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FINAL REPORT

PERFORMANCE OF THREE AGGREGATES ON ALL-WEATHER ROADS

by

David F. Noble
Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Because the Virginia Department of Highways and Transportation had received complaints from the public and Department maintenance personnel concerning the durability of slate used on all-weather surface roadways, a field study was conducted in which the performance of the slate was compared to that of two other aggregates. For the study, two test sites were constructed using granite, slate, and greenstone. Prior to being placed on the road, the aggregates were tested for California Bearing Ratio (CBR), gradation, and Atterberg limits. While in service, the aggregates were sampled and tested for gradation, Atterberg limits, thickness of the layer, and skid resistance. Sampling of the aggregates in service was done on a 2-week schedule from week 3 through week 9, on a 4-week schedule from week 14 to week 22, and then at weeks 50 and 60.

The composition of the Arvonia slate is very high in muscovite, a flaky mineral that is particularly susceptible to winnowing and somewhat self-lubricating. The slate had a much lower CBR than either the granite or greenstone, and this value did not improve when the slate was not soaked before testing. This absence of improvement was attributed to the lubricating effect of muscovite. The gradations of the aggregate samples obtained over time exhibited some variability that was attributed to variations in the sampling of the coarse fractions of the granite and greenstone. Also, it was observed that the slate disintegrated at a much faster rate during the first 5 weeks of service than did the granite or greenstone. Such early wear is extremely important because, normally, very light applications of crusher run are made to all-weather surface roadways, and it is necessary that the larger sizes of aggregate maintain their integrity so they can be reused when the roadway surface is reshaped.

Two changes in the specifications for crusher run and a change in policy were recommended.

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INTRODUCTION

In the construction and maintenance of highways, as in most general civil construction, high quality aggregate is required. However, only in exceptional cases does a highway construction project generate a great enough demand for aggregate that a quarry is opened solely to meet this need. Thus, most quarries that supply construction stone are close to a town or city that constitute their prime markets. Inasmuch as a great deal of highway activity is designed and located so as to serve many of these towns and cities, the highway industry can also use the product of the quarries that serve these markets.

Some rural areas do not have a source of good construction aggregate nearby that can be used for highway purposes. Such being the case, high costs must be paid for importing aggregate or whatever types of stone that are locally available must be used. Some locally available materials are processed for special use. To cite a few examples, the soft nature of soapstone allows it to be cut and shaped easily for decorative uses, the fibrous and heat resistant qualities of asbestos allow it to be woven into fireproof cloth, the response to heat of certain clays and shales allows them to be fired to make bricks, and the luster and slabby cleavage of slate make it useful as roofing shingles and decorative panels for facing buildings. The properties that make these materials special may or may not preclude their use as construction aggregate. Each such material must be considered on an individual basis, with all of its intrinsic properties being weighed against the proposed use.

SPECIFIC SITUATION

Portions of Buckingham and Cumberland counties in the Lynchburg District of the Virginia Department of Highways and Transportation, and Fluvanna County in the Culpeper District, have no nearby source of material that is produced primarily for use as an aggregate in general construction. Thus, some years ago, the Department decided to use some of the waste from the Arvonia slate on a trial basis in the Dillwyn Residency of the Lynchburg District. When the slate appeared to provide satisfactory performance, the Department dropped its local use policy. As the use of slate spread to Fluvanna and Goochland counties, replacing more conventional aggregates, the Department received complaints from its employees working with the slate in road surfacing and from citizens driving the roads. Their complaints focused on rapid degradation of the slate, purported slipperiness of the surface, and alleged puncturing of tires by slate particles.

PURPOSE

In response to the above cited complaints, the study discussed in this report was undertaken to evaluate the field performance of the slate as compared to that of a granite and greenstone when used on all-weather surface roadways.

SCOPE

With the great variety of rocks available, it would have been possible to have a study of much greater scope than could possibly have been handled by the personnel and in the time available. Therefore, the scope was limited to three aggregates placed on two test strips.

It was recognized that

1. statistical analyses of the data might not be possible because the results for the slate and two control materials would be relative, and could be quite variable because of the very broad specifications for crusher run aggregate, and

2. it would be difficult to conclude anything about the relative performances of the three aggregates unless there were large differences in the test results.

MATERIALS

The choice of the aggregates was determined by what was available as crusher run aggregate, the type usually placed on all-weather roads, near the two test sites. Since, as described later, the sites selected for the testing were near Palmyra in Fluvanna County, materials were obtained from the quarries at Arvonia, Red Hill, and Shadwell. The

Arvonia aggregate is a very fine-grained, medium gray, highly micaceous slate; the Red Hill stone is a medium-grained, medium grey granite to granite gneiss; and the Shadwell material is a very fined-grained, greenish grey greenstone. For each aggregate type, 130 tons of no. 25 material were obtained.(1) Detailed descriptions of these materials have been given, respectively, by Brown, Walker, and Webb.(2,3,4)

TEST SITES

The criteria to be used in choosing the locations of the test sites were discussed with the maintenance area superintendent. It was preferred that the roadway should be as level and straight as possible, that the environment (moisture conditions, exposure to sun, etc.) along the road should be as uniform as possible, and that the traffic should be relatively high for an all-weather surface road.

As previously mentioned, the two sites selected are in the Palmyra maintenance area. One is on Rte. 660 near its intersection with Rte. 640, the other on Rte. 663 at the intersection with Rte. 678. The site on Rte. 660 is straight, relatively level, forested on the east side and open on the west, and is well drained. It carries approximately 66 vehicles a day. The Rte. 663 site is relatively level, moderately curved, lined with scrub forestation, and also well drained. It carries about 80 vehicles a day.

INSTALLATION OF TEST SECTIONS

The test sites were 900 ft. long, and were marked at 50-ft intervals with stakes placed just beyond the ditchline. Metal fence posts were placed at the beginning of each site and at 300-ft intervals to delineate the test sections. The Rte. 660 site was laid out from south to north and that on Rte. 663 from west to east. Granite was placed from 0.0 to 300 ft, slate from 300 to 600 ft, and greenstone from 600 to 900 ft.

Rtes. 660 and 663 received 61 and 69 tons, respectively, of each rock type, applied in a compacted thickness of approximately 2 in. While much heavier than the cover applied in normal maintenance, the 2 in layer was thought to be needed to avoid digging into the old surface when sampling the new material. The aggregates were spread from the tailgate, and depending on the distribution of the aggregate within a 300-ft section, alternate trucks would start their runs from opposite ends.

The final spreading and dressing of the aggregate was done with a motor grader. As is usual for this type road, there was no controlled compaction. The construction equipment and local traffic provided the compactive effort. The design called for 3 in of loose aggregate to provide the desired 2 in of compacted material. During the initial stages of application and prior to much compaction, the roadway was quite unstable, and vehicles traversing it at 35 to 45 mph experienced considerable rear end sway.

SAMPLING AND TESTING PROCEDURES

Sampling

It was recognized that contamination of one rock type with another where the 300-ft test sections abutted would be a problem, so, the first 50 and last 50 ft of each section were used as buffer zones and none of the three covering materials were taken from them for tests.

In determining the properties of the aggregates prior to placement, samples were obtained from each truck load (total of four) after it was dumped but before it was spread. In monitoring the performance of the aggregates on the roadway, each 200-ft segment of the test sections between the 50-ft buffer zones was subdivided into four 50-ft segments and a randomly located sample was taken from each after 3, 5, 7, 9, 14, 18, 22, 50, and 60 weeks of service. Each sample was obtained by digging a trench approximately 6 in wide down to the previous surface from the middle of the road to the edge. Because of their limited width, most secondary roads have 3 wheel paths. Thus, approximately half of the middle wheel path, all of the outside wheel path, and the loose rock kicked to the side of the roadway were included in the sample. The four random samples were combined in the field to form one composite sample for each aggregate type.

Tests

Because the physical breakdown of particles was considered to be the characteristic most indicative of the durability of aggregates as used on all-weather roads, gradations were run on the aggregates both before and after they were put in service. Further, as the crushing of rocks to make aggregates and the degradation of the aggregates under traffic create very-fine grained materials, it was decided to also run Atterberg limits on each sample in an attempt to learn something about the characteristics of the fines. On the other hand, while maximum density, optimum moisture content, and California Bearing Ratio (CBR) determinations provide information about a mass of particles, their results are not thought to be drastically affected by changes in gradation of the magnitude expected, so these tests were run only on the aggregate as supplied.

Inasmuch as the fines can be eroded from the roadway by water and wind, the depth of the remaining aggregate was taken as another indicator of degradation. The more aggregate remaining, the greater the durability.

One of the complaints made by citizens was that the slate aggregates were especially slippery when wet. Therefore, while a bit unorthodox, it was decided to take some skid measurements on the three rock types. In addition, photographs and observations were made of the test sections as needed to document an interesting or significant condition.

