

BASE STABILIZATION

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Although the word stabilization has been used in the field of highway engineering for many years, I doubt if there is any other term used to identify a product, an operation, or a condition that has had a less positive or definite meaning. Perhaps the meaning, or intent, has been reasonably clear, only the degree of stability or improvement of the material to which it is applied has been somewhat confusing. Apparently stabilization is recognized as a broad term indicating varying degrees of success. The search continues for that magic potion that can be sparingly sprinkled on poor quality or unstable soils, or aggregates, and immediately transform them into high quality pavements or paving materials. This, of course, is what all of us would like to find. But like alchemy, perhaps this is the goal we must always be looking for.

If we stop to consider the complexities and difficulties involved, I am sure that we would all agree that we have made much progress and should continue to make additional progress in the future.

The purpose of stabilization is to improve the undesirable characteristics or conditions of soils, aggregates, or mixtures of soil and aggregates, to the degree where they can be successfully used as a component part of foundations or the pavement structure. This is necessary in order to satisfy the public's and the traffic's ever increasing demand for more and better highways at less cost. The engineer and highway administrator must always try to use local and the cheapest materials to best advantages. This can be done through stabilization by elimination or improvement of the undesirable characteristics of materials, and upgrading them to a point where they can perform successfully for the purpose for which they were intended. This includes soils, poorer quality aggregates—which may be due to gradation and or quality, and soil aggregate mixtures.

A material may be considered as stable if it has little or no volume change and offers a sustained resistance to deformation under repeated or continuing load applications whether in a wet or dry state. This would include its ability to prevent ravelling and loss of surface materials under traffic. It must not exhibit any detrimental frost action.

For load carrying capacity the degree of stability, for a satisfactorily compacted material, is primarily a function of resistance to lateral flow. Resistance to lateral displacement is a function of internal friction and cohesion. Internal friction is the resistance offered against the sliding of individual particles over one another. Primarily because of their particle size, well keyed granular materials possess high internal friction. Generally, water has little effect on the internal friction or volume change of these larger sized materials. By contrast, fine grained materials, such as clays, depend on cohesion for their stability. Cohesion is a combination of the true cohesion of the soil particles combined with the cohesion furnished by the molecular attraction of water in the form of moisture films which surround each individual soil particle. If this film is extremely thin and is composed of solidified water, then, the soil is not expanded, the surface tension of the moisture envelopes is high and the soil particles have a high cohesive value. In this state the soil has good bearing values and will support large loads. However, as these moisture films increase in size to a point near free water, the materials have expanded or swelled and have a very low bearing capacity.

If a well graded material ranging from coarse aggregates through the soil fraction could be adequately compacted and adjusted to the desired moisture content and then kept permanently in this condition, mechanical stabilization would be accomplished. There would be no volume change and no loss of load carrying capacity. This type mixture would have high internal friction and cohesion. However, since the moisture will not remain fixed without additives, and since the gradation usually varies, stabilizing agents are very important as a further aid to mechanical stabilization.

The stabilization of fine sands and soils that possess little or no internal friction become much more complex. In the absence of a stabilizing agent their stability depends primarily on cohesion. The fact that the total surface area of a cubic foot of fine grained soils may approximate 142,000 square feet, or in excess of 3 acres, almost staggers the imagination. The chemical of the soil affects its reaction with a stabilizing agent, or with the thickness of the surrounding moisture envelope. Colloids high in silica absorb thick moisture films and their volume undergoes great changes. Iron and alumina colloids absorb thin films and, therefore, undergo small volume change on wetting and drying. A change of ions on the surface of the clay and colloidal particles may alter the shrinkage, swell and plasticity of the soils sufficiently to alter its stability. Potassium clays are much more stable than lithium clays. With these many complexities there is little wonder that actual soils stabilization may be difficult.

Stabilizing agents, then, are used to obtain and maintain desired moistures, increase cohesion, to produce a cementing action, and to act as a water-proofing material.

Local materials stabilized in the highway industry range from plastic clays, cohesionless silts and fine sands, poorly graded or poor quality local sands and gravels, or possibly waste materials, through well graded aggregate mixtures. The intent in all cases is to upgrade and improve the materials, which are usually being considered for subgrades, subbases, bases or surfaces.

To describe the uses of all materials that have been used with varying degrees of success or are presently being considered would require much more time than allotted on this program. Therefore, the stabilizing additives or agents to be discussed at this time will be limited to seven, which includes all types of stabilization ranging from soil through well-graded aggregate mixtures, all of which are broadly considered as some form of soil stabilization.

