A Limestone-Calcium Chloride Stabilized Base

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TO: D. V. Terrell  
Director of Research

For the past three years the Research Division has been concerned with factors that contribute to poor riding qualities in high-type flexible pavements, and with construction procedures that may overcome or eliminate these objectionable qualities. One of the conditions that showed up early in our observations was the lack of reasonably constant cross sections in the pavements. This was particularly true of those with waterbound macadam bases, and it was attributed to speed and mechanization which are considered essential in present day construction.

In a report\(^1\) on this subject in December, 1950, we concluded that some mechanical means capable of finishing the base to a desirable and constant section was needed, because the base was at fault and conventional paving machines were incapable of removing irregularities when the bituminous surfaces were placed. At that time several approaches toward overcoming finished base irregularities were suggested, and a test road with different sections was recommended. Among the approaches was a blade-spread plant-mix binder course to provide uniform sections prior to placement of the surface course with a mechanical paving machine.

The test installation was discussed but never accepted by the Division of Design and the District Office of the Bureau of Public Roads because some of the recommendations were considered impractical. Blade spreading of binder material on a resurfacing project was tried with considerable improvement in riding qualities of the road\(^2\) but despite this success the blade-spread binder was rejected as impractical for use on waterbound bases when the subject was again discussed. At that time Mr. Gilbreath called attention to blade-spread aggregate mixes containing calcium chloride, and expressed an interest in having these tried as a means for finishing bases and possibly as a full-depth alternate to waterbound macadam.

At the beginning of this construction season the Rosemont Underpass (State R.S.) project near Lexington offered a convenient location for a trial base of this type. The pavement was designed with two 2-inch courses of blade-spread material as a part of the base, and by a letter of March 24, 1952, Mr. Neiser asked that the Research Division observe and report on the work. Attached is the requested report as prepared by W. B. Drake who made our observations on the job.

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\(^1\) Measurements of Surface Irregularities and Riding Qualities of High-Type Bituminous Pavements, Report No. 2, December, 1950.

\(^2\) Observations on Seal Coats, Tack Coats, Penetration Macadam, and Blade Spread Hot Mix in 1951, December, 1951.
The observations show that base material of this design and placed in the manner described is very dense; it appears to have good structural quality; and it is not unusually difficult to mix and lay. The surface contour which can be obtained by blade spreading is considerably superior to the contour of waterbound macadam placed in what is now the customary way. More machinery but less manpower is required for the new type base than for the waterbound macadam base. This advantage could become greater on longer projects particularly with contractors who are familiar with the work.

Specifications for the blade-spread base were improvised as plan notes for the Rosemont project and others that have been let to contract thus far; but as a result of experience gained on this job and considerations that have gone with it, a recommended Special Specification for Dense-Graded Aggregate Base With Calcium Chloride has been prepared and appended to this report. Most of the essential features of the Rosemont project have been retained, although there are some departures in the provisions for deeper courses, if desired, in plant mixing, and one or two other similar items.

It will be noted particularly that there has been a change from the designation Calcium Chloride Stabilized Base in order to avoid the connotation of questionable value which has become attached to stabilization. In my opinion the calcium chloride does not stabilize the base through any chemical or physical change in the materials themselves, but rather it retains the moisture which enables the base to remain intact particularly during the construction period.

In addition to the Rosemont project, there are five or six projects (Federal Aid) in the current program in which one or two courses of base are of the dense-graded blade-spread design. Hence, by the end of this year we should have a good basis for judging this type construction as a standard procedure. In the meantime, it would be well if some project were given a full-depth base of this design so we would know how to regard it as a base within itself rather than as one part of a combination base.

Respectfully submitted,

L. E. Gregg
Assistant Director of Research

Copies to: Research Committee
Mark Galbreath (4)
Commonwealth of Kentucky
Department of Highways

Report No. 1

on

A LIMESTONE-CALCIUM CHLORIDE STABILIZED BASE

Fayette County RS 34-304
Rosemont - U.S. 27 Road

by

W. B. Drake
Research Engineer

Highway Materials Research Laboratory
Lexington, Kentucky

August, 1952
INTRODUCTION

This report is mainly concerned with the calcium-chloride stabilized portion of a combination base. A 4-inch course of waterbound macadam was placed over a 1-inch insulation course overlying an existing traffic-bound stone surface. The next 4 inches of base above the waterbound material consisted of two 2-inch layers of calcium-chloride stabilized limestone of a design not used here-tofore by the Department.

