USE OF SODIUM CHLORIDE IN ROAD STABILIZATION

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Subcommittee on Treatment of Roads with Sodium Chloride (1936),
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TOPICAL INDEX

THEORY

Report of Subcommittee on Treatment of Roads with Sodium Chloride (1936): The effects of sodium chloride on soil mixtures for road surfaces arise from properties it imparts to properly proportioned soil mixtures through water retention, crystallization, increase in surface tension and physical-chemical changes in the clay component.

Because sodium chloride solutions have a lower vapor pressure than water, the evaporation of moisture from soil mixtures wetted with sodium chloride solution is slower than from similar mixtures moistened with water. Sodium chloride in a stabilized mixture therefore acts to conserve its water content.

The extent of this conservation is most apparent during compaction of the stabilized mat with which sodium chloride solution has been mixed. The plasticity of the clay component is maintained over a longer time, which prolongs the period during which compaction is taking place. This permits compression of the aggregate into a denser mass with thinner, and consequently stronger and more lasting binding films than would otherwise be secured.

As the partially dried road continues to lose water, the sodium chloride solution in the surface becomes concentrated to the saturation point and deposits fine crystals, forming a dense hard crust of salt and aggregate which appreciably retards further evaporation.

Crystallization of sodium chloride within the pores of the compacted mass as evaporation slowly proceeds contributes to its strength and stability. This filling of the voids minimizes the contraction which commonly accompanies loss of moisture, and thus reduces shrinkage cracking. The importance of diminution of shrinkage in this way will be realized when it is considered that any shrinkage of the clay bond causes it either to crack or to pull away from the coarse aggregate which allows the latter to become dislodged and "raveled" under traffic.

Dry weights of up to 152 lb. per cu. ft. of compacted wearing course material from projects which have come to the attention of this committee bear witness to the high degree of compaction which the proper use of sodium chloride makes possible.

Sodium chloride has the property of changing the electric fields around colloidal clay particles to produce flocculation so that the treated clay becomes more cohesive and the soil mixtures become more dense under traffic and less permeable than the untreated mixtures. When water falls upon such a road surface salt dissolves and the brine sinks below the surface. When the clay near the surface is freed of most of its salt following prolonged rainfall, it swells slightly and tends to deflocculate. This expanded clay and finely divided or colloidal material stop up the pores and tend to prevent further percolation of water downward from the surface, thus forcing excess water to drain from the road. This action, together with maintained compaction beneath the surface, greatly retards the leaching of sodium chloride from the stabilized wearing course, thus preventing further deflocculation.

Flocculation of clay and recrystallization of salt again take place in a salt-treated road as drying occurs and the salt brine creeps to the surface by capillary action.

The mechanism of the phenomena of sodium clay flocculated by sodium chloride is explained by E. M. Taylor[1] who says "On replacing the sodium chloride solution with pure water, it will be seen that the rate of percolation rapidly decreases, the percolate contains deflocculated clay in suspension, the percolate becomes alkaline and finally the sodium clay becomes impermeable."

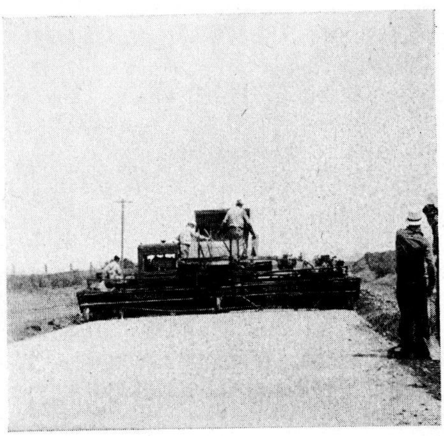


Figure 1. One Method Used in Laying Sodium Chloride Stabilization in Indiana

The fact that sodium chloride depresses the freezing point of water is of interest. The presence of sodium chloride in a stabilized road might minimize surface damage through frost heaving.

The need for the proper amount of water in road stabilization can not be over emphasized. Material will not stabilize until it has been moistened somewhat beyond the plastic limit, compacted and partially dried. Like portland cement concrete it is necessary for the mix to be made workable. After the curing period, stabilized soil becomes hard and is able to withstand traffic loads. By using enough water to make the mix plastic, the road can be compacted thoroughly during the time of construction. While in this condition the aggregate will adjust itself under a roller into the smallest possible space.

It is believed that the high densities of road surfaces treated with sodium chloride are not due entirely to the moisture retaining properties of the mixture but in part to electrolytic action and increase of surface tension which reduce the thickness of moisture films, thus creating greater cohesion. Some benefits, therefore, may be derived from having all of the salt dissolved in water before compaction is completed after salt is placed upon the prepared mixed aggregate and soil binder.

In a recent report on the development of salt-stabilized roads, the salt-soil aggregate wearing courses were reported as compacted most easily to a dense hard surface when the total moisture content was about 15 to 20 per cent of the soil fines. When the recommended quantity of undissolved salt is used, this amount of water is more than sufficient to dissolve all of the salt before final compaction is attained. In Indiana, it was found that from $\frac{3}{4}$ to $1\frac{1}{4}$ gal. of water per sq. yd. per in. of thickness were needed to moisten satisfactorily the stabilized mix. This is slightly more than 20 per cent of the soil fines. In some cases, construction of stabilized roads was planned so that finishing operations took place when the clay and aggregate contained the proper amount of moisture due to rainfall. There is some risk involved in this practice, especially on a subgrade which is lacking in aggregate. Unless the stabilized course is wet to the proper amount and compacted, there is danger that it will

[1] *Journal*, Institution of Petroleum Technologists, Vol. 14, p. 825 (1928) and Vol. 16, p. 681 (1930).

become soft when exposed to rain. If it is subjected to traffic when in this condition there is possibility of vehicles cutting through the entire course and mixing the subgrade into the mixed material. If on the other hand, the proper amount of water is used at the time of construction, rains will penetrate the newly-laid course only a fraction of an inch.