RESULTS AND DISCUSSION

Properties of Aggregates As Delivered

Gradations

The gradations for the aggregates as delivered are plotted in Figures 1 and 2, for Rtes. 660 and 663, respectively. For each of the three aggregates, the curves for the two sites were quite similar, which suggests that the handling, sampling, and testing were done uniformly. Among the aggregates, themselves, there was a wide divergence of the granite from the other two in the fine sizes, and a noticeable spread among the three in the coarse sizes, with the granite in the middle. As can be seen from the figures, the greenstone was the most coarse, retaining less than 10% of the particles on the 1-in-sieve. That the quantities passing the No. 4 sieve ranged from 28.8% for the greenstone to 36.5% for the slate suggests that the producers were aiming for the specified mean of 32.0% for the No. 25 crusher run.(1) It is also noteworthy that the curves for the slate cross under those for the granite close to the No. 4 sieve size and then parallel those for the greenstone. The somewhat greater amount of fines in the granite indicated it to be a little better graded than the other two, and the greenstone was slightly better graded than the slate. These judgements were verified by calculating Hazan's uniformity coefficient for each aggregate.(5)

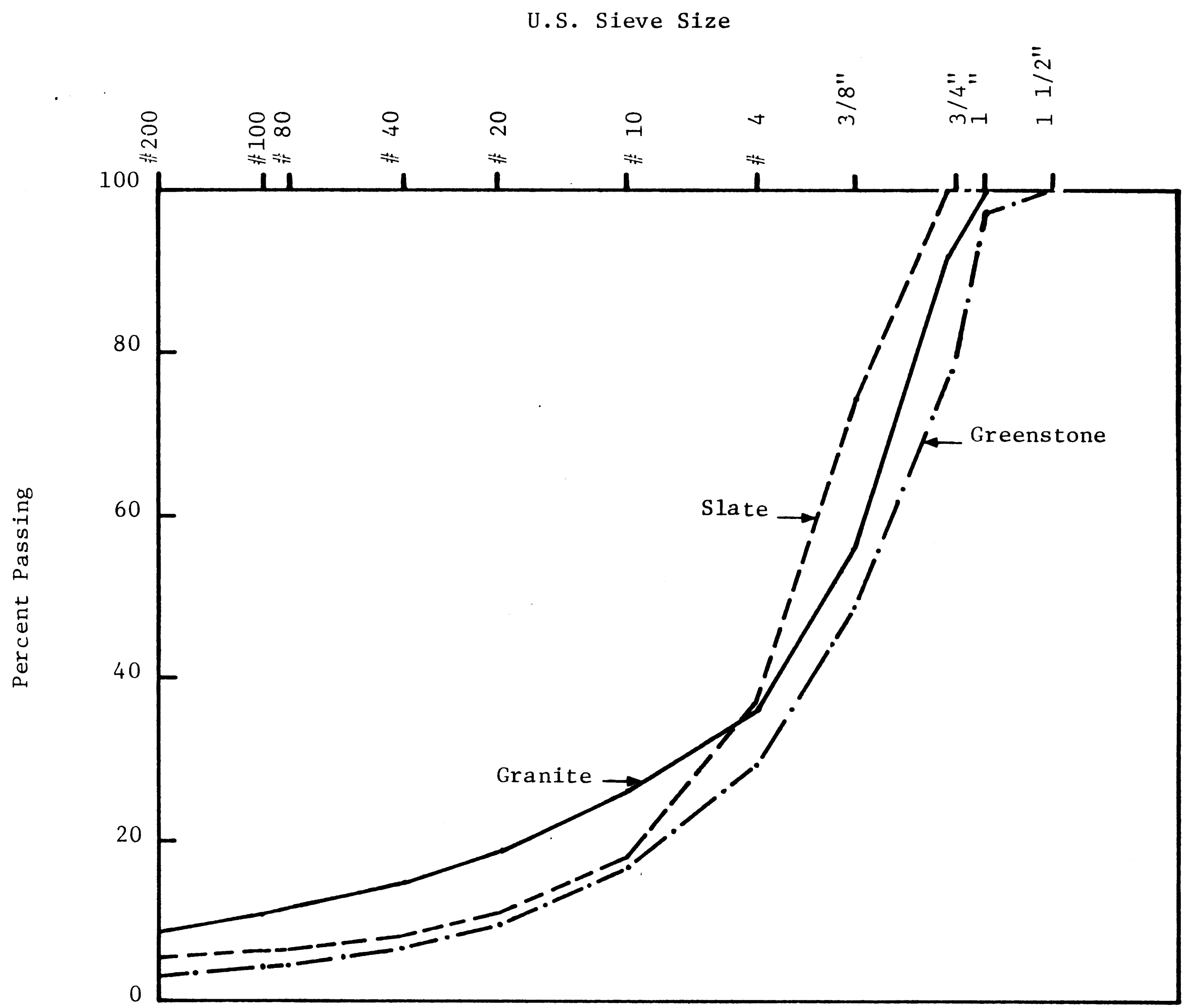

Figure 1. Gradations of aggregates as delivered, Rte. 660.

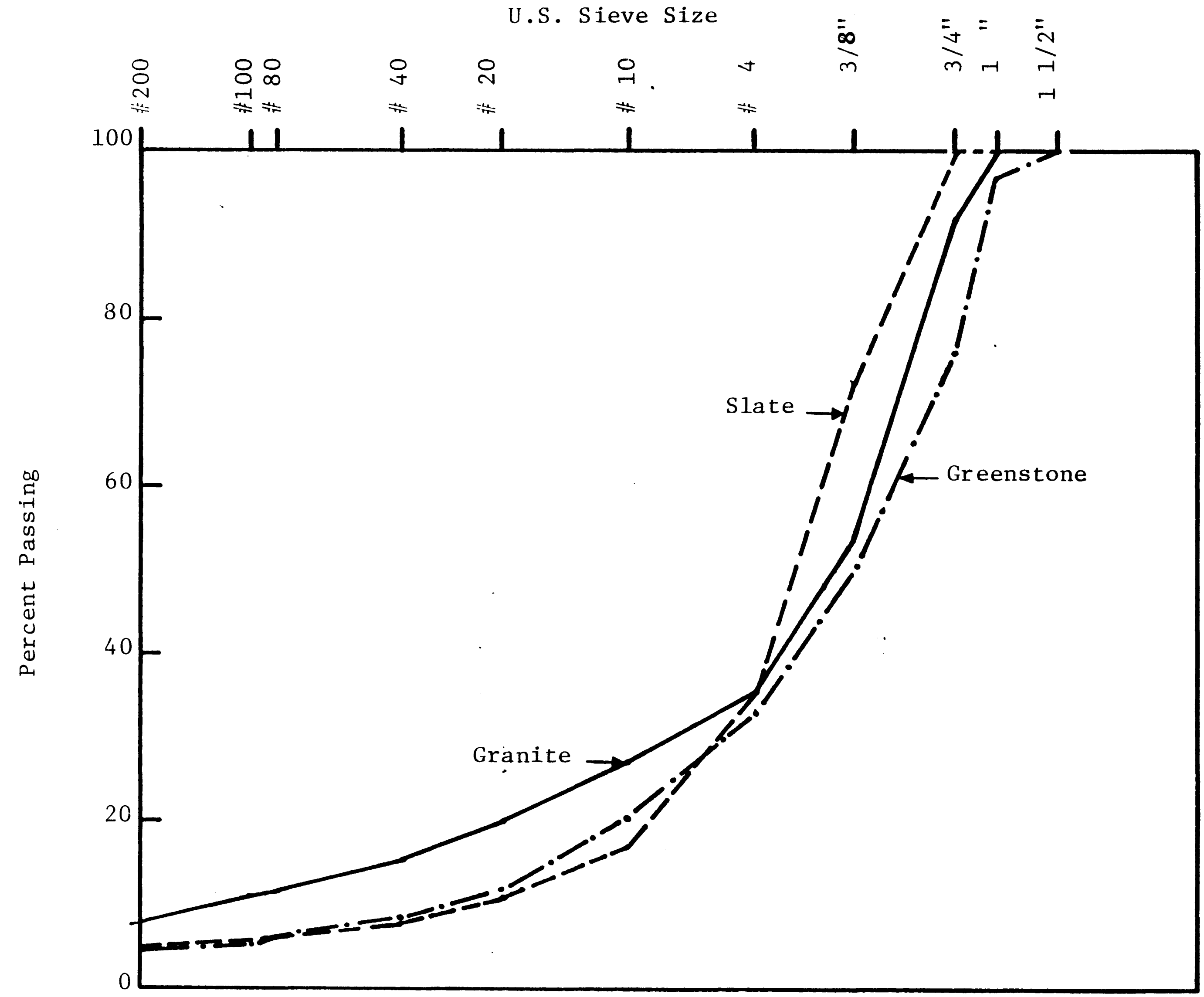

Figure 2. Gradations of aggregates as delivered, Rte. 663.

One of the factors that affects how well an aggregate performs is the degree to which it meets specifications, and, obviously, the ease with which specifications can be met is affected by how broadly they are written. The specified gradations for the three sizes (Nos. 24, 25, and 26) of crusher run are presented in Table 1. The sentence in the specifications that states that "shall be the complete product of a crusher, essentially free of overburden and only oversize removed ....", gives a general description of crusher run aggregate, but aside from the limits on the No. 4 sieve, there is nothing in the specifications that differentiates the three sizes of material. Unfortunately, it would be very difficult to verify that a mass of aggregate obtained is the complete product of a crusher, and the overlap of the limits for the No. 4 sieve is rather wide at 34%. Additionally, the specifications state that 100% must pass the largest sieve and that as much as 100% may pass the next to largest sieve. Thus, it is possible for a No. 26 aggregate to satisfy the specifications for the upper ranges of the No. 25 and No. 24 aggregates. The No. 25 and 24 aggregates could be differentiated from the No. 26 only if they contained from 1% to 10% of particles not passing the next to largest sieve size.

