-five cents per ton equivalent to 49¢ per cu. yd. (3900 lbs.) 1.4¢ per sq. yd. per in. of depth.

per ton. Figures 36 and 37 were compiled from the average figures. Individual projects, of course, will deviate therefrom, depending upon the length of the job and the construction facilities available. Also the costs will probably be lowered as construction efficiency improves, and more economical methods are devised.

The analysis reveals that the principal item of cost in the construction of these roads is that of aggregates delivered on the project.

The weight in tons is the unit used for

gauging quantities herein because the average unit weight of compacted stabilized material is pretty well fixed at 145 lb. per cu. ft. To use cubic or square yard units would add another variable in density depending upon compaction and in quantity depending upon depth.

The cost of the calcium chloride @ $1\frac{1}{2}$ lb. per sq. yd. is figured in the stabilization costs at a carload ($22\frac{1}{2}$ ton minimum) price of $23 per ton f.o.b. destination, which is average for the northeastern states. The quantity provided may be used integrally, or partly in the top-dress mixing and balance on the surface, or all on the surface, depending upon weather and compaction conditions. Maintaining an optimum moisture content during the period of compaction is recognized as the governing factor in attaining maximum density and stability.

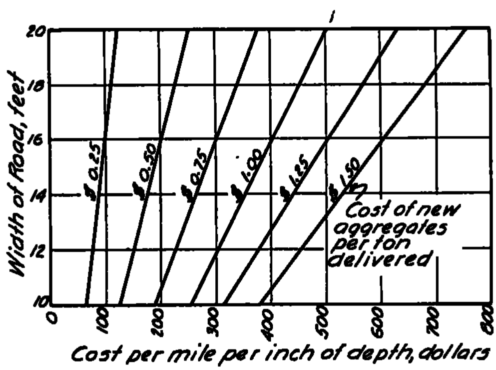

Figure 37. Cost of New Aggregates as Affecting and in Addition to the Cost of Stabilization. Based on the practical assumption that 80 per cent of the compacted stabilized mixture is aggregate (retained on 100 mesh sieve) and the final compacted weight of mixture equals 145 lb. per cu. ft.

Figure 38 shows graphically the distribution of costs of an average designed stabilized road. The diagram shows that the cost of calcium chloride is only 5 per cent of the total, whereas the cost of the aggregates is 72 per cent of the total.

MAINTENANCE

Burggraf: It is fundamental that all types of road surfaces require maintenance to combat the destructive action of traffic and weathering. Prompt action is the keynote of every good maintenance organization, not only to give immediate service to traffic, but to prevent further extensive and costly damage.

The stabilized surface, due to its dense, well-bonded structure, necessitates a somewhat different plan of maintenance than the loosely bound surface. Less frequent blading is required, but it is even more important that it be done at the right time. The maintenance objectives on stabilized roads are: (a) to provide smoothness, (b) to keep the metal compacted without dust and (c) to preserve the crown and thickness.

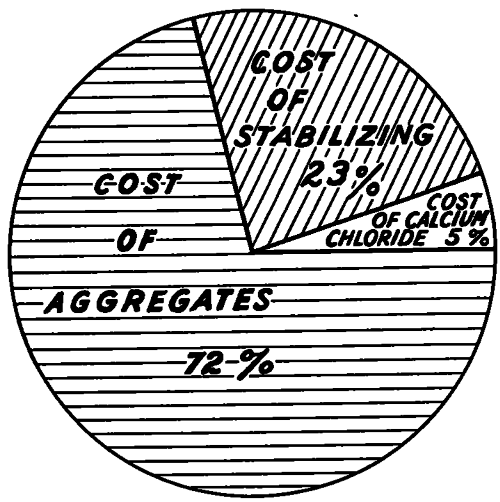

Figure 38. Based on unit cost per mile, 18 ft. wide and 6 in. deep compacted.

Aggregates at $1.00 per ton delivered	**$2,730.00**
Stabilizing at 1.4¢ per sq. yd. per in. of depth	**887.00**
Calcium chloride 1.5 lb. per sq. yd. (8 tons)	**184.00**
Total	**$3,801.00**

Wilford: On a section of surface consolidated road constructed in the middle of July, very little maintenance was required for the balance of the year. In the early fall, after a rain, slight ravelling which had developed during six weeks or more of dry summer weather, was largely corrected by light dragging. In this connection, it would be desirable to bring any loosened material in from the edges toward the center and thus maintain the original crown.

Knight: The art of maintaining stabilized surfaces rests in the hands of the man in the field, of whom the most important is the grader operator.

Stabilized roads under traffic tend to disintegrate. We have found that the maintenance methods which suit stabilized roads are identical with the operations necessary to consolidate ordinary gravel roads.

Blading

Downey: Experience has shown that a minimum amount of blading is desirable on stabilized surfaces. No blading at all, except brushing off loose material, is recommended when the surface is dry.