A few of the stabilizing agents that have been tried, or are presently being tried, but not discussed in this paper, include:

1. Phosphoric acid, with and without trace additives
2. Calcium acrylate
3. Aniline-furfurel
4. Lignins and Resins
5. Sodium silicates
6. Sucrates
7. Dioctadecyl Dimethyl Ammonium Chloride
8. Aliphatic Organic Chemicals

and many, many others.

The materials and methods we wish to present are the ones that have been used and studied over the years by each of the seven subcommittees of ARBA's Committee on Stabilization.

ARBA has published over an extended period of time numerous bulletins describing the work and recommendations of these subcommittees. The material to be presented at this time was furnished by the chairman of each of these subcommittees.

Soil-Asphalt Stabilization

Subcommittee Chairman James C. Johnson

Most crude oil that comes from the ground contains asphalt. Different crude oils contain different amounts of asphalt which may be removed in the refining process. All presently refined asphalt materials may be mixed with some type of sand, soil, or aggregate and soil mixture in a stabilizing process.

Soil or sand materials may be mixed with asphalt for many reasons. Cohesion may be supplied to cohesionless soil grains by asphalt. Waterproofing of some soils with asphalt may be necessary. Asphalt may, in some instances, give strength and stability to rounded particles which are not normally load bearing materials. Soil-asphalt mixtures may be used successfully to upgrade border-line materials.

There are many known places where so-called "unsuitable soils" have been stabilized. "Sugar-sand," "Blow-sand," "Incinterated trash," materials of 100% passing the #200 sieve, and heavy clays have been stabilized with selected types and grades of asphalt materials. However, the normal gradation limits of materials recommended for stabilization with asphalt are as follows:

<i>Sieve Size</i> <i>(Square openings)</i>	<i>Total % Passing</i> <i>(by weight)</i>
1"	100
# 4	50-100
# 30	25-100
# 100	10-65
# 200	5-25
By weight of total mix	3-15% asphalt

By knowing the liquid limit, the plastic limit, and the shrinkage limit of the soil, we are able to make educated estimates of the method of working with each material encountered. Where frost penetration is an important factor, it is doubly important that these soil characteristics be understood.

Some moisture should be present in the materials when mixing is done with rapid-curing cutback, medium-curing cutback, normal emulsion, inverted emulsion, slow-curing asphalt, or foamed asphalt. The moisture requirement will vary with the type of soil and the type of asphalt. No moisture is needed in the hand or soil if the material is to be hot-mixed.

The designation of the asphalt material to be used for stabilization is normally made by penetration grade, or by type and grade for the cutback liquid asphalts and the emulsions. Since asphalts from different crude oil sources may vary in their characteristics, there has been a growing trend toward specifying asphalt materials by their temperature-viscosity relationship.

All soil, or sand-asphalt mixtures, should be designed in the laboratory using some type of stability test.

There are numerous machines on the market for mixing asphalt with sand or soil. They dig the soil direct from the roadbed, or operate on a prepared windrow of materials. Regardless of the type of machine, something must be known about the volume of materials being processed so that the percent of asphalt material being incorporated, and the compacted thickness may be controlled.

After mixing the soil and asphalt by any method other than hot-mix, the mixture must be aerated to remove moisture and hydrocarbon volatiles. Rapid-curing liquid asphalt will contain gasoline or naphtha-type cutter stock which will evaporate by aeration more rapidly than the kerosene-type solvent in the medium-curing liquid asphalt. Normal emulsified asphalt will contain water, but no hydrocarbon volatiles. Inverted emulsified asphalt will contain both moisture and volatiles.

Aeration of moisture and volatiles may be performed by repeated mixing of the materials with special stabilization equipment, or by other means. There will be very little aeration when the mixture is left indefinitely as mixed originally in a windrow or on the roadway. Normally, aeration will best be achieved by moving the mixture back and forth across the roadway, at suitable intervals, using a blade grader. The grader will give additional mixing, and the heat of the sun and movement of air through the mixed material as it is rolled by the blade will help to remove moisture and volatiles.

After aeration, the mixture should be spread and compacted. Compaction may be done with a sheepsfoot or other tamping-foot roller, followed by pneumatic-tire rollers and steel-wheel rollers. Normally, the compaction should be done in two to four-inch courses, although some materials, under special conditions, may be compacted in single courses up to ten inches in thickness. Compaction requirements and capabilities will vary from one locality to another, and what will work satisfactorily in one place may be totally unsatisfactory somewhere else.

Soil, or sand-asphalt stabilization is not new. Both Florida and Oklahoma first built this type of road base in 1930. South Carolina built a similar project at about the same time. Today there are many miles of this type base on roads and streets in the United States.