Looker: Because crushed stone is angular in shape, a well graded mixture furnishes desirable interlocking of pieces which gives greater stability. Because of the rough edges and sides of crushed

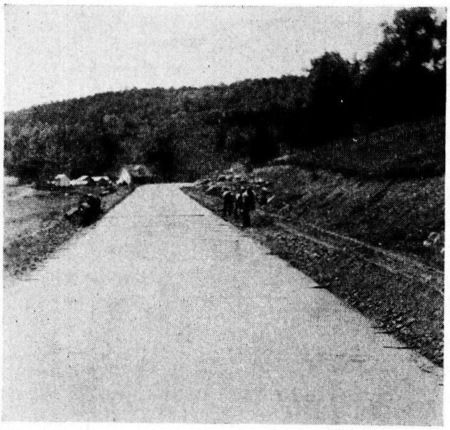


Figure 2. A Completed Section of Sodium Chloride Stabilization Using Limestone. This material was laid in one course.

stone pieces, there is greater internal friction than when smooth aggregate is used. This causes greater resistance to displacement. The natural cementing power of stone dust, especially limestone dust, is enhanced by the use of salt.

The soil stabilization pamphlet illustrating the exhibit of the Bureau of Public Roads at the Convention of the American Road Builders' Association, Cleveland, Ohio, January, 1938, stresses the formation of a gelatinous cement on the surface of certain aggregate particles such as limestone and slag because of partial solubility when wet. Solutions of sodium chloride increase the solubility of some of these rocks, especially limestone and dolomite and provide more gelatinous cement to bind the particles into a stable mass as drying takes place.

As early as 1892 Lubavin (Jour. Russ. Phys. Chem. Soc. 24, 389) (1892) showed that calcium carbonate is more soluble in sodium chloride solution than in plain water. Bureau of Soils Bulletin No. 49, issued November 2, 1907, gives data which show that approximately a five per cent solution of sodium chloride dissolves more than twice as much calcium carbonate as is soluble in plain water.

When once in solution, limestone will recrystallize during the curing period following construction and after each subsequent period of wetting, thus furnishing added binding power induced by salt. Salt is peculiarly adapted for this use because limestone is less soluble in strong salt solutions than in the five per cent maximum, and limestone crystals form as concentration takes place. Furthermore, salt-treated limestone roads stay moist beneath the surface but dry out sufficiently to permit recrystallization of limestone. The additional compaction obtained by treating with salt and the increased resistance of the salt solution films to evaporation tend to conserve the moisture in the stabilized mat.

There is a strong bond between bituminous material and the firm, hard, dry surface of sodium chloride treated roads. The practice of applying the bitumen immediately after final compaction is becoming more and more general. In the past the custom has been to permit the road to undergo a compacting and seasoning period for at least one year before covering with a more permanent wearing surface. This gives an opportunity to correct any defects in the subbase or stabilized mat itself. Both methods apparently are satisfactory.

By the former method the degree of compaction may not be so great as by the latter but sealing the salt in the sub-base tends to retain it there to lower the freezing point of soil moisture and thus prevent frost-boil difficulties. The resistance of sodium chloride surfaces to freezing difficulties is only partly due to the high content of sodium chloride. This property of sodium chloride roads has been noticed even when the sodium chloride content was greatly reduced or had leached out entirely and has been

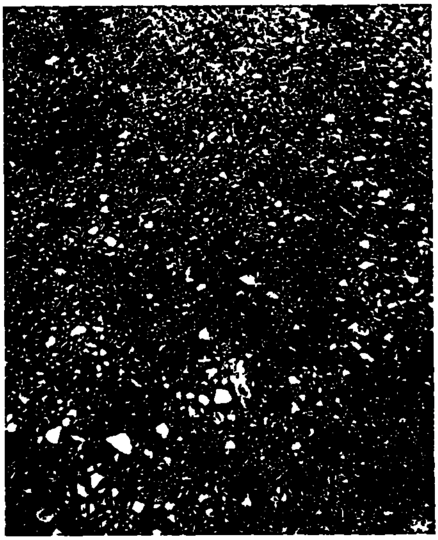


Figure 3. Typical Surface of Salt-treated Stabilized Road

attributed to the maintained compaction and resistance to penetration by enough moisture to cause displacement on freezing.

In connection with the use of sodium chloride to prevent freezing in base courses, it is interesting to note its use in Canada in the sub-base beneath the gravel base course for the definite purpose of preventing frost difficulties. This suggests its possible use in fills for this purpose as well as to secure greater compaction.

No important changes have been made in the gradation requirements for sodium chloride surfaces and base courses since the publication of the Report of the Sub-committee on Treatment with Sodium Chloride, except material passing the two-inch sieve has been permitted in some cases for base courses. For wearing courses, some two-inch material has been used but generally it is preferable to keep the sizes limited to one inch because of simplification of maintenance problems. The plasticity index should best be kept between zero and nine both for wearing surface and base course. This is generally satisfactory for sodium chloride roads.

Summary of the Effects of Sodium Chloride on Stabilized Road Materials

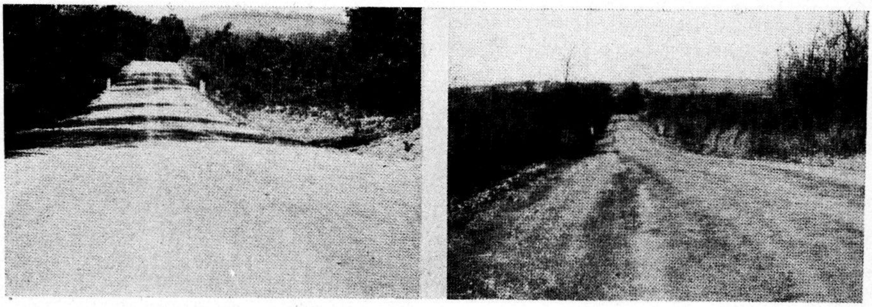
Looker:

1. The presence of increased quantities of sodium chloride at least up to six per cent of the weight of the clay has no appreciable effect on the plasticity index. The presence of sodium chloride causes the clay to take on a sticky texture comparable to increased plasticity at a lower moisture content than unsalted clay.

2. Sodium chloride increases the shrinkage limit of clay generally, that is, the volume or linear shrinkage is decreased. This property is made use of by some brick manufacturers. This is of value in road construction because it indicates less shrinkage of the clay component and less tendency for it to pull away from the aggregate as drying takes place.