Apparently the timely application of water to a surface previously stabilized with calcium chloride revives the effectiveness of the chemical.

Experience also has taught that incipient ravelling and spalling may be corrected by water blading, if the condition is caught in time. Sometimes hand patching may be almost eliminated by this method.

Burggraf: The stabilized road requires much less blading than one which normally carries a loose mulch or floating cover. It is important, both for economy and for preservation of the bond of a stabilized wearing course, that no blading be attempted unless the surface condition justifies it. Small holes or corrugations should be removed by blading only during and after rains have made the surface workable. Cutting of the metal when it is fairly dry or following very light rains, is likely to tear the surface and promote future development of holes; it also disturbs and tends to dissipate the calcium chloride solution which has been brought close to the surface by capillarity in dry weather. (See Figure 39.)

The advantages of blading when the road has been thoroughly wetted are: (a) easier workability, (b) minimum disturbance and dissipation of calcium chloride which has been driven deeper into the road by rains and (c) presence of enough moisture to permit consolidation of re-shaped loose material under traffic.

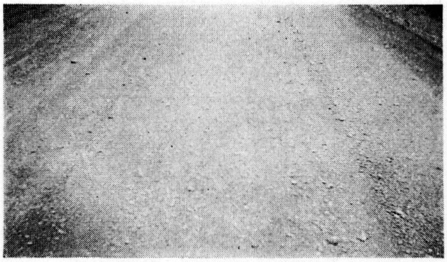

Figure 39. Result of Dry Weather Blading. Excess of Coarse "Float" Material Accelerates Abrasion of the Surface and creates dust nuisance.

In prolonged dry periods where water is easily available it has sometimes been found advantageous to sprinkle sections of a stabilized surface in order to permit effective blading to restore smoothness.

The maintenance superintendent will soon observe that failure to blade a stabilized surface at the proper time will result in the surface becoming so hard that it is impracticable to correct surface irregularities by blading until the next rain.

During dry weather, stabilized surfaces should be kept free from loose floating aggregate in order to avoid abrasion under the wheels of vehicles. During wet weather, it is sometimes desirable to blade in loosened aggregate from the sides in order to consolidate it into the surface. Excess unbound material should be removed.

During periods of heavy rain some of the binder-soil is likely to be washed to the shoulders of the road, thereby permitting development of a slightly loose condition of the surface. Consequently, when blading loosened aggregate from the edges into the road surface, a small amount of soil from the shoulder may be brought in at the same time to add binder, provided the shoulder material contains suitable clay, loam or any cohesive soil. In case the shoulder soil is unsuitable for binder, a satisfactory clay should be distributed in a small windrow on the shoulder where it may be dried, pulverized and held available

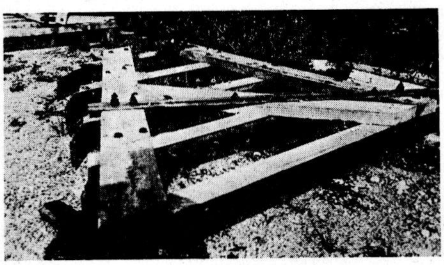

Figure 40. Multiple Blade Drag

for use at the proper time. This method of restoring smoothness is preferable to cutting the bonded surface, but a combination of the two methods is often used to advantage.

Large aggregate in the mixture makes effective blading difficult. A maximum of $\frac{3}{4}$ in. or less adds to the workability of the surface.

To insure adequate surface drainage, a crown of at least $\frac{1}{2}$ in. per foot should be maintained.

Knight: A number of home-made drags have been built in some of our districts and are doing good work. When cutting the shoulders sometimes large pieces of sod form traffic hazards. Figure 40 shows a multiple blade drag with all blades parallel, arranged in such a way that each blade projects 3 in. beyond the blade in front. This is mounted underneath the standard maintainer and shreds the sod as it pulls it in. Sod thus cut up is quickly threshed out by traffic leaving the valuable material on the road.

Figure 41 shows another drag which has been doing very fine work when mounted under the maintainer.

The blades in front of the machine remove the washboard and so reduce the

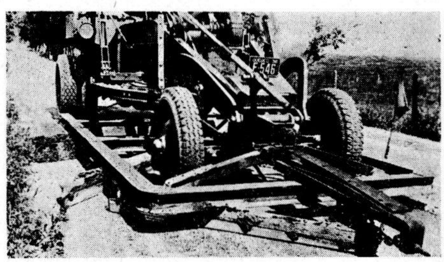

Figure 41. Drag Mounted under Maintainer

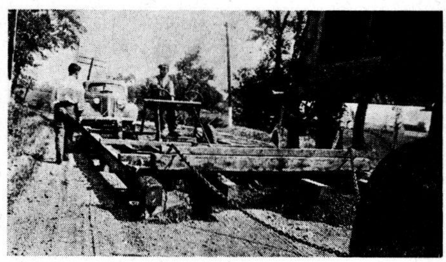

Figure 42. Thirty-foot Drag

vibration of the machine caused by the front wheels. Figure 42 shows a 30-ft. drag which has done excellent work, cutting out the slight waves which are not removed by an ordinary grader.

