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No. 2 F

USE OF CALCIUM CHLORIDE
IN
GRANULAR STABILIZATION OF ROADS

BY

F. L. CUTHBERT

1945

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USE OF CALCIUM CHLORIDE
IN
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OF ROADS

A REVIEW
OF
AVAILABLE LITERATURE

BY
F. L. CUTHBERT
RESEARCH ENGINEER, HIGHWAY RESEARCH BOARD

HIGHWAY RESEARCH BOARD
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WASHINGTON 25, D. C. NOVEMBER 1945.

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FOREWORD

This is the report of a special investigation to evaluate the use of calcium chloride in granular road stabilization.

The project was sponsored and directed by a special subcommittee of the Committee on Granular Stabilization with the cooperation and support of the Calcium Chloride Association.

The investigation and report were made by Dr. F. L. Cuthbert, on leave from Princeton University and consisted of a critical analysis of available literature. Dr. Cuthbert has utilized his background in soil science and his experience in analytical work to study the factors of the problem in an impartial and objective manner.

An important feature of this work is the annotated bibliography. In addition to arrangement of the major divisions of the problem into a classified subject index, all of the references are listed chronologically with a brief statement of the content following each reference. There is also an author index.

USE OF CALCIUM CHLORIDE IN GRANULAR STABILIZATION OF ROADS

By
F. L. Cuthbert, Ph. D.

The following work is a critical review and analysis of available literature on the use of calcium chloride in granular stabilization of roads. The project was undertaken for the purpose of gathering together the sum total of the knowledge on the subject so that it would be more readily available for use and could serve as a springboard for further research.

Granular stabilization, while a relatively new term, can be traced back to C. M. Strahan's work in Georgia, published in 1929 (1).[1] In this report Dr. Strahan pointed out the importance of proper gradation of the constituent fractions of clay, silt, sand, and gravel in the performance of the road. He also elaborated upon the function of each of the materials in contributing to the stability of the road. This work naturally focussed the attention of highway engineers and soils men upon the possibilities of preparing stable, low cost roads by the manipulation of the clay, silt, sand and gravel content.

The use of calcium chloride as an admixture did not enter the picture until a few years later, although it had been used for some time as a dust palliative on dirt and gravel roads. In 1932, an investigation by the Highway Research Board on "The Use of Calcium Chloride as a Dust Palliative" (6) brought out the fact that calcium chloride not only acted as a dust palliative but also tended to maintain a moisture content in the road which had a beneficial effect on the stability of the road itself. Collings and

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[1] - Figures in parentheses refer to the bibliography.

Stewart (21) presented in 1934 the first results of track tests in which different sections of road were constructed with different materials and subjected to traffic and weathering tests. They showed that compaction was facilitated by the use of calcium chloride. Their report also included data on different types of road sections.

From that time on the use of calcium chloride as an admixture in granular stabilized roads rapidly increased until such road projects were being constructed in many states. A resumé of the status was published in 1933 (7). Numerous research investigations by various groups and individuals quickly established information concerning construction procedures and theories were advanced in regard to the part played by calcium chloride in affecting stability.

The main purpose of this report is to review and analyze these papers.

While the references studied were restricted to those on the use of calcium chloride in stabilization it is desirable to mention briefly various other uses in highway construction. These are:

1. Use as a dust palliative.
2. Use as an aid in the prevention of freezing of subgrades.
3. As an aid in decreasing the damage to gravel roads due to frost action.
4. In the treatment of sand and similar materials used as skidding preventatives on icy pavements.
5. Use in the acceleration of early hardening of cement and as a curing agent.

Manufacture and Properties of Calcium Chloride

Calcium chloride, chemical formula $CaCl_2$, is a white, highly deliquescent salt. The following information regarding its occurrence, manufacture, physical and chemical properties has been taken mainly from two very detailed reports; "Calcium Chloride" (22), and "The Story of Calcium Chloride as a Road Binder" (100).

Manufacture and Occurrence - Calcium chloride does not occur naturally except in solution in salt brines and mineral springs, and as a constituent in a few minerals of no commercial importance in this country. The most important sources are natural brines and by-products produced in the manufacture of ammonia or ammonium carbonate, carbon dioxide from marble, potassium chlorate, and sodium carbonate by the Solvay Process. It is interesting to note that the chemical was considered a waste product and difficult to dispose of until research and developments led to its use in several varied fields.

Properties - Deliquescence and Hygroscopicity - Deliquescence is the ability of a material to absorb moisture from the air and thus to be dissolved and become liquid. Hygroscopicity is the ability to absorb and retain moisture without necessarily becoming liquid. Calcium chloride possesses these two characteristics to a marked degree as shown in Table I.

TABLE 1.

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. Water Taken up by 1 lb. CaCl
30	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

The extent to which the chemical exhibits these properties under natural conditions is governed by temperature and humidity in such a manner that the higher the relative humidity of the air the more will be absorbed at a constant temperature; and the higher the humidity, the lower the temperature at which the chemical will dissolve.

VAPOR PRESSURES OF CALCIUM CHLORIDE SOLUTIONS

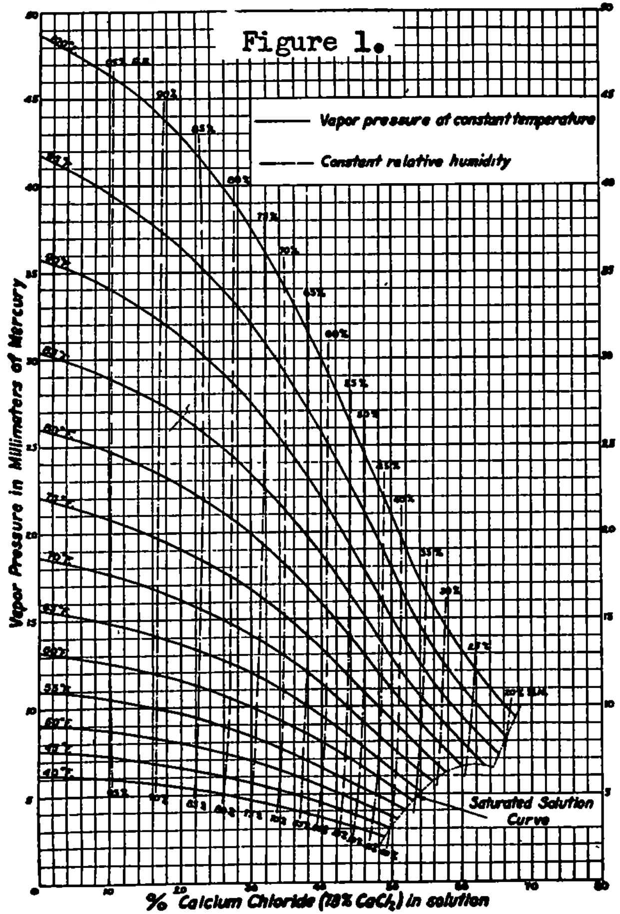

Figure 1.

EXPLANATIONS OF CURVES

1. VAPOR PRESSURE OF WATER is given by the intersection of temperature curves with 0% calcium chloride ordinate Thus vapor pressure of water at 85°F. is 30.4 m.m.

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

Thus at 85°F a solution containing 20% calcium chloride (78% $CaCl_2$) has a vapor pressure of 26.8 m.m. and one containing 50% has a vapor pressure of 12.8 m.m. As noted above, water at this temperature has a vapor pressure of 30.4 m m.

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

Thus at 85°F and 50% relative humidity the vapor pressure of water in the air is 15.2 m.m., i.e. 50% of 30.4 m.m. Under these conditions of temperature and vapor pressure, calcium chloride or any of its solutions having a vapor pressure lower than 15.2 m.m. will absorb water sufficient to make a solution containing 46% calcium chloride (78% $CaCl_2$), which is the strength having a vapor pressure of 15.2 m.m. A weaker solution than 46% at this temperature and humidity will have a higher vapor pressure than 15.2 m.m., 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.

Vapor Pressure and Surface Tension - Vapor pressure is a direct measure of the speed of evaporation and is directly affected by temperature and the strength or concentration of the material. While calcium chloride itself does not evaporate, the water in a solution containing calcium chloride will, although at a slower rate than pure water. This means that soils containing calcium chloride in solution will remain moist longer than if the chloride was not present. Figure 1 shows the vapor pressure of various strengths of calcium chloride solutions.

Surface tension is also related to the rate of evaporation in such a manner that a solution possessing high surface tension will tend to vaporize less rapidly than one having low surface tension, with other factors constant.

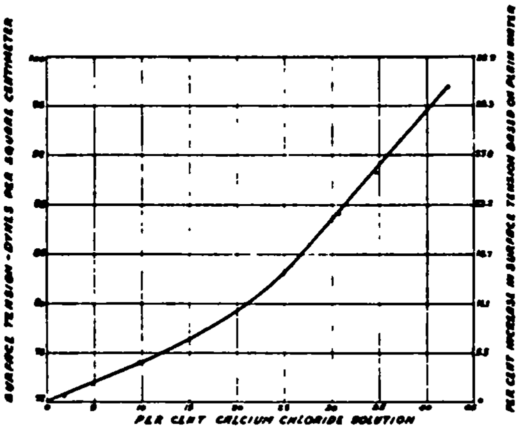

Figure 2. Surface Tension of Calcium Chloride Solutions at 77°F.

Figure 2 shows the increase in surface tension effected by adding calcium chloride to water. This indicates, for example, that a 25 per cent solution of calcium chloride has a surface tension about 14.6 per cent higher than that of pure water.

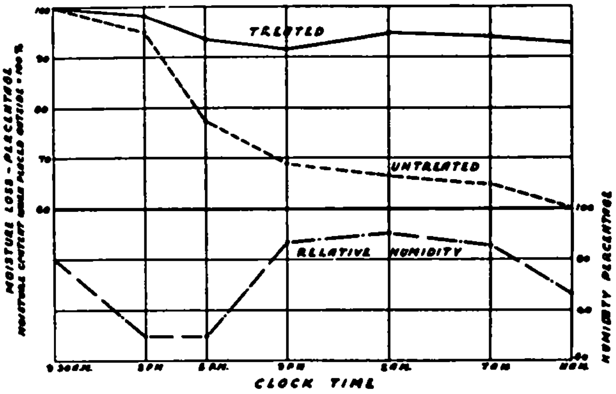

Figure 3. RELATIONSHIP OF EVAPORATION RATES OF MOISTURE FROM TREATED & UNTREATED SOILS & THE EFFECT OF THE RELATIVE HUMIDITY ON THE HYGROSCOPIC PROPERTY OF THE CALCIUM CHLORIDE TREATED SOIL

* DATA FROM PROCEEDINGS OF HIGHWAY RESEARCH BOARD - PART II, 1932

Figure 3 shows the effect of these properties on reducing evaporation of moisture from calcium chloride treated soils in comparison to untreated soils. If dry soil is mixed with water to any fixed percentage of moisture, that water will proceed to evaporate until the soil is again as dry as it was before; but if mixed with an equal quantity of calcium chloride solution which is in equilibrium as to temperature and relative humidity, it will stay continuously as moist as the calcium chloride solution will render that soil.

Freezing Point - The freezing points or freezimg temperatures of calcium chloride solutions vary according to the strength or concentration of the solution. Comparatively small percentages are effective in reducing the freezing point below that of water as shown in Table 2. This property, although it has no direct bearing on the use of calcium chloride in stabilization is important in its use as an aid in the prevention of detrimental frost heaving.

TABLE 2.
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

Principles of Stabilization

Soil stabilization, as defined by Hogentogler (140) is "the process of giving natural soils enough abrasive resistance and shear strength to accommodate traffic or loads under prevalent weather conditions, without detrimental deformation." He goes on to say, "The methods employed include the use of admixtures, compaction, and densification by specific technical theory and laboratory control. Optimum water content is fundamental with gradation. Admixtures may be soil materials, deliquescent chemicals, solutions of electrolytes, soluble cementitious chemicals, primes and neutralizers, and insoluble binders." A broader definition that is frequently used states, "A stabilized road is one that will not flow laterally under a load " (139).

Three factors are fundamental to stabilization; gradation, water content, and compaction or densification. All three of these are also interdependent upon each other in such a manner that they must be considered together.

Del French (30) states that for stability two types of resistance are needed; the "sand-paper effect" produced by the internal friction of the particles of aggregate and the "fly-paper effect" produced by the "stickitiveness" of the finer materials like clay. This is effected by gradation. Each of the components of a well-graded soil adds its own peculiar characteristics to the stability of the whole. Clay, due to its cohesive properties when wet provides cohesion and acts somewhat as a cement between the larger particles of silt and sand which have no cohesive properties. Also, clay, due to its mineral composition and crystaline structure may be considered as the active ingredient, in the sense that its properties can be changed somewhat by chemical action (149) (70). Silt provides pore filler and embedment for the sand grains and contributes to the internal friction of the whole, another essential for stability. Sand and gravel, usually of less than 1-in. maximum particle diameter, supply the greatest amount of internal friction and affords a hard wearing course for the road (118).

As described by Proctor (15) it was discovered that compacted mixtures of such materials possess an optimum moisture content and a maximum density for each degree of compactive effort used in molding specimens. "If a given soil in an air-dry condition is placed in a container and submitted to a definite compactive effort, a certain density (usually measured in pounds per cubic foot) will be obtained. If a small percentage of water is added and the soil is again compacted with the same amount of effort, a greater density is obtained. By repeating this procedure, using the same compactive effort, but increasing the moisture each time, a moisture content will be found for which the density of the soil is a maximum. The moisture in the soil at maximum density is called the optimum moisture content for this compactive effort. If the test is repeated, using a greater compactive effort, a higher maximum density will be obtained at a lower optimum moisture content. On the other hand, if a smaller compactive effort is used, a lower maximum density will be obtained at a higher optimum moisture content. For a given soil, therefore, there are as many 'maximum densities' and 'optimum moistures' as there are compactive efforts used " (194). Hogentogler and Kelley (101) state "that all soil mixtures suitable for road use are stable at some water content", and "water in stable roads is more adhesive than free water and stability depends upon the thickness of the absorbed moisture films, and the principal aims of stabilization are to make the soil as dense as possible and to prevent the thickness of the moisture films from changing". Thus the relationships of water content and density are clearly shown. Burmister (122), Shaw (184), and Maddison (188) have conducted experiments showing the effect of gradation on density. Maddison's results showed that there was a slight reduction in the dry density of the soil mortar with crushed stone contents up to 25 per cent and with larger amounts the dry density of the soil mortar (particles less than 2 mm. in diameter) was considerably reduced and that the optimum moisture content increased with increasing stone content.