Bituminous concrete binder and surface courses laid over the base brought the total mat thickness to more than 11 inches. The surface width was 30 feet, and the length of the project was 1.1 miles.

Although the road is located about 2 miles south of the Lexington city limit, it serves an area which is essentially urban. In addition it is a link between U.S. 27 and U.S. 68 as shown in the sketch map of Fig. 1. The traffic volume anticipated in the near future is approximately 1500 vehicles per day of which a fairly large percentage will be commercial because of the business and industrial zone nearby and the convenience this route offers in avoiding congested streets within Lexington carrying U.S. 27 north and south.

From an investigational standpoint, interest was centered on the so-called stabilized courses, not only because of the unusual stone gradation involved but also the feasibility of mixing and spreading these courses with patrol graders. This process was under observation as a means for simplifying macadam construction and improving the riding qualities of the finished pavement. The length of the project limited possibilities for comparison that would apply to simplified construction procedures; however, the length was not considered an important influence on placement of the base in its relation to improved riding qualities.
Fig. 1 Project Location
ROSEMONT - U.S. 27 ROAD
CONSTRUCTION PROCEDURES

The course of waterbound macadam was placed in the normal manner. Wooden forms were set along the edge of the base and the large No. 1 stone was spread with a mechanical spreader. (See Fig. 4). This stone was rolled and No. 10 screenings were spread with tailgate spreader boxes as shown in Fig. 5. These screenings were broomed and rolled dry, then wet thoroughly and rolled and broomed further (See Figs. 6 and 7). The completed waterbound course was tight and apparently well keyed.

The stabilized courses were constructed of limestone for which there were special gradation requirements as outlined in Fig. 2. Because the limestone was very dense and hard, it was necessary to add fines to crusher-run stone to secure this gradation. The mixture consisted of 75 percent material crusher run through the 1-inch screen and 25 percent fine agricultural limestone. Figs. 8 and 9 illustrate the way in which the two materials were placed on the road separately.

After the aggregate for a 2-inch course had been placed, it was watered and immediately calcium chloride was applied with a fertilizer spreader at the rate of one pound per square yard. This operation is illustrated in Fig. 10. Two passes of the spreader were made for each application, and an obviously uniform distribution was obtained by this method.

Mixing operations began immediately after the calcium chloride application. The mixture was windrowed to the side of the road, then with successive passes of the patrol grader this material was rolled along the blade to the opposite lane (See Fig. 11). More water was added as needed. The final consistency was about that of a dry concrete mix, with moisture contents averaging about 8 percent. Usually after the windrow had been moved two or three times, a thorough mixture was obtained.

Material was then brought to the center of the road and laid out. Edges were kept straight by using an edger attached to the mold board of the blade as shown in Fig. 12. During the laying out process, a pneumatic roller (Fig. 13) was operated continually not only for compaction but also to emphasize irregularities that carried through from the waterbound course or developed in the placement of the stabilized course. Pronounced irregularities could be taken out readily by turning the blade square with the road and "square blading" for a short distance.
Fig. 2 Special Gradation For
Calcium Chloride Stabilized Courses

<table>
<thead>
<tr>
<th>SIEVE SIZE</th>
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<tr>
<td>3/4 INCH</td>
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<td>NO. 10</td>
<td>25-50%</td>
</tr>
<tr>
<td>NO. 40</td>
<td>15-30%</td>
</tr>
<tr>
<td>NO. 200</td>
<td>5-15%</td>
</tr>
</tbody>
</table>
Fig. 3. Aggregates used in base construction.
No. 1 stone in place for the 4-inch course of waterbound. A 1-inch insulation and leveling course consisting of No. 5 and No. 10 stone in equal proportions can be seen in the foreground. Edge boards were removed immediately following the placement of coarse stone and prior to rolling. Three 10.5-foot lanes were placed, the center lane being the last to go down.

Fig. 5. Spreading No. 10 stone for waterbound fines. Stone of this gradation spread uniformly through tailgate boxes.
Fig. 6. Brooming and rolling the dry fines into the No. 1 stone.

