A Water-Bound, Dense-Graded Aggregate Base

Ellis G. Williams
Kentucky Highway Materials Research Laboratory
Report No. 1
on
A WATER-BOUND, DENSE-GRADED AGGREGATE BASE
Casey County Project F' 505 (1)
Phil-Pine Grove Road
by
Ellis G. Williams
Research Engineer
December, 1953
MEMO TO: D. V. Terrell  
Director of Research

Since the time of its inception on the Rosemont - U.S. 27 Underpass Project* in 1952, the so-called dense-graded aggregate base has been used on several different construction jobs. In many instances it has been a part of a combined base as a provision for leveling above or below water-bound macadam, although there are a number of roads on which a single course of dense-graded aggregate was laid over existing traffic-bound material prior to surfacing with a bituminous pavement.

To the best of my knowledge, all the dense-graded base placed in 1952 contained calcium chloride, and the calcium additive has been generally considered a part of this type construction. However, when Special Specification No. 58 covering this class of base was developed, the Specifications Committee made particular effort to provide for other additives, and more so to provide for construction without any additive.

In an effort to examine the merits of a dense-graded base without an additive, the Division of Design chose for study one of several projects of this type let to contract during 1953. This project consisted of approximately 11.6 miles of single course base and surface construction on the Phil-Pine Grove Road in Casey County. The Research Division was asked to follow the work and make records of construction features and other conditions that might have a bearing on the performance of the road. An initial report, prepared by Ellis G. Williams and applicable mainly to construction, is attached.

* "A Limestone-Calcium Chloride Stabilized Base," Report No. 1, August, 1952.
Several significant points are brought out, and most of them are summarized as numbered observations and conclusions beginning on page 11. A satisfactory procedure for placing the material so that it became firm and still did not ravel excessively under construction traffic was worked out as the job progressed. There is no reason to believe that the base will shift under reasonable traffic loads, nor that it will soften. In other words, from the standpoint of actually accomplishing construction of dense-graded bases without calcium-chloride additives, feasibility has been shown.

The records leave some doubt about the relative structural qualities of dense-graded bases with and without calcium chloride, mainly because of differences in the gradation and type of stone used on this project as compared with stone used in other projects where calcium chloride was added. Both the density values and the observed condition of the base, particularly with regard to operation of equipment spreading the overlying bituminous mix, gave the impression that more could have been accomplished under different circumstances.

Obviously the relative merits will not be proved solely by comparisons between this and other projects, but a great deal of pertinent information has been obtained. Best of all, the features observed in several of these projects have led to a point of view which Mr. Williams brought out to a limited extent in his reference to triaxial tests. It can be reasonably assumed that aside from the obvious effects of gradation on the binding qualities of a stone in bases of this type, cementation varies with differences in the composition of the stone, and possibly the extent to which cementation can be facilitated by calcium chloride varies with changes in the stone also. As indicated by Mr. Williams comments at the bottom of page 10 of the report, an extensive series of laboratory tests directed toward cementation values is proposed. The desirability and extent of this approach will be brought up for more specific discussion during the meeting of the Research Committee in January.

Respectfully submitted,

L. E. Gregg
Assistant Director of Research

Copies to: Members of Research Committee
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Department of Highways

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INTRODUCTION

Favorable experience with dense-graded bases containing calcium chloride (1) created interest in similar mixtures containing only water as a bonding agent. As a result of this interest, a project for base and surface construction was set up on the Phil-Pine Grove Road in Casey County (See Fig. 1) to permit study of this method of base construction. The work was carried out during the period of August to October, 1953.

The pavement, which is 11.62 mi. long, was constructed by contract. It had 2 in. of traffic-bound base (creek gravel) and appeared to be in rather uniform condition with few obviously weak areas. Courses constructed in this project were a 3-in. dense-graded base overlain by 1.5 in. of Class C-1 bituminous surface. Aggregate used in both courses consisted entirely of crushed limestone. An RT-2 prime of approximately 0.3 gal. per sq. yd. was applied to the dense-graded base prior to surfacing.