Asphalt Emulsion Stabilization

Subcommittee Chairman C. M. Foard

Generally, the grades of asphalt emulsion for soil stabilization are identified as slow curing grades SS-1 or SS-2, or medium curing MS-1 or MS-2. Cationic grades have been used with certain types of aggregates on an experimental basis and show promise. Grades RS-1 and RS-2 are referred to as "Quick setting" and are not used in stabilization work.

Asphalt emulsions have been used successfully with both cohesive and non-cohesive aggregates. In stabilization work using cohesive aggregates, which possess good strength at relatively low moisture content, the asphalt emulsion after mixing and curing will tend to preserve a large portion of this strength even when the mixture is exposed to water. If the aggregate to be treated is non-cohesive, the asphalt emulsion after curing will bind the particles together and impart cohesion or tensile strength to the mass. Thus, in stabilization work the asphalt emulsion sticks the particles together and waterproofs the aggregate. In addition, movement of moisture in either liquid or vapor form is retarded through the different components of the pavement structure. Varied types of aggregates have been stabilized with asphalt emulsion such as

1. Bank Run or Pit Gravels
2. Crushed Run Aggregates
3. Cinders
4. Local Pit Sands
5. Beach Sands
6. Mine Waste Materials
7. Other in place materials which vary in characteristics.

To evaluate the various aggregates, the Florida Bearing Value Test is a valuable tool for sands and has been used successfully for many years by a number of agencies. Another rather common test for evaluating mixes of non-cohesive as well as cohesive aggregates with asphalt emulsion is ASTM D-915-47T in which the mix specimen is cured and subjected to a 7-day water soaking period. The amount of water absorbed and the change in volume is determined and the strength, or stability, after soaking is measured in an extrusion apparatus. Both methods, although empirical, have been proven reliable in soil stabilization design.

It should be noted that at ambient temperatures aggregates will mix more readily with asphalt emulsion when the aggregate is moist. At times it may be necessary to add mixing water to thoroughly disperse the asphalt emulsion and this can be done by any convenient method, such as controlled batching or metering into stationary plants; sprinkling with water trucks on road mix jobs; and controlled dilution of the asphalt emulsion. Frequently the ideal moisture percentage will be somewhere in the vicinity of $\frac{1}{4}$ of the liquid limit of the aggregate. This certainly is no hard and fast rule however and is dependent not only on the nature of the aggregate itself but also on the type of mixing equipment to be used.

A wide variety of equipment has been used successfully for asphalt emulsion mixes and several types will be reviewed briefly:

1. Stationary Plants—Both batch and continuous types are very satisfactory. Barber-Greene, Cedar Rapids, etc.
2. Travel Plants—Travel plants such as a Wood Mixer, which scoops up a windrow or a controlled cross section of aggregate from the roadbed is excellent.
3. The Pulvi Mixer is used extensively for in place work. Generally, more than one pass of the mixer is necessary to get good uniform dispersion of the asphalt emulsion. It is also used for dry mixing the soil for uniformity as well as aerating the mix after the asphalt emulsion is applied.
4. The P. and H. Single Pass Stabilizer is used extensively for in place work and for dry mixing and aeration as described above for the Pulvi Mixer.
5. Blade mixing.

Aeration of the fresh asphalt emulsion stabilized mix is of utmost importance since it is necessary to reduce the total amount of liquid in the mix. Aeration is really quite simple and merely consists of manipulating the fresh mix periodically to aid in the escape of the water. The mix can be spread the full width of the road with a pulvi mixer or harrow at different time intervals. If traffic is to be maintained, place the mix in a windrow near the edge of the road and periodically spread the windrow across the width of the road.

Spreading and finishing the asphalt emulsion stabilized mix is generally accomplished with the blade grader. The mix should be spread so as to form a smooth riding surface, free from dips and swells with a uniform texture. The mix should be compacted *thoroughly*, so as to obtain predicted stability, and *uniformly*, to maintain a smooth riding surface. The foregoing can be achieved by spreading the well cured mix in uniform lifts or layers and compacting with a rubber tired roller or sheeps foot roller concurrently. Final compaction should be with a pneumatic tire roller followed by a tandem.

Soil stabilization with asphalt emulsion lends itself well to layer construction where additional thicknesses may be added as needed for increased traffic. Asphalt emulsion has successfully stabilized a wide range of aggregate types for use as bases under hot asphaltic concrete, shoulder stabilization, and conventional surface treatment by a multitude of processes.