Fig. 7. Watering, brooming and rolling on the waterbound construction. Note slurry in front of the broom.
Fig. 8. Spreading the coarser of two aggregates used for stabilized course construction. This stone was crusher run through a 1-inch screen with approximately three percent passing the No. 200 screen. Two passes of the Adnum spreader were made in placing enough stone for a 2-inch course. This facilitated a uniform spread and helped to overcome segregation that occurred in the truck bed during the haul from quarry to job.
Fig. 9. Placing finer aggregate for stabilized course over the crusher run material shown in Fig. 8. Because of the insufficient quantity of material finer than the No. 200 mesh in the first stone placed, it was necessary to add fines which are normally sold for agricultural lime from this quarry. This fine fraction represented 25 percent of the total aggregate.

With softer stone, and particularly at plants having a hammer mill, a crusher run aggregate having the desired gradation could be produced and thus eliminate this second step in the application of stone.
Fig. 10. Water was applied to thoroughly wet the stone prior to application of calcium chloride. This was done to assure an adequate moisture content and prevent segregation as well as facilitate manipulation during the mixing process that followed. Two passes of the spreader were made to apply one pound of calcium chloride per square yard in each of the courses.

At this stage it is desirable to begin mixing as early as possible, particularly during rainy periods when there is danger of washing the chloride from the thinly spread stone.
Fig. 11. Mixing the stone, calcium chloride, and water with a patrol grader. The mixture was windrowed, then portions of the windrow were rolled along the blade across the road. Thorough mixing was accomplished after several passes with the patrol graders.

Fig. 12. Placing the edge of the stabilized base with an edge board that was attached to the blade for the last few passes in the laying-out process. This attachment could be easily removed or replaced. A very neat and uniform edge was obtained in this manner.
Material removed from high spots was carried to the depressions. Finished rolling of the stabilized base was accomplished with the pneumatic and a 10-ton three wheel roller in combination, as illustrated in Fig. 14. Final passes were always made with the three-wheel. After rolling was completed the base was sprinkled and allowed to cure. If an irregularity had been overlooked, reshaping and rolling as late as two days after placement was possible. It was necessary to wet the mixture thoroughly in order to recompact it after reshaping.

The stabilized base was placed, mixed, laid out, and rolled in approximately 2000-foot sections, with the first 2-inch course finished throughout the project before the second course was begun. There was no particular waiting period between completion of the first and the beginning of the second course; however, following completion of the second course a 10-day curing period was allowed before the RT-2 prime was applied.

There was no brooming of the base prior to priming even though there was some floater material created by the reshaping operations in a few places and by passing traffic which used the road during the waiting period. One section about 1500 feet in length had an unusual amount of floater, and in order to tack down that material satisfactorily there was an overrun of 2240 gallons in the prime. Generally, the specified amount of 0.25 gallon per square yard of RT-2 was sufficient. Application of the prime is illustrated in Fig. 15.

The binder and surface courses were placed shortly after priming. Fig. 16 shows the Class I, Type A (course textured) binder being placed approximately 1½ inches thick. The surface course was Class I, Type B (medium texture) approximately 1½ inches in thickness.
Fig. 13. Pneumatic roller in operation. The load on each tire was approximately 2000 pounds. This roller was used during the laying-out process not only for compaction but to show up minor irregularities. These rough places were then knocked off with the patrol grader and smoothed out by further rolling.

Fig. 14. Finished rolling using both pneumatic and steel wheel (10-ton) roller. The rollers worked together until the final pass at which time the pneumatic roller was removed.

The second course of stabilized base was started as soon as convenient after the first course has been completed, but a 10-day curing period was allowed between the completion of the top base course and application of prime for the bituminous surface.
Fig. 15. Applying RT-2 for prime over the stabilized base. About 0.39 gallon of RT-2 per square yard was used. This tacked down the small amount of floater present.

Fig. 16. Laying bituminous binder mix. An Admun paver was used to place both the binder and surface. The pavement consisted of Class I, type A (coarse) binder at the rate of 152 pounds per square yard covered by Class I, Type B (medium) surface placed at the rate of 126 pounds per square yard.
Fig. 17. Completed pavement looking west into Southern Railway underpass.
OBSERVATIONS AND TEST RESULTS

Observations and tests were directed mainly toward four aspects of the work:

1. Gradation of the stone in the stabilized courses.
2. Density of the completed stabilized courses.
3. Profiles and sections of the road at various stages of construction.
4. Relative requirements of men and machines for the waterbound and stabilized base course construction.