3. The percentage of water which a soil will absorb under field conditions is determined by its field moisture equivalent. In a statistical soil this increases as the shrinkage limit decreases. Sodium chloride tends to decrease the field moisture equivalent and increase the shrinkage limit thus bringing these values closer together, which may be regarded as a desirable feature. It acts to reduce the tendency to excessive swelling but does not stop swelling entirely. This is also desirable because it assists in

retarding detrimental moisture absorption within the body of the compacted mat. This, in part, accounts for the strong tendency of compacted stabilized salt treated mats to resist penetration by water and retain their compaction even under adverse moisture conditions. This property makes salt treatment valuable for base course construction as well as for surfaces.



October 1935 December 1937

Figure 4. Crushed Gravel Salt-stabilized Road Built in July 1935, New York. No maintenance was needed until August 1936 when it was surface treated with rock salt

4. Sodium chloride solutions have a lower vapor pressure than water. For this reason soil mixtures wetted with sodium chloride solutions retain moisture better than similar mixtures wetted with water. Sodium chloride in a stabilized mixture, therefore, acts to conserve its moisture content.

5. Sodium chloride solutions will not reabsorb moisture from the air unless the relative humidity is above 75 per cent. Nevertheless, due to moisture retentive properties of sodium chloride solutions, increased and maintained compaction and increase in surface tension, stabilized mixtures treated with sodium chloride retain sufficient film moisture to maintain stability to a marked degree. Clay by itself has moisture-absorbing properties. Mixtures of six per cent sodium chloride and clay exposed to a relative humidity of 55 per cent were shown to have moisture absorbing properties comparable to clays treated with the same percentage of other more moisture-absorptive materials. This accounts in part for the satisfactory condition of sodium chloride treated roads during long, continued dry weather.

6. Well compacted and seasoned mixtures of sodium chloride treated stabilized road materials resist the free passage of excess moisture either up or down in the stabilized mat. This is due in part to the extra compaction produced

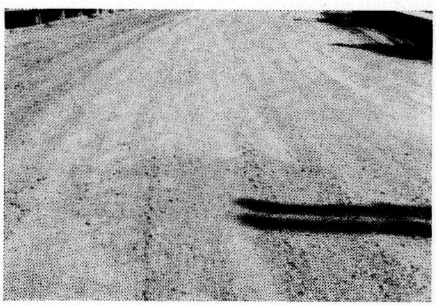


Figure 5. Salt Stabilized Gravel Over Frost Boil in Oil Surfaced Road, Virginia, March 1936.

by the action of sodium chloride in keeping the clay component plastic during the compacting and curing period, thus permitting greater compression of the aggregate into a denser mass with thinner and consequently stronger and more lasting solution films than would otherwise be secured. Furthermore, penetration of moisture is retarded by the swelling of the clay component when the excess of sodium chloride becomes washed from the surface clay thus stopping up the pores, preventing entrance of moisture to the interior. This was shown by the Indiana report in the Highway Research Board Report of the Project Committee on Treatment with Sodium Chloride. A road that averaged 2.6 to 3.8 per cent moisture after extensive drying, only reached 2.6 to 4.1 per cent moisture after a prolonged wet period. This indicates that after compaction water does not penetrate a properly stabilized sodium chloride treated road to any great extent. This has been definitely checked in the laboratory. Sodium chloride treated clay will permit some percolation of water while the sodium chloride content is large, but as percolation continues and the sodium chloride content is reduced, water practically ceases to pass through.

7. During the drying period following construction or prolonged wetting, the sodium chloride solution in the surface becomes concentrated to the point of saturation and fine crystals are deposited within the surface forming a dense hard mat with the stabilized mixture. This hardness is not confined merely to the surface but continues throughout the stabilized layer although it has not been possible to identify sodium chloride crystals within the interior of a stabilized mat even with the aid of a high-powered microscope. It is evident that beneath the surface there is always sufficient moisture to maintain solution films rather than crystal salt.

Spencer: The fundamentals of stabilization are the utilization of the most desirable characteristics of each individual material making up the finished product and the elimination of the undesirable features of each combined material. Engineers have long known that aggregates such as gravel, crushed stone, or slag have high internal friction when properly keyed and confined to prevent their displacement under heavy loads. Because of the large voids and small area of contact, water has little effect on their stability if the base on which they are placed remains firm. As the particle size becomes smaller there is less internal friction in the material and the more unstable it would become unless certain other mechanical forces were developed. As the voids become smaller and the area of contact becomes greater, cohesion begins to play a very important part in their stability. All of these characteristics have long been recognized. In order that these materials might be satisfactorily incorporated in a mixture that would remain stable under all conditions it was evident that some binding agent was necessary which would fill the voids of the granular materials and supply the required additional mechanical force of cohesion. To accomplish this purpose soil was combined with these materials. Since the behavior of the soil under various conditions becomes quite complex while the mechanical features of the coarse and fine aggregates vary but little, the problems for this type of stabilization are predominantly for the soils engineer. Here the various standard soil tests become quite important. It is true that one may select a satisfactory soil binder by visual inspection if he has had some experience and a general knowledge of the particular soil he is dealing with. However, some knowledge of the mechanical and physical analyses is very necessary in order to select a good soil binder and design properly the finished stabilized mixture. Control and performance of the finished mixture can well be governed by field determinations of the mechanical analysis, the liquid limit and the plasticity index.

This type of stabilization is generally proposed as a step in stage construction; therefore, it is very necessary to consider the final role of the proposed soil-aggregate stabilization. If this material is to serve as a base course and is surfaced immediately after construction, very close control of the type of soil binder, the analysis of the finished mixture and its compaction is required. While it is not necessary to have a different aggregate specification for surface and base course stabilization, although it is desirable to keep the coarse aggregate above ¾ of an inch to a minimum in surface courses, it is quite important to differentiate between these two types in the quality and amounts of soil binder used.

For base courses that are to be surfaced immediately, the soil used as binder must be friable. Soils having a plasticity index from 6 to 12 will make a good soil binder for base courses provided all other characteristics are satisfactory.

In any type of soil aggregate stabilization, cohesion is very important. The coarse aggregate furnishes high internal friction and rigidity only when the coarse and fine sand fill the voids and lock it in position. To secure maximum stability there must be just enough silt and clay combined with these materials to help fill the larger voids and furnish a reservoir for the necessary moisture to provide cohesion for binding the mixture together. Since very thin moisture films have tremendous tensile strength it becomes necessary to try to preserve this correct moisture content at all times.