When the three aggregates are examined against the above statements, it can be seen that the greenstone with approximately 97% passing the 1-in sieve and from 29% to 33% passing the #4, clearly satisfied the specifications for no. 25 crusher run, could have satisfied the specifications for the no. 24, but was too coarse to meet the specifications for the no. 26. The two finer aggregates, granite and slate, with 100% of the particles passing the coarse sieves and approximately 35% passing the #4, satisfied the specifications for all three types of crusher run.

Table 1

Specified Gradations for Crusher Run Aggregates

Aggregate Size No.	Percentage by Weight of Materials Passing Designated Sieves					
	2½"	2"	1½"	1"	3/4"	# 4
24	Min. 100	95±5				32±18
25			Min. 100	95±5		32±18
26				Min. 100	95±5	38±22

When, as with the slate, approximately 64% of the aggregate is retained on 2 sieves and 82% on 3 sieves (the #4 sieve of the specifications and one to each side, 3/8 in and the #10 sieves) concern for whether the aggregate is or is not the complete product of a crusher seems to be warranted. In addition, when a material is sold as no. 25 crusher run but has no 1-in nor 3/4-in stone (the second sieve size designated for no. 26 crusher run), one might wonder what size material was initially put through the crusher. The granite, on the other hand, had at least 8% retained on the 3/4-in sieve. The greenstone clearly met the specifications for no. 25 crusher run, with approximately 3% retained on the 1-in sieve and approximately 21% on the 3/4 in sieve.

If part of the understanding of the phrase "shall be the complete product of a crusher...." is the idea that the aggregate will have a relatively normal size distribution, then material such as the slate that has an extreme degree of central tendency does not satisfy the understanding of what crusher run is expected to be. The importance of this is explained under "Laboratory Compaction Test."

Laboratory Compaction Test

The results of the laboratory compaction tests, given in Table 2, are noteworthy in that the maximum densities of both the granite and the greenstone were considerably higher than that for the slate. The differences for the granite and slate and greenstone and slate were 9.4 and 11.3 lb/ft^3, respectively. If these differences cannot be explained by the differences in the specific gravities of the three rocks (granite - 2.83, slate - 2.79, greenstone - 2.94), they may be taken as indices of differences in other properties of the aggregates. Normalizing the maximum densities of the granite and greenstone by the volume in cubic feet that the 134.9 lb of slate would fill if it were solid, and allowing for the differences in maximum density that would be caused by the specific gravities of the rocks, the maximum densities of the aggregates would still differ by 7.5 and 4.0 lb/ft^3 for the granite-slate and greenstone-slate comparisons, respectively. The property of the aggregates that most probably explains these differences is grading, because it has a great effect on the consolidation of particles. The gradation tests showed that the granite was the best graded, followed by the greenstone and the slate. Thus, it would be expected that with the granite having the best distribution of particle sizes, more of it could be compacted into the Proctor mold, as compared to the greenstone and slate.

The maximum densities of the granite and greenstone differ by only 1.9 lb/ft^3. If grading did not affect the maximum density, and the specific gravity of the rock was the only controlling factor, the difference would have been much greater at 5.5 lb/ft^3. These observations illustrate the importance of grading as it relates to maximum density, and they demonstrate the value of receiving the well-graded material normally produced by the crusher.

Table 2

Engineering Properties of Aggregates

Test & Property / Aggregate & Site	Laboratory Compaction Test		California Bearing Ratio										Atterberg Limits
			Specimen A						Specimen B				
			Unsoaked - A		Soaked - A				Unsoaked - B				
	Maximum Density lb/ft^3	Optimum Moisture, Percent	Density, Percent of Max.	Moisture, Percent	Density, Percent of Max.	Moisture, Percent	CBR Value, Percent	Swell, In	Density, Percent of Max.	Moisture, Percent	CBR Value, Percent	Plastic/ Liquid
Red Hill Granite Rte. 660	144.2	7.2	91.8	5.00	93.3	5.02	84.1	.013	95.8	5.12	118.3	NP 21
Red Hill Granite Rte. 663	144.4	6.7	93.3	4.98	94.4	5.46	88.4	.004	95.4	4.66	126.9	NP 19
Arvonia Slate Rte. 660	135.7	7.8	97.9	6.69	98.4	7.37	67.0	.001	98.9	6.85	58.4	NP 24
Arvonia Slate Rte. 663	134.0	7.7	98.0	6.05	99.0	6.81	67.0	.003	96.2	5.80	63.0	NP 23
Shadwell Greenstone Rte. 660	148.0	8.0	98.1	4.83	98.4	5.41	92.7	.008	97.2	4.81	109.8	NP 19
Shadwell Greenstone Rte. 663	144.4	7.8	95.3	5.14	95.6	6.69	88.4	.010	99.9	4.98	94.2	NP 17

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CBR Test

For the CBR determinations, duplicate samples were prepared for tests on some specimens that would be immersed in water and others that would not.

As can be seen from the results in Table 2, the relative density, expressed as a percentage of the maximum density, was lowest for the granite and comparable for the slate and greenstone in both the soaked and unsoaked tests. The percentage moisture used to provide lubrication was highest for the slate and almost identical for the granite and greenstone. However, for the specimens soaked for 4 days, the increases in the moisture values were 1.05%, 0.72%, and 0.25% for the greenstone, slate, and granite, respectively. The most noteworthy differences were in the average CBR values. The granite at 86.3 and the greenstone at 90.6 were comparable and were considerably higher than the slate at 67.0 for the specimens that had been immersed for 4 days to simulate worst conditions. While the values of the specimens that were not immersed, a simulation of best conditions, were expected to be higher, that of the slate was a little lower. Those of the granite and the greenstone were 122.0 and 102.0, respectively.

The CBR values for the soaked specimens of granite and greenstone were 19 and 23 points greater than that for the slate. (A difference of 20 points translates to a difference of 600 lbf/in^2, which is a significant difference in bearing capacity, especially on an all-weather surface roadway.) The results for the unsoaked specimens show surprisingly greater differences among the aggregate types, with the spread being attributable to the much higher values for the granite and greenstone. The CBR value for the granite was 102% and that for the greenstone 69% greater than that for the slate. It is thought that the effects of at least three properties of the aggregates and the rocks (grading, particle shape, and mineral composition) combined to create these very large differences. The better graded aggregates (granite and greenstone) might be expected to consolidate more. The shape of the granite particles, which is more nearly three-dimensional than the others, should promote an interlocking network of particles. These first two properties tend to promote high CBR values, especially with the lesser lubrication from the lower moisture content of the unsoaked specimens. In a negative sense, the high mica content of the slate tends to promote dry lubrication, as the flat cleavage faces of the platy-shaped mineral that line the main surfaces of the particles slide over each other, and the discrete particles of mica contained in the fines tend to lubricate the mass of aggregate, both of which tend to lower CBR values.

Atterberg Limits

As might be expected for the Atterberg limits, the fines of the aggregate as placed on the roadway were nonplastic. The averages of the liquid limits for the granite and the greenstone were 20 and 18, respectively, while the average value for the slate, 24 was a bit higher.

The 2% difference in moisture between the average liquid limits for the granite and greenstone is negligible, and the higher value of 24 for the slate may have been caused by its high mica content. The mica was fine-grained, had a platy shape and, while it was not hygroscopic like some other phyllosilicates, it would tend to tie up more water than the other rock-forming silicates such as quartz and feldspar.

Properties of Aggregates After Placement

Gradations -- Curves

The results of the gradation testing were plotted on 5 cycle semilogarithmic paper, three aggregates per site and sampling period. The gradations for the 3 and 60 week sampling periods in Figures 3, 4, 5, and 6 show that for 3 of 4 possibilities, the slate clearly was finer than either the granite or greenstone. All of the gradations are shown in Appendix A.

The first comparison of all of the gradations was made to determine the degree to which the gradation for a given aggregate at one site was duplicated by the same aggregate at the other site. It was thought that this type of analysis might indicate the consistency and uniformity of the sampling and testing program. Also, it was thought that it might reflect the uniformity or breadth of the size distribution for the aggregate, because with the fewer and finer sizes of particles in a given aggregate, the less opportunity there would be for the coarse particles to be kicked off to the shoulder, which would lessen the possibility of sampling variability.

Unlike the sets of data for the aggregate as placed, none of the sets for the aggregate in service matched each other. Thus, it appears that there was considerable variability in the sampling procedure or that the degree of degradation at the two sites was quite different.