The intent of this information was to show whether the desired gradation could be maintained; whether the indicated structural capacity of the stabilized base was adequate; whether improvement in contours of the pavement could be brought about with the new type base; and whether the new type base was economically sound.

There were numerous other observations and records most of which were best obtained photographically. From that standpoint a complete record of operations was made with still photographs, and in addition 16 mm. movies were taken from time to time as a means of realistically illustrating the important features of the work and the results produced. Finally, there were incidental tests - such as those pertaining to soils - which were included as part of the record.

The pavement design was based on estimated subgrade bearing values since soil samples from the existing grade were taken after the project was under contract. For the lowest CBR value recorded (See Table 1) a total thickness of approximately 12.5 inches under Class V traffic was indicated by the CBR design curves* normally used as a guide for flexible pavement design. The total thickness of approximately 11 inches appears more than adequate in view of the fact that the bearing values were generally high and the anticipated traffic does not warrant a Class V rating.

* As published in Fig. 24, page 51, University of Kentucky Engineering Experiment Station Bulletin No. 13, "Investigation of Field and Laboratory Methods For Evaluating Subgrade Support in the Design of Flexible Pavements," Sept., 1949.
Here again it was realized that pronounced variations in sections at intervals of less than 50 feet account for the poorest riding qualities, but limitations in time and personnel made it a choice of sections at closer intervals throughout a 100-foot distance or sections at greater intervals over a longer distance.

A stringline stretched between blue tops, and measurements down to the surface, were used in the determination of cross sections. Measurements to the nearest 1/8 inch were made on the top of the waterbound course, the top of the second stabilized course, and the finished pavement surface. Plots of the sections are contained in Fig. 19.

Invariably the blade-spread courses had a contour which was much more uniform than the contour of the waterbound course, and almost invariably the newly formed surface more nearly approached the theoretical design section that the finished pavement was supposed to meet. In one or two instances there was very little crown in the stabilized courses.

Generally speaking, two passes of the Admnum paver laying the bituminous courses did not improve the sections. At Stations 35.50 and 36.50, the sections of the finished pavement were decidedly poorer than the corresponding sections of the stabilized base. It appears that settings of the paver screed were unnecessarily altered at these locations, particularly on operations in the center lane. Despite this and other influences, the few measured sections indicate that with the blade spread courses in place the paver had a better surface on which to operate than it would have had with the waterbound course alone.

**Manpower and Machinery**

Insofar as possible, records were made to determine the equipment and personnel requirements for construction of each of the two types of base. Approximately the same quantity of stone was required for each 4-inch course and essentially the use of trucks and similar equipment was the same also. Consequently, these factors and some others such as spreader boxes for fine aggregate were disregarded in the summation of required manpower and machinery.
Fig. 19a. Cross sections taken over waterbound base, stabilized base, and surface measured to nearest 1/8 inch. Horizontal scale: 1 inch equals 4 feet; vertical scale: 1 inch equals 2 feet. Sections were taken from a string line stretched between blue tops. The second section at each station was blade spread. There were two passes of the Adnum paver above the blade spread course. Typical section is shown in red.
The various pieces of equipment were tabulated and a record was made of the days each piece was in use. Similarly records were made of the labor by class and by time spent. This compilation is given in Table 4. While the stabilized courses required more equipment-hours than did the waterbound construction, their requirement in man-days of labor was less than half that of the waterbound construction.