Use is made of these principles of stabilization in working toward two objectives; the most stable combination of the available materials, and as great a degree of permanence of that stability as is possible by means of mechanical consolidation and the use of admixtures (58).

Soil Tests

The Division of Physical Research of the Public Roads Administration has done a great deal in investigating, simplifying and standardizing a few soil tests which aid in determining the suitability of earth materials for stabilization and in the construction of stabilized roads. Limits have been defined within which the soil tests or soil constants must fall for optimum stability (118). These tests and the functions of each have been described in numerous papers and it is not purposed to describe them in detail in this work but merely to mention them and the part played by each (21) (186). "Wartime Road Problems", No. 5 on "Granular Stabilized Roads" (186) published by the Highway Research Board in 1943 presents an excellent description of the soil tests most commonly used and the following is taken mainly from that source.

Mechanical Analysis - The gradation of the particles of a soil is determined by sieve analysis. Recommended limits, based on the Specifications of

A.A.S.H.O. and A.S.T.M., within which the gradation should fall for various types of construction, are given in Wartime Problems No. 5, on Granular Stabilized Roads (186). Figure 4 shows gradation limits for a base course mixture (118).

Plasticity Tests - These tests are indicative of the activity of the clay portion of a soil, and are made only on that material passing a No. 40 sieve, which is the fraction that supplies the greatest amount of cohesion to a soil. The plastic limit is the moisture content at which the soil passes from the semi-solid state to the plastic state; and the liquid limit is the moisture content at which a soil passes from the plastic state to a liquid state and begins to flow. The plasticity index (P. I.) is the difference between the liquid and plastic limits and is an index of the cohesive power of the material and also of its flowability under pressure. A low plasticity index indicates low cohesiveness and a high index a tendency to instability when wet.

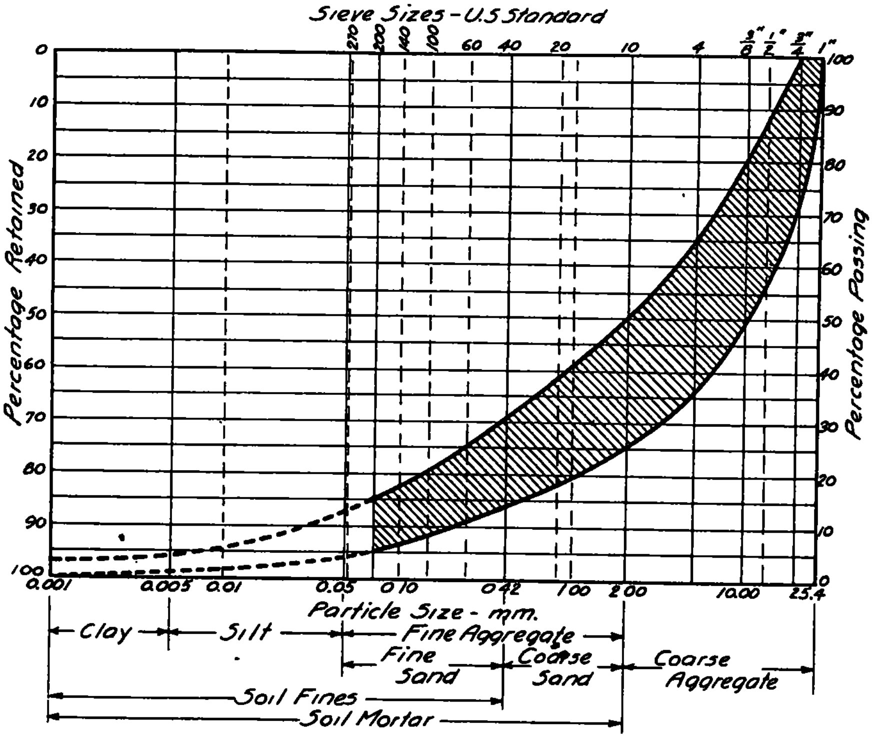

Figure 4. Stabilization Chart for 1-in. Maximum Size Aggregate for Base Course

Function of Calcium Chloride

From the foregoing Principles of stabilization it is noted that water plays a prominent role in stabilization. First, it is necessary to make the clay cohesive and second, it provides the medium by which maximum density can be obtained by compaction. An excellent review of the influence of internal friction and cohesion upon the stability of soils is given in the General Theory of Soil Stabilization, Part I, of the Progress Report of the Highway Research Board Project Committee on Stabilized Soil Road Surfaces (58). Data are given which show that a decrease in cohesion of a soil may result in a decrease in the supporting value of that soil from about 12,000 lb. per sq. ft. to less than 400 lb. per sq. ft. This indicates the importance of maintaining the proper moisture content in stabilized soils.

Practically all of the water added to a clay, silt, sand, and gravel mixture will be preferentially adsorbed by the clay fraction (82), which is why this fraction is sometimes termed the "active fraction" (86). It is also known that clays are made up for the most part of very small plate-like minerals called clay-minerals (149) and that these minerals have peculiar water adsorbent properties. Due to the electro-chemical activity of the clay-mineral, water is adsorbed in such a fashion that it actually exists in different forms, from the surface of the clay-mineral particle outward through the thickness of the water film (81). The molecular layer of water closest to the surface of the particle is adsorbed so strongly that it is more like a solid than liquid water. As the water layer or film thickens this solid character is lost due to the decreased strength of adsorption as the distance from the clay-mineral particle increases. Consequently, the outer layers are more like the water that we commonly think of. The Public Roads Administration's investigations have shown that the line of demarcation between

not ground-
What about
porewater?

"solid" water and "free" water is relatively sharp (70). Figure 5 is a sketch of these different phases of water surrounding a clay-mineral particle. Rapp and Mizroch show that the property or ability of clay to adsorb water may vary considerably with the clay due to the fact that it may be composed of different types of clay-minerals (149). Thus it can be seen that it is possible for these moisture films to exert tremendous binding forces between the clay particles and that any treatment designed to effect changes in the nature of these films is bound to have great influence in either strengthening or weaking this bond.

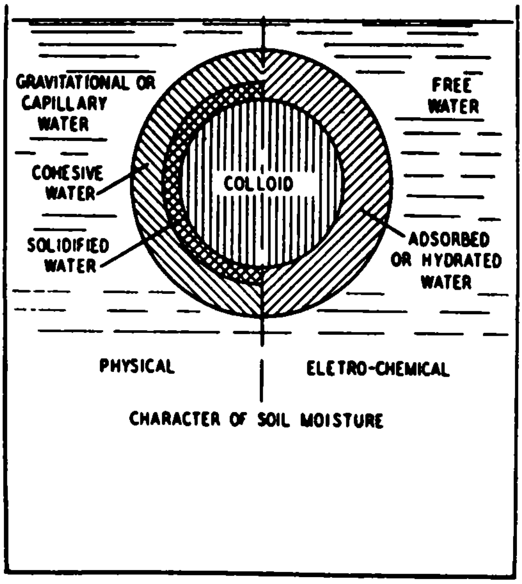

Figure 5. Clay particles in suspension

These moisture films must play a part in compaction and may be critical from the standpoint of obtaining and maintaining stability. The tests described by Proctor (15) are in a fashion, a measure of the ability of the clay to adsorb moisture. Moisture-density curves, as determined by the Proctor method show that maximum density is obtained over a relatively narrow range of moisture content with soils containing small percentages of clay and that with either greater or lesser amounts of water the density decreases, when the compactive effort is kept the same. Figure 6 shows a typical moisture-density curve. This narrow moisture range is further indication of the importance of moisture control in stabilization and of the possibility of obtaining improvements in stabilization through the manipulation of the clay-water relationships either by chemical or physical methods or combinations of both.

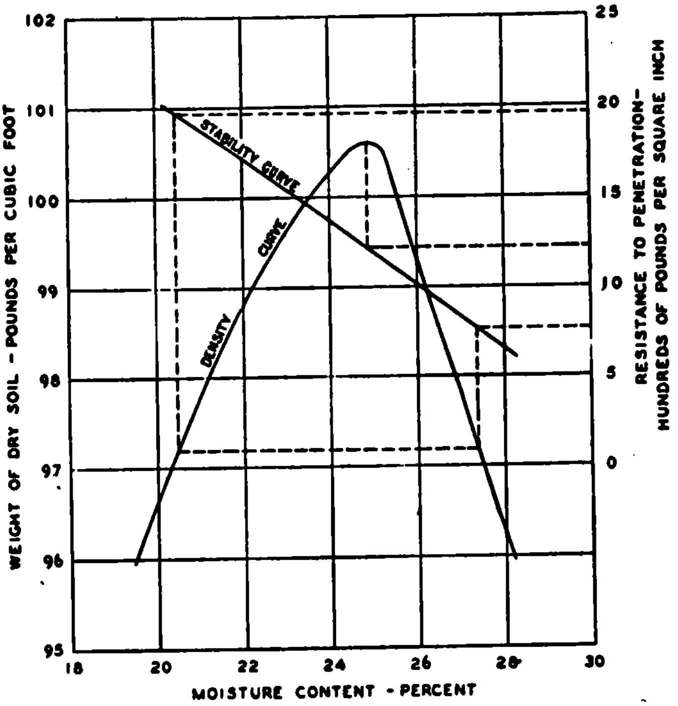

FIGURE 6.—EFFECT OF VARIATIONS IN MOISTURE CONTENT UPON THE DENSITY AND STABILITY OF A SOIL.

Calcium chloride, when used in granular stabilization, due to its hygroscopic and deliquescent properties will attract moisture and dissolve so that a calcium chloride solution is formed. Therefore, when this chemical is used we no longer have a clay-water relationship to consider but a clay-calcium chloride solution relationship and the critical problem is to determine how these two relationships differ.

In order for a calcium chloride solution to have any effect on stabilization it is necessary for it to move throughout the material being treated and stabilized. The efficiency of the movement of the calcium chloride solution, whether applied superficially or mixed integrally depends upon a number of factors. Slesser (185) reported an extensive laboratory and field study upon the movement of calcium chloride in soil which points out that the most important variables affecting movement are; evaporation, soil texture, percolating water, soil cover, and temperature. He found that the calcium chloride solution migrated downward by leaching from the surface and that under conditions of evaporation it was not found on the surface but that it did have a tendency to be concentrated in the upper layers, so that any beneficial effect which might occur from its presence would be repetitious. Since the chemical did not crystallize on the surface during evaporation very little was lost by run-off. The permanence of the calcium chloride solution was found to be directly affected by the type of soil; a sandy-clay soil apparently holding the chemical better than others. One of the final conclusions of this excellent piece of work was that the chemical should be mixed integrally with the soil for best results.

This work showed that movement of calcium chloride does take place when used as an admixture in stabilized soils and when it is applied in the solid form. Of course, if applied in a brine or pre-mixed solution the same will hold true. In view of this phenomenon we can see that we are not so particularly concerned with clay-water relationships in calcium chloride stabilized roads as we are with clay-calcium chloride relationships.

The absolute differences between the clay-water and clay-calcium chloride relationships are not definitely known. There is some evidence to indicate that the increased surface tension of the calcium chloride solution may make the films around the clay particles stronger and thus increase the cohesiveness or strength of the bonds between the sand grains (81). It is also very likely that the phenomenon of base-exchange plays some part (70) (149). Base-exchange is defined as the substitution of a base for another base or hydrogen in the soil. An example of this reaction is given by Rapp and Mizroch (149); "A sample of soil that showed an acid reaction was placed in a funnel and neutral potassium chloride was leached through the soil. The leachate was tested and found to be acid; on analysis the soil was found to contain more potassium than the original soil." The reaction is written as follows: "Hydrogen clay + potassium chloride = potassium clay + hydrochloric acid." This process is reversible and follows well defined chemical laws. Hogentogler and Willis (70) show that the physical properties of calcium clay are different than those of hydrogen clay and potassium clay. However, the exact determination of this difference in a stabilized road and how it affects the stability of the road remains for further investigation.

As stated previously the principal aims of stabilization are to make the soil as dense as possible and to prevent the thickness of the moisture films from changing. Elleman (139) says, "Stabilization hinges on the bonding action of these films." Evans (95) states, "Calcium chloride operates to conserve water in soil by reducing the rate of evaporation in dry spells and by absorbing water from the atmosphere under conditions of high humidity." Hogentogler, Jr. (9) suggests that moisture film cohesion furnished by calcium chloride is greater and lasts longer than that furnished by water alone. This fact is of great importance in promoting stability since it has been shown that one of the main requisites of stabilization is not only to supply the correct amount of water during construction so that maximum density can be attained by compaction but also to maintain the proper moisture film thickness to insure stability.

The overall results of incorporating calcium chloride in granular stabilization have been determined by several laboratory and field investigations by various groups. Hogentogler and Willis (70) state, "Treatment with either calcium chloride or sodium chloride (common salt) effects a decrease in the volume change and an increase in the density and stability of graded road mixtures; the calcium chloride does this through electrolytic and deliquescent properties, and the sodium chloride through electrolytic and crystalline properties. Generally the surfaces treated with sodium chloride are harder with a dryer appearance and slightly more dust, than the surfaces treated with calcium chloride." They also say, "Because solutions of calcium chloride and sodium chloride have lower vapor pressures than water, the evaporation of moisture from soil mixtures wetted with these salt solutions is definitely slower than from similar mixtures moistened with water. These salts in a stabilized road mixture therefore tend to conserve its moisture." The tendency of calcium chloride treated soils to maintain their moisture content to a greater degree than untreated soils was well illustrated by Burggraf (6). Figure 7, from that work, shows that the tendency toward loss by evaporation is greatly reduced when soils are treated with calcium chloride.

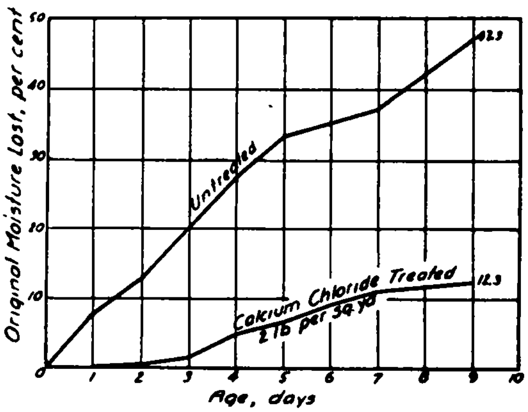

Figure 7. Relation of Evaporation Losses from Treated and Untreated Soil Aggregate Road Mixtures. (Composite Data on Laboratory Tests from Three States, Highway Research Board Proceedings, Vol. 12, Part II, 1932.)