The equalizing device in the center is used to vary the weight from front to rear. If cutting is necessary, the front is set down. If smoothing is needed, the weight is applied on the rear blades.

Application of Calcium Chloride

Knight: The minimum maintenance treatment should be 1 lb. per sq. yd. and if traffic is over 500 vehicles per day, this should be increased to 2 lb. per sq. yd. Several applications should be made during the year, and in areas where frost action is serious the first one should be made after the surface has dried, but before the frost is out. This toughens the surface and helps to minimize the frost breaks. A large amount of the calcium chloride used in Canada is applied with a box spreader suspended from the back of a truck. This box has no agitator but we find that the vibration of the truck keeps a good flow of flakes.

Wilford: In 1936, on our work the maintenance applications of calcium chloride varied from slightly less than 2 tons per mile to slightly over 7 tons per mile with an average for all the work of slightly over 4 tons per mile.

Burggraf: It is necessary to keep the sand-clay aggregate mixture damp in order to retain stability and prevent ravelling. This is accomplished by periodic applications of calcium chloride at such intervals as to prevent the road from ever becoming thoroughly dried. Once a surface is allowed to dry, it will tend to disintegrate under traffic. Mr. C. A. Hogentogler, Senior Engineer of the U. S. Bureau of Public Roads, says "... It is the function of deliquescent chemicals to assist in maintaining that surface dampness which is so important in soil roads. Calcium chloride is the principal chemical used for this purpose."

About 2 lb. of calcium chloride per square yard per year are required for this result. The usual practice is to apply 1 lb. per sq. yd. early in the summer, when the moisture from the spring rains is still in the road. This is followed by two applications of ½ lb. each later in the season, applied as required to maintain proper moisture content. After a road has been maintained for a year or so with calcium chloride, in many cases the total yearly amount required will drop to 1½ lb. or even as low as 1 lb. per sq. yd. The best time for calcium chloride application is following a rain and after any necessary blading or patching operations are completed.

Care should be taken that the calcium chloride be spread uniformly. In the case of the drill type of distributor, the spreader or baffle board should always be used and should be kept clean so that the distribution of the calcium chloride on the road will be uniform and not in small windrows. Slight over-lapping of the spreads in the middle of the road, however, is considered good practice and is a safeguard against narrow untreated strips. If calcium chloride is

TABLE 10

QUANTITIES OF CALCIUM CHLORIDE REQUIRED FOR SURFACE TREATING ONE MILE OF ROAD

Width of Road, ft.	Sq. Yds. per Mile	½ lb. per sq. yd.		1 lb. per sq. yd.		1½ lb. per sq. yd.		2 lb. per sq. yd.	
		Tons per Mile	Bags per Mile 100 lb. Each	Tons per Mile	Bags per Mile 100 lb. Each	Tons per Mile	Bags per Mile 100 lb. Each	Tons per Mile	Bags per Mile 100 lb. Each
8	4,693	1.17	24	2.35	47	3.52	71	4.69	94
10	5,867	1.47	30	2.93	59	4.40	88	5.87	118
12	7,040	1.76	36	3.52	71	5.28	106	7.04	141
14	8,213	2.05	42	4.11	82	6.16	124	8.21	165
16	9,387	2.35	47	4.69	94	7.04	141	9.39	188
18	10,560	2.64	53	5.28	106	7.92	159	10.56	211
20	11,733	2.94	59	5.87	118	8.80	176	11.73	235

applied just before a heavy washing rain, considerable will be lost in run-off water. Weather bureau reports may be consulted to advantage before the application is started. If application cannot be deferred until a rain occurs, it is desirable to apply calcium chloride at night or early in the morning, in order that the higher humidity of the air may provide more rapid solution and penetration.

Patching

Burggraf: Blading only after rains is usually sufficient to preserve smooth riding qualities, but in prolonged dry periods it is sometimes desirable to eliminate any scattered pits which may develop by hand-patching. A good mixture for such work consists of graded aggregate under ½ in. in size, mixed with at least an equal weight of stable sand-clay, water to the extent of 6 to 10 per cent, and calcium chloride at the rate of 100 to 150 lb. per cu. yd.

UTILITY OF CALCIUM CHLORIDE STABILIZED ROADS AS FUTURE BASES

Burggraf: Calcium chloride stabilized roads furnish excellent foundation bases for higher type surfacing when traffic conditions warrant further improvement. The chief advantages of properly designed stabilized roads as future bases are that they possess:

(1) A designed stability that assures uniform supporting value for the higher type surfacing.

