Relationship of Forest Road Aggregate Test Properties to Sediment Production

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Abstract

This study investigated the sediment production from various aggregates. The objectives of this study were 1) to evaluate the erodibility of a range of aggregate surfacing materials and relate it to standard and non-standard specification tests, 2) provide a means of specifying aggregate materials and understand the sedimentation implications, and 3) to provide a relative ranking of the erosive potential of aggregates. To accomplish this, eighteen aggregates from the Pacific Northwest were selected based on quality and geologic parent material. A suite of aggregate specification tests were performed to characterize each aggregate. The sedimentation from a simulated rain storm on a plot representing a freshly constructed road section was measured. Traffic was applied and the sediment production from a simulated storm again measured. The two best indicators of aggregate quality were Sand Equivalent and Oregon Air P20 test results. Knowledge of whether an aggregate was classified as good or marginal was not sufficient to estimate sediment production. The best indicator of sediment production was the percent passing the number 30 sieve.

Introduction

The United States Forest Service road network consists of 590,000 km; approximately 75 percent are un-surfaced, 20 percent are aggregate surfaced, and 5 percent are paved. In wet climates, such as western Oregon and Washington, most roads are surfaced with 200 to 400 mm of aggregate to provide structural support during wet weather. In drier climates, such as the Intermountain West, placement of aggregate is more often used to reduce sedimentation. In both situations, the aggregate thickness is selected to provide adequate bearing strength to "protect" the subgrade from significant deformation, from intrusion of the subgrade into the aggregate, and reduce the amount of sediment produced from the road.

Aggregate quality is a subjective rating used by road engineers to describe the suitability of an aggregate for use on forest roads. Resistance to both mechanical breakdown from traffic and chemical breakdown from weathering are considered. A good

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quality aggregate in one area may be only a marginal quality in another area because of differences in climate and road use. This degree of subjectivity makes comparisons based on aggregate quality alone difficult. Many Forest Service road engineers believe aggregate quality is an important factor in determining the quantity of road sedimentation. High quality road aggregate is not always available in many localities, and marginal quality aggregates are often used to reduce road building costs.

A four-year aggregate quality study was conducted on the Lowell Ranger District of the Willamette National Forest, Oregon. This study's results demonstrated that aggregate quality made a substantial difference in the amount of sediment produced (Foltz and Truebe, 1995). Log truck traffic similar to that associated with a typical timber sale was incorporated in this research. A section of road with marginal quality aggregate produced 4 to 17 times as much sediment as a similar section with good quality aggregate. The mechanisms that caused the increase in sediment production from the marginal aggregate were a longer runoff flow path on the marginal aggregate and the inability of the marginal material to resist mechanical crushing and chemical weathering.

Objectives

A study was undertaken to investigate the sediment production of various aggregates. The objectives of this study were 1) to evaluate the erodibility of a range of aggregate surfacing materials and relate it to standard and non-standard specification tests, 2) provide a means of specifying aggregate materials and understand the sedimentation implications, and 3) to provide a ranking of the erosive potential of the selected aggregates.

Methods

Selection of Aggregates. Forest Service personnel from the states of MT, ID, UT, SD, WA, and OR responsible for aggregate selection for forest roads were asked to nominate both good and marginal aggregate that was widely used on their forest. Eighteen aggregates were selected, 11 of which were believed to be good, and the remainder to be marginal. In Table 1 the aggregate samples are delineated by the forest, state, quality, and geologic parent materials.

Performance Tests. Various tests exist to quantify the performance of aggregates when subjected to traffic and moisture. Performance is generally characterized by an amount of degradation, and is reported as an index of how the material degrades.

The Sand Equivalent test (AASHTO T-176) indicates the relative amount of fine dust or clay size material. The Durability test (AASHTO T-210) is an index which indicates the resistance to production of clay size fines during exposure to water. The DMSO test is similar to the Durability test with the substitution of dimethylsulfoxide to accelerate the weather process. Sodium Sulfate Tests (AASHTO T-104) measure the resistance to weathering action such as freeze-thaw and wetting-drying cycles. The Oregon Air Degradation tests are similar the Durability test with the addition of a jet of air.

For each performance test an analysis of variance (ANOVA) was used to determine if there was a difference between good and marginal aggregates. A test was deemed acceptable if it had a p-value of 0.05 or less.

These performance tests were also used to find the best single estimator of sediment production potential. Both an ANOVA and a correlation coefficient between the test and the sediment production were used.

Aggregate plot preparation. Steel frames, 1.25 m wide, 4.83 m long, and 0.20 m deep, were constructed to hold the aggregate during rainfall and traffic application. Aggregate was compacted in two lifts at optimum moisture and 95% of maximum density. Each lift was compacted with a 130 kg vibrating roller.