The effect of calcium chloride on density of soil was illustrated by an investigation made by Hogentogler, Jr. (81). He showed that by using the same compactive effort, 135 lb. per sq. in., an untreated soil had an optimum moisture content of 41.2 per cent compared to 33.0 per cent for the same soil treated with calcium chloride; also that to have the same optimum moisture content of 33 per cent, the untreated soil required a pressure of 1,100 lb. per sq. in. whereas the treated soil required only 135 lb. per sq. in. These data also indicated that, at the same pressure of 300 lb. per sq. in., the untreated soil attained a density of 104.4 lb. per cu. ft. as compared with 114.5 lb. per cu. ft. for the treated soil. Other tests indicated that under the same compactive effort the weight of untreated and treated calcium chloride soils was 97 and 108 lb. per cu. ft. respectively, an increase of 11 per cent in favor of the treated soil.

An investigation by Willis and Carpenter (136) involving the use of an outdoor circular track to determine the effects of calcium chloride and other chemicals on nonplastic granular mixtures under controlled traffic and moisture conditions showed that: 1. The use of calcium chloride expedited compaction and reduced ravelling while the base courses were carrying traffic prior to the construction of the bituminous wearing courses, and 2. mixtures which contained calcium chloride during the initial compaction period reached a condition considered suitable for starting the test at somewhat less than one-third the wheel trips required to produce a similar condition in tracks which did not contain calcium chloride. In other words, the use of calcium chloride facilitated compaction so that the desired condition was obtained with much less compactive effort.

Belcher (161) reported the results of a very carefully controlled investigation in which a test road was constructed composed of sections constructed in various manners. One of these sections was made up of 88.5 per cent pit-run gravel and 11.5 per cent soil plus 0.5 per cent calcium chloride incorporated in the top 2 in. and 0.51 lb. per sq. yd. added to the surface. Inasmuch as the road was not part of a regular highway system controlled traffic was introduced to simulate road conditions. The conclusions state that the incorporation of calcium chloride will materially decrease dusting and will also increase the resistance of the mixture to ravelling; and that the chemical should be incorporated in the mix when feasible since surface applications are subject to being washed off before they have an opportunity to migrate into the mix.

Blomquist (178) used an indoor circular track to study the effects of using calcium chloride in stabilized mixtures. The conclusions reached in his study as they pertained to the use of calcium chloride were:

1. The general behavior of sections with calcium chloride admixtures were superior to those with no calcium chloride added. These sections were surface bound and this reduced ravelling.
2. Calcium chloride expedited compaction in all sections in which it was incorporated.
3. Binding of aggregate securely in place with stable soil mixtures and calcium chloride eliminates most of the destruction and loss of road material due to the action of traffic.

Burggraf designed an apparatus to test the resistance of the structural components of a road to lateral displacement which gives the stability resistance of the section tested in lb. per sq. in. (130) (137) (151). He concluded from use of this apparatus that; stabilized mixtures containing calcium chloride attain the same degree of compaction with less than half as much rolling as untreated mixtures, that the inherent stability in a calcium chloride stabilized road increases during the seasoning or "drying out" period, and that it is highly important to maintain stabilized roads as open surfaces until full stability is obtained, since 90 per cent of the ultimate stability develops during the seasoning period, roller compaction accounting for only 10 per cent.

Swinton (126) planned and carried out an investigation to determine the loss of gravel from stabilized road sections. The results of this investigation showed that the loss in gravel was decreased from 100 per cent for an ordinary untreated gravel road to 37 per cent for a calcium chloride stabilized road.

A detailed study of calcium chloride and all phases of its use in the stabilization of roads was made by Collings and Stewart in 1934 (21). This study is perhaps more complete than any other made. Among the various items studied was the effect of using calcium chloride in stabilization as determined by the use of a carefully constructed and controlled indoor road. The construction of the road involved a humidity controller and a "rainmaker." An 8700-lb. gross weight truck was run back and forth in the same path over the test sections, both during and after a "rain" to determine the relative stability. By alternately wetting and drying test sections, and sampling they showed that considerable movement downward and upward of calcium chloride resulted when subjected respectively to wetting and drying tests. Stability tests on treated and untreated sections showed that the use of calcium chloride resulted in a firmly, bound, dustless surface. This report also contains an excellent description of the preparation or construction of calcium chloride stabilized roads, and data on their costs and maintenance.

Construction

Methods of construction for building calcium chloride stabilized roads are perhaps best introduced by Blessing and Smith's (24) statements on the use of this type of construction. They state, "The usual applications of stabilization are:

1. "For binding loose stone or gravel.
2. "For adjusting properties and proportions of soil fines in existing wearing courses by adding needed binder or aggregate and then scarifying to a depth of 3 in. or more and mixing thoroughly.
3. "For improving wearing properties and hastening consolidation of resurfacing material and of new construction on gravel, stone, or slag roads.
4. "For increasing the supporting value of grades before construction of stabilized wearing courses, done by addition of clay to sand grades or of sand or low cost stone screenings to clay roads."

Calcium chloride has been used mainly in three types of construction; (128, 139, 155) surface consolidation, stabilization and dust laying. All three of these are really a phase of stabilization. Miller (128) says that: "Stabilization involves the adjustment of soil composition by standard methods so that it will consist of a dense wearing course or base composed of a designed mixture of graded aggregate, binder soil, and calcium chloride. Surface consolidation involves the use of gravel or stone already in place by adding binder soil to fill the voids and to furnish the cohesive constituent and calcium chloride to maintain the proper moisture content. Dust laying involves the addition of calcium chloride to stone or clay surfaces to supply moisture."

Surface consolidation is also considered by some to be a form of improvement in maintenance of gravel roads (116, 182). Knight (91) considers surface consolidation to be a form of stage construction. He states:

"In the past, the stages of construction were; dirt surfaces, gravel, black top, and finally a hard surface. Now the gravel surface itself can be built in stages by a method called surface consolidation." In another report (53) he says, "All maintenance shall be considered as progressive steps towards the goal of a stabilized road." The same term is applied when calcium chloride is used to consolidate limestone or similar surfaces. Stegner (182) reports that this usage results in more durable roads, reduces maintenance blading and upkeep costs, and increases the safety factor through dust reduction.

Stabilization, as the term is used by Miller (128) implies the construction of a road designed from the beginning to be stabilized throughout, from the subgrade to the wearing course. However, the same principles and methods of construction are used in all layers for in low-cost surfaces such as stabilized roads it is difficult to demarcate the roadway structure and its foundation, as the only distinction appears to be in the types and sources of materials used (63).

The construction methods used are largely governed by local conditions; including type of equipment and available labor, source of binder soil and aggregate (frequently material is obtained from the shoulders that can be utilized efficiently) and other conditions which necessarily vary from one locality to another.

Numerous references are listed in the bibliography that describe in detail the methods of construction used in various stabilized road projects, and these can be consulted for reference. However, a study of these reports brings forth a few items worthy of special mention.

Careful observation and study of a number of calcium chloride stabilized roads by Burggraf (57) revealed that the amount and type of crown is particularly important. The recommended crown is a modified "A" type, of at least ½ in. per lineal foot and never less than 3/8 in.

B. C. Tiney (106) reports that the trend of design of stabilized mixtures has been to reduce the proportion of binder soil and thereby lower the plasticity index of the mixture. When constructing stabilized bases for bituminous surfaces the P. I. (Plasticity Index) should be lower than when constructing for traffic wear. The general specification requirements are for a P. I. of not more than 3 or 6, depending on the gradation, for base courses, and a plasticity of not less than 4 or more than 9 for surface courses. (118). There is an increase in the plant production of mixes, in the use of multiple wheel pneumatic tired rollers, and a greater emphasis on obtaining the optimum moisture content for maximum density.

In order to utilize available local materials, individual state requirements are generally elastic (107, 112).

A tremendous growth has taken place in the number of State highway department soil laboratories equipped for conducting tests necessary for the construction of stabilized roads. In 1932 a survey indicated that 13 States and the District of Columbia had soil laboratories. Seven years later 41 highway departments were equipped.

Many reports recommend that the calcium chloride be mixed integrally with the other materials rather than merely applied on the surface (39, 95). This practice has undoubtedly lead to the increase in the use of plant mixed or prepared materials. Excellent reviews covering the equipment needed, design of plant, and types of mixes have been prepared by Stewart (104) and Olmstead (152, 153) among others. The advantages claimed for this type of preparation of stabilized mixes are:

1. Better control of proportions of ingredients and consequently more uniform mixes.
2. Traffic is not tied up for long periods of time.
3. Weather is not a decided factor.
4. It makes stabilized construction available to those who may not have all the necessary equipment for road mixing.
5. Producers of aggregate may utilize overburden which ordinarily would have to be stripped thus adding to the total expense.

Several instances in which utilization of plant mixed materials has found particular application is in the construction of streets and the stabilization of shoulders, although both plant mix and road mixed materials may be used. The entire shoulder is excavated to a depth of 4 to 6 in., 2½ to 3 ft. wide, and the pre-mixed stabilized mixture then compacted into this excavation (71). Experiences in which city streets have been built of stabilized materials indicate that the general construction procedures used are similar to those in road construction (69, 73, 88, 99, 129, 131). In the majority of cases the stabilized street after being compacted by traffic has been covered with a light bituminous mat (73, 109, 131). These reports of the use of calcium chloride stabilization in the construction of city streets all express satisfactory results. A central mixing plant is suggested to prepare a calcium chloride stabilized mix containing gravel, crushed stone or slag with enough sand or fines to fill the voids and enough binder soil and water to supply cohesion, and calcium chloride at the rate of about 18 lb. per cu. yd.

Maintenance

The type and amount of maintenance required to keep calcium chloride stabilized roads in good condition throughout the year varies from one locality to another dependent upon the amount of traffic, weather conditions, and local practice. There are unique characteristics of this type of road that warrant specific mention in regard to maintenance.

There are three objectives to fulfill in the maintenance of calcium chloride stabilized surfaces; (1) to provide smooth riding surfaces, (2) to keep wearing courses compacted with elimination of dust, and (3) to preserve the original crown and thickness (58). Dow (52) states that maintenance is as important as construction and the most important factor in maintenance is timing. The right operation must be done at the right time. Maintenance practices may be outlined in three general phases; blading, retention of moisture bond with calcium chloride, and patching (55).

Blading should be done immediately after a rain or even commenced near the end of a rain. This is due to the fact that during a dry spell the calcium chloride tends to concentrate near the surface of the road and blading at this time is likely to cause loss of the chemical. Also the blade can cut deeper without tearing when the road is wet (8, 52). Under average conditions calcium chloride stabilized roads require considerably less blading than untreated roads (181). Stegner (182) reports that about 75 per cent less blading is required. Downey (159) recommends fairly light blading from the center of the road towards the sides to eliminate chatter bumps, pot holes and other minor irregularities during light rains. Then after the rain, while the road surface and accumulated material are still moist, the loose material is bladed back into the road and shaped. Final blading and finishing is continued with multiple blade maintainers while the surface is compacting under traffic.

Moisture is maintained in the stabilized road by light applications of calcium chloride, 3/4 lb. per sq. yd. in spring, and 1 lb. per sq. yd.

in the summer or whenever the surface begins to show signs of drying or dusting (61, 150). It is much better to make frequent light applications of calcium chloride than heavier treatments less often (118).

Patching is only necessary during long dry spells, as blading after rains is usually sufficient to preserve smooth riding qualities. Any scattered pits which may develop during dry spells can be eliminated by patching with a mixture of graded aggregate under ½ in. in size, mixed with an equal weight of stable sand-clay, water to the extent of 6 to 10 per cent, and calcium chloride at a rate of 100 to 150 lb. per cu. yd (118). Wagner (76) recommends a patching procedure consisting of sweeping the depressions clean of loose material with a stiff brush, covering the depression with calcium chloride and filling with gravel. The surface of the patch is then covered with calcium chloride. This method has been found to be particularly adaptable in the maintenance of calcium chloride stabilized roads in public parks.

Cost

The costs of surface consolidation and stabilization vary considerably depending on the following factors: (118).

1. Condition of pre-existing road in surface consolidation.
2. Costs of delivered fine and coarse aggregate.
3. Cost of the soil binder.
4. Applying water, if necessary.
5. Mixing.
6. Spreading.
7. Compaction.
8. Calcium Chloride.

The cost of the aggregate is by far the greatest item and is the primary cause of the great variation in total cost. Excellent symposiums have been prepared on total costs of various projects in different sections of the country.

A review (118) of construction costs in Indiana, Illinois, Michigan and Minnesota showed remarkable uniformity when the costs of the aggregate was considered separately from the other costs of construction and materials. Charts were prepared of these costs and are presented in Figures 8 and 9.

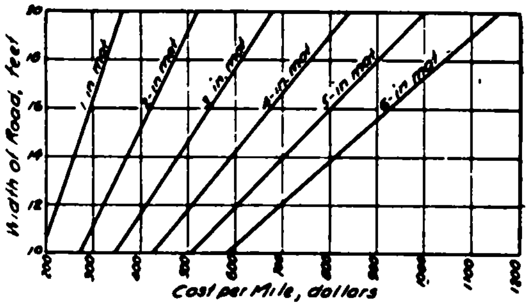

Figure 8. Cost of Stabilization Process per Mile. (Does not include cost of new aggregates.) Items included are (1) Prepared Binder-Soil, (2) Water Applied, (3) Mixing, (4) Spreading, (5) Compaction and (6) Calcium Chloride (1½ lb. per square yard). Based on cost of 25¢ per ton for compacted (145 lb. 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.

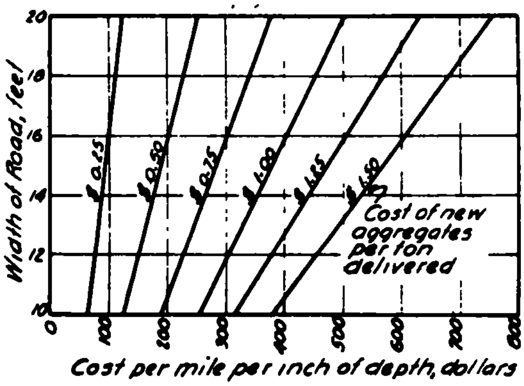

Figure 9. Cost of New Aggregates as Affecting and in Addition to the Cost of Stabilization. Based on the practical assumption that 80 per cent of the compacted stabilized mixture is aggregate (retained on 100 mesh sieve) and the final compacted weight of mixture equals 145 lb. per cu. ft.

Farnsworth (138) reported in 1939 the construction cost of 3-in. stabilized surfaces 20 ft. wide as $2321.00 per mile.

Glasgow (138) gave a cost of $2500.00 per mile for stabilized surfaces 18 ft. wide and 3 in. deep.

Moreland (138) cited a cost of $0.47 per sq. yd. for 6-in. depth of stabilized gravel base.