On the basis of rental rates applicable to equipment operated by the Department and minimum wage rates applicable to this particular project in Fayette County, the relative costs on the factors in which the two types of construction differed were $4536.00 for the waterbound base and $3464.40 for the stabilized base. This comparison, of course, applies only to the 1.1 miles of construction in this instance, and it contains several approximations. For construction in other parts of the state, the relative costs would at least vary in accordance with variations in the minimum wage rates.
Table 4. Equipment and Personnel Required For The Two Types of Base

### Equipment

<table>
<thead>
<tr>
<th>Stabilized Base</th>
<th>Days Used</th>
<th>Waterbound Base</th>
<th>Days Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Adnun Spreader</td>
<td>7</td>
<td>Apasco Spreader</td>
<td>9</td>
</tr>
<tr>
<td>2. 3-Wheel Roller</td>
<td>8</td>
<td>3-Wheel Roller</td>
<td>16</td>
</tr>
<tr>
<td>3. Pneumatic Roller</td>
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<td>Water Wagon</td>
<td>11</td>
</tr>
<tr>
<td>4. Water Wagon</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Grader</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. CaCl₂ Spreader</td>
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<tr>
<td><strong>Total Equipment Days</strong></td>
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### Personnel

<table>
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<th>Man Days</th>
<th>Waterbound Base</th>
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</tr>
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<tbody>
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<td>Supt. &amp; Foreman</td>
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<tr>
<td>2. Skilled</td>
<td>28</td>
<td>Skilled</td>
<td>46</td>
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<tr>
<td>3. Semi-skilled</td>
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<td>Semi-skilled</td>
<td>65</td>
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<tr>
<td>4. Unclassified</td>
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<tr>
<td><strong>Total Man Days</strong></td>
<td><strong>109</strong></td>
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This Special Specification No. ___ covers the materials requirements and construction methods for dense-graded aggregate base containing calcium chloride admixture. It shall be applicable when indicated on plans, proposals, or bidding invitations.

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DENSE-GRATED AGGREGATE BASE WITH CALCIUM CHLORIDE

1. DESCRIPTION. This base course shall consist of dense-graded crushed stone or crushed slag mixed with calcium chloride. The materials may be mixed on the road or at a stationary plant and placed on the road in accordance with these specifications and in conformity with the lines, grades, and typical cross-section shown on the plans.

2. MATERIALS.

   A. Mineral Aggregate. Aggregate shall consist of a graded mixture of limestone, sandstone, or slag; but in any case shall be composed of sound, tough, durable fragments. The final mixture shall conform with the requirements of Article 3. The quality of the stone or slag used in the mixture shall meet the requirements of Article 7.4.2, 7.4.5, or 7.4.3 in the 1945 Standard Specifications.
B. Calcium Chloride. Calcium chloride shall conform to the requirements set forth in Article 7.29.0 of the 1945 Standard Specifications.

C. Water. Water shall be obtained from a source approved by the Engineer.

3. COMPOSITION. The composition of the final mixture of graded aggregates shall conform to the following limits by weight:

<table>
<thead>
<tr>
<th>Sieve Size*</th>
<th>Per cent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch</td>
<td>100</td>
</tr>
<tr>
<td>3/4 inch</td>
<td>70-100</td>
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<tr>
<td>3/8 inch</td>
<td>50-80</td>
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<tr>
<td>No. 4</td>
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<td>No. 10</td>
<td>25-50</td>
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<tr>
<td>No. 40</td>
<td>15-30</td>
</tr>
<tr>
<td>No. 200</td>
<td>5-15</td>
</tr>
</tbody>
</table>

The fraction passing the No. 200 sieve shall be less than two-thirds of the fraction passing the No. 40 sieve.

4. CONSTRUCTION METHODS.

A. Equipment. The methods employed in performing the work, and all tools, machinery and other equipment used in handling materials and executing any part of the work shall be subject to the approval of the Engineer before work is started and, whenever found unsatisfactory, shall be changed and improved as required by the Engineer. All tools, machinery and other equipment used must be maintained in a satisfactory working condition.

B. Preparation of Stable Subgrade or Base. When the material in the subgrade consists of a firm soil or traffic-bound macadam, it shall be bladed, shaped, or cut to the specified grade and cross-section unless otherwise provided on the plans. When the dense-graded aggregate base is being placed over an existing aggregate base such as waterbound macadam, no additional preparation of the existing base shall be required unless specified for on the plans.

Any unsuitable material, including solid rock and boulders, encountered in the treatment of the existing subgrade or base shall be removed and replaced with material acceptable to the Engineer and any such removed material, and the material replacing it, shall be measured and paid for as roadway excavation. Any additional earth needed solely to bring the existing subgrade or base to the proper grade or cross-section shall be placed as the Engineer may direct and such additional earth shall be measured and paid for as roadway excavation.