The principle objectives of the project were; to determine the feasibility of using dense-graded bases without additives, other than water; and to establish construction methods which avoid raveling or disintegration of the base prior to surfacing.

CONSTRUCTION

Construction was carried out with the road open to traffic. This is, however, a rural connecting link and normal traffic volume is small.

(1) "A Limestone-Calcium Chloride Stabilized Base" by W. B. Drake, Presented to Research Committee January 2, 1953.
Fig. 1. Sketch map showing the general area of the Casey County project. The Phil-Pine Grove road is indicated by heavy dashed line connecting SR 35 and SR 70. Crushed limestone was produced by the Casey Stone Company near Bethel Ridge.
The material haul for surface construction passed over freshly constructed base and provided the principal traffic loading.

Prior to construction the roadbed was dressed with a grader to correct deficiencies in section and when necessary, in width. Shouldering material was placed at the edges to permit its use as earth forms during construction of the base. Construction started at the western end of the road on August 24, and proceeded eastward.

**Equipment.** Base stone was placed with a towed spreader box featuring a gate opening in line with the axle assembly (See Fig. 2). This box proved very satisfactory as a means of uniformly distributing stone regardless of the height of the towing truck.

Two sprinkler trucks, each having a capacity of 1000 gal. were used for the wetting of aggregate prior to mixing.

Manipulation of aggregate was accomplished with a motor grader of the usual type. An edger was attached to the grader blade for laying out base stone.

Two types of rollers, a pneumatic and an ordinary three-wheel, were provided for base construction. The pneumatic roller (Fig. 3) was designed by the contractor and could be operated either forward or backward. This eliminated turning of the roller and risking damage to the base. The roller had 16 wheels in two rows - the rows staggered to give complete coverage for the entire width of the roller. Sixteen thousand pounds of loose stone, added to the roller box, provided a loading of 1000 lb. per wheel.
Fig. 2. Spreader box used in placing dense-graded aggregate. Note mounting of adjustable gate in line with the axle. This feature, permitting rotation of the box without effecting gate height, prevented variations in the windrow even though truck tow bars were not all at the same height.

Fig. 3. Pneumatic roller in operation. This roller has 16 wheels mounted in two rows of 8 and staggered to give complete coverage. Ballast of 16,000 lb. provided a loading of 1,000 lb. per wheel. The roller features center mounting of the wheels which enables operation in either direction without turning. Tow- ing tractor operated both forward and backward during the operation.
Mixing. As a result of the road being open to traffic, an attempt was made to construct the base in single-lane widths. A section 0.2 mi. long at the western end of the project was constructed in this manner (Fig. 4). After completion of this short section, the method was abandoned as impractical. Proper manipulation could not be accomplished, the result being undesirable segregation of aggregates. The remainder of the project was constructed in full 18-ft. widths, which, of course, required the base to carry traffic during all stages of construction and curing.

Mixing on all but the initial section of the road was accomplished as follows: The full quantity of stone was placed in one windrow and spread to approximately one-half the full width after which wetting commenced. Sufficient water was added to raise the moisture content of the aggregate to a range of about seven to nine percent. For a completely dry stone in a 3-in. depth, 27,000 to 32,000 gal. of water per mi. would be required, but stockpiled or even fresh crushed aggregates have moisture contents in the range of one to three percent. This being the case, actual water applied to produce desired moisture contents was in the range of 18,000 to 25,000 gal. per mi.

As the work progressed a number of observations pertinent to the addition of water were noted as follows:

Visual inspection of the material during and after mixing is probably the best method of determining when proper wetting has been accomplished. Apparently, the best densities are achieved when the moisture content is just high enough to cause water to surface under roller action. Small quantities of fines are flushed to the surface and a slurry is formed. Aggregate wetted to this extent flows evenly from the blade during mixing but does not slump appreciably when
Fig. 4. Grader attempting to lay out aggregate for one lane construction. This method of construction was impractical and was abandoned after completion of the 0.2-mi. section partially shown here.