The following reports are individual cases not considered in the symposiums.

Tiney (20) reported in 1934 the costs of surface consolidation including construction and first application of calcium chloride varied from $100 to $400 per mile depending upon the location of clay and other factors.

Miller (38) in 1935 presented the breakdown of costs for a 1½-in. compacted stabilized mat using calcium chloride on 1400 sq. yd. of surface as:

60 cu. yd. gravel - $54.00
Screening and delivering gravel - $12.00 (½-mile haul)
Clay, 20 cu. yd. - $1.00
Delivery of clay - $9.00
Mixing, spreading, and compacting - $18.00
Calcium chloride, 2520 lb. - $36.00
Total - $130.00

The total cost of a new base, 3 in. deep, 20 ft. wide constructed in 1935 in Michigan was $1650 per mile (39).

Bateman (108) reported in 1938 the costs of surface consolidation using additional binder soil and calcium chloride and gravel mixed at the pit as being $80 to $100 per mile.

The Effect of Calcium Chloride on Frost Heaving

The use of calcium chloride in granular stabilization cannot be entirely divorced from its uses as a dust palliative and in some areas, from its effect on frost heaving and frost boils since these are directly involved in the use of the chemical as a stabilizer. Thus, it is impossible to construct a calcium chloride stabilized road having a firm well-knit wearing course without that surface being less dusty than it would be under ordinary conditions. This fact is brought out forcibly when we remember that the first effects of calcium chloride on stabilization or in securing a more dense road course were observed during a study of the chemical as a dust palliative (6).

The same is true of frost heaving. The most detailed work on the migration of calcium chloride solutions through soil was not undertaken with the purpose of its effect on stabilization but rather on frost heaving (185). The lower freezing point of calcium chloride solutions is well known and has many uses in other fields. Davis (171) has prepared a series of calcium chloride nomographs which give the properties of calcium chloride solutions such as specific gravity, concentration, and freezing points. Lang (83) suggests the lowering of the freezing point of the soil moisture by the use of calcium chloride as being beneficial in the reduction of frost heaving. Winn (117) states that Calcium chloride definitely reduces frost action because of the lowering of the freezing point and that 2 or 3 per cent of calcium chloride will reduce frost action to a minimum by preventing freezing at minus 10 to minus 15 deg. F. On a construction job in Maryland the problem of cold weather concreting and the protection of the subgrade from freezing between the time the grade was prepared and the placing of the concrete was critical (166). In this situation the frozen earth was excavated, stockpiled, and thawed by applying 2 lb. of calcium chloride over each 2 ft. layer in the stockpile. The stockpiled material was thus kept in excellent condition except for a slight crust even though sub-freezing temperatures prevailed. An application of 1½ lb. of calcium chloride per sq. yd. was made on the grade and worked in to a depth of 2 in. and then covered with 9 in. of marsh grass hay. This protected the grade from freezing before paving.

A special Committee of the Highway Research Board is now studying the problem of subgrade treatment for frost prevention and an outline for the investigational work has been prepared and arrangements made with several State highway departments for experimental installation.

These are just a few of the references to the use and effect of calcium chloride in reducing detrimental frost action. The bibliography includes others for completeness of the subject.

Summary

A critical review and analysis of the available literature dealing with the use of calcium chloride in granular stabilization has been made and a comprehensive bibliography has been prepared with comments on the subject of each reference. Classified and author indexes to this bibliography have also been made to facilitate its use.

This study has brought out a number of facts concerning the use of calcium chloride that are substantiated by laboratory or field investigations. These are:

1. Calcium chloride migrates through soil in the form of a solution. During dry spells it tends to concentrate near the surface and during wet spells it is carried downward by leaching.
2. The rate of evaporation of moisture from soil is reduced by calcium chloride, thus maintaining the moisture that is necessary for the development of cohesion in soils, an essential of stability.
3. Compaction is facilitated so that the desired density is obtained with less compactive effort.
4. Aggregate loss is reduced. A reduction from 100 per cent for an untreated road to 37 per cent for a treated road is given for a controlled project.
5. Treated stabilized roads are less inclined to dusting than untreated roads.

6. Laboratory studies show that the detrimental effects of freezing are materially reduced by the use of calcium chloride.
7. Maintenance blading and upkeep costs are less on calcium chloride treated stabilized roads.

On the basis of the foregoing facts it is concluded that the use of calcium chloride is justified from the viewpoint of obtaining a more stable wearing or base course which will give better traffic service with less maintenance. This includes the following road types:

1. Stabilization, which involves the adjustment of soil-aggregate composition so that it will consist of a dense wearing course or base composed of a designed mixture of graded aggregate, binder soil, and calcium chloride.
2. Surface consolidation, which involves adding binder soil to fill the voids and to furnish the cohesive constituent and calcium chloride to maintain the proper moisture content to gravel or stone already in place.
3. Dust laying, which involves the application of calcium chloride to aggregate or clay surfaces to supply moisture.

Further Research

The data reviewed show that there is a definite relationship between the use of calcium chloride and compaction since the densities of calcium chloride treated soils and soil-aggregate mixtures are greater than those of the untreated materials. The exact reason for this relationship is not clearly established. There is some indication that, because of the increased surface tension of calcium chloride solutions over that of water and the possibility that calcium chloride solutions provide thinner moisture films, greater density is obtained. However, this point is not definitely proven. A study designed to determine the exact nature of the effect of calcium chloride on density should be of value for it might well lead to better utilization of the material through changes in practice.

There has been a decided tendency toward the reduction of the plasticity index of the soil binder used in stabilization. There have been numerous instances in which the nature of the soil binder has changed radically from one locality to another and even from one road section to another. This difference is undoubtedly due to a change in the clay fraction of the binder. Hogentogler and Willis (70) and Rapp and Mizroch (149) have indicated the importance of this fraction in determining the behavior of soils particularly through base-exchange. Since, in granular stabilization, we are dealing with clays which are partially saturated with calcium chloride we can expect such reactions to take place, and because of the fact that clay will differ from one location to another it is reasonable to expect that the results will differ with different clays or clay-minerals. A study of these differences might cast further light upon the exact nature of the behavior and effect of calcium chloride in granular stabilization and particularly upon its beneficial effect on density.

As one reviews the literature that has been written on the use of calcium chloride in stabilization he cannot help but be impressed by the large number of reports describing its use in various localities. Most of these reports have been written either during the construction of the road, or immediately after, and consequently include only brief mention of the behavior of the road usually covering only one year or one season. While these reports are of great value in establishing references which can be cited when precedents are required they would be of much greater value if they covered a longer period of time. A survey of the behavior of these roads over a period of years covering such items as performance, maintenance, and cost would add much to the general knowledge of this type of construction.

The writer is indebted to the Library Staff of the Public Roads Administration, Washington, D. C. for assistance in assembling most of the reference material from which this study was made.

APPENDIX

ANNOTATED BIBLIOGRAPHY
ON USE OF
CALCIUM CHLORIDE IN
GRANULAR STABILIZATION
OF ROADS

HIGHWAY RESEARCH BOARD
1945

O - yet to read -

CLASSIFIED SUBJECT INDEX

The numbers listed are those of the references in the bibliography.

Principals of Stabilization: Fundamental articles on granular stabilization and the use of calcium chloride.
1, 6, 8, 9, 13, 15, 18, 21, 24, 35, 36, 37, 40, 58, 70, 79, 81, 85, 86, 101, 118, 139, 140, 141, 194.

Frost Prevention: Articles dealing with theory of frost prevention and the use of calcium chloride.
2, 3, 4, 5, 25, 31, 83, 84, 117, 119, 143, 148, 163, 166, 169, 170, 172, 173, 175, 176, 177, 189.

Construction Procedure: 14, 40, 43, 53, 54, 57, 63, 71, 92, 105, 107, 116, 142, 146, 150, 157, 159, 162, 165, 174, 179, 180, 190, 191, 192, 194.

Cost: 20, 38, 44, 89, 91, 94, 108, 118, 138, 182, 191.

Pit or Plant Mixing: 26, 50, 60, 66, 68, 75, 80, 104, 112, 113, 127, 152, 153, 168.

General: Articles containing information of general interest to those concerned with problems of granular stabilization.
7, 21, 30, 41, 45, 56, 58, 70, 79, 85, 87, 95, 97, 101, 103, 106, 118, 121, 123, 125, 128, 132, 139, 145, 155, 156, 186, 187.

Properties of Calcium Chloride: Physical and chemical properties of calcium chloride important in stabilization.
15, 22, 33, 35, 37, 70, 81, 86, 100, 111, 122, 133, 171, 193.

Stage construction: Description of road projects in which stage construction was the goal.
10, 51, 61, 67, 87, 90, 105, 106, 112, 131, 144, 168, 183, 191.

Road Project Reports: Reports giving information of actual construction jobs in which calcium chloride has been used. Mostly of a general nature.
11, 12, 16, 17, 19, 23, 27, 29, 32, 34, 39, 42, 47, 48, 49, 54, 59, 61, 62, 64, 74, 77, 78, 89, 92, 93, 96, 98, 102, 105, 115, 120, 135, 142, 154, 158, 162, 167, 174.

Maintenance: 13, 24, 44, 52, 55, 72, 76, 114, 116, 150, 159.

Surface consolidation: 28, 39, 42, 49, 65, 91, 108, 110, 116, 124, 131, 134, 135, 159, 160, 164, 180.

Streets: Articles describing the use of calcium chloride in the construction of streets.
46, 69, 73, 88, 99, 109, 129.

Technical: Reports describing laboratory and field experiments designed to test and improve the use of calcium chloride in granular stabilization.
81, 82, 122, 126, 130, 136, 137, 147, 149, 151, 161, 178, 184, 185, 188.

AUTHOR INDEX

The numbers listed are those of the references in the bibliography.

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1. "A Study of Gravel, Topsoil and Sand-Clay Roads in Georgia." C. M. Strahan. Public Roads, Vol. 10, No. 7, 1929.
   Can be considered fundamental work on stabilization establishing for first time the relationship between gradation and quality of sand-clay roads.

2. ✓ "Illustrations of Frost and Ice Phenomena." I. B. Mullis. Public Roads, Vol. 11, No. 4, 1930. X
   Physical characteristics of ice formation in soils and how it is manifested in highways and soils.

3. ✓ "The Relation of Certain Frost Phenomena to the Subgrade." V. R. Burton and A. C. Benkelman. Proc. Highway Research Board, Vol. 10, 1930. ✓
   Data on subject of title supported by laboratory evidence.

4. ✓ "A New Theory of Frost Heaving." A. C. Benkelman and F. R. Olmstead. Proc. Highway Research Board, Vol. 11, 1931. ✓
   Results indicate excessive heaving may occur in soils of any grading or texture providing sufficient water is present.

5. ✓ "Discussion on Frost Heaving." A. Casagrande. Proc. Highway Research Board, Vol. 12, 1932. ✓
   Differences in various theories of frost heaving are presented and conclusions of experiments.

6. "The Use of Calcium Chloride as a Dust Palliative." Fred Burggraf. Proc. Highway Research Board, Vol. 12, 1932.
   Recognition that use of calcium chloride as a dust palliative has definite effect on stability of road.

7. "Soil Stabilization in Highway Construction through Calcium Chloride." Public Works, Vol. 64, No. 6, 1933.
   General report of all types of stabilization being done in various sections of the country.

8. "Stabilization of Traffic Bound Roads through the Calcium Chloride Method." S. S. Warren. Better Highways, Vol. 16, No. 6, 1933.
   Points out advantage of getting same bearing or incorporation of sufficient metal in road bed in one year or one spread as could take three to five years under ordinary gravel road maintenance procedure.

9. "Stabilization of Low-Cost Roads by Calcium Chloride." C. A. Hogentogler, Jr., Roads and Streets, Vol. 76, No. 10, 1933.
   Considers physical aspects of what makes a stable soil mixture and why.

10. "Moisture-Film, Cured Macadams." C. A. Hogentogler, Jr., Public Works, Vol. 64, No. 11, 1933.
    Stabilized bases with calcium chloride, properly seasoned, afford good bases for macadam covering.

11. "Stabilizing Earth Roads." Engineering News Record, Vol. 111, No. 19, 1933.
    Short note of general type of work being carried on in Michigan and in Onondaga county, New York.

12. "Stabilizing Michigan Gravel Roads with Clay and Calcium Chloride." E. E. Blomgren and J. W. Kushing. Public Works, Vol. 64, No. 12, 1933.
    Method of construction described.

13. "Preparation and Maintenance of Stabilized Gravel Roads." W. R. Collings and L. C. Stewart. Am. Road Builders' Assoc., Bull. No. 36, 1933.
    General review of all phases of calcium chloride granular stabilization.

14. "Gravel Type Stabilized Surfaces for Secondary Roads." R. B. Traver and W. B. Hicks. Proc. Highway Research Board, Vol. 13, 1933.
    Methods and materials of construction described in some detail.

15. "Fundamental Principles of Soil Compaction." R. R. Proctor. Engineering News Record, Vol. 111, Nos. 9, 10, 11, 12, 13, 1933.
    Theory and practice of soil compaction.

16. "Stabilization of Gravel Roads by Use of Calcium Chloride." W. O. Dow. Twentieth Ann. Road School, Purdue University, 1934.
    General use is described and brief accounts of various road projects presented.

17. "Stabilization of Gravel Roads by Use of Calcium Chloride." C. W. McClain. Twentieth Ann. Road School, Purdue University, 1934.
    Brief account of project in Indiana.

18. "Principles of Road Stabilization." S. S. Warren. Highway Topics, Vol. 11, No. 8, 1934.
    General review of practice of soil stabilization.

19. "New Application of Old Principle." F. H. Eno. Ohio State University Engineering Experiment Station News, Vol. 6, No. 1, Part I, 1934.
    Refers to Strahan's work in Georgia. Note that calcium chloride stabilized road is being tested in Ohio.

20. "Soil Stabilization Insures Good Low-Cost Roads. B. C. Tiney. Highway Magazine, Vol. 25, 1934.
    Utilization of fine material in gravel, construction, and maintenance of gravel roads cost $100 to $400 per mile.

21. "Stabilized Soil-Bound Surfaces." W. R. Collings and L. C. Stewart. Engineering News Record, May 24, June 7, 14, and 21, 1934.
    Complete series of articles on all phases of use of calcium chloride in granular stabilization.

22. "Calcium Chloride." P. M. Tyler. U. S. Bureau of Mines, Information Circular 6781, 1934.
Nature, manufacture, occurrence, and properties of calcium chloride.

23. "Ohio Engineers View Stabilized Roads in Oakland County." Michigan Roads and Airports, Vol. 31, No. 21, 1934.
Announcement of visits of engineers to project.