If the proposed stabilized course is to serve as a surface at time of installation but is to be used as a base course eventually, careful consideration should be given to its design and construction. In such a case the mixture should contain a limited amount of soil binder and have a low P.I. However, more chemical will be needed to furnish the necessary cohesion to prevent ravelling while this friable mixture is used as a surface.

The maintenance of the necessary moisture films for cohesion can be accomplished by the use of a satisfactory chemical such as sodium chloride. As water evaporates from the surface of a stabilized mixture to which sodium chloride has been added, salt crystallizes and forms a very dense, hard surface. The crystallization of the salt on the surface tends to close the exposed ends of the small capillary tubes and greatly retards further evaporation, resulting in the moisture being sealed in. After a rain when sufficient water has collected or been absorbed on the surface, the crystallized sodium chloride is dissolved. This newly-formed brine penetrates the stabilized course allowing the small particles of the binder soil in the surface to disperse, which tends to plug the capillary tubes on the surface and prevent more water from entering the mass.

During long, dry periods or in arid climates, a sodium chloride stabilized road when used as a surface may become so hard and crystalline that it will tend to pot rather severely. This type of surface must only be maintained when the moisture content of the surface will permit. A maintainer or a blade will have very little cutting effect on the surface of a properly proportioned and compacted road of this type when it is extremely dry. The crystallization of the salt on the surface makes it extremely hard.

Indications are that sodium chloride has little if any effect on the plasticity of a soil binder. It is the opinion of some that sodium ionization of some soils will improve their stability characteristics.

DESIGN

Allen: The requirements for aggregate for this type of stabilized road are essentially the same as those described in specification M56-38 "Standard Specification for Materials for Stabilized Base Course" and M61-38 "Standard Specification for Stabilized Surface

Course" of the American Association of State Highway Officials. Typical gradation requirements from these specifications are as follows:

Passing	Percentage by Weight Base Course	Percentage by Weight Surface Course
1 inch sieve	100	100
¾ inch sieve	70–100	85–100
⅜ inch sieve	50–80	65–100
No. 4 sieve	35–65	55–85
No. 10 sieve	25–50	40–70
No. 40 sieve	15–30	25–45
No. 200 sieve	5–15	10–25

The fraction passing the No. 200 sieve should be less than one half of the fraction passing the No. 40 sieve for base course materials and less than two-thirds for those used in surface course construction.

The liquid limits and plasticity indices of the fractions passing the No. 40 sieve should conform to the following requirements:

Type	Liquid Limit	Plasticity Index
Base course	25 Max.	0–6
Surface course	35 Max.	4–9

Report of Subcommittee on Treatment of Roads with Sodium Chloride (1936): The design essentials of stabilized mixtures with sodium chloride are similar to those with other admixtures for soil densification in that design depends upon the proper proportioning of soils, aggregates and admixture. These constituents must be uniformly mixed in amounts required to obtain firmness and density under compaction in order to retain the moisture so necessary to prevent dusting and pot-holing under traffic.

The kinds of aggregate used are not of prime importance providing they consist of reasonably sound, tough, durable particles which will withstand weathering conditions. Gravel, crushed stone, blast furnace slag, and sand are common aggregates used. Fine granular material should be added if the coarse aggregate does not contain sufficient fines to lower the plasticity index of the soil binder and to provide the grading required for embedment of the larger particles. Pit run gravel usually contains enough fine aggregate to provide the necessary grading. Crushed particles of aggregate add to the stability of the mix but are not absolutely necessary for a satisfactory road. In many cases there is enough loose aggregate on an old road to provide a large percentage of the needed material.

It is possible to use soil binders having high percentages of sand and silt providing their plasticity indexes are not appreciably less than 15. The characteristics of the stabilized mix may be controlled by varying the relative proportions of soil binder and aggregate. Soil binders containing as little as 20 per cent clay (particle sizes smaller than .005 mm.) have been satisfactorily incorporated in stabilized mixes where the aggregate was deficient in sand. It has been found that clays having a low plasticity index are much more easily pulverized than clays of high plasticity index. This is an important characteristic as the clay soil binder must be thoroughly pulverized when incorporated in the finished mix. The trend at the present time seems to be for the use of the least amount of soil binder that will provide necessary cohesion.

The engineer should bear in mind that good results can be obtained with considerable variation in the size and amount of the fine and coarse aggregates. The percentage of soil fines, however, is much more critical. Since the soil binder is usually prepared separately and added to the aggregate during construction, the amounts can be varied in order to get a satisfactory grading. If the percentage of soil fines is not excessive and the material is properly placed on a suitable subgrade, excellent results will be obtained.

Salt: In most of the salt stabilized roads constructed in the United States rock salt has been used. Evaporated salt was used in the salt stabilized roads in Ontario, Canada. Any commercial type of salt or salt brine is satisfactory. The finer grades of salt may show some tendency to cake when stocked along the road.

The mined "CC" grade has been the rock salt most commonly used. The specifications are as follows:

Size: Maximum retained on No. 4 sieve (U. S. Standard with an opening of 0.187 inch) —2 per cent.

Maximum retained on No. 8 sieve (U. S. Standard with an opening of 0.0937 inch)—90 per cent, minimum 65 per cent.

Maximum through No. 30 sieve (U. S. Standard with an opening of 0.0232 inch)—2 per cent.

Tolerance plus or minus 5 per cent.

Chemical Composition: Not less than 98 per cent pure sodium chloride.

In the design of a stabilized road, provision must be made for a suitable crown. Recent investigations have shown that 0.4 to 0.5 in. per foot of roadway is satisfactory as a minimum. When using this crown the slope should be uniform from center to side with the peak at the center slightly rounded off. A surface with a flat sloping crown will be easier to drive upon than one with a circular crown of the same height. If immediate bituminous surfacing is proposed, a crown as low as 0.35 in. per foot may be used. It is always necessary to have the surface a true plane in order that no water pockets will be retained. If water stands on a newly-constructed stabilized road that has not received its full compaction, there is danger of potholes forming and also possibility of the moisture softening the entire stabilized course and subgrade beneath, which will result in failure. Experience has shown that crowns of 4 or 5 in. on a 20-ft. stabilized road are not excessive.