Traffic simulator. A traffic simulator consisting of the rear two axles of a standard tractor-trailer and loaded to a near highway legal 14,180 kg was constructed. The simulator was pulled at a speed of 0.3 kph for a distance of 7.3 meters by an hydraulic powered winch.

Traffic application. Each plot received the equivalent of 200 logging truck passes determined by converting the 14,180 kg dual axle load to a Single Axle Equivalent (Whitcomb, et. al., 1990). The traffic simulator reproduced near-static loads well. Dynamic loads were not as well represented because the axles were not driven resulting in no wheel slip.

Simulated road conditions. Three road conditions were simulated for each aggregate. These simulations varied the rut depth and effective cross drain spacing. One was a short road section (~30 meter) on a 6% grade without sufficient traffic to leave wheel ruts. This treatment will be referred to as "short section". The second was a short section (~30 meter) on a 6% grade with deep (50 to 100 mm) wheel ruts and will be called "short, rutted section". The final treatment was a long road section (~140 meter) on a 6% grade with deep (50 to 100 mm) wheel ruts, subsequently called the "long, rutted section". Both short sections received a simulated rainstorm with an intensity of 50 mm per hour for 30-minute duration from a Purdue-type rainfall simulator. The long section received the same simulated rainstorm plus added flow of 28 lpm to simulate the additional runoff from a longer road section. Runoff was measured with an Isco 3230 flow meter. Sediment concentrations were determined by oven-drying grab samples taken at one minute intervals.

Added fines - Occasionally, fines are added to an aggregate if it is deficient in fine material. The impact of these additional fines on sediment production was tested by adding fines to two of the test aggregates. These aggregates had the rainfall-traffic-rainfall sequence repeated.

Near-saturated traffic conditions - Four of the aggregates came from the west side of the Cascades where traffic often occurs on nearly saturated roads. To simulate these conditions a constant rainfall of 6 mm/hr was applied during the traffic application. This kept the plot in a near-saturated condition. The rainfall-traffic-rainfall sequence was repeated for these four aggregates.

RESULTS AND DISCUSSION

Aggregate gradations. Forest Service specifications require a material with a liquid limit maximum of 35 and a plastic limit of 2 to 9. Eleven of the 18 aggregates did not meet these specifications with approximately an even split between marginal and good aggregates.

Seven of the aggregates had material exceeding the 1 inch maximum size class. Five of these were marginal aggregates suggesting a preference by forest road designers to use larger sized gradations when known marginal aggregates are used.

Only six of the aggregates tested met the size requirements with all but one being good quality. The most notable variation was a deficit of number 4 sieve (4.75 mm) size fines.

Predictors of aggregate quality. An analysis of variance was used to determine which tests showed significant differences between good and marginal aggregates (Table 2). Six tests had statistically significant differences between the two aggregate qualities. The Sand Equivalent test had a p-value of 0.002. Because of the ease of performing this test compared to the other five tests, the authors prefer this test.

Five of the six tests were on the fine material portion of an aggregate. This indicated that the characteristics of the fine material in an aggregate had a greater impact than the coarser sizes on the quality classification.

Sediment Production and Aggregate Quality. Sediment production for each of the three road conditions grouped by aggregate quality is shown in Table 3. For each road condition the marginal aggregates produced more sediment. In the short section there was 2.9 times as much sediment from the marginal aggregates. Analysis of variance showed that there was a statistically significant difference (p-value of 0.04) between the average sediment production of marginal and good quality aggregates for the short road section. This indicated a statistically significant difference in sediment production between aggregate qualities for a short un-rutted road section.

For the rutted conditions, the marginal aggregates produced 1.2 to 1.8 times as much sediment as the good aggregates. However, the analysis of variance indicated that there was no statistically significant difference between the average sediment production between marginal and good quality aggregate when the road section was in a rutted condition (p-value of 0.26 for the short, rutted section; p-value of 0.60 for the long, rutted section).

These tests indicated that differences in aggregate quality became less apparent as the plot length or the degree of rutting increased. This suggests that in order to derive maximum benefit from the better quality aggregate deep ruts should not be allowed to remain in the road during heavy rainfall periods.

The importance of testing aggregates under traffic conditions was highlighted by these results. Had the study been conducted without traffic, the conclusion would have been that aggregate quality was sufficient to determine sediment production potential. In the presence of traffic, however, the opposite conclusion was reached. Testing of sediment production potential from aggregate should include traffic.