(2) A compacted and dense structure which will not soften by water nor act as a capillary medium to lift the water from the subsoil.

(3) A low void and impervious structure, which will not expand under the action of frost due to its low moisture holding capacity.

It is highly desirable that such bases be used as wearing courses for a year or more before placing the higher type surfaces, in order that maximum compaction may be attained and any disturbance of subgrade corrected.

The November, 1938 issue of Public Roads contains an excellent report on, "A Study Of Sand-Clay Materials For Base Course Construction" by C. A. Carpenter and E. A. Willis of the Bureau of Public Roads. In discussing the need of adequate compaction the authors state, "Compaction of base courses having plastic properties should be completed to essentially maximum practical density before surfacing courses are applied because movements in the base course that are common during compaction of good materials will cause damage to prematurely constructed surfacing courses." "The importance of thorough compaction, even of ideal base-course materials, prior to the application of a surfacing course cannot be over-emphasized."

RESEARCH

Laboratory Investigation on the Density of Stabilized Soil Mixtures

Hogentogler, Jr.: The design of a stabilized soil road mixture, it is generally agreed, involves two principles; the selection of such mechanical grading of the granular materials as will produce maximum density, and the addition of binder-soil of such quality and in such quantity that there will be obtained a maximum binding strength combined with a minimum volume change. Research in soil mechanics at The George Washington University, under the Department of Civil Engineering, Professor Frank A. Hitchcock, executive officer; has for its principal objectives a general study of the above principles with special emphasis on the simplification of test methods and procedures for designing soil mixtures and the investigation of the various factors which influence mechanical stability.

A discussion of the effect of admixtures of the stabilizing chemical, calcium chloride, on the density of soils is presented.

A modified compaction test which was developed[4] in order that the effect of variables such as gradation, chemical composition, base exchange, chemical admixtures, etc., on the compacted density of soils could be accurately measured was used to determine the effect of calcium chloride on the compaction characteristics of some standard soils tested without admixture and with 2 per cent calcium chloride by weight of dry soil.

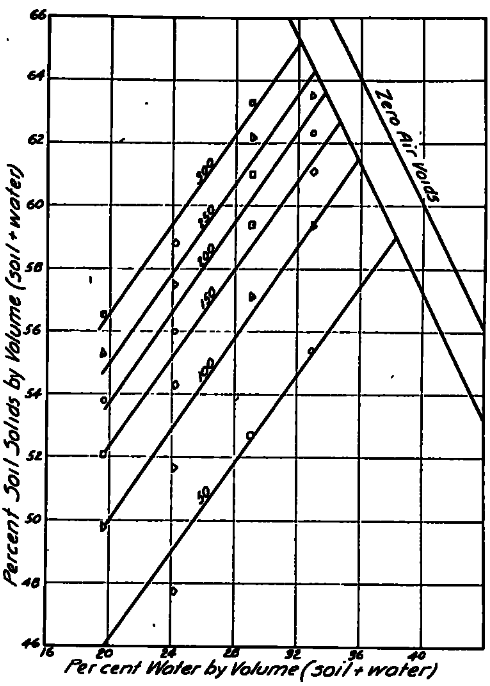

Figure 43. Relation of Compaction to Static Load, No Admixture

Figures 43 and 44 show the curves for an A-2 type of soil. This is the type usually found in the soil-fines fraction of a stabilized road mixture. Figure 45 shows the relation between static load and per cent soil solids (density) as determined from Figures 43 and 44. From this figure it will be noted that calcium chloride causes an increase in density and a considerable decrease in compactive effort. Thus; 100 lb. per sq. in. static load produced a density of 61.4 per cent solids without admixture and 63.7 per cent solids with a calcium chloride admixture, an increase of ap-

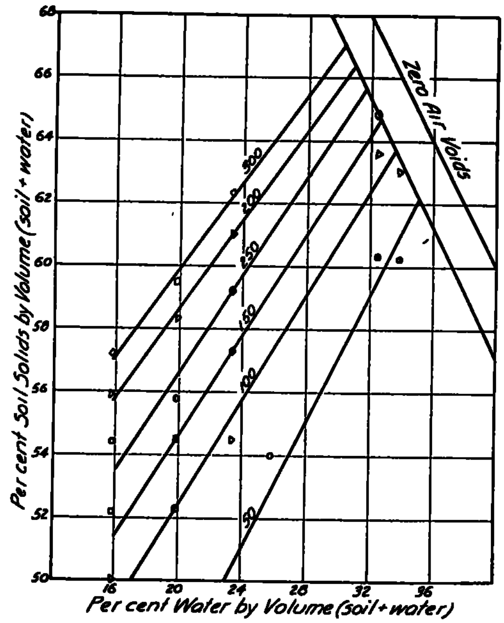

Figure 44. Relation of Compaction to Static Load, 2 Per Cent Calcium Chloride

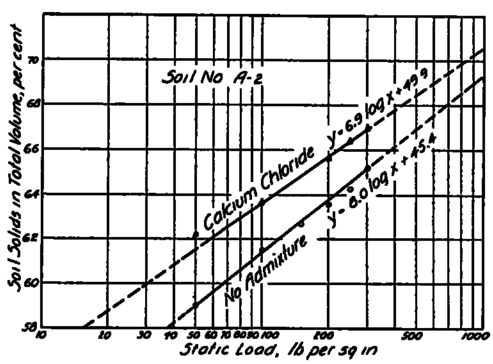

Figure 45. Relation between Static Load and Density

[4] See Page 27.