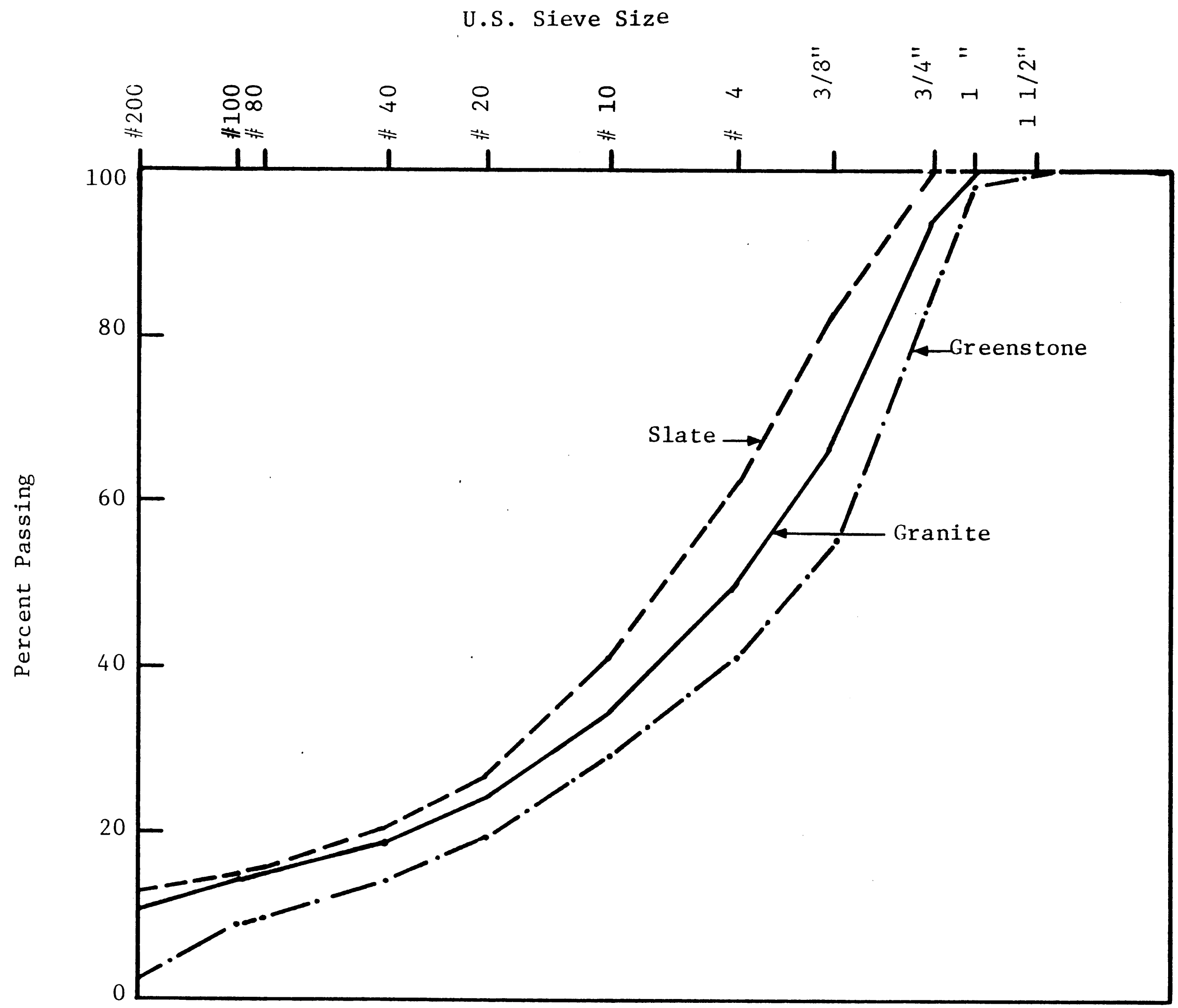

Figure 3. Gradations of aggregates in service 3 weeks on Rte. 660.

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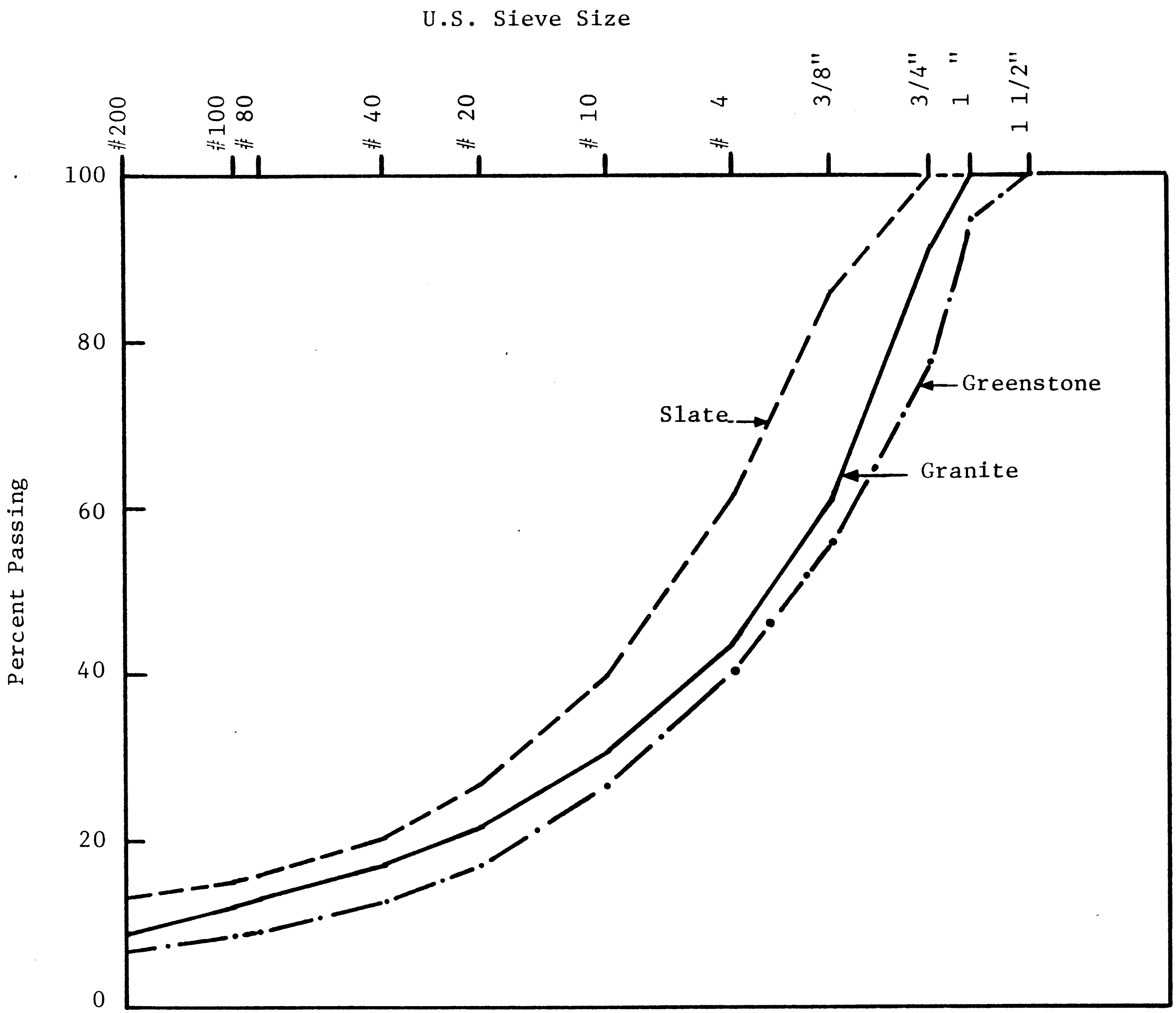

Figure 4. Gradations of aggregates in service 3 weeks on Rte. 663.

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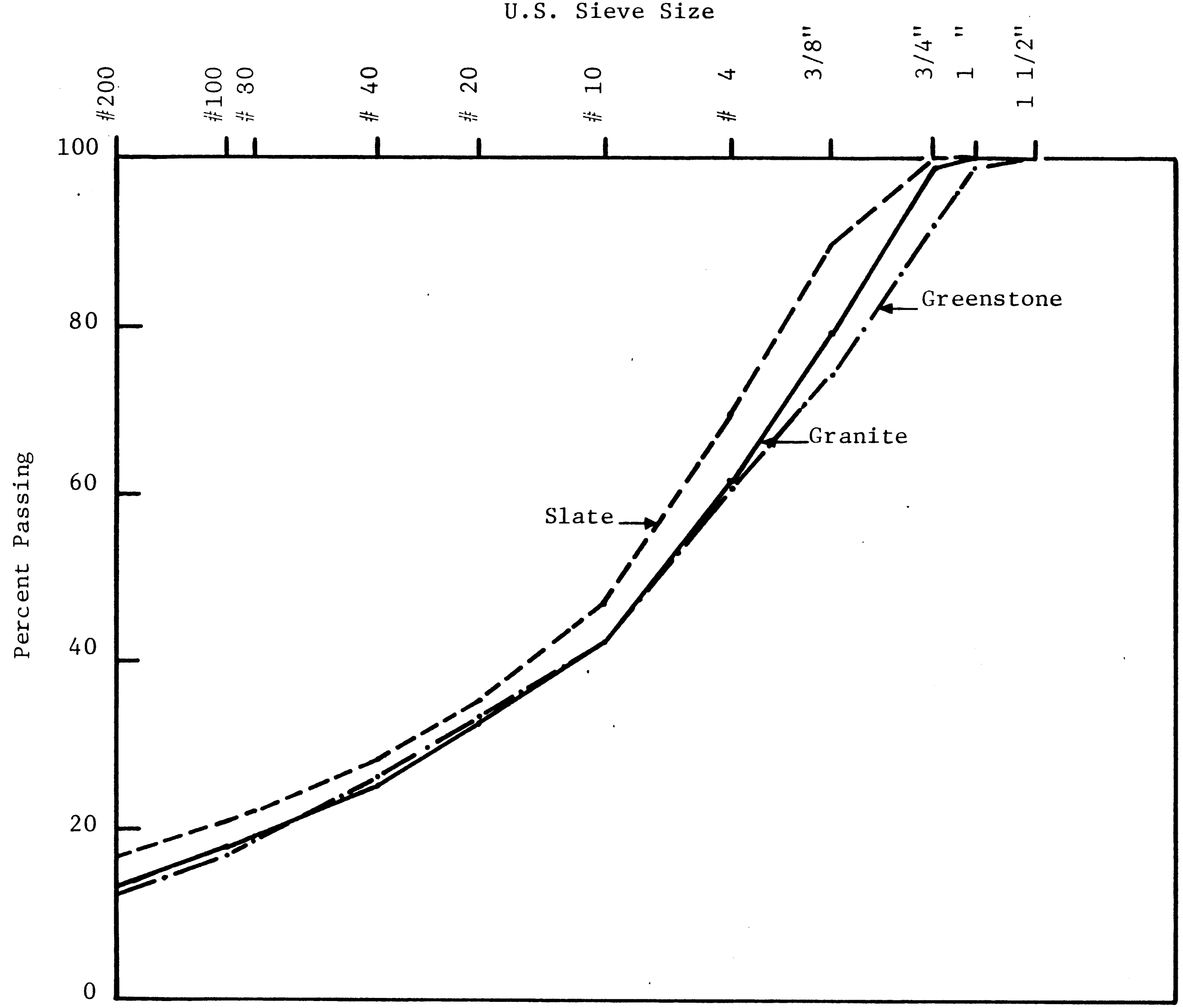

Figure 5. Gradations of aggregates in service 60 weeks on Rte. 660.