Spencer: The sodium chloride stabilized roads constructed in Indiana during the construction season of 1937 were designed and constructed as base courses and were surfaced during the season of 1938. The surface consisted of a compacted two-inch thickness of bituminous materials. Both the surface and base courses were plant mixed. The stabilized materials were batched and proportioned by weight to meet the requirements in Table 1.

TABLE 1

(1) Indiana Gradation Requirements

Sieve	Retained (Present Specifications) Per Cent	Retained (Proposed Specifications) Per Cent
1-in.	0–15	0–15
¾-in.	5–35	5–30
½-in.	20–70	20–55
No. 4	40–75	40–70
No. 10	60–80	55–75
No. 40	70–85	70–85
No. 270	85–95	85–95

(2) The fraction passing the No. 270 sieve not to be more than ⅔ of the fraction passing the No. 40 sieve.

(3) The fraction passing the No. 40 sieve to have a plasticity index as follows: gravel, from 1.5 to 4.5; limestone, from 0 to 3.0. The liquid limit not to exceed 25 as determined by the physical methods of the U. S. Bureau of Public Roads.

(4) The aggregates to comply with the specifications for class "C" or "D". These specifications require the fraction retained on the No. 4 sieve to have at least 35 per cent crushed material.

A very satisfactory binder soil for this product would have a plasticity index range from 6 to 12. Such a soil would normally be a top soil, loam, sandy loam, or silty loam. If the aggregate is deficient in lime-rock particles, the pH of the soil binder should not be less than 6.

The proportions for the finished mixture were first determined by the use of the triangular-graph method and computation of the plastic index. After production was started at least two complete tests were run daily in the field. If the mixture bordered on the specification limits, additional tests were necessary.

Looker: A wide variety of materials

has been used in the construction of roads with sodium chloride. The majority have been built of soil binder and different kinds of aggregate including natural gravel, slag, caliche rock, ground oyster shells and crushed limestone. Limestone dust is also being used as binding material instead of clay along with various types of aggregate.

In a salt-stabilized road the quality of material is just as important as in any other kind of road. The materials survey should include possible quarry sites for placing crushed rock plants and sand-gravel plants. It should also include the location of river sand, hillside deposits of clay, natural deposits of sand, and well graded soil-sand-gravel mixtures or other types of aggregates which could be economically utilized.

In certain parts of the country the natural gravel deposits are sufficiently well graded to satisfy the gradation requirements. In many such cases the overburden supplies the necessary soil binder. In other cases extra material must be brought in to supply deficiencies. It is the rule rather than the exception to mix the overburden with the gravel in the pit by means of a power shovel and then run the whole mixture through a crusher. The size is reduced to a maximum of one inch. This is comparable to the plant mix method except that the unsalted dry, crushed and graded material is distributed on the prepared sub-base and shaped to the proper cross section to be salted and wetted afterwards.

In building up the foundation, either crushed gravel is laid to a depth of 8 to 12 in. or coarse, less stabilized gravel is used to form the bottom 6 or 8 in. which is then topped with finer crushed gravel. Salt is evenly spread and worked into the top two or three inches only and the road is finished in the usual manner by wetting and rolling. Often rains are depended upon to provide the necessary moisture. Very little road mixing has been done in the past two or three years.

Extensive satisfactory use has been made of limestone as aggregate. In New York, Maryland and elsewhere, small amounts of limestone dust have been used to replace clay.

Still other roads have been built entirely of crushed limestone with limestone dust acting as binding material instead of clay. Preferably such material should be plant mixed but very good results have been obtained by applying salt and water after distributing the screenings on the prepared sub-base.

These roads are referred to as salt-bound-stabilized limestone roads or salt-bound-stabilized macadam. They differ from the old type of macadam or crushed stone road in that the gradation of material is such that stability is obtained just as soon as the road has become compacted and seasoned.

CONSTRUCTION

Report of Subcommittee on Treatment of Roads with Sodium Chloride (1936): Preparation of the subgrade is one of the most important items to consider in the construction of a stabilized road. The soil-aggregate mixture can be very satisfactorily placed on a new grade which has been rolled until it is firm and solid. All soft spots must be located and remedies applied. In many cases soft and spongy sections are due to moisture bearing strata which intersect the grade line. In cases of this nature, it is necessary to investigate the area thoroughly by means of soil augers or posthole diggers. It is important to divert the water by intercepting drains before it enters the grade rather than to drain it from the soft spot after the damage has been done. Failures of this type are often mistaken for frost boils.

When for any length of time the water table is near the stabilized base, there is possibility of failure due to softening of the road bed. Such a failure will also affect the stabilized course especially if the percentage of soil fines is high. It is necessary in cases of this kind, either to lower the water table by means of drains or ditches, or to provide a fill of suitable height to insure firmness during the entire year.

On most newly-constructed grades, rain will enter material which has not been thoroughly consolidated and soft places will develop. These places can be excavated, drained, backfilled and compacted with suitable materials or, where possible, a firm base may be constructed by working additional aggregate into the subgrade.

On old gravel or stone roads the matter of providing a compacted base has usually been well taken care of. Old roads which have been compacted over a period of years should not be scarified down to the sub-base but merely given a light leveling in order to provide a uniform base.

It is not practicable to place stabilized material over old oil mats or bituminous surfaces since a seal is interposed between the sub-base and the stabilized course. There is, therefore, no opportunity for the small amount of moisture needed to maintain the stabilized material in a slightly damp condition, to enter from beneath the bituminous course. Experimental sections placed over old bituminous surfaces have pot-holed badly due to rapid drying during periods of dry weather. If the bituminous surface is good enough for further use, it should be repaired. If it is badly broken up and beyond repair, it is possible to scarify the road deeply enough to break the bond of bituminous material, add soil binder and stabilize, using the old material for aggregate.

Mixing Methods: A number of different methods have been used for placing stabilized materials. Perhaps the road mix is the most common method. John H. Barr reports the following practice used in Oakland County, Michigan.