proximately 3.7 lb. per cu. ft. Similarly, the density produced by 200 lb. on the natural soil can be reproduced by a load of only 100 lb. if calcium chloride is added.

Since soil of the A-2 type is often used in low-type road construction, the effect of calcium chloride on the resulting density of this soil has considerable practical significance.

Shrinkage Density

The second part of the investigation was to determine the effect of shrinkage on density. The same samples that were used in the compaction test, were mixed with water to above the liquid limit and allowed to dry to constant volume. They were then oven-dried and the density computed from the weight and the volume. The results are tabulated in Table 11.

TABLE 11

Soil Group	Shrinkage Density	
	No Admixture	2% Calcium Chloride
1	67.3	72.1
2	65.9	67.4
4	63.9	65.5
5	41.1	40.9
7	60.3	59.8
8	52.2	47.0

A plat of the shrinkage densities against those obtained in the compaction tests indicates a direct linear relation between the two as shown in Figure 46. From this curve the compacted densities obtained by static loads of 200 lb. per sq. in. may be obtained by inspection from the shrinkage densities. Similar curves could have been drawn for any of the compaction loads used in the series of tests.

The result of this work is an accurate linear relation between the density obtained by static load compaction tests and the more simple determination of shrinkage density. This phenomena also agrees with the theory since shrinkage density is accomplished through the evaporation of water and the subsequent contraction of moisture films binding the particles together and exists as a measurable force as shown in Table 12.

This force varies with the size of the capillary pores. It is probable that the slope of the curve indicating the relation between shrinkage and compacted den-

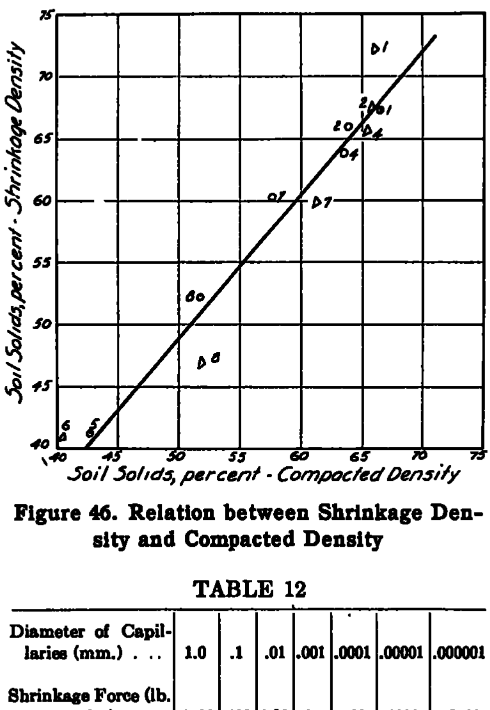

Figure 46. Relation between Shrinkage Density and Compacted Density

TABLE 12

Diameter of Capillaries (mm.) . . .	1.0	.1	.01	.001	.0001	.00001	.000001
Shrinkage Force (lb. per sq. in.)	.0422	.422	4.22	42.2	422	4220	42200

sity is due to the variation in the size of the capillaries. The positions of the soils of the different identification groups may later prove interesting in other problems.

The supposition that a soil should be considerably more dense under a compaction load than when subjected only to natural shrinkage forces in the field is not substantiated by the results of these tests. A comparison of the shrinkage densities with compacted densities under different static loads indicates that shrinkage forces may average 200 lb. per sq. in. for the groups A-4 to A-8 and for the A-1 approximately 350 lb. per sq. in. For the A-2 soils, there was one reported value of 4400 lb. per sq. in.

The following tangible conclusions have been drawn from this work:

1. The substitution of static loads and a smaller compaction cylinder enables compacted density of fine grained soils to be determined over a complete range of loads as compared with the one value obtained by the Proctor test. Also, the results are more accurate and can be obtained with considerably less manual labor.

2. The elimination of the factor, specific gravity, enables density to be expressed as percentage of solid material. Thus, the basic density of different soils can be compared.

3. A change in the method of expressing moisture content converts the Proctor density curves into two straight lines from which maximum density and optimum moisture content can be more accurately obtained, and the density or moisture content values can be obtained for a complete series of compaction loads.