Fig. 5. Pneumatic rolling of base. Rolling started at the edges and proceeded toward the center. Rolling continued until the base had a uniformly dense appearance - usually accomplished in four to six passes.
windrowed. Addition of excessive quantities of water results in segregation of fines and consequent loss of fine aggregate and water to the subgrade. Slightly insufficient water permits good mixing but it produces a bulking condition which prevents proper compaction by the roller.

Water requirements also depend upon factors other than the aggregate. Moisture content of the stone has already been noted. Porosity of the stone may also be important in that porous aggregates will require more water than will dense aggregates. Condition of the subgrade is also important; its degree of saturation and type may have considerable influence. A dry subgrade, especially one sandy in nature, may absorb a considerable portion of the mixing water.

In most cases the full quantity of water was added prior to manipulation. The mixture was bladed back and forth until all portions of the material appeared to be uniformly wetted and mixed. When mixing was completed, the windrow was immediately broken and laid out. Additional water was sometimes added during the rolling operation; however when it was applied to the surface in slight excesses, the tendency toward later raveling seemed to increase.

Rolling. Pneumatic rolling, as illustrated in Fig. 5, started immediately after the material was spread with coverage progressing from the edges toward the center. Rolling continued until the base appeared firm, which usually required from four to six coverages (each consisting of one pass of the roller in each direction). When the mixture appeared dry - actually damp, but no evidence of surface water - additional water was added in some cases and omitted in others. As previously noted, there were indications that water added at this stage slightly increased raveling later, but also it improved the density of the
base. Regardless of the treatment with respect to added water, the surface appeared very dense and well-bound at the completion of pneumatic rolling (See Fig. 6).

In the early stages of construction, rolling with a 10-ton, three-wheel roller followed pneumatic rolling. This phase of compaction was eliminated since it appeared to produce no additional compaction and had some detrimental effects. The very dense surface resulting from pneumatic rolling was disturbed and loosened during three-wheel rolling. Intimate contact between fine and coarse aggregate seemed to be destroyed, leaving the coarser particles loosely bound and easily disturbed by traffic. It is possible that additional water prior to flat-wheel rolling would have improved this condition by creating a slurry on the surface. No attempt was made to investigate this possibility since the condition obtained with pneumatic rolling alone was considered highly satisfactory.

Curing. Probably curing presented the greatest problem encountered during construction. It was feared that serious raveling would result from traffic action prior to priming.

Base material laid in the first 0.5 mi. was left unprimed for three days. Traffic caused moderate raveling over the entire section, but in general raveling was no more severe here than on sections exposed for shorter curing periods (See Fig. 7). Severe raveling occurred where segregation of coarse aggregate was appreciable. Inspection revealed that all raveling, except where segregation had occurred, was no more than a single stone in thickness (See Fig. 8) and underlying material comprising the actual substance of the base was tightly bound. It was
Fig. 6. Typical surface texture at the completion of pneumatic rolling. The base at this location was rolled slightly dry and no appreciable surface slurry was formed.

Fig. 7. Moderate raveling occurred over the majority of the base during the curing period. The base shown had cured for 24 hrs. Additional curing resulted in little additional raveling. Only in spots where segregation occurred was the condition more severe than shown here. When the base was primed as soon as the surface was dry, raveling was reduced slightly.
Fig. 8. Near view of base exposed three days without priming. Raveling is evident, but floater material is but one stone in depth and underlying material is firmly bound.

Fig. 9. Pot holes where the base was deficient in material passing the No. 40 and No. 200 sieves. This section had been primed but affected areas were continuing to deteriorate.
felt that floater material resulting from raveling would be incorporated into the surface and thus serious loss of material would be avoided.

All of the base in the remaining 11 mi. of the project had curing periods varying from a few hours to five days. Those sections having no curing were primed as soon as the surface dried. Under these conditions the base did not harden to a desirable extent, in fact, it could be generally characterized as soft and spongy. Mixing C-1 surface material on these uncured bases was relatively difficult because of tendencies toward pulling and scuffing of the base.

Where the base was cured for three to five days before priming, the compacted material was hard and firm. Slight raveling - one stone thickness - developed very quickly, but additional exposure to traffic had very little effect on the surface condition except where the aggregate was seriously deficient in fractions passing the No. 40 and No. 200 screens. In those cases potholes developed (See Fig. 9). Conditions of this type were noted at sample locations No. 11 and No. 12.