"It has been found convenient to work each project in half-mile sections, and the method used is as follows:

1. All loose material on the roadway is windrowed to the center.
2. Enough new material is added to the windrow to bring the total quantity to approximately 1,000 cu. yd. per mile. This is done by measuring the windrows. This quantity, when stabilized, will produce a wearing course 3 in. deep and 20 ft. wide.
3. Soil binder is then delivered and windrowed on each shoulder in sufficient quantities to produce a stabilized mix of the desired plastic index; the quantity having previously been determined by test in the laboratory.
4. As soon as the soil binder has become dry, it is spread, pulverized and bladed back into its original position on the shoulders.
5. The gravel windrow from the center is then spread over the prepared subbase between the rows of soil binder and the pulverized soil binder is then spread uniformly over the gravel.
6. The mass is then thoroughly mixed by blading and, after mixing, it is split into windrows on each shoulder of the road."

Some traveling plants have recently been developed for use in placing soil stabilized roads. These plants usually pick up the material from windrows, run them through a continuous mixer and deposit them upon the road. Water is sometimes added while the material is being mixed.

The trend at the present time seems to be toward the use of plant mixed materials since the soil binder may be added to the aggregate as it is being produced. Several jobs have been successfully constructed in this manner. For best results the soil binder is pulverized and added to the aggregate production line in a continuous stream. After the material passes through the processing screens, the result is a finished mix. When pug mill mixers are used, as in the case of several of the more elaborate plants, it is possible to use the soil binder in a dampened condition. In this case the production of stabilized material is not so dependent upon weather conditions.

The sand-soil binder and coarse aggregate for several projects have been proportioned in a concrete batcher plant and mixed dry in a regulation concrete paver. By this method it is possible to get good results in 30 seconds of mixing.

Placing Material: Stabilized material should be placed in layers thick enough for speed in placing but not too thick for good compaction. In the case of road mixed material, the mixture is usually bladed over the dampened grade from a windrow on the shoulder. Unless there is sufficient moisture on the grade, the course should be wet, either with brine or water, until slightly above the plastic limit. Long base leveling devices or maintainers should then be used in smoothing up the course before compaction. For best results, not more than 3 in. of loose material should be applied at any one time. Enough water should always be added to make the entire mix somewhat plastic. In case the water or brine has not penetrated the entire course, the material should be lightly disked or harrowed to avoid dry pockets. If more than 3 in. of this material are placed at one time, there is difficulty in getting the moisture to penetrate uniformly. Compaction is also difficult as plastic material does not have stability. With more than 3 in. the road becomes spongy and rolling is of no benefit. Ordinarily, 3 in. of loose material will compact to about two inches. Each course should be allowed to season and set partially before the next one is placed. In order to secure satisfactory bond between courses it is necessary to apply brine or water prior to the placing of additional dry material. Since plant mixed material is delivered to the project already mixed, it can be placed upon the grade immediately. The mix may be placed by spreader boxes, by asphaltic pavers, or by dumping on the grade and blading into position.

When run-of-bank gravel, including the clay overburden is suitable for stabilization, mixing on the road may be eliminated. The usual practice is to set the shovel in the pit at the proper height to secure the correct gradation of soil binder and coarse aggregate. A few passes of the shovel through the material will thoroughly mix it. This pit mixed material, when it satisfies the requirements for stability, is ready for placing on the prepared sub-base and from this point on is handled the same as road or plant mixed material.

Incorporation of Salt: Rock or evaporated salt is usually incorporated in the upper 3 in. of a course but may be distributed throughout the entire thickness of the stabilized mat. It is sometimes placed between layers as the material is laid but it may be mixed with the aggregate and soil binder. There is some question as to the necessity for placing salt in the lower portion of a stabilized road where it exceeds 3 in. in thickness. There is no doubt but that some salt will rise and crystallize on the surface. Some observations made in Indiana indicate that a 6 in. road, having salt in the lower 3 in. has a better surface condition than an adjacent section having salt in the top 3 in. only. A reservoir of moisture and salt from which the surface can draw as needed seems to be provided.

The amount of salt used varies somewhat in the different States. A common amount seems to be about 2 lb. per sq. yd. for a 3 in. thickness of stabilized road. The salt is applied in the form of brine throughout the entire depth. In some sections of the country brine is more available than solid salt and results indicate that either may be used satisfactorily. Brine may be made conveniently by dissolving salt in water.

Water or brine is usually added by means of pressure distributors, sprinkler wagons, or gravity tank trucks. Several short trips over the course, sprinkling lightly on each trip, should be made. This gives the moisture a chance to penetrate the entire course and does not result in a sloppy condition on the surface. If the wetting of the stabilized material is delayed until subjected to rain, there is danger that many of the valuable soil fines will be lost during dry periods. There is also the danger, as stated previously, that the entire course may become soft and unstable. If the material has been placed on an old compacted gravel or stone road this feature is not of prime importance.

Compacting: Various methods have been used in compacting the moistened stabilized course. Two and three-wheeled rollers, truck-drawn single rollers, multiple-wheeled pneumatic tire rollers, and dual-wheeled trucks have been commonly used. In some cases, the material was shaped up and compacted by traffic only. However, this practice should be discouraged in order to shorten the seasoning period as much as possible.

It is considered good practice when placing plant mixed material to work away from the plant and haul over each course as it is deposited. By using this method, the trucks hauling the material will compact the road and provide the maximum amount of rolling at the time it is needed. Stabilized roads should be rolled by equipment which will provide both a compacting and kneading action. Usually a combination of dual-wheeled trucks and ordinary power rollers will provide this action.

The importance of placing material in layers should be stressed, since compaction can be easily obtained during construction at very little expense. Each layer, if properly placed, will iron out into a smooth firm mass under traffic, trucks and rollers. If the course has been placed too thick or if the subgrade support is insufficient, the road will become spongy until such a time as the mix sets up or the subgrade becomes firm. Stabilized material placed on anything but a firm subgrade will not give satisfactory results.

After the course has been compacted it will usually need a slight leveling or smoothing before it can be considered a finished road. This can be done with long-base maintainers or graders during or immediately after a rain, or after the road has been sprinkled enough to form a thin plastic mulch on the surface. Any maintaining done when the surface is dry and hard will result in an unsatisfactory torn condition and loss of material. Aggregates torn loose will leave holes which will retain rainfall and enlarge into pot-holes.

Field Checking, Sampling and Testing: Field control is necessary in order to assure the quality and proportions of the various constituents of a stabilized road. One of the most important items is the selection of suitable soil binder in the vicinity of the project. As stated previously, it is usually not necessary that the soil binder conform to any narrow set of limits, but it is important that complete knowledge of the materials be available. The laboratory tests usually performed to determine the characteristics of the soil binder have been well covered elsewhere and will not be discussed here.

