roads in getting to and from work; and in addition, there has been a large volume of heavy truck hauling, since generally the cement used in the dams and a great deal of the construction machinery, supplies and materials have been transported over these roads. The maximum loaded truck using these roads regularly has weighed approximately 20 tons, and on some roads there have been as many as 50 vehicles of this weight per day for long periods. In very rare cases, heavy construction equipment weighing as much as 70 tons has passed over these roads. The passage of such extreme weights, however, has been limited to not more than one or two times for any road.

Stabilized granular base and light bituminous surfacing has also been used by the Authority on both state and county highway relocations on roads constructed to replace existing roads that were flooded by the various reservoirs. A thickness of 6 in. of stabilized base has been used on all State highway replacements. Thicknesses of 4 in., 4.5 in., and 5 in. have been used for county highway replacements. Traffic on the sections of state highways which have been replaced has averaged from 500 to 2000 vehicles per day, and most of these sections have had a large volume of heavy truck traffic. Traffic on county highways constructed as replacements has been light, varying from 100 to 400 vehicles per day, and with little heavy truck traffic.

As indicated in Mr. Moreland's paper, the cost of the first stabilized base construction will average approximately 15 cents per inch of depth for crushed stone, and approximately 8 cents per inch of depth for gravel. In the years 1940 and 1941, there was a slight decrease in cost to an average of about 12 cents per inch of depth for crushed stone. For roads which have been contracted for or constructed by force account after January 1, 1942, the cost has been almost double the cost which was being obtained in the years of 1940 and 1941. In fact, the cost of roads contracted for or constructed since 1942, has been between 21.5 cents and 30 cents per square yard per inch of depth for crushed stone.

MECHANICS OF CALCIUM CHLORIDE TREATMENTS

By J. F. Tribble, *Assistant Construction Engineer, Alabama State Highway Department*

The predominating type of road construction in Alabama is a bituminous surface carried by a carefully designed and controlled soil bound base course. Due to climate and the local materials available, double bituminous surface treatments on soil bound aggregate base courses are used principally in the northern half of the State. In the southern and coastal sections, sand clay and top soil base courses are used to carry single bituminous surface treatments with hot plant mixed wearing surfaces.

In general the base courses are compacted and consolidated in two layers with no specific waiting period between layers or between completion of base course and laying the bituminous surface.

On such base courses a density of at least 100 per cent AASHO is required. Experience has shown that something more is needed. To this end, several experimental roads have been constructed, are under observation, and have given from 3 to 5 years of strenuous service without serious fault.

Problem:

During the hot dry part of the construction season there is a tendency to rush the bottom layers of base courses to the required density by heavy rolling of materials containing too little moisture. The top layers, of necessity, get more thorough processing and consequently, enough moisture for clay slaking, particle lubrication and consolidation before priming. Then the bituminous surface is laid. The wet season arrives. The bottom layer goes through a softening and reconsolidating stage. The entire overlying road structure is disturbed. This internal disturbance not only causes an uneven riding surface but breaks up and shatters the primed crust of the base course. In brittle sand clay base courses a separation of the base course and bituminous surfacing results.

Approach:

Both theoretical and practical approaches to this problem have been made. It would seem at first glance that nothing more is needed than strict compliance with some definite moisture requirement. This is true of gravel and aggregate base courses but when it is practiced with sand clay it does not work.

As described in construction procedure, all sand clays have a maximum moisture content at which they can be rolled in safety against layering and rupturing. Unfortunately this moisture state for the rollers used is several percentage points drier than optimum. Correction delays are so serious that superintendents instinctively avoid wetness even approaching the rupture state. This results in the dry bottom layers which constitute the problem.

A rational analysis of the underlying causes of the difficulties experienced involves several principles now generally accepted in the field of highway engineering.. These may best be discussed briefly one at a time and then considered as a whole.

1. By nature, sand clays are densely graded and have a relatively small total surface area of particles. They, therefore, reach the hydration limit with small percentages of moisture and have a very narrow particle lubrication range. Over this range, moisture film thicknesses increase rapidly in proportion to increments of water, and since sand clays have very few large particles, uncompacted, unconfined masses rapidly lose in shear strength. Attempts at normal compaction while the shear strength is low, only result in a ruptured stack of partially compacted and sheared layers. The only remedy for this condition is to pulverize the layers, allow them to dry slightly, then make a fresh start toward compaction.

2. Within a certain range, a given soil has an optimum moisture and a maximum density for each kind and amount of compactive effort. In general, the greater the effort, the lower the optimum moisture, and the higher the maximum density.

3. Soils compacted by great compactive effort, to a required density, at a moisture content lower than the optimum moisture for that maximum density, will show a pronounced settlement under load when the internal surface tension is relieved by exposure to the consolidating effect of moisture equal to or exceeding the optimum for the required density.