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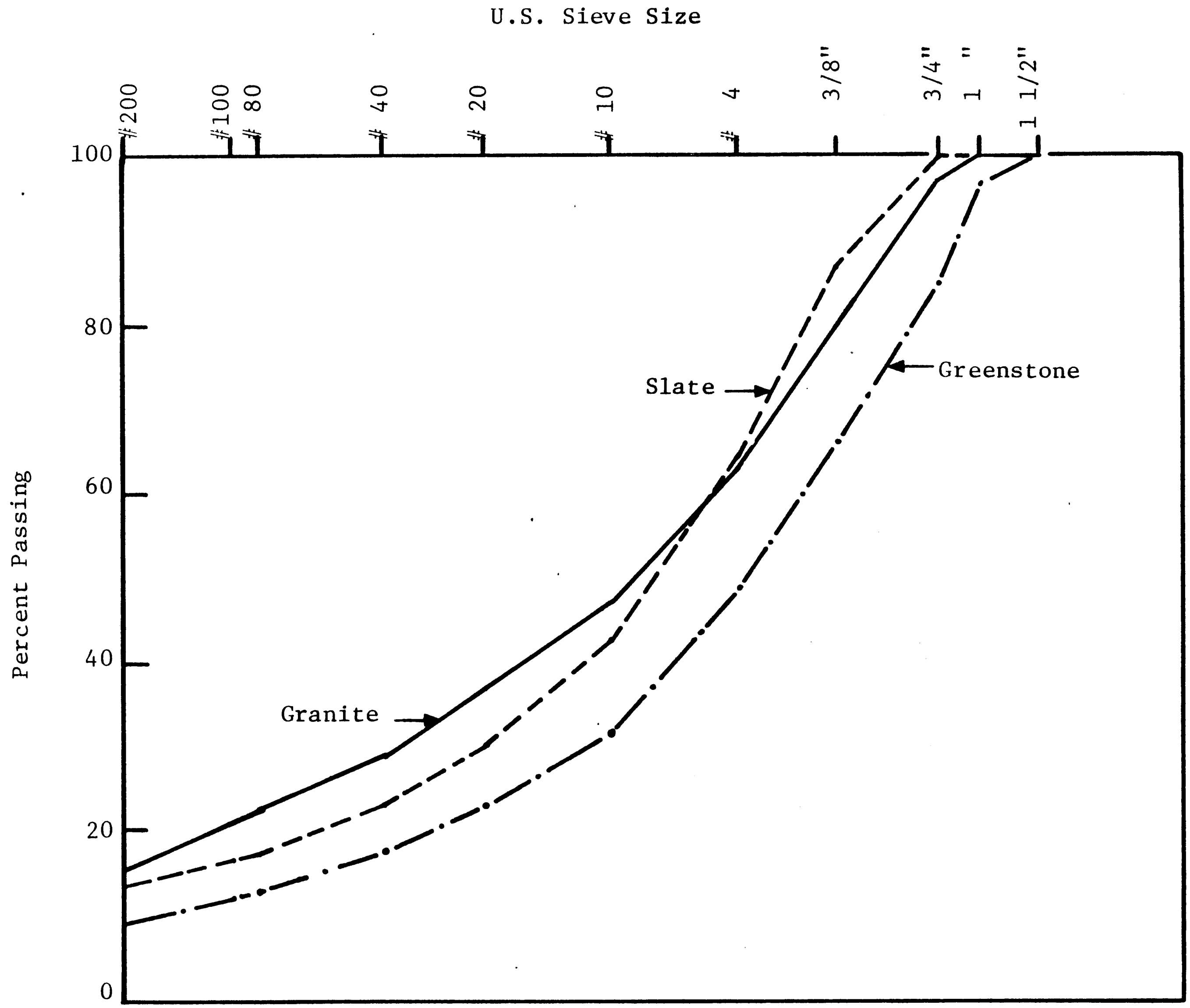

Figure 6. Gradations of aggregates in service 60 weeks on Rte. 663.

In comparing the same aggregates at the two test sites for the nine sampling periods, it was found that 6 (those for weeks 3, 5, 7, 9, 14, and 18) out of the 9 curves for the slate were similar. Only 2 of the sets for the granite and 1 of those for the greenstone were found to be similar. Five of the 9 sets for the greenstone differed by large margins. It is suggested that the progressively diminishing similarities reflect the relatively fine grained and narrow size distribution of the slate as compared to the somewhat coarser and broader band for the granite, and the still coarser and broader band for the greenstone.

When the gradations for the same aggregate and sampling time differ between sites, the material at one site may have degraded more than at the other, or the sample from one site may contain an overrepresentation of coarse particles. Of the 27 comparisons among the three materials and nine sampling periods, 2 for the slate were virtually identical, and in the other 25 comparisons, 20 of the samples from the Rte. 660 site were finer. Inasmuch as the surfaces at the two sites were observed to be quite different (closely compacted with the aggregate held in place on Rte. 660 and loose with the coarse aggregate segregated onto the shoulders and between the wheel paths on Rte. 663), there is a strong possibility that the disproportionate sampling of the coarse sizes at the Rte. 663 site accounts for the differences in the gradations.

In 18 comparisons of the gradations of the three materials (2 sites times 9 sampling periods), the slate and granite were virtually identical in 2 and in the remaining 16, slate was the finest 13 times and granite 3 times. Eight of those 13 were for the Rte. 660 test site on which there would be much less possibility that the comparative fineness of the slate was caused by the disproportionate sampling of the coarse sizes of the granite and greenstone. Therefore, it appears that the slate must be judged to have been the finest of the three aggregates throughout the study period.

Rate of Degradation

For an evaluation of performance, the durabilities of the aggregates are important factors, and the rate of degradation is an important criterion in judging durabilities. Therefore, the differences in the percentages passing the various sieve sizes over time were divided by the numbers of weeks in the sampling periods and the values plotted on a linear scale. For crusher run aggregates, the #4 and #10 sieves are very important, especially the no. 4 sieve, which is the size about which the specifications for crusher run are centered. The curves for these two sieves are presented in Figures 7, 8, 9, and 10.