24. "Stabilization and its Relation to Maintenance of Traffic-Bound Roads." Olin D. Blessing and Don N. Smith. Better Roads, Vol. 4, No. 6, 1934.
Explains purpose of stabilization and its usual applications.

✓ 25. "Methods for Prevention of Road Failure Due to Frost." H. H. Miller and Don N. Smith. Roads and Streets, Vol. 77, No. 6, 1934. ✗
Two treatments which have successfully eliminated frost failures in roads.

26. "Producer Makes Special Mixture for Calcium Chloride Treated Road Surfaces." Rock Products, Vol. 37, No. 6, 1934.
Title explanatory.

27. "State Tests New Type Road Surface." Minnesota Highway News, July 25, 1934.
Note that calcium chloride stabilized roads are being constructed and tested in Minnesota.

28. "Stabilization of Resurfacing Gravel." Leon Belknap and John Barr. Public Works, Vol. 65, No. 8, 1934.
Methods of construction described for this type of work in Oakland county, Michigan.

29. "Indiana Stabilizes Many Miles of Gravel-Surfaced State Highways." Outdoor Indiana, Vol. 1, No. 7, 1934.
More than 250 miles of gravel surfaced roads being treated.

30. "Soil Concretes, Performances and Possibilities." Prof. R. Del French. Canadian Engineer, Vol. 67, No. 12, 1934.
General review of principles of stabilization.

✓ 31. "Frost Heave in Highways and its Prevention." Henry Aaron. Public Roads, Vol. 15, No. 1, 1934. ✗
Title explanatory.

32. "Stabilized Roads in West Virginia." West Virginia Highways, January, 1935.
Report of use of stabilized gravel roads.

33. "Soil Stabilization." C. A. Hogentogler. Proc. of the Eleventh Ann. Convention, Assoc. of Highway Officials of the North Atlantic States, 1935.
General discussion on subject utilizing physical-chemical relationships of soils.

34. "Stabilized Surfaces in Oakland County." John H. Barr. Twenty-first Ann. Highway Conference, University of Michigan, 1935.
Description of experiences in Oakland county, Michigan using both plant and road mix methods of preparing calcium chloride stabilized materials.

35. "Stabilized Gravel Roads, Theory and Practice." C. M. Hathaway. Twenty-second Ann. Conference on Highway Engineering, University of Illinois, 1935.
Title explanatory.

36. "Practical Soil Stabilization." V. L. Glover. Twenty-second Ann. Conference on Highway Engineering, University of Illinois, 1935.
General review of field of stabilization.

37. "Practical Soil Stabilization." C. A. Hogentogler. Twenty-second Ann. Conference on Highway Engineering, University of Illinois, 1935.
Discussion of the physical properties of soils concerned with stabilization.

38. "Cost of Building Stabilized Roads." R. W. Miller. American City, Vol. 50, No. 2, 1935.
Detailed costs of two projects in Minnesota presented. Costs vary with thickness of mat, cost of materials, etc.

39. "Stabilized Surfaces in Oakland County." John H. Barr. Michigan Roads and Construction, Vol. 32, No. 11, 1935.
Complete descriptions of methods of construction, costs, and findings on one project.

40. "Progress in Road Stabilization by Use of Calcium Chloride." F. Burggraf. Roads and Streets, Vol. 78, No. 4, 1935.
Developments in road stabilization such as; specifications, design, construction, and maintenance.

41. "Progress in Stabilized Traffic-Bound Roads." H. G. Sours. Better Roads, Vol. 5, No. 4, 1935.
General review of stabilization. Two methods of application of calcium chloride described; surface application and integral mix.

42. "Resurfacing Gravel or Stone Roads in Townships." J. D. Flanders. Canadian Engineer, Vol. 68, No. 19, 1935.
Methods of stabilization used in Dereham township.

43. "Stabilized Roads a Real Job." H. G. Sours. Contractors and Engineers Monthly, Vol. 30, No. 5, 1935.
Results and conclusions of experiences with stabilization in Ohio. Methods of construction described.

44. "Notes on the Maintenance of Stabilized Gravel Roads." W. O. Dow. Better Roads, Vol. 5, No. 5, 1935.
Time of repair is critical. Methods described. Breakdown of costs.

45. "Low-Cost Road Building, A Symposium." Contributors, J. H. Barr and H. G. Sours. Engineering News Record, Vol. 114, No. 26, 1935.
Accounts of experience and practice condensed from recent papers presented at meetings of road builders covering federal standards, farm service, oil mix, stabilized soil, and tar-retread.

46. "Improving City Streets Through Low-Cost Stabilization." Mark Chambers. American City, Vol. 50, No. 7, 1935.
Soil tests of existing surfaces revealed lack of binder material and some gravel in earth surfaces. Treatments described.

47. "Stabilized Roads, Practical, Simple and Economical." S. O. Linzell. Highway Magazine, Vol. 26, p. 209, 1935.
General description of work in Morrow county, Ohio.

48. "Stabilization of Ontario Roads with Calcium Chloride." Canadian Engineer, Vol. 69, No. 11, 1935.
Impetus in interest caused by manufacture of calcium chloride at Amherstburg, Ontario. General description of construction work being carried out.

49. "Huron County's (Michigan) Experience in Stabilizing Gravel Roads." T. R. Patterson, Canadian Engineer, Vol. 69, No. 13, 1935.
Title explanatory.

50. "Premixed Stabilized Soil for Road Surfaces." L. C. Stewart and S. J. White. Engineering News Record, Vol. 115, No. 12, 1935.
Details, including design of demonstration plant built for producing stabilized gravel.

51. "Stabilized Gravel as Base Course for Bituminous Surfacing." J. Huber and M. Dick. Public Works, Vol. 66, No. 9, 1935.
Description of work in Washtenaw county, Michigan in which stabilized gravel road was constructed, maintained for one year, and then a thin bituminous coating applied. Very satisfactory results.

52. "Maintenance of Stabilized Gravel Roads." W. O. Dow. Michigan Roads and Construction, Vol. 32, No. 42, 1935.
Maintenance is as important as construction. Most important factor is time. Practice described.

53. "Stage Stabilization of Gravel Roads." J. A. Knight. Canadian Engineer, Vol. 69, No. 27, 1935.
Maintenance of gravel roads should be considered as progressive step toward the goal of a stabilized gravel road. Stages necessary for this development are described.

54. "Experimental Stabilization in Ohio." J. W. Reppel. Roads and Streets, Vol. 78, No. 12, 1935.
Title explanatory.

55. "Maintenance of Calcium Chloride Stabilized Roads." Calcium Chloride Assoc. Bull. No. 18, 1935.
Title explanatory.

56. "Outline for Low-Cost Road Improvement Through Stabilization with Binder Soil and Calcium Chloride." Calcium Chloride Assoc. Bull. No. 22, 1935.
Title explanatory.

57. "Importance of Crown on Calcium Chloride Stabilized Roads." F. Burggraf. Calcium Chloride Assoc. Bull. No. 23, 1935.
Recommendations for type of crown based on observations and measurements of many roads in service.

58. "Calcium Chloride Stabilization." Report of Special Committee, Highway Research Board, 1935.
Complete report on calcium chloride stabilization.

59. "Stabilization of Soil and Gravel Roads." F. C. Lang. Convention Proc. Am. Road Builders Assoc., 1935-1936.
Review of methods used in construction of stabilized roads in Minnesota. Progress of stabilization is retarded by lack of proper equipment and insufficient knowledge as to proper construction and maintenance methods.

60. "Pioneer Gravel Equipment"- Michigan Roads and Construction, Vol. 33, No. 2, 1936.
Description of a portable gravel clay stabilizer plant designed to work in conjunction with a crushed gravel plant and to prepare and mix materials for stabilization.

61. "Low-Cost Stabilized Road Construction." R. B. Traver. Canadian Engineer, Vol. 70, No. 8, 1936.
Methods of procedure and construction of stabilization in Onondaga county, New York described in detail.

62. "Stabilizing Gravel Roads in Victoria County." H. D. Wilford. Canadian Engineer, Vol. 70, No. 8, 1936.
Report of construction.

63. "Subgrade Stabilization." W. S. Housel. Twenty-second Ann. Highway Conference, University of Michigan, 1936.
In low cost surfaces such as stabilized roads it is difficult to demarcate between roadway structure and its foundation. Discussion on principles and methods.

64. "Stabilized Soil Road Withstands Erosion." Roads and Streets, Vol. 79, No. 2, 1936.
Illustration showing calcium chloride stabilized road after torrential rain, near Vincennes, Indiana.

65. "Gravel and Broken Stone Surfaces." Bernard Atkin. Twenty-third Ann. Conference on Highway Engineering, University of Illinois, 1936.
Value of calcium chloride use in stabilization recognized on all road sections built during past two years.

66. "Detroit Plant Uses Crushed Slag to Make Stabilized Road Mixture." Pit and Quarry, Vol. 28, No. 8, 1936.
Title explanatory.

67. "Smoothing Stabilized Gravel for Asphalt Surfacing." E. G. Hurst. Engineering News Record, Vol. 116, No. 15, 1936.
Unique problem of one particular road and its preparation for asphalt surface.

68. "Plant Production of Stabilized Mix." F. A. Slater. Canadian Engineer, Vol. 70, No. 15, 1936.
Production of stabilized gravel containing specified proportions calcium chloride, clay, sand, and pea gravel described.

69. "Stabilization for Street Improvement." Public Works, Vol. 67, No. 4, 1936.
Brief descriptions of street stabilization jobs in Lansing, Michigan; Ames, Iowa; and Detroit, Michigan. Both road and plant mix methods used.

70. "Stabilized Soil Roads." C. A. Hogentogler and E. A. Willis. Public Roads, Vol. 17, No. 3, 1936.
Discussion of the physical and chemical properties of soil involved in stabilization; effect of deliquescent chemicals described.

71. "Shoulder Stabilization." B. C. Tiney. Roads and Streets, Vol. 79, No. 7, 1936.
Methods of construction of calcium chloride stabilized road shoulders. Central mixing plant suggested.

72. "Solving Gravel-Road Maintenance Problems." Better Roads, Vol. 6, No. 8, 1936.
Reports of very satisfactory results by using calcium chloride and clay in maintenance.

73. "Detroit Builds Soil Pavements." Calcium Chloride Assoc. News, August, 1936, p. 5.
Brief note of what is being done.

74. "State Highway Department Builds Test Stabilized Road." Pennsylvania Road Builder, Vol. 9, No. 9, 1936.
Limestone screenings, clay, and calcium chloride added to gravel road according to tests showing deficiencies.

75. "Michigan Gravel Firm Takes Advantage of Demand for Stabilized Road Material." Pit and Quarry, Vol. 29, No. 4, 1936.
Description of production of stabilized soil aggregate mixture.

76. "Patching Calcium Chloride Roads." H. S. Wagner. Parks and Recreation. Vol. 20, No. 2, 1936.
Suggest expensive blading, planing, and reshaping can be eliminated or confined to once or twice a year by proper patching. Method described.

77. "Stabilized Road Construction in Minnesota." Earth Mover, Vol. 23, No. 10, 1936.
Use of three methods; road mixed by blading, machine mixed on road, and plant mixed for preparing stabilized material. Calcium chloride used in all.

78. "Stabilized Road Surfacing in Ohio." S. O. Linzell. Roads and Streets, Vol. 79, No. 11, 1936.
Calcium chloride used in surface application only.

79. "Stabilization of Soils." H. F. Clemmer. Roads and Streets, Vol. 79, No. 12, 1936.
General review of principles of soil stabilization.

80. "Plant Mixing Stabilized Aggregates for Low-Cost Roads." Calcium Chloride Assoc. Bull. No. 24, 1936.
Design of plant and details of mix for preparing plant mixed stabilized aggregate.

81. Essentials of Soil Compaction." C. A. Hogentogler, Jr. Proc. Highway Research Board, Vol. 16, 1936.
Report largely concerned with principles of compaction, conditions of moisture, film thickness, and the effect of electrolytes in stabilized soils.

82. "Effect of Quality of Clay on Soil Mortars." R. W. Miller. Proc. Highway Research Board, Vol. 16, 1936.
Compaction and swell tests indicate that Plasticity Index limits of 4 to 12 for soil fines or minus 40 mesh material cover range usually encountered in various localities.

83. "Combating Frost and Drainage Problems." F. C. Lang. Twenty-third Ann. Road School, Purdue University, 1937.
Report on mechanics of frost heaving and methods of combating problem.

84. "Combating Frost and Drainage Problems." C. W. McClain. Twenty-third Ann. Road School, Purdue University, 1937.
General discussion of problem.

85. "Soil Stabilization." C. A. Hogentogler. Proc. of the Thirteenth Ann. Convention, Assoc. of Highway Officials of the North Atlantic States, 1937.
Review of principles of soil stabilization.

86. "The Physical Chemistry of Highway Subsoils." C. A. Hogentogler. Twenty-third Ann. Highway Conference, University of Michigan, 1937.
General study of physical-chemical properties of soil and their influence in soil stabilization.

87. "Methods of Soil Stabilization and Low-Cost Roads." F. C. Lang. Twenty-third Ann. Highway Conference, University of Michigan, 1937.
Stresses importance of good subgrade for all types of road. Methods described.

88. "Stabilized Streets for a Housing Project." American City, Vol. 52, No. 2, 1937.
Short article briefly describing use of calcium chloride stabilized mixture in street construction of low cost housing project.

89. "Low-Cost County Road Construction." H. D. Wilford. Canadian Engineer, Vol. 72, No. 9, 1937.
Review of construction completed and brief statement of future planned work in Victoria county, Ontario.

90. "Developments in Road Stabilization." A. R. Brickler. Extension Series No. 38, Engineering Extension Department, Purdue University, 1937.
Concerned with stabilized bases. Details on use of several methods of stabilization employing various mixes.

91. "Surface Consolidation Method Produces the 'Costless' Road." J. A. Knight. Highway Topics, Vol. 14, No. 11, 1937.
In past, stages of construction were; dirt surfaces, gravel, black top, finally hard surface; now, gravel surface itself can be built in stages by method called "Surface consolidation." Construction details given.

92. "North Carolina Stabilized Job Stands Winter Well." W. Vance Baise. Contractors and Engineers Monthly, Vol. 34, No. 5, 1937.
Methods given that were used to construct 5.6 miles of calcium chloride stabilized road. Reported to be in good condition after winter.

93. "Stabilizing Roads with Calcium Chloride." Ainslie Sellars. Canadian Engineer, Vol. 73, No. 3, 1937.
Brief account of experience in construction of 1.25 miles of construction in North Malden, Ontario.