Information on Asphalt Emulsion Stabilization is available in ARBA Bulletings, Highway Research Road Proceedings, and in various technical literature which can be obtained from the Asphalt Institute.

Tar Stabilization

Subcommittee Chairman P. F. Phelan

In general, the materials to be stabilized with tar can be designated as "soil," or "sand" or "sand" or "gravel." Soils are stabilized with lighter grades of tar in order to minimize the softening effects of excess moisture. Sandy

materials are stabilized by the use of somewhat heavier grades of tar—where the tar is intended to bind the particles together and provide stability by confining the coated sand particles. In effect, this provides desired “adhesion” to the non-plastic material. With gravel, tar is used to both waterproof and bind particles. The grade of tar used depends upon the emphasis that must be placed upon the waterproofing vs. the binding function. This, of course, depends upon the amount, gradation and characteristics of the fines in the gravel aggregate.

Regardless of the reason for using tar—whether to waterproof, or bind, or both—it is essential to realize that a tar-stabilized mixture is a lean, rather than rich, mix. The color of the finished tar-stabilized course should be chocolate brown rather than black. The stabilized base course, being low in tar content, is not designed to withstand the surface abrasion of traffic. It must be given at least a tack or prime and seal treatment before being opened to traffic.

In selecting or evaluating a raw material that is to be stabilized with tar, the ARBA Committee on Tar-Soil Stabilization has suggested the following criteria:

FOR SOIL:

Plasticity Index—15 or less.
Minus #200 mesh—50% max.
Mica—no more than a trace.

FOR SAND:

Florida Bearing Value—at least 25 lbs./sq. in.
Minus #200 mesh—10% max.

FOR GRAVEL:

Max. Particle size—no greater than $\frac{1}{3}$ the depth of the finished course.
Gradation—fairly well graded from coarse to fine.
Minus #200 mesh—10% max.

As to the grade of tar to use, it could vary anywhere between RT-3 and RT-9, depending upon whether the material to be stabilized is predominately soil, or sand, or gravel—and whether it is to be mixed with the tar by means of a blade grader, a rotary tiller mixer, a traveling mixer, or in a central mixing plant. Prevailing weather conditions also affect the choice of the tar grade to be used for any given project.

The proper percentage of tar to be incorporated may be determined by means of a number of laboratory tests. The choice of test method again is determined by the type of material to be stabilized, whether soil, sand or gravel. However, for most county work, where laboratory facilities may not be available, a rule of thumb is often used. In general, these materials should require from $\frac{1}{3}$ to $\frac{1}{2}$ gal. of tar per sq. yd. per inch of compacted depth. Thus for a 6" compacted depth, 2 to 3 gals. of tar/sq. yd. should be used. If laboratory tests indicate more than 3 gals./sq. yd. are required, then it would probably be economical to improve the unstabilized material—by the addition of sand (to soil) or soil (to sand).

Once the amount and grade of tar are decided upon the actual stabilization procedure is fairly simple, but each of the following five steps is necessary and important:

1. Scarify the material to be stabilized, to prepare it for mixing—modifying it, and adjusting the moisture content, if necessary.
2. Apply and mix the tar so as to get all of the particles coated—or at least obtain a uniform mixture.
3. Spread and shape the tar-stabilized mixture to proper grade and cross-section—at the desired moisture content.

4. Compact thoroughly to obtain maximum density under job conditions.
5. Tack (or prime) and seal the surface to provide resistance to traffic abrasion.

Although soil stabilization with tar is often a low type of construction, it is important that attention be paid to the quality of materials used, to proper proportioning of tar and soil, to moisture control during mixing and compaction, and to the provision of adequate compactive effort.

Complete specifications for bituminous stabilized base construction have been published by the ARBA Subcommittees on tar, cutback asphalt and emulsified asphalt.

Soil-Cement Stabilization

Subcommittee Chairman E. G. Robbins

Portland cement stabilization is commonly referred to as soil-cement. Soil-cement is simply a mixture of soil, portland cement and water lightly packed in a moist condition. When cured it becomes a hard rigid base course material. A bituminous surface is placed on top of the soil-cement to complete the pavement.

Portland cement is one of the older chemicals for stabilization. It differs somewhat from other forms of stabilization in that the cement actually hardens the soil material and structural strength is obtained from the cementing action rather than only from internal friction, cohesion and waterproofing of the materials.

Soil-cement as a base course material is commonly used for roads, streets, airports, parking and storage areas. In addition, it is being used as a sub-base for portland cement concrete pavements, for paving highway shoulders and for other miscellaneous uses (dam facings, slope protection, etc.).