Soil binder samples should be very carefully selected as experience has shown that the characteristics of borrow pits and subgrades change frequently even in small areas. Examination of a clay deposit overlying limestone in Indiana showed that the clay was deposited in five layers, each of a different plasticity index. It was necessary, in this case, to mix the various clays and determine the plasticity index of the mixture. A check on the soil binder during construction showed that the plasticity index of the mixture was equal to the weighted average index of the various layers.

Each soil having different feel, appearance, color, bedding, etc., should be tested separately. In glacial deposits of clay it is sometimes found that high or low plasticity index clays are formed in pockets rather than in layers.

The engineer should not attempt to determine the suitability of soil binder by visual tests in the field. It is preferable to sample any fine graded material which seems satisfactory and base a decision on test results. This is necessary because some soil binders vary materially in appearance with variations in moisture content. Complete analysis of the aggregate should be made in order that a mix can be satisfactorily designed. From knowledge of the characteristics of the aggregates and the soil binder, it is possible to compute very closely the results of any mixture of these ingredients. When a mix has been selected, a sample of the soil binder and the aggregate should be mixed in the proposed proportions in order to determine if the mix as calculated will be satisfactory. In general, if the grading of the mix, and the plasticity index of soil fines are within the limits set up by experience, good results will be obtained.

It is unnecessary to detail the methods of field testing since information concerning standard test procedure is generally available.[2] It should be mentioned, however, that constant field testing of the binder, aggregates and mixtures is essential for uniformly satisfactory results. These tests should cover the gradation of particle size in both the final mix and its constituents, and the determination of the liquid limit, plastic limit and plasticity index of material finer than the 40 mesh sieve.

Spencer: On some Indiana projects the proportioned materials were mixed in concrete mixers at a central mixing plant and truck hauled to the project. On other projects pugmills and continuous screwmixers have been used satisfactorily. The specifications required that a minimum of 25 per cent of the required optimum moisture content be added at the time of mixing to prevent segregation of the component parts of the mixture. Sodium chloride was added as brine. By adding all of the required sodium chloride brine and water at the central mixing plant, many small details were eliminated. It also permitted the laying of this material in an entirely different manner than any of our previously constructed roads of this type.

Rock salt was used to make the sodium chloride brine. The contractors on these projects were able to rent a very simple, compact and efficient briner from the company supplying the sodium chloride. Water was fed through a bed of rock-salt and came out of the briner as a saturated solution. This was run into tanks and then diluted with water until the salometer readings indicated the desired solution. Due to the variable moisture content in the aggregate it was found very desirable to have two separate measuring devices on the mixer—one for adding a uniform amount of a known solution of brine, and the other for adding enough clear water to bring the mixture to the optimum moisture content. The sodium chloride used amounted to 2½ lb. per sq. yd. for a 6-in. thickness, or 2½ lb. for every 667 lbs. of stabilized mixture.

Mixing time on this material required from 40 seconds to one minute for a satisfactory product. The materials mixed

[2] American Association of State Highway Officials, *Standard Specifications for Highway Materials and Methods of Sampling and Testing;* also *Public Roads*, Vol. 12, No. 8, Oct., 1931.

well and uniformly and did not tend to stick or ball up in the mixer. The finished mixture was discharged into trucks and hauled to the projects. The consistency and appearance of the mixed materials was very similar to concrete except for color.

The first project provided for an experimental test section with all the material to be placed in one lift and compacted with a sheepsfoot roller. Previous experience with a very short experiment of this type where the mixture was placed dry in one 9-in. lift on the subgrade, then wet to optimum moisture and rolled with a sheepsfoot roller, seemed to be very satisfactory. This material under these conditions was compacted to a final thickness of 5½ in. Our regular practice was to lay the mixed materials with little or no water in 3-in. uncompacted layers, then wet and roll them until satisfactorily compacted. This procedure required from 9 to 9½ in. total uncompacted thickness to obtain a total compacted thickness of 6 in. The placing of the materials in multiple lifts proved undesirable for numerous reasons,—(1) the additional cost of placing material in three courses; (2) the additional cost of sprinkling and rolling of each course; (3) the placing of the materials in layers in many cases produced cleavage planes at the junction of each course; (4) and more important, the placing of such a thin, low P.I. course and wetting to optimum moisture on the subgrade and then rolling in many cases softened the subgrade to the point where it involved the incorporation of part of the subgrade in the bottom layer. To overcome these objectionable features of the multiple courses the stabilized mixture was placed in one course on this short experimental section. This material contained all of the sodium chloride brine and enough additional moisture to bring the total moisture to the optimum. With the addition of this moisture and without compaction of any kind, the optimum moisture alone reduced the thickness of a square yard of this material from 9 or 9½ in. dry to 6½ or a maximum thickness of 7 in. when placed wet.

The sheepsfoot roller was used on a short section of this material laid in one course with the optimum moisture added at time of mixing. Operation of the roller under various total weights in this material was very unsuccessful. The material would not compact further until aeration of the mix, produced by the turning of the roller feet, dried the mix to such a point that further compaction could be obtained. Although this sheepsfoot roller was not satisfactory under these conditions it is possible that a much larger foot, probably one with an end area of as much as 8 or 10 sq. in. would be satisfactory.

After this experience with the sheepsfoot roller, various thicknesses of lifts and types of rolling, including the 5 and 10-ton, three-wheeled roller, and truck rolling were tried on the mix placed with the optimum moisture content. Cores were taken from the various experimental sections for the purpose of making density determinations. After these density determinations were made it was decided to place the stabilized material at optimum moisture in one course on the basis of 4000 lb. per cu. yd. When the material was sufficiently dried on the surface to prevent excessive lateral movement it was rolled with either a 5 or 10-ton, three-wheeled roller. The time for this rolling operation varied with the weather conditions and the weight of the roller. Although the materials in the upper portion of the course were below the optimum moisture at the time of the first rolling, the bottom part of the course was still near the optimum moisture. This initial rolling obtained maximum compaction only in the bottom portion of the course. After the bottom portion had dried out enough to offer a firm plane to roll against, the upper portion was wet with clear water by means of a sprinkling tank, then dragged with a long base drag and compacted with a ten-ton, three-wheeled roller while the upper surface was sufficiently wet for satisfactory compaction.