94. "Estimating Construction Costs for Road Stabilization." Public Works, Vol. 68, No. 7, 1937.
Charts presented showing costs of stabilization and new aggregate.

95. "Soil Stabilized Road Construction." W. E. Evans. Roads and Road Construction, Vol. 15, No. 176, 1937. (England).
General review of practice in United States.

96. "Outstanding Stabilized Road Built Under Contract." Highway Builder, Vol. 16, No. 5, 1937.
Previously most stabilization had been done by highway department. Contract work successful.

97. "Developments in Municipal Road Surfaces." H. F. Clemmer. Canadian Engineer, Vol. 73, No. 14, 1937.
Maximum density utilizing existing sources of supply of materials is prime requisite of stabilized soil mix design. Review of practice in United States.

98. "Stabilized Secondary Roads in Summit County, Ohio." Arthur F. Ranney. Better Roads, Vol. 7, No. 11, 1937.
Method of construction described.

99. "Low-Cost Improvement of Streets." V. E. Best. Pennsylvania Road Builder, Vol. 10, No. 11, 1937.
Street sections withstood winter without any repairs.

100. "The Story of Calcium Chloride as a Road Binder." Part I - Introduction, Part II - History, Occurrence, Manufacture, and Utility, Part III - Deliquescence and Hygroscopic Properties, Part IV - Surface Tension and Vapor Pressure. Calcium Chloride Assoc. News, May-June, July-August, September-October, November-December, 1937.
Title explanatory.

101. "Role of Soil Binders and Aggregates in Soil Stabilization." C. A. Hogentogler and J. A. Kelley. Proc. Am. Road Builders Assoc., 1937.
Whole theory of soil stabilization based on two facts: (1) all soil mixtures common for road usage are stable at some moisture content, (2) moisture in stable roads is more adhesive than free water and stability depends upon thickness of adsorbed moisture films.

102. "Road Stabilization." L. L. Allen. Proc. Am. Road Builders Assoc., 1937.
In 1932 survey showed 13 states and District of Columbia had laboratories capable of performing soil classification tests. Two years later 27 state highway departments were equipped. Reviews Minnesota experience.

103. "Stabilization with Aggregates, Binder-Soil and Calcium Chloride." F. Burggraf. Proc. Am. Road Builders Assoc., 1937.
General review article on all phases of subject.

104. "Plant Mixed Materials and Pulverization of Clay." L. C. Stewart. Proc. Am. Road Builders Assoc., 1937.
Reviews entire field of plant mixed stabilizers; types of plants, construction of plants, mixers, etc.

105. "Building a Stabilized Gravel Road." Improvement Bulletin, Vol. 85, No. 8, 1938.
Stabilized gravel road built under contract. Methods given.

106. "Important Details in Stabilization with Calcium Chloride." B. C. Tiney. Public Works, Vol. 69, No. 1, 1938.
Trend of design of stabilized mixtures has been to reduce proportion of binder soil and thereby lower Plastic Index of mixture. Changes in practice developing.

107. "Pennsylvania Utilizes Local Materials in State-Wide Road Stabilization. Construction Methods and Equipment, Vol. 20, No. 3, 1938.
Testing laboratory has set up and written specifications for five general designs of mixtures. General construction methods.

108. "Surface Consolidation and Dustless Maintenance of Gravel Roads." L. L. Bateman. Better Roads, Vol. 8, No. 4, 1938.
General practice of surface consolidation. Most failures because of insufficient mixing on surface of road.

109. "Residential Street Improvement." John H. Ames. American City, Vol. 53, No. 4, 1938.
Low cost methods required commensurate with traffic. Details of experience given.

110. "Consolidating Gravel County-Road Surfaces." Better Roads, Vol. 8, No. 5, 1938.
Michigan experiments on gravel road maintenance. General practice.

111. "Consolidation of Roads with Calcium Chloride." Canadian Engineer, Vol. 74, No. 23, 1938.
Brief description of practice.

112. "Stabilized Base for Black Top Road on U. S. 10." Michigan Roads and Construction." Vol. 35, No. 23, 1938.
Base course is calcium chloride clay stabilized gravel mixed in plant as required by Michigan specifications.

113. "Production and Use of Stabilized Maintenance Material." J. C. Black. Roads and Streets, Vol. 81, No. 6, 1938.
Clay and admixture mixed with gravel at plant and used in repair of shoulder ruts at edge of concrete.

114. "Sprinkling of Stabilized Roads Proves Success." B. R. Downey. Michigan Roads and Construction, Vol. 35, No. 31, 1938.
Sprinkling helps keep gravel trunk lines in good condition during summer.

115. "Many County Roads Stabilized with Calcium Chloride." Contributors, A. M. Williams, Otto Hess, and A. L. Burridge. Michigan Roads and Construction, Vol. 35, No. 42, 1938.
Comments of three county engineers all favorable to calcium chloride stabilization.

116. "Betterment in Maintenance by Partial Stabilization." B. C. Tiney. Public Works, Vol. 69, No. 10, 1938.
Methods of surface consolidation described.

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117. "Frost Action in Stabilized Soil Mixtures." H. F. Winn. Proc. Highway Research Board, Vol. 18, Part I, 1938.
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Presentation of experimental data on the relation of frost action in stabilized soil mixtures to gradation of soil mixture, type and percentage of admixture, and moisture content at beginning of freezing period.

X 118. "Use of Calcium Chloride in Road Stabilization." "Symposium". Contributors: C. F. Briggs, F. Burggraf, B. R. Downey, J. Elleman, C. A. Hogentogler, Jr., J. A. Knight, and H. D. Wilford. Proc. Highway Research Board, Vol. 18, Part II, 1938.
Complete series of short articles on all phases of use of calcium chloride in stabilization.

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119. "Prevention of Detrimental Frost Heave in Sweden." G. Beskow. Proc. Highway Research Board, Vol. 18, Part II, 1938.
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Title explanatory.

120. "Stabilized Roads." Geo. J. Cormier. Proc. Am. Road Builders Assoc., 1938.
Stabilization experiences in Brown county, Wisconsin.

121. "Developments in Soil Stabilization." C. A. Hogentogler. Proc. Am. Road Builders Assoc., 1938.
Emphasis on stabilization of subgrade, which is one of the most important problems in road building.

122. "The Grading-Density Relations of Granular Materials." Prof. D. M. Burmister, Columbia University. Proc. Am. Soc. for Testing Materials, Vol. 38, Part II, 1938.
Title explanatory.

123. "Current Developments in Stabilized Gravel and Crushed Stone Roads." Ernst Lieberman. Fifth Ann. Mineral Industries Conference, State Geological Survey, Urbana, Illinois, Circ. No. 23, 1938.
Three applications of calcium chloride recommended; of 3/4 lb. per sq. yd in May, July, and September.

124. "Calcium Chloride Road Construction." J. E. Tremayne. Canadian Engineer, Vol. 76, No. 2, 1939.
An outline of a practical and economical method of providing adequate surfaces for gravel road traffic.

125. "Stabilization by Use of Chemicals." R. B. Traver. Twenty-fifth Ann. Road School, Purdue University, 1939.
General review of field of stabilization.

126. "Gravel-Road Surface Wear Measured in Michigan Investigations." R. S. Swinton. Better Roads, Vol. 9, No. 1, 1939.
Under closely controlled conditions calcium chloride stabilized road showed 36 per cent wear compared to 100 per cent for an untreated gravel road.

127. "Production of Stabilized Gravel." Construction Methods and Equipment, Vol. 21, No. 2, 1939.
Note that stabilized mixture is being produced at rate of 90 cu. yd. per hour in plant.

128. "Stabilization, Surface Consolidation and Dust Laying." Herman Miller. Dowflakes, Vol. 1, No. 1, 1939.
Definitions of different types of stabilization and use of calcium chloride in both.

129. "Calcium Chloride for Streets in Belgian Congo." American City, Vol. 54, No. 5, 1939.
Brief report on use of calcium chloride for stabilizing streets.

130. "Field Tests Reveal Calcium Chloride Increases Density and Structural Stability." F. Burggraf. Calcium Chloride Assoc. News, May-June, 1939.
Stabilized mixtures containing calcium chloride attain same degree of compaction with less than half as much rolling as untreated mixtures.

131. "Slag and Calcium Chloride Give Good Base for Black Top Surface." E. L. Mills. Public Works, Vol. 70, No. 6, 1939.
Main street of Deersville, Ohio prepared for black top surface by calcium chloride stabilization.

132. "Consolidation of Gravel Roads." Surveyor (England), V. 96, No. 2477, 1939.
Standard procedures of calcium chloride stabilization in Quebec, Canada.

133. "Calcium Chloride in Construction." Engineering Journal, Vol. 22, No. 8, 1939.
Physical and chemical properties of calcium chloride and general methods of use in construction.

134. "Good Surfaces from Cheap Local Gravel." Paul E. Glasgow. Better Roads, Vol. 9, No. 11, 1939.
Utilization of cheap local gravel in calcium chloride stabilization.

135. "Stabilized Gravel Roads in Muscatine County, Iowa." F. P. G. Halbfass. Public Works, Vol. 70, No. 11, 1939.
Description of construction.

136. "Studies of Water-Retentive Chemicals as Admixtures with Nonplastic Road Building Materials." E. A. Willis and C. A. Carpenter. Public Roads, Vol. 20, No. 9, 1939.
Article on use of outdoor circular track to determine the effect of chemicals including calcium chloride on non-plastic granular mixtures both with and without a thin bituminous surface treatment.

137. "Field Tests on Shearing Resistance." F. Burggraf. Proc. Highway Research Board, Vol. 19, 1939.
Tests with field shearing apparatus correlated with tests on calcium chloride stabilized road.

138. "Economics of Stabilization with Calcium Chloride." "Symposium". Contributors: W. F. Abercrombie, A. L. Brown, F. L. Brown, H. F. Clemmer, G. Farnsworth, P. Glasgow, J. E. Moreland, and R. M. Whitton. Proc. Highway Research Board, Vol. 19, 1939.
Symposium on subject of title.

139. "Use of Calcium Chloride in Road Stabilization." John H. Elleman. Proc. Am. Road Builders Assoc., 1939.
General article of review nature on use of calcium chloride in stabilization.

140. "Soil Stabilization." Victor J. Brown and others. Gillette Publishing Co., 1939.
Reprinted from six 1938 issues of Roads and Streets. General principles of stabilization.

141. "Fundamentals of Road and Subgrade Stabilization." W. R. Woolley. Twenty-sixth Ann. Road School, Purdue University, 1940.
Title explanatory.

142. "Stabilized Base for County Roads." Paul E. Glasgow. Contractors and Engineers Monthly, Vol. 37, No. 1, 1940.
Procedure described in converting traffic bound surfaces or more heavily traveled roads into low cost, more stable surfaces in Wayne county, Ohio.

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X 143. "A Survey of the Frost-Heaving Problem." J. O. Osterberg. Civil Engineering, Vol. 10, No. 2, 1940.
Review on mechanics of frost heaving.

144. "Gravel Bases for Bituminous Surface." J. G. Schaub. Twenty-sixth Ann. Highway Conference, University of Michigan, 1940.
Michigan adopted practice of placing bituminous surface treatment on newly laid gravel bases or reconstructed old gravel roads. Procedures presented in construction of calcium chloride stabilized bases.

145. "Soil Stabilization." C. A. Hogentogler. Twenty-sixth Ann. Highway Conference, University of Michigan, 1940.
General discussion on volume changes in soils with moisture.

146. "Evolution of Low-Cost Roads." W. H. Root. Better Roads, Vol. 10, No. 6, 1940.
Procedure in stabilizing loose gravel surfaces.

147. "Chemical Treatment of Chert-Gravels for Use in Base-Course Construction." E. A. Willis and P. C. Smith. Public Roads, Vol. 21, No. 4, 1940.
The use of admixtures to chert gravels for base course construction tested by means of a laboratory circular track.

148. "Frost Damage on Roads." H. H. Ravn. (Denmark). Highway Research Abstracts, No. 71, 1940. Highway Research Board.
Types of frost damage described and methods of prevention presented.

149. "Effect of the Chemical Properties of Soil Fines on the Performance of Soil-Aggregate Mixtures." Paul Rapp and Jacob Mizroch. Public Roads, Vol. 21, No. 10, 1940.
Data presented showing the relationship of chemical properties to physical properties and the behavior of roads.

150. "Calcium Chloride Surface Consolidated Roads." J. H. Elleman. Proc. Highway Research Board, Vol. 20, 1940.
Description of construction and maintenance of calcium chloride stabilized roads.

151. "Field Tests and Their Application to the Design of Stabilized Soil Roads." F. Burggraf. Proc. Am. Road Builders Assoc., 1940.
Describes apparatus designed to test resistance to shear of components making up a road structure. Results of tests given.

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Complete article on use of plant mix materials in Michigan.

153. "Plant Mix Stabilized Aggregate for the Michigan Secondary Road System." F. R. Olmstead. Better Roads, Vol. 10, No. 1, Jan. 1940.
Reviews the methods used to assure the uniform production of stabilized materials.

154. "Road Base Construction of Graded Aggregate in Wisconsin." A. Smith, Jr. Dowflakes, Vol. 2, No. 6, 1941.
General account of work in Wisconsin.

155. "Calcium Chloride for Base Stabilization." George Hemmerick. Canadian Engineer, Vol. 79, No. 3, 1941.
Brief review of general practice.

156. "Developments in the Construction Field." C. M. Hathaway. Twenty-eighth Ann. Conference on Highway Engineering, University of Illinois, 1941.
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157. "A Rational Approach to the Secondary Road Problem." E. H. Nunn. Crushed Stone Journal, Vol. 16, No. 3, 1941.
Procedure based on soil tests, conditions of temperature, humidity, and traffic.

158. "Stearns County Experiments with Calcium Chloride Stabilization." John S. Schmitt. Public Works, Vol. 72, No. 6, 1941.
General account of practice.

159. "Soil Control in Consolidated Maintenance." B. R. Downey. Proc. Highway Research Board, Vol. 21, 1941.
Detailed procedures presented of actual construction and maintenance of this type of road. Stress laid on systematic organization.

160. "Surface Stabilization in DeKalb County, Indiana." W. T. Van Auken. Proc. Twenty-seventh Ann. Road School, Purdue University, 1941.
General account of treatment.

161. "A Field Investigation of Low-Cost Stabilized Roads." D. J. Belcher. Engineering Bulletin of Purdue University, Research Series, No. 81, Vol. 25, No. 2a, 1941.
Field tests supported by laboratory experiments involving use of several types of admixtures. Methods of construction presented.