Simple shrinkage densities bear a direct linear relation to compacted densities. By a series of graphs showing this relation, the compacted densities, for a wide range of static compaction loads can be obtained from just one shrinkage test.

This work shows that calcium chloride increases the density of the clay binder soils used in stabilized soil roads. It is thought that calcium chloride "seals" up the road by increasing the density of the binder-soil, thus preventing the entrance of detrimental amounts of water during rains and wet spells. It is not feasible to run density tests on the entire mixture but, since the binder fraction is subject to the volume change, etc., its stabilization is of prime importance. Unless the mixture is very poorly graded it is unlikely that the presence of the inert granular materials would alter the conclusions of this work.

Field Testing

Burggraf: In order to facilitate the determination of the causes of failure by facts instead of opinion the author has designed a portable hydraulic testing machine for field use.[5] It is also thought that by accumulation of field data it may be possible to set up limits for general structural design purposes by determining the minimum quantitative values for the individual components in a road structure and thus eliminate the present unsatisfactory term —stabilization.

The machine has been used extensively for not only determining the quality of different stabilized road mats but also for testing the underlying subgrades and the overlying bituminous mats, if the latter were over 1½ in. thick. The general plan for the field testing was to make stability tests on adjacent failed and unfailed areas by testing individually the various components, which made up the road structure. That is, on a road made up of an oil-mat on a stabilized base on a clay subgrade, tests were made on each of the components. By making these tests on both failed and unfailed areas which were adjacent, a quantitative set of results was obtained which revealed the weakest component or the one causing the failure.

The test is made by applying a horizontal thrust to an exposed vertical section of the road surface, base or subgrade, by means of a hydraulic jack as shown in Figure 47. This figure shows the nature of the failure at the completion of the test.

[5] For description of machine see page 23.

Figure 48 shows the plane of failure after the displaced material has been removed. The angle of this plane to the horizontal surface is determined by measuring the vertical and horizontal dimensions of the disrupted area. The surface area of this plane is also measured by fitting in the proper paper template the area of which is known. This area divided into the pressure gauge readings for the different deformations gives the unit pressure or stability stress in pounds per square inch.

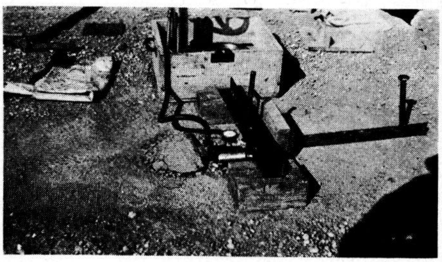

Figure 47. Portable Hydraulic Stability Testing Machine in Action

Figure 48. View Showing the Plane of Failure after the Removal of the Displaced Material.

Figure 49 shows the set-up for testing the undisturbed subgrade under a stabilized road.

Figure 50 shows the relationship of stress and deformation on some typical calcium chloride stabilized roads. The figure shows the wide variation in the structural strength of the different projects and the effect of the density, expressed as weight per cubic foot, on the quality. Unfortunately there were no density tests made on the projects from which curves C and D were drawn. The figure also shows that the "yield point" of these roads is close to 0.10 in. There is a slight tendency for this value to decrease as the structural strength increases.

Figure 51 gives the relationship of stress and deformation on some subgrades found under stabilized roads, showing the wide variation in the struc-

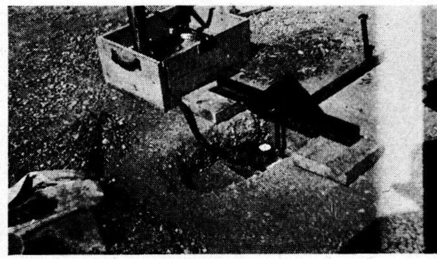

Figure 49. View Showing the Set-up for Testing the Undisturbed Subgrade under a Stabilized Road.

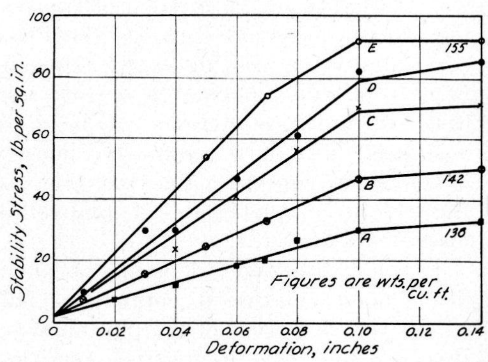

Figure 50. Typical Stress and Deformation Relationship in Calcium Chloride Stabilized Roads.

tural quality of this important component of a road structure. The general shape and location of the different curves is a function of the type, density and moisture content of the soils. Note the absence of any distinct "yield point" on subgrades of low structural strength. It is for this reason that deformation determinations are necessary, for a structural strength factor alone would give a