4. When the surface of a sand clay base course is primed the soil in the top crust (about ¼-in.) goes through all of the fixation states accomplished by bituminous stabilization. If the crust is then shattered, being water resistant and without further binding qualities, it does not reconsolidate. The base course and the bituminous surface are thus separated and insulated.

Viewing the problem as a whole we find that in order to avoid the laminated condition described in (1), subbases and base course bottom layers have been placed and compacted with too little moisture for the density required. When they did get wet, there was movement in the base course due to settlement as described in (3), which shattered the prime as described in (4). This led to surface irregularities and failures often followed later by base course failures.

The principles involved in the problem were soon recognized and it was believed, that the addition of moisture after compaction would overcome the difficulty and leave the entire base course in an enduring state. This would not necessarily be a state of extreme density but merely a state of density and consolidation that could be expected to survive all reasonably anticipated moisture, weather and traffic exposure without material internal movement.

Moisture Curing:

As just stated, it was believed that the structural deficiency caused by dry compaction of bottom courses could be overcome by adding moisture after compaction. It was expected that this subsequent wetting would furnish pre-settlement to the layer as well as the benefits of shrinkage compaction and moisture consolidation. In order to study this problem of construction and to establish some data on a few other features the construction of a job-size experimental road was undertaken.

While this experimental road (now 40 months old) has been quite successful and demonstrated that by certain technique in moisture increments, rolling and drying, the bottom course moisture of a previously compacted base course can be increased as necessary for enduring consolidation, it, also, showed that time and relatively large amounts of water are essential and that the method is exacting on engineers and operators of equipment. Since its development, however, moisture curing has been used on numerous contract projects by supplementing standard base course specifications with the following requirement:

"The bottom course of the base course shall be brought to the minimum compaction of 100 per cent, then moistened by sprinkling until the binder fraction has a minimum moisture content of 10 per cent before laying the top course. The entire top course, after placing as otherwise required, shall be gradually and uniformly moistened before or during rolling until the binder fraction contains at least 10 per cent moisture and is compacted to at least 100 per cent of the Standard Density. It shall be held in this state, with sprinkling and rolling continued as necessary, for at least two full days. If it is subjected to satisfactory equivalent rainfall at this time, the two day moisture period may be eliminated. Beginning at this stage, a minimum three day curing period shall follow, during which time the base course moisture should be allowed to dry out gradually, retaining only enough on the surface to maintain a surface with the proper texture until when ready for priming the moisture in the top inch of base course, judging by the appearance of the surface, shall be satisfactory to the Engineer. On any section of base course that it becomes necessary to rework, the foregoing process shall be repeated, beginning at the time the required moisture and compaction are restored."

Due to war conditions, progress on the few base course projects that have been underway has been handicapped, somewhat relieving the problem, so, use of this special requirement has been relaxed. When normal progress on road construction may again be expected, the need for control of consolidation will again arise. Moisture curing or its alternate, moisture conservation by calcium chlorides, will then be an essential requirement for rapid granular soil base course construction.

Moisture Conservation Treatment:

The alternate for moisture curing of base courses is incorporation of some moisture retaining substance such as calcium chloride, in order that the natural moisture and moisture placed in the base may be conserved for bottom course consolidation after compaction is effected. Conditions offering particular advantage for this method are rapid construction long dry seasons, in areas where there is a scarcity of roadside water.

Several experimental roads were constructed during the summer of 1941 in which this moisture conservation treatment was used and particular attention given to the bottom course. One was constructed using small percentages of calcium chloride in both courses. It has since been turned into a "war road" and still shows no signs of distress.

The chief complaints of construction men are not that the treatment fails to function during dry weather but that if they are caught by a rainy season they are handicapped by a treated base course material that dries too slowly. They observe in dry weather, however, that there is an immediate toughening of what would otherwise be a friable brittle base course material and that the cost of the treatment is only slightly higher than an all-water process though the rate of progress is noticeably faster.

Mechanics of Treatment:

Moisture conservation treatment is not stabilization. It is designed to insure the uniform presence of sufficient moisture for compaction and consolidation purposes to alleviate the seasonal sprinkling equipment shortage or strain, and to remedy, by removing the necessity for it, some of the ills of surface leaching.

This treatment is conducted under the requirements of normal base course construction specifications where calcium chloride is admitted as an alternate to or, as in this case, as an assistance to water consolidation. Where calcium chloride is available for treating only one course of the base course, it will, in general, be used in the bottom course. A maximum rate of use of 1 lb. per sq. yd. for each 4-in. course is recommended and unless otherwise provided the 1-lb. per sq. yd. rate will be used. This is the minimum rate recommended by the calcium chloride producers for mixing but it should be borne in mind that it is not proposed that enough calcium chloride will be used to change seriously the normal procedure or technique of base course building. Concentrations such as produced by surface applications of calcium chloride should be avoided on bases that are to be primed the same summer.