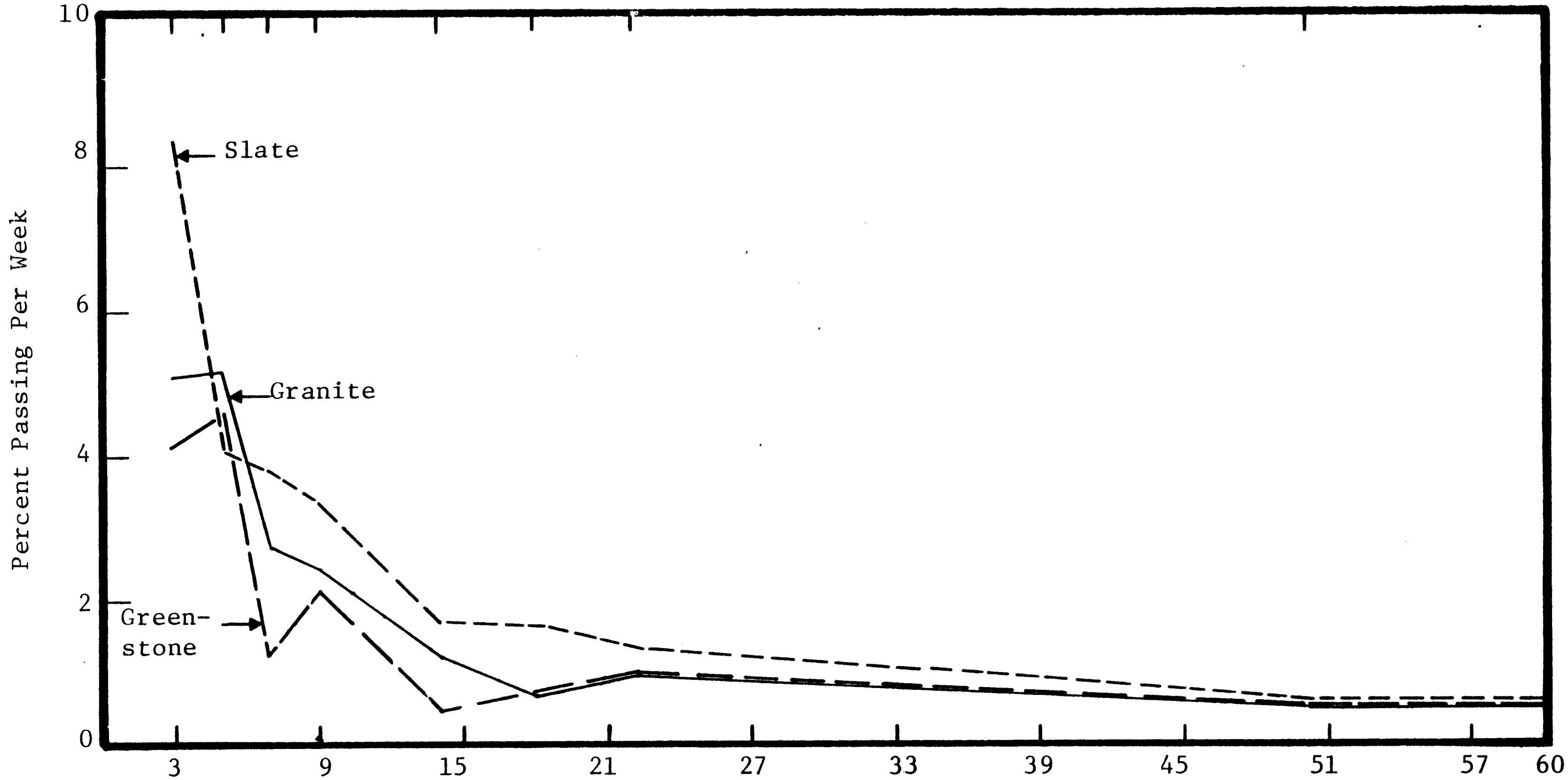

Figure 7. Rates of percent passing per week for the #4 sieve, Rte. 660.

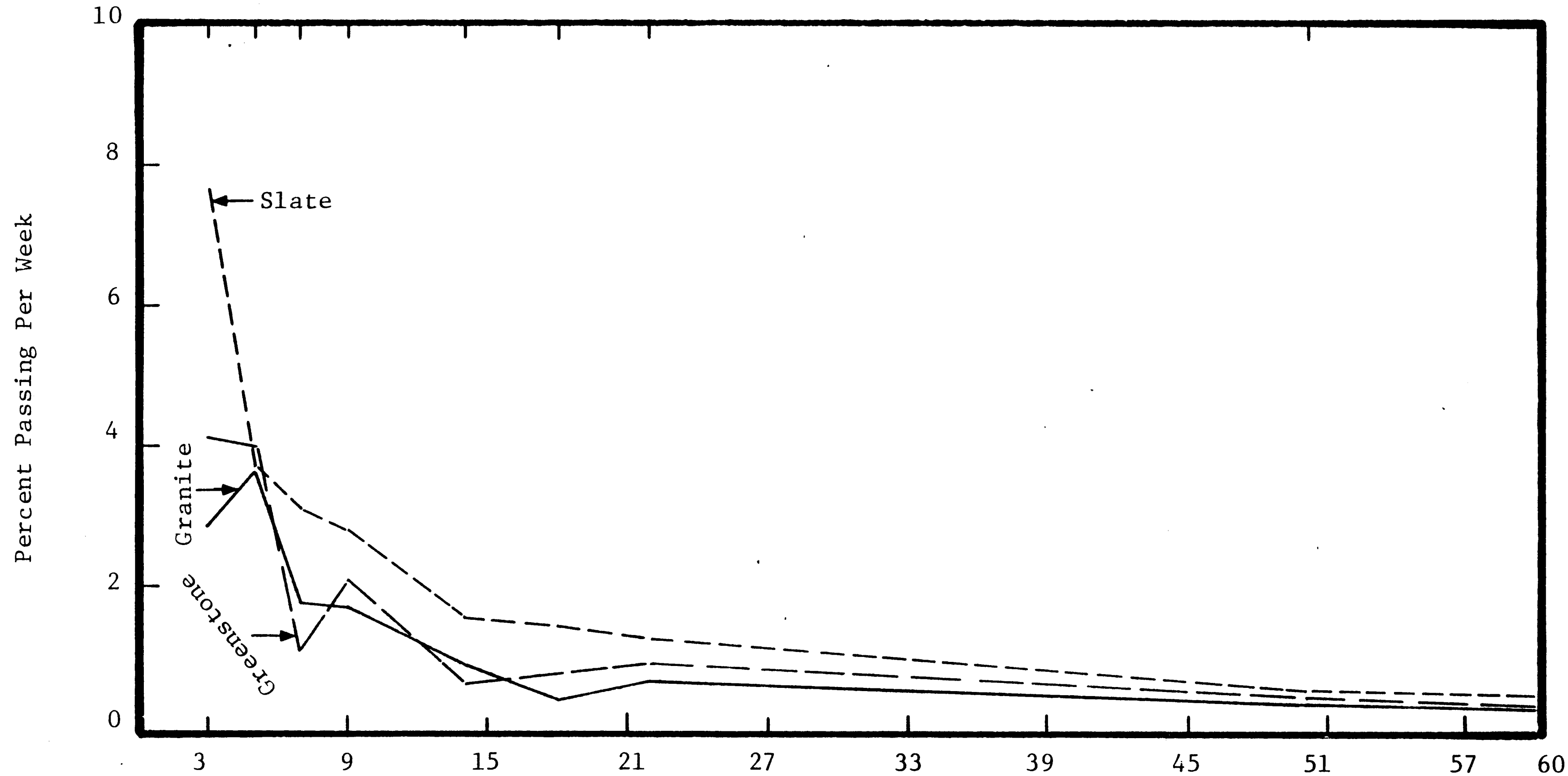

Figure 8. Rates of percent passing per week for the #10 sieve, Rte. 660.

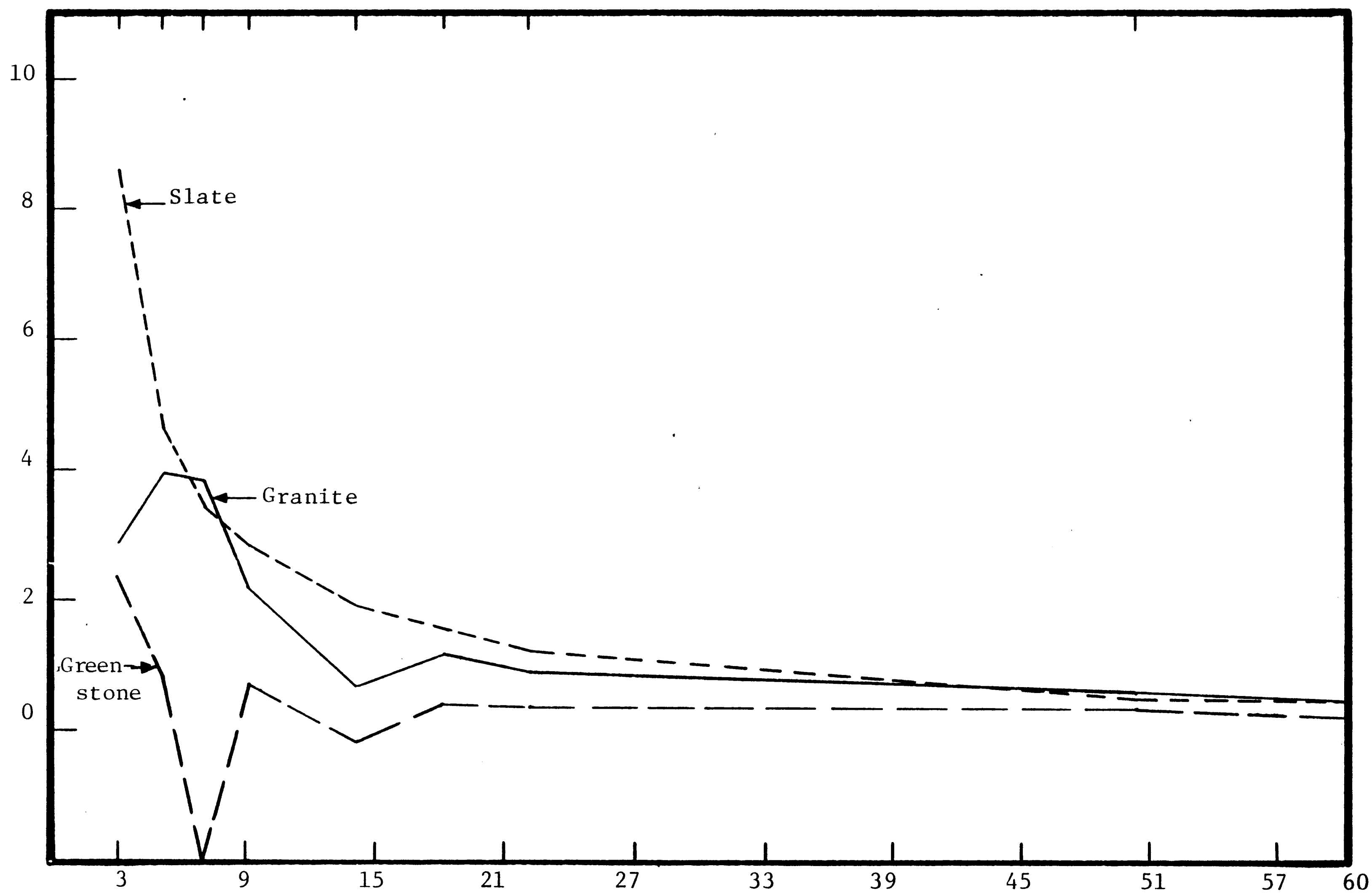

Figure 9. Rates of percent passing per week for the #4 sieve, Rte. 663.