**Priming.** An RT-2 prime was used throughout the project. Quantities varied from approximately 0.3 gal. per sq. yd. to approximately 0.4 gal. per sq. yd. Prime applied to cured base early in the project penetrated very deeply. There the rate of application was approximately 0.4 gal. per sq. yd.; however, much more could have been applied with no appreciable runoff. The deep penetration reflected both the type of priming material and the porosity of the base.

It was desired to prevent deep penetration and the consequent use of excessive prime. The first attempt to accomplish this was by
priming the base as soon as surface drying occurred. At this time, the voids were practically full of water and deep penetration was prevented. The method was partially successful in that deep penetration was largely prevented; however, as previously noted, the base failed to cure properly and the spongy condition previously referred to resulted.

A third alternative for curing and priming proved most successful. By this method the base was permitted to cure three to five days after which it was sprinkled lightly with water - enough to provide dampness on the surface but not enough to cause deep penetration. When RT-2 was applied (approximately 0.3 gal. per sq. yd.) water blocked the surface voids sufficiently to prevent deep penetration. No loss of firmness in the base was noted when this method was used, and a hard working surface for paving operations was retained. Whenever the grader blade came into contact with the base during paving operations, the tendency was to cut the base cleanly without weakening it, rather than to pull or scuff it thus leaving loose and unstable material.

FIELD AND LABORATORY TESTS

Tests were directed mainly to the determination of aggregate grading and compacted density of the base. Gradation tests were made on aggregate from both windrows and compacted base. Windrows were sampled at four locations (approximately the quarter points of the project) and the compacted base was sampled at thirteen locations where base density samples were obtained. Data concerning these gradings are contained in Table 1.
Table 1. Gradation of Aggregate in Samples From The Road

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location, Miles From West End of Project</th>
<th>Percentage Passing Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In.</td>
</tr>
<tr>
<td>1*</td>
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</tr>
<tr>
<td>6*</td>
<td>3.2</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>3.8</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>4.5</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>5.2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>5.4</td>
<td>Sample Accidently Destroyed</td>
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<td>8</td>
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<td>100</td>
</tr>
<tr>
<td>7*</td>
<td>6.5</td>
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</tr>
<tr>
<td>9</td>
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</tr>
<tr>
<td>10</td>
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<td>100</td>
</tr>
<tr>
<td>11*</td>
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<td>12*</td>
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<td>100</td>
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</tr>
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<td>W2</td>
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</tr>
<tr>
<td>W3</td>
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<td>W4</td>
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<td>Avg. Grading From Windrows</td>
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<td>100</td>
</tr>
<tr>
<td>Specification Limits</td>
<td>100</td>
<td>70-100</td>
</tr>
</tbody>
</table>

* Samples from primed locations

"W" Indicates windrow samples. W1 was sampled near the western end of the project and W4 near the eastern end; W2 and W3 were sampled near the quarter points.
The crushed limestone used in this project had a generally uniform particle shape and was blended at the crushing plant to meet grading requirements of Special Specification No. 58. Aggregate coming from the plant met specification requirements but it tended to be near the fine limit in the large stone sizes and near the coarse grading limit for the fine stone. At many locations on the road - particularly when material was sampled from the compacted base - the gradation fell outside specification limits. In some locations this may have been partially due to the sample containing small quantities of RT-2 prime. Samples from primed base are indicated in Table 1. Eight of thirteen samples from the compacted base had less than 5 percent passing the No. 200 sieve, and nine of the thirteen had less than 15 percent passing the No. 40 sieve. For all samples from compacted base, the average percentage passing the No. 200 sieve was one-half of one percent low, and the average passing the No. 40 sieve was one percent low. Windrow samples were all near the coarse grading limit in the fine sizes (See Table 1) and one of the four was outside the specification limit on the No. 40 sieve size.