Almost all types of soils can be used for cement stabilization except highly organic topsoils and very heavy clays. Generally the more granular soils are used because they pulverize and mix more easily and are generally more economical in that they require the least amount of cement.

There are three fundamental control factors for soil-cement; proper moisture content, adequate compaction, and proper cement content. These are determined before construction by laboratory testing of representative soil samples from the project. These tests are standards of both ASTM and AASHTO.

Cement requirements vary for different types of soils. Cement requirements may range from a low of 3 or 4 percent to a high of about 16 per cent. Generally as the clayey portions of the soil material increases the amount of cement required increases. These cement requirements are for hardened soil-cement.

AASHTO

<i>soil Group</i>	<i>Percent by Volume</i>	<i>Percent by Weight</i>
A-1-a	5-7	3-5
A-1-b	7-9	5-8
A-2-4)		
A-2-5)	7-10	5-9
A-2-6)		
A-2-7)		
A-3	8-12	7-11
A-4	8-12	7-12
A-5	8-12	8-13
A-6	10-14	9-15
A-7	10-14	10-16

Cement may be used also for modifying soil-materials to make them more acceptable base, subbase or subgrade materials. An example of this is the reduction of the plasticity of a soil material with increasing amounts of portland cement. The addition of relatively low percentages of cement also increases the bearing strength. Thus, it is possible to obtain a wide range of properties of cement-treated materials simply by varying the amount of cement added to a particular soil material.

Most soil-cement base courses are built 6 in. in thickness, however, it may be as thin as 4 in. for light traffic and good subgrade conditions. For thicknesses greater than 8 in., soil-cement bases are built in two or more lifts.

Soil-cement construction follows a prescribed procedure. The objective is to mix pulverized soil with the correct amount of portland cement and enough water to permit maximum compaction.

1. Spread the prescribed amount of portland cement.
2. Mix cement and soil with sufficient water to bring the mixture to its optimum moisture content.
3. Densify the moist mixture by compaction.
4. Finish to grade and produce a smooth surface.
5. Apply a cure coat to seal in the moisture permitting the cement to hydrate.

For spreading portland cement there are commercially available cement spreaders, or on small jobs bagged cement is used. Mixing is accomplished with any of several types of mixing equipment. The mixing can be done on the roadway, or if borrow soil is used, at the pit in a central plant. Compaction and finishing are done in the usual manner with normal road-building equipment.

The same basic factors control construction:

- Proper cement content
- Proper moisture content
- Adequate compaction

In addition there must be obtained a thorough mixture of the pulverized soil, cement and water. If these basic factors are under control, a good job should result.

The type, quality and thickness of bituminous surface placed on soil-cement depends on the traffic volume, availability of materials, costs and local practices. A common type of wearing course for lightly travelled roads and streets is a double bituminous surface treatment about $\frac{3}{4}$ in. thick. As traffic volumes increase, thicker, higher quality surfaces are warranted.

Costs vary widely, but a 6 in. soil-cement base course may be about 65 to 85 cents per square yard.

As stated previously soil-cement is one of the older types of stabilization and is well documented in the technical literature. ARBA Technical Bulletin No. 191, "Soil-Cement Stabilization—A committee report-questions and answers" gives much information. Additional information is available in other ARBA bulletins, as well as in the Proceedings and Bulletins of the HRB, and in the technical literature on soil-cement published by the Portland Cement Association.

Lime-Soil Stabilization

Subcommittee Chairman R. S. Boynton

Lime stabilization, one of the newer base stabilization methods, has been applied to all types of roads—secondary to interstate, as well as several non-highway uses such as airport runways, parking lots, railroad beds, and building foundations. This type of stabilization involves the use of burned lime products, quicklime or hydrated lime—usually hydrate due to safety and convenience, and *not* any carbonate forms of lime such as pulverized limestone. The latter reacts mechanically, but is relatively inert chemically. Lime, on the other hand, is a

strong base which reacts chemically with clays, causing a base exchange, with the calcium ions displacing sodium or hydrogen ions and combining with available silica and alumina in the soil to form complex silicates or cementing materials. Either high calcium or dolomitic lime can be used.

Lime is most effective with plastic clayey soils ranging from granular clay-gravels, caliche, etc., to clays or silty-clays with Plasticity Indices ranging from 10 to 50+. It also reacts with some silts, but should not be used alone with sandy soils. For the latter from 8 to 15% pozzolans, like fly ash or volcanic ash are also required.

Principal changes occurring during lime stabilization are as follows:

1. Reduction in P. I. and volume change.
2. Flocculation of clay particles, making the soil more friable; clay clods disintegrate readily.
3. Increase in optimum moisture content, thereby permitting compaction under wetter conditions; soils dry out more rapidly.
4. Increase in strength and stability through cementing action.
5. Resistance to water absorption and capillary rise.