Cores taken from the projects where this type of compaction was used had very good densities and are listed in Table 2.

We found that this method of placing and compacting sodium chloride stabilized material was quite satisfactory with these low P.I. mixtures.

TABLE 2

CORE DATA

Type of Aggregate Used	Average Specific Gravity of Material	Wet Densities as Received at Laboratory	Moisture Per Cent	Computed Dry Densities
Gravel and soil binder	..	150.7	5.00	143.5
	.	148.6	5.40	141.0
		150.7	5.00	143.5
	2.60	150.0	5.60	142.5
	2.60	150.5	4.70	144.0
	2.60	153.5	2.94	149.0
	2.60	153.5	3 64	148.0
	2.60	153.5	4.17	147.0
Limestone	..	143.5	0.80	142.2

Our experience with chemical stabilized roads clearly indicates that the cost of the chemical is a very small part of the total cost of the road. These costs, based only on the stabilized materials and excluding any type of surface for the sodium chloride projects referred to and constructed during the summer of 1937, are given in Table 3.

Looker: Where stability must be obtained by compounding the aggregate and soil binder, the plant mix method is preferable to the road mix. This affords a means of incorporating salt throughout the mix in a much more uniform manner than by any other method. The water required for optimum moisture content is usually more than sufficient to dissolve the salt. Salt is almost universally used as an integral mixture and not a surface treatment.

In constructing roads of plant mixed materials some difficulty has been experienced in maintaining a smooth surface when loaded trucks were permitted to travel over the freshly laid material before compaction had taken place. Loaded trucks are an excellent means of securing compaction if all the conditions are right but sodium chloride roads often set up hard and firm during the construction period and any irregularities should be corrected before this occurs. This difficulty has been corrected by laying the

TABLE 3

Type of Aggregate Used	Contract Price per Ton for Furnishing, Mixing, Placing, Shaping and Maintaining of Stabilized Mix	Cost of Furnishing and Incorporating Sodium Chloride	Cost of Sodium Chloride Per Cent of Cost of Stabilized Mix
Gravel......	$1.63	$10.00	2.3
	2.01	15.00	2.8
Limestone....	2.87	20.00	2.6

plant mixed material toward the plant rather than away from it. Another plan sometimes used is to permit the road surface to set up somewhat rough and then give it sufficient scarification to permit final shaping and compacting.

MAINTENANCE

Report of Subcommittee on Treatment of Roads with Sodium Chloride (1936): For a few weeks after construction, the mixture is undergoing compaction and the particles are finding final positions. This period, which has been called the "curing period," is very important in the development of a well stabilized surface. During this phase excess clay binder and fines are concentrated on the surfaces and whenever there is enough rainfall to utilize the slightly plastic surface formed, the surface should be bladed. In this way all small depressions will be filled and the proper crown can be established.

With the coarser mixes containing maximum aggregate and minimum soil binder, loose float material may develop on the surface after the road has been completed and opened to traffic. Experience has shown that under rains and traffic and with proper maintenance most of this material will be incorporated into the road. There is an advantage in keeping this floating material on the surface during the seasoning process in order to prevent tendency toward slipperiness when the road is subjected to its first few rains. If the road is subjected to a heavy rain before it is completely compacted, traffic may rut the surface to a depth of several inches. If the surface has been constructed on a compacted gravel or stone road, this condition will not be serious as the road can be shaped up and compacted after it has lost some of its moisture. On a fresh grade, however, some of the subgrade material may push up through the course and result in an over amount of soil binder. Traffic should not be allowed on a stabilized road which shows signs of serious rutting. A stabilized course on a firm grade, in which the proper amount of water has been used, should not be affected by rains except for slight softening of the surface. This condition is ideal for reshaping and maintenance.

Stabilized roads usually continue to show improvement for several months after construction. Much of the loose material which appears immediately after the course has been placed, disappears leaving a firm, hard, dustless surface which normally remains in this condition. During periods of rainfall, however, the top eighth or quarter inch becomes plastic but not slippery. Some treatment of this plastic layer may become necessary if rainfall is excessive and particularly if the float material which appears after construction has not disappeared.

While the surface is in a wet, plastic condition about 50 to 70 tons of crushed aggregate per mile can be added to the surface. This should have a maximum size of about ½ in. and be free from dust or sand. This material should be lightly floated over the surface immediately after application and kept uniformly distributed as long as the surface is wet. The thin layer of fines acts as a cementing agent. This method makes a more satisfactory driving surface, adds some additional thickness to the road, fills up any depressions which may have developed and minimizes the tendency to "potting."

When the surface begins to dry, the loose aggregate should be bladed off to the side, for as drying continues the surface becomes hard and any loose aggregate would act as an abrasive, tending to destroy the stabilization. Repetition of this process of blading loose aggregate on and off the surface becomes less and less necessary as complete stabilization takes place, and finally the need no longer exists. Care should be taken not to cut into the surface when moving the loose material.

When a salt stabilized surface enters a prolonged dry period, the condition changes. High speed traffic has a tendency to wear off the fines leaving the larger aggregate particles protruding. This tends in time to become objectionable.

Any one of several courses may then be followed. A bituminous surface treatment may be applied; or density of traffic warranting, a higher type wearing course constructed; or additional salt treatment may be used.

During spring maintenance the surface may be given a thorough blading or scarifying and additional salt added if necessary. If salt is thoroughly mixed with moist surface and stabilized material the road will again consolidate to its original condition. Damp material makes satisfactory bond with the worn surface without scarification.

During spring maintenance, additional clay, clean sand or gravel may also be worked into the surface to correct any stabilization deficiencies.

In addition to spring maintenance, salt stabilized wearing surfaces may also be maintained by blading near the end of or immediately following fairly heavy rain or when the road material is in thoroughly moistened condition. This will give an opportunity to smooth the surface by filling in the irregularities with available stabilized material from the shoulders and the small amount scraped from the surface itself. More salt may be added during this maintenance if necessary.

During alternately dry and wet weather occasional holes may develop. These may be patched with damp stabilized material with which salt has been mixed at the rate of 100 lb. salt per cu. yd. of material.