Comparison of aggregate grading from windrows and compacted base indicates slight degradation during construction. Aggregate from the compacted base generally showed increases in the percentages passing the 3/8 in. sieve, and some apparently increased in percentage passing the No. 4 sieve. This degradation was not great and had the original stone been nearer center grading it would have had little effect, so far as remaining within specifications limit was concerned.
Decreases in percentages passing the No. 40 and No. 200 sieves were noted in the compacted base as compared to windrowed aggregate. These decreases probably reflect a small loss or separation of slurry during manipulation and spreading operations.

Density determinations were made at 13 random locations representing a reasonable coverage of the project. These measurements were made in the compacted base by use of the Reinhart Density Apparatus (See Fig. 10). This method consists of carefully removing a small, roughly cylindrical section without disturbing the surrounding base. The volume of removed material is then determined by measuring the volume of water (enclosed in a rubber balloon) required to fill the hole. Density data are contained in Table 2 and sample locations are tabulated in the order of their distance from the western end of the job rather than by sample number.

Unit weight (dry) of these density samples averaged 144.5 lb. per cu. ft., with a variation from 138.0 to 155.0 lb. per cu. ft. The data indicate that as the job progressed construction became more uniform, at least from the standpoint of base density. Average densities on this project are 8.6 lb. per cu. ft. lower than the 153.1 lb. per cu. ft. average attained of the Rosemont Underpass project near Lexington (1). Graded base on the Rosemont project was constructed under the same grading specification but it contained a different stone, a more desirable grading, and 0.5 percent calcium chloride additive. It should

(1) See "A Limestone-Calcium Chloride Stabilized Base," mentioned in footnote on page 1 of this report.
Fig. 10. Density measurement being made in a location where the base was primed immediately after rolling. Compacted stone is being removed from a cylindrical section approximately 4 in. in diameter and full-base depth. Volume of removed material was determined by use of the Reinhart Density apparatus shown in right foreground.
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location From West End of Project</th>
<th>Unit Dry Weight lbs/cu.ft.</th>
<th>Percent of Solid Density</th>
<th>Percent Voids</th>
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<td>2.0</td>
<td>141.9</td>
<td>83.2</td>
<td>16.8</td>
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<td>81.0</td>
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<td>6.0</td>
<td>139.5</td>
<td>82.0</td>
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<td>11.0</td>
<td>144.8</td>
<td>85.0</td>
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</tr>
<tr>
<td>Avg.</td>
<td></td>
<td>144.5</td>
<td>84.9</td>
<td>15.1</td>
</tr>
</tbody>
</table>

* Samples from primed locations

Table 2. Results of Base Density Measurements

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was considered important to obtain some indication of the desirability of calcium chloride additions in the aggregate. Toward this end, aggregate passing a No. 40 sieve was selected for testing since any measurable difference in the bonding properties would be most readily observed in the dust fraction. Specimens were prepared and tested in tri-axial shear, both with and without calcium chloride additions. This test consists of failing a cylindrical test specimen by axial loading while it is confined by a uniform lateral pressure. Only a few specimens were tested and the data were too limited to supply more than an indication, however, for these tests, specimens containing 0.5 percent calcium chloride showed an appreciable advantage in some properties. Additional tests will be conducted to better define the differences in bonding properties of limestone dust with and without calcium chloride.
be noted that on the Rosemont project the percentage passing a No. 200 sieve never fell below 7.0 percent, and it averaged almost three times as great as the average on the Casey County project.

Percentage voids on this project averaged 15.1 with the values ranging from 9.2 to 19.0 as compared with an average of 9.9 and a range from 4.8 to 14.7 percent voids on the Rosemont project.

The wide spread of base densities apparently resulted from variations in moisture content of the stone when compacted since rolling was approximately equal throughout the project. Those areas where slurries were developed - even intermittently - appeared to have the more firm and dense base when cured, however, sufficient density measurements were not made to definitely establish this.