The following procedure is recommended for carrying out the moisture conservation treatment by road-mixing:

Place in the usual manner all component materials for one layer of base course.

Do all of the usual operations of pulverizing, blending, and bringing the material to a state of uniformity. This is best done in a field dry state.

Work the width of material to be treated into a windrow of uniform section, then flatten it down into a layer of some uniform thickness, preferably the maximum the mixing plows or harrows willl turn over comfortably. Ordinarily this will spread into a width of 16 or 20 ft.

With the layer flattened down and struck off plane, place the sacks of calcium chloride flakes at whatever interval is calculated for the rate of treatment provided.

The sack of calcium chloride is now opened and broadcast or "snowed" over the section of the layer prepared for it by any means by which it can be done uniformly. Where it is done by hand, broadcasting from the sacks with shovels is ordinarily satisfactory. Mechanical spreading by use of agricultural lime spreaders is desirable where such equipment is available, and contributes to progress.

Using the same base course mixing equipment dry-mix the calcium chloride into the entire layer. If the work is such that the layer can be left at this stage to take up moisture from the humid night air, it will effect a considerable saving in water and time. The final windrows of the motor patrol used in mixing and shaping should leave the material on each side on or near the shoulders.

After all of the material has been windrowed to the sides and it is clear that it has been uniformly mixed it is then bladed back toward the center of the roadway in thin layers. Water is added by sprinkling until the moisture content is uniformly near the optimum (on the dry side) for the base material. Initial rolling is done at this time with a sheep's foot roller while watering. The material is then rolled until the roller is "walked out" of the material.

When this "walking out" has been accomplished the layer should be bladed and reshaped closely to section. This removes any irregularities in surface, or unequal compaction planes that have developed. A surface of uniform texture and density is thus presented for final rolling. This should be done with a pneumatic tired roller of light or medium weight. The roller weight can be increased as compaction is obtained.

Before placing any further layers rolling accompanied by the addition of water as needed, is continued until at least 100 per cent of standard compaction (for the treated mixture) has been attained. Some rain at this stage would help, but this being an expediency for dry weather, rain is ordinarily out of the question.

The top course should be finished and shaped in the same way. If it, too, has calcium chloride treatment, the only difference that will be noticed is the arrest of rapid evaporation.

While most sand clays are inclined to rupture when rolled too wet, or even at a moisture content near optimum they should always be gradually and uniformly moistened to a moisture content near optimum, then rolled and compacted while drying out. In this manner, advantage is taken of the shrinkage action of the base which is increased by the applied power of the rolling.

Unfortunately all sand clay materials are highly susceptible to "scabbing" or "scaling." After a layer is once compacted and a surface glaze forms over it any subsequent blading of material over it while it is wet will cause this lamination. In fact, blading lightly over the compacted surface of a base when it is too wet is the chief cause of scabbing. When it becomes necessary to reshape the surface of a base by blading, the utmost care should be taken to work it only in a dry state, certainly with a moisture content not over 6 or 7 per cent. One must also be sure that the surface glaze has been broke over the entire area to be reworked, or lamination will invariably result when moisture is applied and the base rerolled. Usually when a section of base gets out of shape due to rain or uncontrolled traffic, it often proves more economincal to scarify lightly and completely rework it rather than try to blade it back into shape.

After the density and curing of the base is satisfactorily established and accepted by the engineer, the finished base is then clipped or hard bladed with a motor patrol. This hard blading removes any small surface irregularities, small scabs, surface glaze, and trues up the final surface. Immediately following this hard blading the base is sprinkled lightly and rolled with a rubber tired roller to further iron out and smooth the surface for priming.

The surface of a base course that has been lightly treated with calcium chloride has an attraction for prime or other bituminous materials that is even greater than an untreated one.

As a base dries out prior to priming, the wet and dry spots on the surface are quite evident. Prime should be applied immediately, when the entire section shows that it is uniformly dry.

Unlike base materials containing aggregates, it is absolutely essential to keep all traffic off of sand clay bases after rains until they have dried enough that the surface does not become deformed or marred. After priming, the prime should be allowed to lie open, where possible, until it has thoroughly dried. This usually takes three or four days. Where detours are unavailable the freshly primed base may be sanded and used immediately.

FUNDAMENTAL FUNCTIONS OF CALCIUM CHLORIDE IN MOISTURE CONSERVATION TREATMENTS

The principles of behavior of base course materials into which calcium chloride has been mixed are based upon the presumption that these mixtures possess satisfactory mechanical gradation with enough fines to assure slight cohesive and capillary action. These features are generally provided by base course requirements.