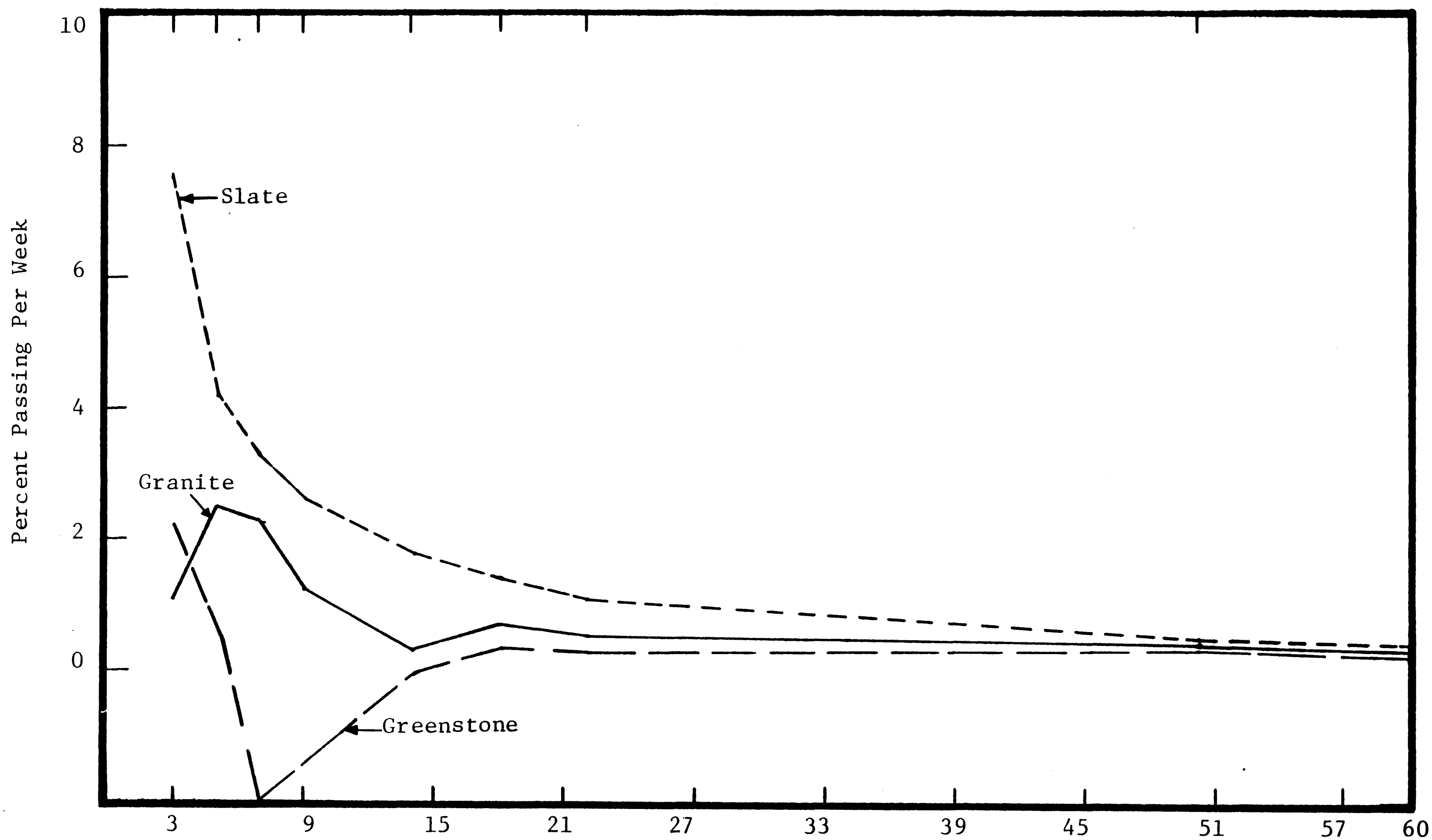

Figure 10. Rate of percent passing per week for the #10 sieve, Rte. 663.

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These curves show that for almost all the sampling times the slate had degraded at a faster rate than the granite and the greenstone. For 76% of the comparisons, the slate degraded 1.4 or more times as fast as the other aggregates. The 3-week samples are of special interest because, considering the usually light applications of aggregate that are made to all-weather surfaces, high early rates of degradation are quite detrimental.

Atterberg Limits

That the aggregates remained nonplastic and the liquid limit decreased with time in service, though in an inconsistent manner, stimulates very little discussion. However, the fact that the aggregates remained nonplastic demonstrated that no significant amounts of clay were formed by chemical weathering of the aggregates, that clay did not migrate into the aggregates, and that no clay was sampled from the native soil below the aggregates.

Depth of Aggregate Remaining on Roadway

The depth of the aggregate remaining on the roadway was determined 17 months after construction of the test strips. Only the middle 100 ft of the 300-ft segments of aggregates were tested and samples were taken at two locations per aggregate. The depth was checked at the centerline of the roadway. While it was demonstrated that somewhat less slate than granite or greenstone remained on the roadways, the differences between aggregates was not very large.

Skid Tests

Because the public and at least one school official had complained about the slipperiness of wet roadways on which slate-like materials had been used, it was decided to run skid tests on the test sites. The procedure for running a skid test is such that to do so on a roadway with large quantities of loose aggregate on the surface is dangerous and virtually useless, because it is difficult to maintain control of the vehicle and the locked wheel tends to skip about on the loose aggregate and thus provides an erratic record. Therefore, no skid test was run on the Rte. 663 site because of the loose aggregate there. The Rte. 660 site was tested because it was much smoother with much less loose aggregate, as a result of having been treated with calcium chloride to allay the dust from the roadway prior to placement of the experimental surfaces.

The tests were run on a clear, warm, midsummer day. Three runs, netting nine tests, were made after two passes of a water truck. There was a short wait between wetting the roadway and running the tests to allow the surface to become relatively free of standing water; however a few potholes still held some water when the runs were made. The roadway was rewetted and two more runs were made.

The results of the skid tests are presented in Appendix B. While the means for each group of five tests on the three aggregates appeared to be quite different, the variability of the data was so great that when the variance ratio test was applied, the differences between the means were shown not to be significant.

Observations

The flow of the slate from the tailgate during spreading was judged to be reasonably good, though not as good as for the granite and greenstone. See Figure 11 for slight necking of the slate.

As has been indicated, there were three residences along Rte. 660 and calcium chloride had been applied as a dust palliative at that site. Apparently, the moisture held within the roadway by the salt promoted binding of the newly placed materials. Thus, the Rte. 660 test site maintained a relatively smooth, tight appearing surface. Because there were no dwellings close to the Rte. 663 site, calcium chloride was not applied, and a relatively loose, rutted surface was maintained.

Figure 11. Tailgate spreading of slate with slight necking of the distribution pattern at arrows.

The sheen of the segment constructed of slate was evidence of the high mica content of this aggregate and that many of the flakes were oriented parallel to the roadway. It is quite probable that the parallel orientation of the flakes and the naturally poor adhesion between them account for the relatively easy removal of the slate during sampling.

Particle shape, the use of calcium chloride on the Rte. 660 test site, and the effort required to dig the samples from the roadway all seem to be related to the degree of consolidation attained by the aggregates and the toughness of the layer. The difficulty in digging the samples of granite was attributed to its extreme densification, which was thought to result from the nearly three-dimensional shape of the aggregates and the lubricating and binding action of the moisture held by the calcium chloride. Of course, this moisture contributed to greater consolidation of all the aggregates at the Rte. 660 test site as compared to the aggregates at the Rte. 663 site.

CONCLUSIONS

The purpose and the scope, as stated earlier, clearly limited the study to the evaluation of the field performance of slate and two general construction aggregates as used on all-weather surface roadways. Thus, it is within these limitations and the limitations imposed by time, the availability of test procedures, working around the normal maintenance procedures, and the many variabilities inherent in this type of study that the following conclusions have been drawn.

1. The extreme degree of central tendency for the gradation of the slate as delivered, with approximately 83% of the material being retained on the 3/8 in and #4 and #10 sieves, leads to a question of whether the slate was "the complete product of the crusher" and emphasizes the need for guaranteeing that crusher run will be relatively well graded, which rationally should be expected to be the natural state of crusher run.

2. The various approaches to analyzing the gradations of the aggregate in service clearly showed that the slate wore to a greater extent than did the granite or the greenstone. In normal maintenance, much less aggregate than the 3 in used in this evaluation would be placed on an all-weather surface roadway. Therefore, the relatively faster rate at which the slate wore over the first 4 months, as compared to the granite and greenstone, is probably of more relevance in the maintenance of all-weather surface roadways than are the much closer rates of wear experienced after a year of use.

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3. **The bearing capacities of the granite and greenstone were far superior to that of the slate, principally because the slate was poorly graded and because of its very high mica content and elongated shape.**

RECOMMENDATIONS

1. To increase the possibility of receiving "the complete product of the crusher....", the percent passing the second designated sieve size should be changed from 95 ± 5 to 93 ± 3, or to an even broader, more realistic band.

2. Slate is obviously a specialty stone and its manner of use in the construction industry should be given special consideration. It is recommended that inasmuch as it has been demonstrated that "crusher run slate" did not perform as well as other readily available, competitively priced crusher run aggregate when used on all-weather surface roadways, the Department should not be obliged to purchase "crusher run slate" to be used for that purpose. **Such a decision would not mean that crusher run slate could not be used for other purposes, nor that other types of slate aggregate could not be purchased for purposes for which they have performed adequately in the past.** In addition, it should be clearly stated that when no other competitively priced construction aggregate of proven good performance is available, it is the Department's intention to use such special stone as is available to provide as good service as is possible.