In addition to testing the base as constructed on this project, it was considered important to obtain some indication of the desirability of calcium chloride additions to the aggregate. Toward this end, aggregate passing a No. 40 sieve was selected for testing since any measurable difference in the binding properties should be most readily observed in the dust fraction. Specimens were prepared and tested in tri-axial shear, both with and without calcium chloride additions. This test consists of failing a cylindrical test specimen by axial loading while it is confined by a uniform lateral pressure. Only a few specimens were tested and the data were too limited to supply more than an indication, however, for these tests, specimens containing 0.5 percent calcium chloride showed an appreciable advantage in some properties. Additional tests will be conducted to better define the differences in bonding properties of limestone dust with and without calcium chloride.
OBSERVATIONS AND CONCLUSIONS

Evaluation of water-bound dense-graded aggregate bases in general would require observations on several projects involving stone of different characteristics, a variety of weather conditions, and a considerable range in traffic using the road during construction. However, the length of this project and the number of factors that entered as the work progressed provide reasonable opportunities for significant observations and measurements. In summary these are:

1. Weather conditions permitted uninterrupted construction, but the hot, dry atmosphere kept water requirements high, kept curing time low, and favored raveling of the base under traffic.

2. From the standpoint of particle shape and physical properties conducive to cementation, the stone used in this project was highly satisfactory.

3. Gradation of aggregate produced and delivered to the project was generally within specification grading limits. However, for the majority of locations tested, aggregate from the compacted base fell outside these limits. This could be attributed primarily to "border-line" grading, by which there was a tendency to approach the fine limit in coarser sizes and the coarse limit in the fine sizes of the blended aggregate. Small changes in gradation caused by loss of fines during mixing and also degradation of coarse aggregate by the roller were other contributing factors.
Deficiencies in the coarser sizes would probably cause little difficulty in performance of a base, however, lack of fines (material passing the No. 40 and particularly the No. 200 sieve) would seriously affect binding qualities and the density of a compacted base. A change in specification requirements to increase the minimum amount of material in fine sizes seems necessary to assure desirable gradation of stone in place.

4. Degredation of aggregate during construction was appreciable but probably not as great as it would have been with a stone having more flat and elongated particles. The principal effect of degredation was increased percentages of material in the intermediate sizes. This indicates that degredation occurred mostly during rolling. Had degredation occurred during mixing, an increase in the fine sizes would have resulted. It is doubtful that degredation had any significant effect on results obtained in this project.

5. On the basis of density test made at 13 locations, voids in the compacted base ranged from 9.2 to 19.0 percent as compared with 4.8 to 14.7 percent voids in the base on the Rosemont project where different stone, a more desirable grading, and calcium chloride were used. The average percent voids for this project was 15.1 as compared to an average of 9.9 on the Rosemont project. Densities obtained on this project indicated good compaction considering the gradation.
6. The amount of water added, the curing period, and the procedure used in applying prime had a marked effect on the quality of the base. Most satisfactory results were achieved when:

(a) Water was added in quantities sufficient to fill the voids and barely surface under roller action. Excessive quantities washed fine stone from the surface, and insufficient water caused bulking and resistance to compaction.

(b) Curing of the base extended long enough to permit hardening prior to priming - three to five days on this project. Raveling occurred under moderate traffic during the curing period but this developed to only one-stone depth when gradation and other factors were favorable.

(c) The base was sprinkled lightly immediately before the RT-2 prime was applied. This prevented complete absorption of the prime and held the requirements to no more than 0.3 gal. per sq. yd.

7. Construction was best when carried out in full road widths. Single lane construction is impractical and produces erratic results.

8. Water requirements on work of this type vary with weather and atmospheric conditions. On this project 11.5 to 16 gal. per ton of aggregate were used. (18,000 to 25,000 gal. per mi.).
Wetting should be completed prior to mixing, however water may be added during mixing or even during rolling if necessary.

9. Mixing should begin immediately after water has been added and continued until the mix is uniform. Relatively short sections - not over 2000 ft. in length - permit rapid mixing and thus reduce evaporation losses.

10. Satisfactory densities and surface characteristics were produced by pneumatic rolling. The steel-wheel roller tended to loosen coarse particles at the surface and thus increase raveling. Addition of water to the base just prior to steel-wheel rolling might have eliminated the tendency to loosen the surface by creating a slurry. Since pneumatic rolling produced satisfactory results, this was not attempted.