The above changes, result in a more moisture-resistant barrier and strong working table for construction of the overlying pavement. Since the stabilized layer remains firm during rain, construction can proceed with little delay.

When granular soils are used, the stabilized layer can serve as a base or subbase. When fine-grained soils, such as clays, are used the stabilized layer can serve as a subgrade or subbase. In either case, the stabilized layer can be given credit in the design, reflecting savings in pavement thickness. The stabilized layer should not be used as a wearing surface (other than such temporary uses as haul roads).

The determination of the amount of lime to use is based on lab testing, the principal tests being particle size gradation, P.I., and some type of strength or stability test such as unconfined compression or C.B.R. Typical amounts of lime used in the field are 2-4% for granular soils and 3-6% for fine-grained soils (based on dry weight); however, as little as 1% has been used successfully for low P.I. gravels.

Standard stabilization construction procedures are employed, including scarifying, lime spreading, mixing and pulverizing, compacting and curing. With heavy clays, however, which are difficult to break down, mixing is done in two stages, with a 1-4 day curing period preceding the second mixing. During the curing period, lime and water mellow the clay (break down the clods), so that during final mixing, the pulverization requirement of 100% passing 1 inch and 60% passing $\frac{1}{4}$ inch is readily attained.

Lime spreading is handled by bag, bulk, or slurry methods; in addition, lime can be incorporated in central-mixing plants. In bulk application, lime is spread evenly by mechanical spreaders or flexible boots extending from the unloading augers. In the slurry method, lime and water are mixed in a central mixing plant, or directly in the water truck by means of a recirculating pump or compressed air, and the slurry is discharged through spray bars. A typical mix comprises 1 ton of lime to 500 gals. of water—about a 32% solution.

Scarifying is generally accomplished with a grader-scarifier or disc harrow; and mixing with the grader, rotary speed mixer, or disc harrow. Some form of rotary mixer is desirable although graders have been used successfully with granular soils. However for heavy clays the rotary mixer or the disc harrow are required for adequate mixing and pulverization.

Compaction can be obtained in single lifts using the sheepsfoot and light pneumatic roller in sequence, or the vibrating roller, or the heavy pneumatic; or in multiple lifts using light pneumatic rollers. Steel rollers are generally used for

finishing. Because lime is slow setting, it is not necessary to compact the base immediately; a delay of two days is not detrimental.

A 5-7 day curing period to prevent drying out is required, during which time the base hardens. Curing comprises two types; moist curing in which the base is sprinkled as needed, and membrane curing, which is accomplished by sealing with a thin coat of asphalt, either in one or several applications. During the curing period it is desirable to keep heavy vehicles off the roadway.

Lime stabilization is a relatively low cost method of base construction, since 100% in-place material can be used, eliminating excavation and replacement with better aggregate. The total stabilization cost averages about 40¢/sq. yd. (based on 6-in. compacted thickness). This cost is divided about equally between the lime and manipulation. On large projects the cost has been as low as 25¢/sq. yd.

Complete details on lime stabilization are given in the ARBA Tech. Bull. 243, "Lime Stabilization Construction Manual," which was prepared by the ARBA Lime Stabilization Committee.

Calcium Chloride Stabilization

Subcommittee Chairman W. E. Dickinson

Calcium Chloride is used with well graded aggregate mixtures, ranging from coarse aggregates through the soil fractions, to produce dependable mechanically stabilized materials.

Two common applications of mechanical stabilization of granular materials are:

1. Dense graded aggregate base courses.
2. Dense graded aggregate wearing surfaces, usually referred to as aggregate surfaced unpaved roads.

The control of moisture during construction and throughout the life of the graded aggregate base or surface is a vital factor in its performance. During construction, it is extremely important that the proper amount of moisture is always present to insure uniformity and adequate compaction. High densities not only provides support for traffic loads but also reduces voids making it difficult for excess moisture to enter the mixture. Maintenance of an aggregate surface road in a smooth and stable condition depends on the ability to maintain the proper amount of fine material in the surface. Excessive amounts of heavy clay binder will harden the surface during dry weather but will become soft when wet. A well graded aggregate material with adequate fines for stability will compact into a smooth surface when moist but traffic abrasion will loosen the fines during dry weather and cause them to be lost in the form of dust. Subsequently, the coarse aggregate becomes loose and is lost through abrasion. The key to successful performance is the proper maintaining of moisture.