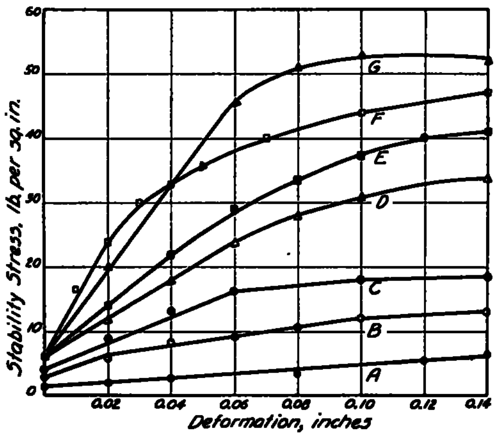

Figure 51. Typical Stress and Deformation Relationship of Subgrades under Calcium Chloride Stabilized Roads.

false value, as the yield point deformation may be 3 or 4 times that of the overlying stabilized road.

Table 13 gives a typical record sheet of test results.

Figure 52 shows the relation between structural strength, age and moisture loss in a calcium chloride stabilized road-mix. This figure shows the importance of proper "seasoning" or evaporation loss on a suitably compacted stabilized road. The stability increased from 12 lb. per sq. in. at one day to approximately 48 lb. per sq. in. at 10 days, while the moisture content decreased from 6.4 to 3.2 per cent. The effect of the age factor should be mini-

TABLE 13

STABILITY TEST DATA

Project: Stabilized Gravel Road About 2 years old, with Calcium Chloride Surface Treatment.
Coarse Aggregate: Uncrushed Gravel.
Fine Aggregate: Sand.
Thickness of Sample Tested: 4 in.
Moisture in Sample as Tested: 2.8%
Density of Sample as Tested: 138 lb. per cu. ft.

Gradation of Material in Sample

Sieve	1-in.	¾-in.	½-in.	⅜-in.	No. 4	No. 10	No. 40	No. 100	No. 200
Passing %....	100	93	85	77	65	52	24	15	14

Liquid Limit: 18.4%
Plasticity Index: 5.00

	Increment of Load								Shearing Area	Angle of Shear
Test	1	2	3	4	5	6	7	8		
Test No. 1										
Load	200	400	680	1060	1580	1800	2200	2200	60	27
Unit Shear. ..	3	7	11	18	26	30	37	37		
Deformation....	0	0.02	0.04	0.06	0.08	0.10	0.15	0.20		
Test No. 2										
Load......	200	460	760	1020	1700	1800	1800		60	27
Unit Shear...... ..	3	8	13	17	28	30	30			
Deformation	0	0.02	0.04	0.06	0.08	0.10	0.14			
Average										
Load..	200	430	720	1040	1640	1800	2000	2200	60	27
Unit Shear.... ..	3	8	12	18	27	30	33	37		
Deformation..........	0	0.02	0.04	0.06	0.08	0.10	0.15	0.20		

mized as it is dependent upon prevailing weather conditions, which in this case were practically ideal. But the importance of the moisture loss, providing the material is adequately compacted and the loss is not too rapid, is an important factor in obtaining suitable structural strength. This factor may also be used in determining the suitability of a base for a bituminous covering.

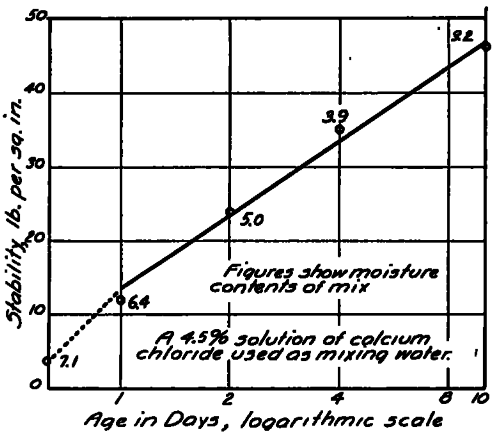

Figure 52. Structural Strength, Age and Moisture-Loss in a Calcium Chloride Stabilized Road-Mix.

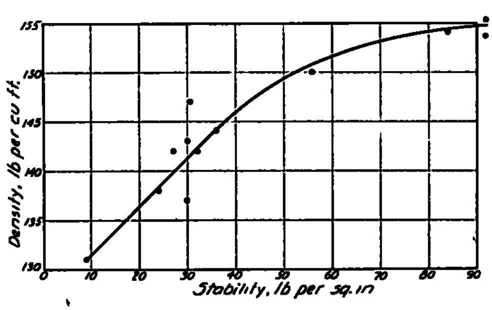

Figure 53. Structural Stability and Density of Calcium Chloride Stabilized Roads

Figure 53 shows graphically the relationship of structural stability and density of calcium chloride stabilized roads. In general there is a linear relation up to a density of approximately 146 lb. per cu. ft.; above this limit the gain in stability is much greater for equivalent increment gains in density.