In connection with certain such base courses to be constructed during the hot dry summer season, calcium chloride may be used at a minimum rate as a mixture with the materials of at least the bottom course of the base. This is intended more as a means of relieving some of the seasonal hazards and handicaps of construction and as an aid to uniformly satisfactory results than as a stabilization agency for materials that, under favorable construction conditions, need no stabilization. Such use has just been discussed.

Our experience in Alabama has demonstrated to our satisfaction that with, a given soil bound base course material, calcium chloride, when used as described, performs one or all of the following beneficial functions:

Reduces Water Requirements:

1. Attracts moisture from the air.
2. Retards evaporation.
3. Keeps the soil moisture constant, within narrow limits.
4. Makes the soil slightly alkaline and so reduces the thickness of the moisture films the soil particles will attract.
5. Thinner moisture films not only decrease the thirst of the soil for moisture but reduce the percentage at which the optimum moisture state is attained.

Less Rolling Necessary, Results Better:

1. Since the moisture films are made thinner, there is less resistance to squeezing or tamping the soil particles into position, and so lets them fit more closely together.
2. Greater density may be obtained and maintained with less compactive effort and at moisture contents one-third lower. (Proctor compaction tests indicate standard densities 2 to 6 lb. per cu. ft. greater with consistently lower optimum moisture contents.)
3. Since the calcium chloride draws a large part of the moisture needed for compaction from the air, moisture may be supplied to parts (such as several inches below the finished road surface) that would be inaccessible to wetting by any ordinary amount of sprinkling. This is an immediate help to the rolling operations as the full advantage of shrinkage compaction is effected at once. It is also a great aid toward uniformity in density and lasting riding surfaces.

Makes the Base Stronger and Tougher:

1. Thinner moisture films within a soil mass tend toward greater surface tension. Greater surface tension promotes cohesion and cohesion toughness. Both interlocking and toughness contribute to shear strength and both are enhanced by the calcium chloride that made the moisture film thinner and keeps it thin and present.
2. The whole base course structure is strengthened by insuring the consolidation of the bottom course and avoiding a bottom course that is so poorly or unevenly consolidated that whenever it is

exposed to sufficient moisture melts and runs together, possibly seriously and permanently damaging a well constructed top course and prime.

3. The natural bonding action is preserved and the base strengthened (especially when there is calcium chloride in both courses) by eliminating much of the repeated sprinkling made necessary by rapid evaporation of moisture by the sun. This repeated sprinkling leaches the binder clay toward the bottom and leaves a sandy brittle surface crust to receive the prime. The calcium chloride treated base tends to restore these binders through capillarity, and is in a better condition to shed water during a rain and, consequently, is easier to maintain in shape.

Accelerates Seasoning Processes:

Presence of constant moisture causes milky mineral gels to exude from most rock fragments. These gels form a small film of natural cement on the surface of the soil particles which, together with continued shrinkage compaction, greatly enhances the structural stability of the base course. Calcium chloride promotes and accelerates this action.

Extends Some Benefits to Both Courses:

Calcium chloride in solution with the moisture of the bottom layer of the base course will migrate to some extent to the top layer through capillarity and rising vapors. This will tend to improve the top course even after the bituminous surface is placed and will accelerate the knitting together of the base and the surface mat.

Affords Freeze Protection:

Decreased soil moisture film thicknesses and increased consolidation, together with the brine action, lower the susceptibility of the base to freeze damage during severe winter weather. This function is an advantage particularly during the first winter.

PROGRESS REPORT OF SPECIAL PROJECT ON STRUCTURAL DESIGN OF NONRIGID PAVEMENTS

SURVEY OF SUBGRADE MOISTURE CONDITIONS

By Miles S. Kersten, *Special Investigator,*
Highway Research Board

SYNOPSIS

Information on subgrade moisture contents, chiefly below flexible pavements, was collected from several State Highway Departments, most of the data being received from States in the Mississippi Valley. An attempt has been made to assemble this information so as to give a general picture of subgrade moisture conditions and to study the variations which occur.

The moisture values are expressed in three different ways: percentage of saturation, percentage of plastic limit, and percentage of optimum moisture content. It was found that the percentage of saturation of the soils varies, in general, with soil texture, being high for clays and progressively less for clay loams, loams, and sandy loams. The moisture content of the fine textured soils, such as clays, generally exceeds their plastic limit; that of loessial silty soils is usually equal to or just under the plastic limit; and that of sandy loams rarely exceeds and is generally less than this constant. A substantial proportion of the moisture values in all textural classes of soil was in excess of the optimum moisture contents.

Only one project showed a marked change of moisture content over a period