The principal properties of calcium chloride are:

1. It dissolves readily by attracting moisture from the air and other sources.
2. When in solution, it retards the rate of evaporation of moisture.
3. The moisture films of calcium chloride are stronger than plain water.

These properties can be used to improve the performance of well graded aggregate materials when used either as a base course or as the surface of an unpaved road. Calcium chloride is used to get maximum performance from properly graded quality aggregates, not to modify the characteristics of poor or questionable materials.

A—BASE COURSES

Once a sound road structure is designed and quality base materials of good gradation are selected, performance will depend on construction procedures.

The most important factor in obtaining maximum density and uniformity,

which are necessary requirements for good performance, is the maintenance of optimum moisture during construction. Moisture limits for maximum compaction are strict. A variation of only 1 percent from optimum may reduce density by over 2 pounds per cubic foot and increases the voids by as much as 8 percent.

With rapid evaporation of water during construction, especially during hot, dry summer months, it is almost impossible to hold the moisture content at or near optimum when plain water is used. The excessive use of water wagons usually disrupts uniformity by making spots too wet and tends to disrupt distribution of fines. It is not likely that water applied to the surface will penetrate the materials uniformly. In some cases excess water will pass through a loose or segregated material and soften the subgrade.

On new construction calcium chloride should be added at the rate of 7 to 10 pounds of Type 1, or 5.6 to 8 pounds of Type 2, per ton of aggregate. The higher rate should be used during hot, dry summer periods and when construction traffic is appreciable. When the base is to remain an open surface under traffic for a period of time, such as through a fall and winter season, it is advisable to add a surface application of calcium chloride at the rate of about 1 pound per square yard.

B-UNPAVED ROADS

Material for aggregate surfaces that are to be suitably maintained in a smooth, dustless condition with calcium chloride, should be well graded from a maximum top size of 1 inch to between 10% and 25% passing a No. 200 sieve.

When used with such material, calcium chloride serves these three main purposes:

1. Eliminates dust.
2. Conserves road material.
3. Aids in producing a dense surface.

There is only one maintenance standard for unpaved roads in many secondary road systems. This consists of frequent blading and periodic replacement of worn out aggregate surfacing. The use of calcium chloride provides a solution to the problem of providing an improved maintenance standard as an intermediate measure on many miles of roads that may justify paving but funds will not be available for several years. Calcium chloride is effectively used in stage construction, making it possible to provide good maintenance until such time that the aggregate surface may be incorporated in the finished pavement as a subbase or base.

Calcium chloride is usually applied as a surface treatment to existing roads but may be mixed with new material either before or when it is spread on the road. For normal conditions, the seasonal requirement is 2 pounds of Type 1, or 1.6 pounds of Type 2 calcium chloride per square yard.

The use of calcium chloride in new construction can be accomplished by either road-mix or plant-mix procedures. The blending of the calcium chloride with aggregates and water through a pug-mill provides the ultimate in control and uniformity.

On unpaved roads, routine maintenance procedures are required plus the uniform spreading of calcium chloride. This can be done with any material spread with adequate controls to one-quarter pound per square yard. It also may be applied in solution form through a pressure distributor equipped for recirculating to thoroughly dissolve the calcium chloride.

Contractor's bid prices in several states indicate a range of \$40 to \$70 per ton of calcium chloride including mixing with aggregate base materials, or an average of about 25 cents per ton of aggregate. This cost is balanced by a reduction in the use of water and compactive effort plus insurance of improved moisture control.

Annual maintenance of unpaved roads with calcium chloride usually averages between \$400 to \$600 per mile, depending on location and traffic. This cost is partially and often completely justified by savings in aggregate and reduced blade maintenance. A 16 year maintenance study showed an average of 5 bladings required per year on unpaved roads maintained with calcium chloride, while 30 bladings per year were required on untreated roads maintained in a comparable condition. Average aggregate loss on the calcium chloride maintained roads was recorded as 23.5 cubic yards per mile per year. The average aggregate loss on untreated roads is estimated at $\frac{1}{2}$ inch per mile per year, or 168 cubic yards.

The following literature on the use of calcium chloride in graded aggregate base and surface courses is available from the Calcium Chloride Institute, 909 Ring Building, Washington 6, D. C.

“A Program for Progressive Improvement of Secondary Roads”

“Calcium Chloride for Stabilization of Bases and Wearing Courses”—Manual SM-1

“Handling, Storing and Applying Calcium Chloride”—Manual HM-1

“Maintenance Tips for Unpaved Roads”

Sodium Chloride Stabilization

Subcommittee Chairman R. L. Greenman

Sodium Chloride is normally furnished in a dry form meeting ASTM Specifications for highway use.