The upper two sets of bar diagrams in Figure 54 show the relative service behaviors of stabilized mats of different thickness constructed on subgrades of rather low quality. The one having a thickness of only 3 in. failed, while the other with a mat thickness of 7¼ in. remained intact. The rather high strength in the 3-in. stabilized mat was due to a "reseasoning" action which partially dried out the mat but not the subgrade. The lower sets of bar diagrams in Figure 53 show the effect of the quality of the subgrade on the service

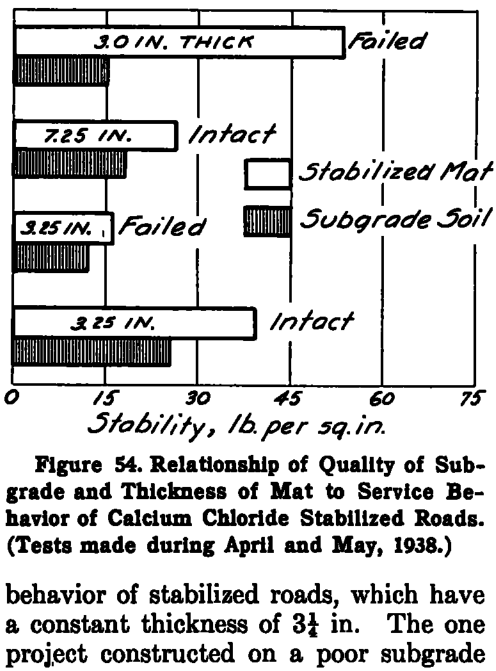

Figure 54. Relationship of Quality of Subgrade and Thickness of Mat to Service Behavior of Calcium Chloride Stabilized Roads. (Tests made during April and May, 1938.)

behavior of stabilized roads, which have a constant thickness of 3¼ in. The one project constructed on a poor subgrade (structural strength only 13 lb. per sq. in.) failed badly, whereas another part of the same project constructed on a good subgrade (structural strength 27 lb. per sq. in.) showed no signs of distress.

Conclusions: (1) Experience with this testing instrument has shown that to fully evaluate the significance of the stability factor of each component, it is necessary to obtain the stress and deformation data along with the moisture content and density of the structure at the time of test. These tests should be supplemented by the gradation and regular soil constant tests, as there is some indication that a soil factor may be derived from a combination of these tests which is related to the stability factor.

(2) Experience has also shown that a thorough study of the stress and deformation relationships of the different components that make up a non-rigid type road structure offers a very promising field for the development of a rational design method, as from the characteristics of the individual components and their interrelationships we may be able to predict the performance of the road structure as a whole.

(3) Another advantage of this machine is that it permits the testing of the undisturbed components in a road structure under their actual environmental conditions. This direct method of testing is desired especially in the case of a three component road structure—bituminous top, stabilized base and subgrade. In such a structure we have the combined effect of the temperature and moisture variations over the year and these influence the structural integrity of the various components in different ways. The temperatures prevailing during the early Spring lower the yield point and increase the strength of the bituminous top, whereas the moisture content tends to increase in the subgrade and to a lesser extent in the stabilized base, which means higher yield points and lower strengths. This set of conditions generally leads to "Spring-break-up" failures if the subgrade moisture becomes excessive. In the summer the conditions are reversed; the bituminous top, due to heat absorption, possesses a higher yield point and slightly lower strength, whereas the two sub-strata components have lost moisture and show a lower yield point and much higher strengths. This is an ideal set of conditions, as the more rigid components of the road structure are in their proper places—as bases, and the upper component can conform to them without cracking.

Research on Loss of Gravel Under Traffic

Burggraf: At the 1938 meeting of the Highway Research Board, Professor R. S. Swinton, of the Engineering Experiment Station of the University of Michigan reported the results of a four year study[6] of loss of material from gravel roads. The investigation consisted of a quantitative determination of the loss of material from three types of roads located in five different counties, as follows:

(1) Ordinary untreated gravel.
(2) Ordinary gravel with surface treatment of calcium chloride.
(3) Stabilized gravel with surface treatment of calcium chloride.

A set of these sections, each one mile long, and located adjacent to each other constituted a county unit. By this arrangement the different sections were subject to the same type and amount of traffic.

The work involved not only measurement of wear, but corollary studies of surface density, moisture content, record of treatment, chemical content and gradation of materials. To guard against a general shift of foundation, level measurements were taken to plates buried beneath the roadway. In taking the last readings the road surfaces were swept and the weight of loose material per mile determined. The surfaces carried no loose material when first constructed.

The results show that taking the loss of material on the ordinary untreated gravel road as 100 per cent, the loss from the ordinary, but treated, road was 50

[6] *Proceedings*, Highway Research Board, Vol. 18, Part I, p. 323.

per cent and from the treated stabilized road 37 per cent. The study also indicated that the losses were not proportional to the amount of traffic.

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