* Sieves for Gradation Analysis shall have square openings and shall be the U.S. Standard Series for No. 4 and finer.
C. Preparation of Unstable Subgrade or Base. Treatment to be as provided in the plans or special provisions pertaining to the project.

D. Use of Existing Aggregate. When provided in the plans or proposals, loose aggregate present as floats on an existing base may be incorporated into the final dense-graded aggregate mixture either wholly or in part, if found suitable. All such materials shall be bladed onto the shoulder of the road and left in windrows for subsequent use and measurement.

When the gradation of the aggregate thus obtained is found by sieve analysis not to meet the requirements hereinbefore prescribed for the final mixture, or when additional material is necessary to provide the total thickness called for in the plans, supplemental aggregate shall be delivered and distributed in sufficient quantity to produce, in combination with the existing aggregate, a compacted layer of desired thickness.

The existing material, the supplemental aggregate, and the necessary calcium chloride, shall then be thoroughly mixed together as hereinafter described.

E. Placing Materials. Aggregate shall be delivered and distributed by means of approved mechanical aggregate spreaders in sufficient quantity to produce a desired layer of compacted mixture which will meet all the gradation requirements and physical test properties as hereinbefore prescribed. Calcium chloride shall be uniformly distributed by mechanical means.

F. Road Mixing of Aggregates and Calcium Chloride. If it is necessary to use two aggregates to obtain the desired gradation, the coarser of the two shall be spread on the prepared subgrade first. The finer aggregate shall then be placed over the coarser material, and water applied immediately. The calcium chloride in quantity specified on the plans shall then be spread. The aggregate and calcium chloride sufficient to give the desired depth of stabilized course shall be thoroughly mixed by alternately spreading and windrowing the material, or by multiple blade maintainers, or by a traveling mixer. Water shall be added as needed to maintain optimum moisture content* during mixing.

G. Plant Mixed Materials. This item shall include material mixed in a central mixing plant and transported to the road for spreading.

The equipment used for mixing the materials shall be so designed, operated, and controlled as to deliver a uniform and intimate mixture of all the ingredients, including water. The mixing equipment shall be of such design that a thorough and uniform mixing of the material is accomplished with a single passage of the material through the mixer.

* This moisture content for the prescribed gradation of limestone is about 8 per cent.
H. Spreading and Compaction. The stabilized mixture shall be spread in layers not to exceed four inches compacted, or as specified on the plans. A pneumatic type roller with at least 1000-pounds loading per tire shall be used during the spreading process. Irregularities that develop during this initial rolling shall be corrected with the patrol grader or multiple blade maintainer during the rolling process. Edges shall be kept true to line in the spreading operation. The mixture shall be kept at optimum moisture content prior to and during compaction, and rolling with the pneumatic roller shall continue until the base has reached maximum density. Finished rolling shall be accomplished with a 10-ton three-wheel roller. A curing period of from 7 to 10 days shall elapse before placement of a succeeding layer of base or priming for bituminous surface.

I. Shoulders. Earth shoulders, when shown on the plans, shall be constructed as provided in Article 2.9.0 of the 1945 Standard Specifications.

J. Sampling. Samples of the finished mixture, either from the windrows or from the compacted mat, shall be taken at intervals not exceeding 2500 feet and submitted to the laboratory.

5. METHOD OF MEASUREMENT AND BASIS OF PAYMENT.

A. Method of Measurement. The quantities to be paid for shall be the number of tons of aggregate delivered; the number of cubic yards of roadway excavation as set out in Article 4-B and 4-I; and the number of tons of calcium chloride used. Deductions will be made for any moisture in excess of three (3) per cent of dry weight of granular material.

All materials for which measurements are obtained by weight shall be weighed on truck scales of e type as set out in Article 1.9.9-d of the 1945 Standard Specifications.

B. Basis of Payment. The accepted quantities for "Dense-Graded Aggregate Base With Calcium Chloride" thus measured shall be paid for at the contract unit price; per ton for "Aggregate"; per cubic yard for "Roadway Excavation"; per ton for "Calcium Chloride." Said items shall include all mixing, shaping, wetting, compacting, and applying calcium chloride, which prices shall be full compensation for furnishing, hauling, and placing all materials, and for all labor, equipment, tools, and incidentals necessary to complete this work.