- a. In such form, sodium chloride consists of solid crystals which dissolve in the presence of moisture and are hygroscopic. Sodium chloride is used in various parts of the country for different purposes:
 1. as a dust palliative for open surface gravel roadways. Hardens the surface.
 2. as an aid to stabilization of base course and shoulder aggregates. Retains moisture and allows easier compaction.
 3. as a means of up-grading aggregates which are high in fines, allowing the treated mixture to be used in place of higher grade aggregates. This use of sodium chloride is still in the experimental stage.
 4. to reduce frost action in base courses.

Sodium chloride should be used preferably with well graded aggregates unless specifically added to up-grade poorer material.

The finished product should be a well stabilized soil-aggregate mixture, suitable for constructing satisfactory base or shoulder courses, providing a relatively dust free surface.

Michigan has some rather extensive experimental test sections, supplemented by laboratory studies, to obtain more information concerning optimum amounts of salt treatments to be used with different soil-aggregate combinations.

- a. Michigan normally incorporates 6 lb. of sodium chloride per ton of aggregate but for their experimental sections they have increased the quantities to 12 to 18 pounds per ton. Other states use from 15 to 20 tons per mile for a 20 ft. width of treatment. The practice in many states is to use $\frac{1}{2}$ lb. per square yard per inch of compacted depth.

Normal construction mixing equipment is used, the type depending upon whether the additive is plant or road mixed—either of which method is acceptable. In plant mix operations, additives can be mixed in a pugmill or applied to the aggregate on the belt as it is transferred to a truck.

Road-mix methods may be used depending in most cases upon the equipment that is available.

Old roads are first scarified, then graded and treated with dry salt, usually applied by controlled spreaders. The materials are mixed dry, or at existing moisture content, preferably with a mechanical mixer. Water is added to obtain optimum moisture content and the moistened mixture blended uniformly by thorough mixing. New construction is handled the same way except that no preliminary scarification is required.

In all methods, proper compaction is obtained by rubber tired rollers, supplemented by the action of construction equipment and other rollers. Compaction continues until the required density is obtained.

a. Principal controls used are directed toward obtaining a uniform blend of soil, aggregate, salt and water or brine and the obtaining of maximum density. Proper grading and drainage should also be provided, and differential compaction avoided.

The finished stabilized product has much the same appearance as a normal compacted aggregate base or surface. However, the surface tends to hold moisture and, upon drying, becomes very hard. Experience indicates that the material becomes more dense as it dries and salt crystals form near the surface. Unless being used as an open surface road, the recommended next phase of construction is priming and surfacing.

Costs of salt treatment varies considerably in different localities and are dependent upon how the material is used. Generally salt is bid per ton mixed with the aggregate. This cost is usually about 40¢-60¢ per ton of mixture.

The experiments in Michigan are expected to establish the optimum amounts of salt to be used with different quantities of fines ranging from 5 percent to 12 percent, using 12 to 18 lb. of salt per ton of aggregate.

After two winters of exposure all of the one half mile test sections of this experiment are in excellent shape.

Rock salt has recently been used to stabilize a 600 ft. by 255 ft. helicopter landing strip at Ft. Belvoir, Virginia. Although not yet surfaced this treated area is reported to be dust-free and durable under all helicopter landing operations. It is planned to surface this mixture with a 1/16 inch plastic membrane. A report of the project is being prepared by the Corps of Engineers.

The North Carolina Highway Department is using salt in base construction west of a line through the town of Hickory. This is done to prevent frost heaving in frost susceptible materials. Evaporated salt, in bags, is used for this treatment and is applied in quantities of 15 tons per mile in the top 3-inches of base for a 20 foot roadway width.

Several counties in Wisconsin are using salt for base courses in a form of state construction. The bases are left as open surface roads for a period of time but eventually are surfaced. The same procedure is also being used extensively in the towns of western New York State for their secondary roads constructed under the Erwin Plan.

Ohio has about 700 miles of salt stabilized bases in their secondary state roads system. In this program salt is used at a rate of 1/2 pound per sq. yd. per inch of compacted aggregate. Minimum required compacted depth is 4-inches. Ohio roads are primed and sealed subsequent to compaction. Ohio is planning to increase their salt treatment by one-third of the present requirement.

Colorado and Wyoming are using sodium chloride for some of their unsurfaced county aggregate roads.

Stabilization should always be thought of as an economical method of obtaining better roads. The methods discussed in this paper are proven methods. However, it must be remembered that they must be correctly used with the materials for which they are best suited.