162. "Gravel Road Stabilization with Calcium Chloride." L. B. Griffin. Proc. Twenty-eighth Ann. Road School, Purdue University, 1942.
Method of construction in Johnson county, Indiana.

163. "What Has the Frost Damage of Last Year Taught Us?." L. Casagrande (Germany). Highway Research Abstracts, No. 86, 1942. Highway Research Board.
Title explanatory.

164. "Modernization in Minnesota: Consolidation of Gravel Surfaces in Stearns County." H. V. Pehrson. Better Roads, Vol. 12, No. 4, 1942.
High maintenance costs of gravel roads lead to surface consolidation with calcium chloride.

165. "The Technique of Road Stabilization." H. Miller. Dowflakes, Vol. 4, No. 4, 1942.
Presents chart to determine quantity of clay required to give a certain Plastic Index when combined with a given aggregate.

166. "Subgrade Protection and Winter Paving on Access Roads." E. H. Nunn. Calcium Chloride Assoc. News, Vol. 8, No. 4, 1942.
Calcium chloride prevents freezing of subgrade, thaws frozen earth and protects concrete in Maryland. This facilitated construction when faced with problem of cold weather concreting and protection of subgrade from freezing between time grade was prepared and placing of concrete.

167. "Stabilization Today is Basis for Future Roads." H. Miller, P. Caslin, and K. Goetz. Dowflakes, Vol. 4, No. 5, 1942.
General report on method of construction in St. Clair county, Michigan.

168. "Stabilized Bases Mixed at Pit." M. E. Amstutz. Better Roads, Vol. 12, No. 9, 1942.
Binder soil added to gravel at pit before going to crusher. Method of construction given.

169. "Preventing Detrimental Frost Heaving." Pennsylvania Road Builder, ~~Check~~ Vol. 15, No. 9, 1942.
Calcium chloride affords protection under tests at temperatures down to 10 degrees below zero.

170. "Inexpensive Treatment for Frost Boils Helps Prevent Costly Pavement Repairs." Engineering and Contractors Record, Vol. 55, No. 42, 1942. Check
Method of using calcium chloride in treatment of asphalt heaves and boils.

171. "Calcium Chloride Nomographs." D. S. Davis. Industrial and Engineering Chemistry, Industrial Edition, Vol. 34, No. 1, 1942.
Nomographs presented for calculation of properties of calcium chloride solutions by hydrometric methods of analysis.

172. "Use of Calcium Chloride in Subgrade Soils for Frost Prevention." F. O. Slate. Proc. Highway Research Board, Vol. 22, 1942.
Studies of migration of calcium chloride solution through subgrade of test road. Effect of additions of calcium chloride on freezing of laboratory specimens.

173. "Thawing Frozen Subgrades." B. P. Thomas. Calcium Chloride Assoc. News, Vol. 9, No. 1, 1943. ~~Check~~
Application of calcium chloride, from two to six lb. per sq. yd. will definitely thaw subgrades and base course materials so work can proceed.

174. "Stabilized Crushed Rock Surfaces." J. E. Herzog. Better Roads, Vol. 13, No. 2, 1943.
Method of construction and costs presented for using crushed limestone aggregate treated with calcium chloride; Steele county, Minnesota.

175. "Frost Heaving in Soils and Modern Road Construction." A. Schmid. Highway Research Abstracts, No. 99, 1943. Highway Research Board. X
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177. "The Rate of Freezing in Soil and Its Dependence on the Thickness of the Snow Layer." H. Geslin (France). Highway Research Abstracts, No. 99, 1943. Highway Research Board.
Observations showed that a snow layer or blanket of 6.24 inches was necessary to completely prevent freezing of underlying soil.

178. "Stabilized Soil-Bound Surfaces with Calcium Chloride as an Admixture." G. C. Blomquist. Michigan State College Engineering Experiment Station, Project No. 71, Bulletin No. 97, 1943.
Circular track tests used to investigate materials both treated and untreated with calcium chloride.

179. "Michigan's Practice in Gravel Stabilization." B. R. Downey. Roads and Streets, Vol. 86, No. 6, 1943.
Title explanatory.

180. "A Stitch in Time." H. Miller. Dowflakes, Vol. 5, No. 4, 1943.
General information on construction and surface consolidation.

181. "Maintenance is Negligible on Surface-Consolidated Roads." J. S. Schmitt. Calcium Chloride Assoc. News, Vol. 9, No. 4, 1943.
Stearns county, Minnesota reports on maintenance.

182. "Minnesota County Reduces Maintenance Costs." A. F. Stegner. Calcium Chloride Assoc. News, Vol. 9, No. 4, 1943.
Fillmore county consolidates limestone surfaces with calcium chloride and gets more durable roads, also reducing maintenance blading by 75 per cent.

183. "Stabilized Base Gives Surprising Durability to Low-Cost Surface." Calcium Chloride Assoc. News, Vol. 9, No. 4, 1943.
Success of a tar and asphalt emulsion coating on a calcium chloride stabilized base attributed to the stability of the base.

184. "Determining the Proportion of a Well-Graded Road Gravel." J. Shaw. Road and Road Construction (England), Vol. 21, No. 249, 1943.
Title explanatory.

185. "Movement of Calcium Chloride and Sodium Chloride in Soil." Charles Slesser. Proc. Highway Research Board, Vol. 23, 1943.
Experimental data presented on the migration of chemicals in soil and the reduction of frost heave by the use of chemicals.

186. "Granular Stabilized Roads." Wartime Road Problems No. 5, Highway Research Board, 1943.
A "short course" on granular stabilized roads.

187. "Factors Related to the Design of Stabilized Mixtures." F. R. Olmstead. Journal of Asphalt Technology, Vol. 2, No. 4, Aug. 1943.
Contains numerous shortcuts in the practical design of stabilized mixtures and stresses importance of material inventory, soil survey maps and aerial photography.

188. "Laboratory Tests on the Effect of Stone Content on the Compaction of Soil Mortar." L. Maddison. Roads and Road Construction, Vol. 22, No. 254, 1944. (England).
Tests indicate that course material impedes compaction of soil mortar.

189. "Calcium Chloride Treated Roads Guard Against Spring Break-Up." Calcium Chloride Assoc. News, Vol. 10, No. 3, 1944.
Calcium chloride treated roads less than one tenth as susceptible to spring breakup as untreated roads.

190. "Stabilization and Maintenance of Roads for Heavy Armored Traffic." Major Ben H. Petty. Proc. Highway Research Board, Vol. 24, 1944.
Describes the successful use of calcium chloride with large sized crushed stone to provide surfaces to withstand tank traffic.

191. "Granular Stabilized Base Construction of Access and Relocation Roads by Tennessee Valley Authority." F. W. Webster and F. H. Kellogg. Proc. Highway Research Board, Vol. 24, 1944.
Method of quick construction allowing heavy traffic in short period of time.

192. "An Example of Gravel Base Construction in Maryland Under Heavy Traffic Conditions." J. E. Wood. Proc. Highway Research Board, Vol. 24, 1944.
Reviews construction procedure on a bank-run gravel stabilized access road.

193. "Mechanics of Calcium Chloride Treatments." J. F. Tribble. Proc. Highway Research Board, Vol. 24, 1944.
Describes the function of calcium chloride in the solution of the troublesome problem caused by the heavy rolling of the bottom layers of base courses containing too little moisture for adequate compaction.

194. "Compaction of Subgrades and Embankments." Wartime Road Problems No. 11, Highway Research Board, 1945.
A "short course" on soil compaction.

Table 6
SOIL TEST CONSTANTS, SOIL CONDITION, TRAFFIC AND PUMPING
(Soils Data from Samples from Detail Study Sections)

									Mechanical Analysis					Soil Condition				24 Hour Traffic						Pumping Joints and Cracks (Per Cent)							
														Soil Water Content (%) At Depths Shown						Truck Axle Loads in Kips (Cumulative)				From Reconnaissance Survey for Project				From Test Sections Only			
Project No.	Soil No.	L.L.	P.L.	P.I.	F.M.E.	C.M.E.	S.L.	P.R.A. Soil Group	Gravel and Sand	Silt	Clay	Colloids	Textural Soil Type	0-1"	2"-4"	5"-8"	Range of Density (p.c.f.)	Total No. Vehicles	Total No. Trucks	Over 12	Over 14	Over 16	Over 18	Class 1	Class 2	Class 3	Total	Class 1	Class 2	Class 3	Total
239BS	1*	37	16	21	21	35	14	A-6	14	56	30	12	SiC	21	21	21	104-106	1625	377	217	154	63	12	5.6	1.5	0.2	7.3	28	-	-	28
239I(2)	3	64	22	42	35	31	15	A-6-7	35	26	39	24	C	-	-	-	-	1017	236	137	97	40	8	Severe Pumping (No Count Made)							
239C	4	46	19	27	30	27	14	A-6	30	36	34	19	C	34	24	31	100-104	6115	1419	818	580	238	47	16.6	6.9	-	23.5	4	46	17	63
220AS	13	52	22	30	29	27	21	A-7-6	29	24	47	33	C	-	-	-	-	2620	524	256	136	90	27	Severe Pumping (No Count Made)							
36DS	10*	46	23	23	35	30	20	A-7	9	60	31	6	SiC	26	25	26	96	3740	748	367	196	130	40	21.0	7.6	1.6	30.2	28	30	-	58
56A(2) (3)	5*	58	25	33	41	34	15	A-7	27	26	47	29	SiC	27	27	39	85-86	6575	1525	878	622	255	50	24.5	2.8	0.1	27.4	30	54	-	84
"	(0-5") 14*	37	17	20	34	31	15	A-6	52	30	18	9	SL	22	18	-	(107-115	"	"	"	"	"	"	"	"	"	"	20	39	-	59
"	(5"-10") 14	49	23	26	28	25	14	A-7	25	40	35	20	C	-	-	30	(	"	"	"	"	"	"	"	"	"	"	"	"		"
240A	18	29	16	13	22	21	14	A-4	43	32	25	9	Cl	-	-		-	2185	507	292	207	85	17	4.7	1.7	6.3	12.7	-	-	4	4
"	19	28	17	11	24	21	15	A-4	29	40	31	10	C	-	19	20		"	"	"	"	"	"	"	"	"	"	7	-	-	7
58AS	26*	64	30	34	38	35	19	A-7	13	28	59	39	C	24	29	28	95-98	4610	844	437	318	159	30	3.5	3.3	0.3	7.1	94	-	-	94
339CS	27*	65	27	38	39	35	15	A-7	27	31	42	25	C	38	38	29	85-94	3030	554	287	209	104	20	6.4	2.2	0.6	9.2	15	30	6	51
231CS	28	76	30	46	45	39	23	A-7	24	13	63	48	C	32	31	34	91-92	1415	259	134	98	49	9	2.4	0.2	0.0	2.7(5)	17	57	9	83
"	29*	64	24	40	43	34	19	A-7	20	18	62	41	C	20	27	30	89-94	"	"	"	"	"	"	"	"	"	"	46	-	-	46
324AS	30*	58	27	31	38	34	17	A-7	15	30	55	27	C	30	33	34	90-93	970	203	94	47	19	12	Severe Pumping (No Count Made)				45	32	13	90
"	31*	59	28	31	47	34	17	A-7	18	21	61	45	C	21	27	-	89	"	"	"	"	"	"	"	"	"	"	47	3	-	50
313AS	32	60	35	25	47	36	21	A-7	23	18	59	47	C	-	-	-	-	1825	334	173	126	63	12	27.2	16.7	8.3	52.2	No Count Made			
41AB (Reop.)	33	69	48	21	56	40	23	A-7-5	22	12	66	53	C	-	-	-	-	3310	606	314	229	115	22	38.0	0.2	-	38.2	No Count Made			
244BS	6c	48	23	25	30	29	20	A-7	8	40	52	32	C	-	-	-	-	1100	230	106	53	22	14	Severe Pumping in Some Areas (No Count)				40	20	10	70(1)
R-8-A(3)	11c	40	21	19	29	27	20	A-7	11	65	24	10	SiCl	-	-	-	-	4250	1024	140	76	36	7	Moderate Pumping (2) (No Count Made)							
147CS -DS	156	42	24	18	33	26	20	A-7	10	56	34	19	SiC	-	-	-	-	2820	680	92	49	23	4	Slight Pumping (3) (No Count Made)							
60AS	23	83	38	45	55	44	22	A-7	18	11	71	57	C	41	39	40	-	1110	203	104	76	38	7	9.6	6.2	1.9	17.7	32	32	-	64
Average All Soils		53	25	28	36	32	18		23	32	45	28		28	28	30	94-97	2842	604	285	193	90	19								
239I(2)	2	56	20	36	37	30	15	A-6-7	25	35	40	24	C	23	26	26	103-108	1017	236	135	97	40	8				None				
121BS	12*	30	20	10	26	21	20	A-4	15	63	22	10	SiCl	18	20	20	106-110	2475	495	242	129	86	26				"				
220AS	7*	46	25	21	39	29	19	A-7	8	50	42	24	SiC	24	28	31	90-95	2620	524	256	136	90	27				"				
51AS & Ext.	8*	38	13	25	21	18	13	A-6	58	19	23	20	SCl	17	18	16	111-114	1200	240	117	62	41	12				"				
36DS	9*	45	22	23	32	29	19	A-7	11	61	28	12	SiCl	23	26	27	93-96	3740	748	367	196	130	40				"				
51CS	11*	39	19	20	28	24	17	A-7-6	22	53	25	10	SiCl	21	24	22	101-108	950	190	93	50	33	10				"				
56A(2) (3)	6	35	19	16	28	21	21	A-7-6	72	15	13	7	Sl	21	21	23	104-107	6575	1525	878	622	255	50				"				
"	(0-6") 15	47	21	26	34	29	18	A-7-2	62	17	21	13	SCL	22	18	-	109	"	"	"	"	"	"				"				
"	(6"-11") 15	64	34	30	50	40	22	A-7	34	17	49	41	C	-	-	43	97	"	"	"	"	"	"				"				
486A (2)	(0-4") 17	17	12	5	16	14	12	A-1-2	73	16	11	4	Sl	11	11		(109	1920	445	256	182	75	15				"				
"	(4"-11") 17	29	18	11	23	24	18	A-4	21	47	32	17	C	-	-	19	(	"	"	"	"	"	"				"				
240A	20	34	18	16	28	16	18	A-7-2	58	16	26	16	SCL	16		-	-	2185	507	292	207	85	17				"				
269B	22(07)	35	16	19	24	22	14	A-6	61	14	25	15	Gr.SCL	-	-	-	-	2975	690	398	282	116	23				"				
"	22(47)	39	17	22	27	24	14	A-6	57	13	30	18	Gr. SC	-	-	-	-	"	"	"	"	"	"				"				
	22(87)	32	15	17	22	22	13	A-2-6	66	14	20	11	Gr. SCL	-	-	-	-	"	"	"	"	"	"				"				
78BS	24	52	21	31	33	31	17	A-6-7	67	10	23	15	Gr. SCL	-	-	-	-	2870	525	272	198	99	19				"				
78AS	25	33	20	13	25	25	15	A-2	80	10	10	6	Sl	-	-	-	-	2880	527	274	200	100	19				"				
371C	34	20	13	7	18	13	14	A-2	67	13	20	12	SCL	-	-	-	-	1100	220(4)	108	58	38	12				"				
280F	35		NP	NP	27	5	-	A-3	90	1	9	5	S	15	15	15	-	550	110	54	29	19	6				"				
"	36	31	18	13	26	19	17	A-2	88	5	7	4	Gr.S	-	-	-	-	"	"	"	"	"	"				"				
"	37	37	19	18	26	22	18	A-7	18	52	30	14	SiC	18	18	18		"	"	"	"	"	"				"				
21(Reop.)	38*	-	NP	NP	25	5	-	A-3	92	2	6	4	S	9	9	9	95-97	2230	446	218	116	77	23				"				
"	39	36	16	20	24	23	15	A-6-7	34	38	28	13	Cl	-	-	-	-	"	"	"	"	"	"				"				
244A	1-6	28	16	12	22	20	16	A-2-4	45	28	27	14	Cl	-	-	-	-	1425	298	137	68	28	18				"				
"	1-C	33	19	14	27	19	19	A-2-7	52	19	29	19	SCL	-	-	-	-	"	"	"	"	"	"				"				
"	2-6	25	15	10	21	18	14	A-2	54	19	27	14	SCL	-	-	-	-	"	"	"	"	"	"				"				
"	3-6	23	14	9	19	15	13	A-2	54	21	25	13	SCL	-	-	-	-	"	"	"	"	"	"				"				
"	4-6	20	13	7	17	15	13	A-2	58	21	21	8	SCL	-	-	-	-	"	"	"	"	"	"				"				
"	8-6	35	21	14	32	21	15	A-2-4	49	15	36	27	C	-	-	-	-	"	"	"	"	"	"				"				
244B	5-6	28	16	12	22	17	14	A-2-7	49	22	29	16	CL	-	-	-	-	1100	230	106	53	22	14				"				
"	7-C	33	20	13	27	24	19	A-4	30	40	30	14	Cl	-	-	-	-	"	"	"	"	"	"				"				
R-8-A (4)	10-C	36	21	15	28	25	22	A-4	10	67	23	10	SiCl	-	-	-	-	5740	1383	189	102	48	9				"				
31CS	12-6	32	21	11	27	19	22	A-4	25	61	14	7	SiL	-	-	-	-	1730	417	57	31	15	3				"				
39AS	13-C	40	22	18	32	25	20	A-7	10	61	29	16	SiCl	-	-	-	-	1660	400	54	29	14	3				"				
147CS -DS	14-C	35	18	17	24	22	18	A-7-4	19	61	20	8	SiCl	-	-	-	-	2820	680	92	49	23	4				"				
Av. (All Soils)		34	18	16	27	21	17		47	29	24	14		19	20	23	102-105	2370	516	219	138	68	17								
Av. C, SiC, SiCl & Cl		37	19	18	30	25	18		25	46	29	15		21	24	24	-	2397	530	165	91	54	15								
Av. for Soils with 50% S & Gr.		30	15	15	24	18	15		67	14	19	11		17	16	20	-	2355	502	273	184	85	19								