3. Specifications should be written with usage in mind, and when bearing capacity is important to the usage of crusher run material, such as in the construction of a base for a road at a housing development or in the surfacing of an all-weather surface roadway, it should be possible to introduce bearing capacity into the specifications.

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METRIC CONVERSION SHEET

4/30/85 **SI CONVERSION FACTORS**

To Convert From	To	Multiply By
Length:		
in	cm	2.54
in	m	0.025 4
ft	m	0.304 8
yd	m	0.914 4
mi	km	1 . 609 344
Area:		
in^2	cm^2	6.451 600 E+00
ft^2	m^2	9.290 304 E-02
yd^2	m^2	8.361 274 E-01
mi^2	Hectares	2.589 988 E+02
acre (a)	Hectares	4.046 856 E-01
Volume:		
oz	m^3	2.957 353 E-05
pt	m^3	4.731 765 E-04
qt	m^3	9.463 529 E-04
gal	m^3	3.785 412 E-03
in^3	m^3	1.638 706 E-05
ft^3	m^3	2.831 685 E-02
yd^3	m^3	7.645 549 E-01

NOTE: $1m^3 = 1,000$ L

To Convert From	To	Multiply By
Volume per Unit Time:		
ft^3/min	m^3/sec	4.719 474 E-04
ft^3/s	m^3/sec	2.831 685 E-02
in^3/min	m^3/sec	2.731 177 E-07
yd^3/min	m^3/sec	1.274 258 E-02
gal/min	m^3/sec	6.309 020 E-05
Mass:		
oz	kg	2.834 952 E-02
dwt	kg	1.555 174 E-03
lb	kg	4.535 924 E-01
ton (2000 lb)	kg	9.071 847 E+02
Mass per Unit Volume:		
lb/yd^2	kg/m^2	4.394 185 E+01
lb/in^3	kg/m^3	2.767 990 E+04
lb/ft^3	kg/m^3	1.601 846 E+01
lb/yd^3	kg/m^3	5.932 764 E-01
Velocity: (Includes Speed)		
ft/s	m/s	3.048 000 E-01
mi/h	m/s	4.470 400 E-01
knot	m/s	5.144 444 E-01
mi/h	km/h	1.609 344 E+00
Force Per Unit Area:		
lbf/in^2	Pa	6.894 757 E+03
lbf/ft^2	Pa	4.788 026 E+01
Viscosity:		
cS_t	m^2/s	1.000 000 E-06
P	Pa's	1.000 000 E-01

Temperature: °F-32)^5/9 = °C

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APPENDIX A

AGGREGATE GRADATIONS

Table A-1

Gradations - Granite, Percent Passing

Time in Weeks

Sieve Sizes	0.0	3	5	7	9	14	18	22	50	60
Route 660										
1 1/2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4	91.7	94.0	97.1	96.0	96.8	93.9	92.3	95.0	95.6	98.8
3/8	53.5	66.7	78.6	74.1	74.0	70.1	65.4	73.6	76.3	79.5
4	35.2	50.3	60.8	54.3	57.0	51.9	47.0	56.4	59.6	61.9
10	26.0	34.4	44.3	38.3	41.2	38.1	32.9	40.4	43.2	42.5
20	18.9	24.1	30.1	26.3	27.9	28.0	23.5	30.1	32.9	32.4
40	14.9	18.8	23.1	20.2	21.3	22.1	18.1	23.8	25.9	25.4
80	11.7	14.8	17.9	15.5	16.4	16.9	13.9	18.4	20.1	19.2
100	11.0	14.0	16.9	14.6	15.4	15.8	13.1	17.3	19.0	18.0
200	8.3	10.6	12.8	11.1	11.5	11.6	10.6	14.3	14.8	13.5
Route 663										
1 1/2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1	100.0	100.0	99.3	100.0	100.0	98.7	100.0	100.0	100.0	100.0
3/4	91.8	91.1	94.6	99.3	96.5	92.7	94.5	94.4	97.9	97.3
3/8	53.2	60.6	71.2	80.7	73.6	63.0	73.4	72.0	81.6	80.2
4	35.1	43.7	54.7	61.7	54.7	44.7	55.7	54.6	65.2	63.4
10	27.2	30.5	39.7	43.2	38.3	31.3	39.6	38.6	47.6	46.8
20	19.8	21.8	28.1	29.5	26.3	22.2	28.0	28.3	37.0	36.7
40	15.3	16.7	21.9	22.9	20.4	17.3	21.8	21.8	29.1	28.8
80	11.6	12.9	17.0	17.8	15.8	13.4	16.9	16.6	22.2	22.2
100	10.9	12.1	16.1	16.8	14.8	12.6	15.9	15.5	20.8	20.9
200	8.2	9.1	12.1	12.6	11.1	9.4	12.5	11.8	15.0	15.8

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Table A-2

Gradations - Slate, Percent Passing

Time in Weeks

Sieve Sizes	0.0	3	5	7	9	14	18	22	50	60
					Route 660					
1 1/2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4	100.0	100.0	100.0	100.0	99.3	100.0	100.0	99.1	97.0	100.0
3/8	72.3	83.2	82.8	87.2	84.1	89.8	84.4	89.8	85.1	89.7
4	36.5	61.5	57.0	63.0	66.6	60.2	66.4	66.2	67.1	70.4
10	18.2	41.2	36.9	40.3	43.7	40.2	44.3	46.2	46.8	47.5
20	11.8	26.7	24.6	25.8	28.0	26.0	31.2	33.8	34.5	35.6
40	8.4	20.2	18.5	19.3	19.9	19.4	24.2	26.6	27.4	28.3
80	6.6	15.8	14.1	14.9	14.9	14.7	19.1	21.0	22.1	22.2
100	6.4	15.1	13.4	14.3	14.2	14.0	18.2	20.1	21.1	21.0
200	5.4	13.0	11.3	12.2	12.0	11.5	15.7	18.3	18.0	17.2
					Route 663					
1 1/2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	98.7	100.0
3/8	72.0	85.9	81.7	82.4	84.2	85.9	87.1	84.8	80.2	86.8
4	34.8	61.3	58.3	58.7	60.2	61.6	63.0	61.3	59.6	64.7
10	17.0	39.6	38.1	40.0	40.6	42.1	42.3	40.7	40.7	42.6
20	11.0	26.7	24.8	26.3	26.0	28.3	28.9	28.3	29.2	30.1
40	7.8	20.2	19.1	19.8	19.8	21.7	22.4	21.9	22.8	22.9
80	6.0	15.8	15.2	15.4	15.6	17.1	17.9	17.3	18.3	17.6
100	5.7	15.1	14.5	14.7	15.0	16.3	17.2	16.6	17.5	16.7
200	4.9	13.0	12.5	12.5	12.8	13.9	15.0	15.1	15.0	13.9

Table A-3

Gradations - Greenstone, Percent Passing

Time in Weeks

Sieve Sizes	0.0	3	5	7	9	14	18	22	50	60
					Route 660					
1 1/2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1	97.0	98.2	94.2	98.5	97.8	95.8	100.0	100.0	96.7	99.2
3/4	74.7	85.2	86.4	79.8	83.0	76.4	85.5	86.2	87.9	92.1
3/8	46.5	53.8	63.5	50.8	60.9	46.9	55.4	62.6	68.5	74.4
4	28.8	41.1	51.6	37.6	48.9	35.4	42.3	50.3	55.4	60.8
10	16.8	29.2	36.8	23.9	35.7	25.6	30.5	37.1	39.3	42.5
20	10.2	19.5	25.5	14.7	23.0	18.0	21.7	26.5	28.5	33.8
40	7.0	14.0	18.0	10.6	16.6	13.5	16.6	21.8	21.8	26.2
80	4.8	9.8	12.2	7.7	11.8	9.7	12.3	14.5	16.2	18.7
100	4.5	9.1	11.2	7.2	11.0	8.9	11.4	13.5	15.2	17.2
200	3.5	2.0	8.6	5.7	8.4	6.8	9.2	11.1	11.8	12.5
					Route 663					
1 1/2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1	96.8	94.7	98.9	98.4	98.9	98.1	98.8	100.0	98.8	96.6
3/4	75.9	77.1	82.0	65.3	81.4	77.4	87.0	87.3	88.6	84.8
3/8	49.8	55.5	56.2	37.9	57.5	48.3	59.7	59.7	60.7	66.0
4	33.1	40.1	37.1	19.2	39.1	30.5	39.9	40.8	50.6	48.8
10	20.2	26.8	23.6	5.8	25.7	18.9	25.7	25.7	36.2	31.7
20	11.7	17.2	15.6	3.7	16.6	12.3	16.9	17.1	26.4	22.8
40	8.1	12.6	11.3	2.7	12.4	9.2	12.6	12.7	20.4	17.5
80	5.8	9.1	8.1	2.0	9.3	6.8	9.4	9.5	15.5	13.0
100	5.4	8.5	7.5	1.9	8.7	6.4	8.8	8.9	14.5	12.1
200	4.3	6.7	5.9	1.5	7.0	5.0	7.2	8.0	11.3	9.4

APPENDIX B

SKID TEST DATA NORMALIZED TO 40 MPH

Runs	Granite	Slate	Greenstone
6, 7, & 8	43.6	36.3	25.9
12, 13, & 14	47.4	37.1	29.3
15, 16, & 17	37.3	30.1	32.3
18, 19, & 20	35.0	31.5	28.6
21, 22, & 23	33.1	37.0	37.7