(1) 70% of joints and cracks in 2500 ft. sections pumped. Distribution estimated. (2) Pumping over small area at low point in grade where shoulders were high.
(3) Slight pumping at corner break in short cut sections. (4) Truck traffic and distribution estimated. (5) Reconnaissance count for combined projects 231 GF and C.
*Tested for consolidation.

TABLE 2. WARTIME HAULING FROM PERTH AMBOY TO COLTS NECK

Tabulation showing the present condition of pavement (Oct 1944) and types of soils and subbases in various areas over which heavy wartime hauling was done, during the period Dec, 1943 to Aug 1944. The unladen weights of the trucks used were 21500# (2 axles), 24650# (2 axles); 29850# (3 axles). The average weight of loaded trucks was approximately 60000#. The estimated number of loaded trucks (60000#) passing over this pavement per day, during this period was 212. This was in addition to a normal daily traffic of 300 trucks.

New Jersey Route	Year Laid	Concrete Thickness	Joint Type	Subbase Thickness	Location Miles	Pavement Condition				Sample Nº	Sieve Analysis - % Passing										Hydro. Analysis - % Smaller			S.G.	L L	P I	Shrinkage		F.M.E.	Comments (Unless otherwise noted, samples are of native soil from immediately under the pavement)
						General	Pumping	Faulting	Cracks		2"	1½"	1"	¾"	⅜"	#4	#10	#40	#60	#200	.05 mm	.005 mm	.001 mm				Limit	Ratio		
4&35	1936	9"	Channel Dowel	No Subbase	2 73	Excellent	No	No	No	25							100	97	44	1	0 8	0.4	0 1	270	N P	N P	—	—	28	Pavement immediately adjacent to some joints cracked due to excessive sliding resistance of dowels - No cracks due to loads
4 & 35	"	"	"	"	3 18	"	"	"	"	26				100	94	86	70	29	22	10	3 0	2 0	1.0	268	N P	N P	28	1.40	30	" " " " " " " " " " " "
4	1941	"	"	See Comment	4 00	"	"	"	"	27		100	98	95	81	73	63	41	21	13	12	6	3	275	20	0	19	176	17	Sample of subbase material
4	"	"	"	" "	4.00	"	"	"	"	28			100	97	94	92	88	67	49	35	32	11	4	271	21	1	22	1.67	21	Sample of 9" layer of native soil immediately below subbase
4	"	"	"	" "	4.00	"	"	"	"	29				100	99	98	97	76	29	16	15	6	2	2.70	N P	N.P	16	173	19	Sample of soil underlying the 9" layer shown above, extending to at least 4' below the pavement surface
4 Alternate	1928	"	¾" ϕ(6)	No Subbase	7 27	Rebuilt	Severe	Severe	Severe	1							100	99	99	96	88	37	17	275	36	9	23	157	25	
"	"	"	"	" "	7 47	Poor	"	¼" ±	Many	4					100	99	99	97	79	32	28	8	4	270	16	N.P	17	176	17	Pavement maintained in serviceable condition by mudjacking
	"	"	"	" "	7 84	Fair	Probable	¼" ±	Few	5					100	99	99	98	76	12	9	2	2	271	NP	NP	—	—	25	Pavement not seriously cracked.
"	"	"	"	" "	8.15	"	"	⅛"-¼"	"	6							100	98	66	7	6	3	2	271	N P	N P	18	157	26	" " " "
"	"	"	"	" "	8.60	Poor	Severe	Severe	Many	7							100	98	88	64	55	13	5	273	26	5	17	1.71	20	Short stretches reconstructed, remainder maintained passable by mudjacking: localized settlements due to pumping
"	"	"	"	" "	9 12	Rebuilt	Severe	Severe	Severe	352399							100	99	99	87	72	20	5		37	7	31	1 41	33	" " " " " " " " " " "
"	"	"	"	" "	9 15	"	"	"	"	8		100	96	92	83	79	75	69	65	54	48	18	9	277	30	9	17	175	22	" " " " " " " " " " "
"	"	"	"	" "	9 38	"	"	"	"	3		100	98	96	92	89	81	77	69	53	47	21	10	275	27	9	15	183	21	" " " " " " " " " " "
"	"	"	"	" "	9 75	"	"	"	"	9			100	98	94	91	88	83	75	61	57	30	16	2.81	40	10	19	168	41	" " " " " " " " " " "
34 Sec 1	1929	"	"	" "	10 89	"	"	"	"	352400							100	99	98	80	73	38	14		41	16	18	1.69	22	Very badly pumping area, soil layer at least 3 thick
" "	"	"	"	" "	11 18	Good	Indefinite	Minor	Few	10	96	96	95	95	93	90	87	80	50	17	16	10	6	274	N P	N P	19	1 65	20	
"	"	"	"	" "	11 66	"	Doubtful	"	Very Few	11				100	99	99	98	94	64	15	13	5	3	273	N P	N P	15	1 69	20	
"	"	"	"	" "	12 26	Rebuilt	Severe	Severe	Severe	12		100	99	99	98	97	95	80	55	29	26	11	3	276	27	2	19	171	21	
"	"	"	"	" "	12 43	Good	Minor, if any	No	Very Few	S-1						100	99	98	62	11										Soil sample from adjacent cut, probably same as immediately under pavement. Sieve analysis is that for subbase
"	"	"	"	" "	12.63	Fair	Indefinite	Minor	Few	13		100	99	98	96	93	92	88	76	30	26	11	4	278	19	N P	19	171	20	
"	"	"	"	" "	13 43	Very Good	No	No	Negligible	14	100	98	97	96	95	95	94	85	37	11	10	6	2	275	N P	N P	16	1.64	22	Road in 20 cut
"	"	"	"	" "	14.02	Fair	Indefinite	Minor	Few	15		100	97	95	89	84	77	73	66	31	20	12	7	282	26	5	18	1.75	22	
"	"	"	"	" "	14 18	Poor	Definite	⅛"-¼"	Many	16						100	99	92	76	52	45	10	1	271	31	4	19	165	28	
"	"	"	"	" "	14 39	Good	Doubtful	Minor	Very Few	17				100	99	98	96	64	38	28	27	12	4	291	31	7	19	174	26	
"	"	"	"	" "	14 81	Fair	Probable	"	Few	18							100	88	43	19	18	10	5	293	27	N P	18	175	25	
34, Sec 2	"	"	"	" "	16 23	Rebuilt	Severe	Severe	Severe	39							100	92	68	13	12	2	0	279	28	N P	26	151	37	Pavement destroyed as a result of pumping.
"	"	"	"	" "	16.24	"	"	"	"	40						100	99	93	68	16	14	6	1	273	29	N P	23	153	34	" " " " "
"	"	"	"	" "	17.43	"	"	"	"	34					100	99	98	94	67	21	20	12	3	2.70	27	N P	18	163	27	Probably fill to replace overcut · this is likely to be the same material as indicated by sample 31
"	"	"	"	" "	17 46	"	"	"	"	31				100	97	95	94	87	60	22	20	10	3	274	21	N P	20	166	18	" " " approximately 6" thick
"	"	"	"	" "	17.46	"	"	"	"	32							100	95	69	16	4	2	0	274	31	6	28	150	28	This layer underlying the fill described immediately above
"	"	"	"	" "	17 50	"	"	"	"	33	96	96	98	98	93	90	87	80	39	7	6	3	2	274	N P	N P	20	154	26	At this location this material underlying the layer of soil indicated by sample 31
	"	"	"	" "	18.65	Excellent	No	No	No	41		100	99	97	93	90	87	80	57	20	18	7	2	275	24	1	15	214	22	
"	"	"	"	" "	18 66	"	"	"	"	354114			100	99	98	96	95	91	75	28	27	15	5	2 80	35	11	17	1.64	28	Sample of 3" layer immediately under pavement, probably fill to replace overcut
"	"	"	"	" "	18.66	"	"	"	"	354113							100	70	31	15	14	6	2	2.81	28	N P	23	1.64	30	Sample of native soil under the material shown immediately above
"	"	"	"	" "	19.03	Poor	Definite	Av ⅜"-Max ¾"	Severe	35		100	98	96	94	91	87	76	52	30	27	11	4	298	26	4	16	176	21	
"	"	"	"	" "	19 06	"	"	Max ⅜"	"	36		100	99	98	96	93	92	76	54	36	31	20	12	2.76	35	13	21	1.86	31	
34, Sec. 3	1930	"	"	" "	21 41	Excellent	No	No	No	420					100	96	84	64	31	10	8	3	1	2.69	N.P	N.P	14	1.65	16	
" "	"	"	"	" "	21 62	Poor	Indefinite	Max ⅛"	Severe	354203				100	99	98	98	88	40	15	14	12	11	274	32	N P	15	1.64	20	This layer 2± thick, damp when sampled
" "	"	"	"	" "	21 62	"	"	"	"	354204					100	99	94	82	70	34	28	10	6	273	19	0	16	177	17	This layer 0.6 ± thick underlying that indicated by sample 354203 · under this a grey, sandy clay

MISCELLANEOUS ROUTES

New Jersey Route	Year Laid	Concrete Thickness	Joint Type	Subbase Thickness	Location	Pavement Condition				Sample Nº	Sieve Analysis - % Passing										Hydro. Analysis % Smaller			SG	LL	PI	Shrinkage		F.M.E.	Average, Total Daily Truck Traffic, both Directions, 1940 Count *	Comments
						General	Pumping	Faulting	Cracks		2"	1½"	1"	¾"	⅜"	#4	#10	#40	#60	#200	.05 mm	.005 mm	.001 mm				Limit	Ratio			
6	1923	8"	¾" ϕ	8"-10" ±		Excellent	No	No	No	354110	95	91	82	75	64	57	49	33	27	18	15	7	1	279	22	3	13	181	17	558	Subbase sample immediately under pavement
6	1923	8"	"	" "		Fair	Indefinite	5/16"	Very Few	354111	100	96	92	89	82	76	67	46	36	20	16	4	1	275	19	NP	13	180	17	558	Subbase from joint that had faulted 5/16"
29	1929	9"	"	No Subbase	Joint 1164	Very Poor	Severe	Severe	Severe	354381					100	99	88	60	52	42	39	20	8	290	29	2	11	197	19	1997	Sample from immediately under pavement
25	1936	9"	Channel Dowel	" "	" 393	Poor	Definite	No	Frequent	354253				100	99	97	95	80	74	67	63	39	21	278	48	20	24	140	24	2096	" " " "
25	1936	9"	"	" "	" 424	"	"	"	"	354254				100	99	99	97	92	85	43	38	19	13	270	48	14	22	1.66	34	2096	" " " " "
26	1932	9"	¾" ϕ	See Comment	" 904	Very Poor	See Comment	Severe	Severe	354234							100	93	90	52	45	19	10	274	22	0	14	178	18	2341	Sample of subgrade under 9" of 2½" crushed stone
26	1932	9"	"	No Subbase	" 357	Good	Doubtful	Very Slight	No	354235					100	99	99	89	26	4	3	2	1	273	NP	NP	-	-	-	2341	Sample from immediately under pavement

* Truck traffic on pavements tabulated is approximately ½ the total shown.