Prediction of Sediment Production. The best predictor of sediment production was the percent passing the number 30 (0.60 mm) sieve with p-values ranging from 0.0005 to

0.0001 and correlation coefficients from 72% to 79% depending on the treatment. A measure of the fines as the best predictor of sediment production was a logical result. Infiltration was controlled by the size of the pore space between larger aggregates. Increasing fines filled the pore space and reduced infiltration resulting in increased runoff. Additionally, this size range is most susceptible to erosion by raindrop impact and concentrated flow erosion. Figure 1 shows the relationship between sediment production and percent passing number 30 sieve for the short, rutted section.

It would appear that to minimize sediment production one should minimize the percent passing the number 30 sieve. However, aggregate gradations must be considered. A dense graded aggregate, one that contains all material sizes from the maximum to the fines, will have the larger pore spaces occupied with sand and fines. This is a highly desirable condition because it provides for stability and waterproofing. Alternatively, an aggregate that is too open graded, one that lacks sufficient sand and fines to occupy the larger pore spaces, will be unstable and allow water to infiltrate and saturate the subgrade. An unstable surface causes a high rate of aggregate loss from traffic "kicking" the material off the road as well as the sensation of driving on ball bearings. Neither of these are desirable in a road.

A conflicting relationship exists between gradation and sedimentation. Dense graded materials will have more fine material (percent passing number 30 sieve) and will produce more sediment. Gradations, and specifically the percent passing number 30 sieve, have to be selected to satisfy the conflicting requirements of sediment production and aggregate performance under traffic.

Relative Ranking of Aggregates. Since there were three road treatments (short section, short, rutted section, and long, rutted section), ranking could be done on any of the three conditions. To determine if there was a statistical difference between the rankings a Spearman's Rank Correlation was performed. A high correlation between ranks meant there was no statistical reason to prefer one ranking scheme over the alternative one.

The p-value for the correlation of ranks between the short section and the short, rutted section was 0.0001. For the rankings between short section and the long, rutted section, the p-value was 0.0002. The combination of short, rutted and long, rutted sections had a p-value of 0.0001. These values show that the relative rankings of the aggregates based on sediment production were not statistically different regardless of the ranking method. One can use any of the treatments and the relative ranking of the aggregates tested will not be statistically different.

In Table 1 the aggregates are ranked based on the short, rutted section sediment production. The range of sediment production covers two orders of magnitude. Note that knowing the geologic parent material provides only little indication of sediment production potential. For example, the basalts are scattered throughout the table.

Effect of added fines. The BWG aggregate had a small percent passing the number 200 sieve (5.7 percent vs. 6 to 15 required) and the LG had a small percent passing the number 4 sieve (24 percent vs. 36 to 60 required). Additional fines were added to the BWG aggregate to meet the specification. The LG site was revisited and samples taken that met the grading criteria. In both instances the sediment yield increased after the fines were increased. As shown in Figure 1, (compare BWG to BWG+ and LG to LG+) these aggregates with increased fines had sediment production consistent with other aggregates having the same percent of fines passing the number 30 sieve.

Traffic under near saturated conditions. - Four of the aggregates, BYM, AHM, BWM, and BWG+, were tested under a wetter traffic regime. Three of the aggregates produced more sediment compared to the base conditions. One produced substantially less sediment. In Figure 1 these aggregates are shown with an open circle and a lower case 'w' appended to the abbreviation.

CONCLUSIONS

For the suite of aggregates tested, the Oregon Air P20 and the Sand Equivalent test were the best indicators of aggregate quality. Both tests had statistical significance corresponding to a p-value of 0.002 or less. The authors prefer the Sand Equivalent test due to its simplicity.

For the rutted condition treatments (both short, rutted condition and long, rutted condition) simply knowing whether an aggregate was considered good or marginal quality was not sufficient to determine whether it would have a high or a low sediment production. Only for the short road section was one able to use the classification of good or marginal to predict whether the sediment production would be high or low. Relying on the classification of aggregates into good or marginal alone was not useful to determine the sediment production potential.

Sediment production was directly proportional to the percent passing the number 30 sieve. The Forest Service specification for the percent passing the number 30 sieve ranges from a low of 12% to a high of 31%. To minimize sediment production, one should minimize the percent passing the number 30 sieve. This desire to minimize the percent passing the number 30 sieve is in conflict with the need to have sufficient fines to keep the aggregate stable and on the road.

A relative ranking of the aggregates was found. The range of sediment production was two orders of magnitude. The geological parent materials in this test did not provide sufficient information to determine if an aggregate would have a high or a low sediment production.

Fines are occasionally added to meet specifications. The sediment production potential of the resulting aggregate is the same as an aggregate with a similar fines content.

Three of four aggregates tested under a near saturated condition produced more sediment than they did under a drier condition. This illustrates the importance of attention to traffic under wet conditions.

The 18 aggregates tested showed a wide range of runoff, and sediment production potential. Careful attention to aggregate selection appears necessary to minimize impacts to the environment.

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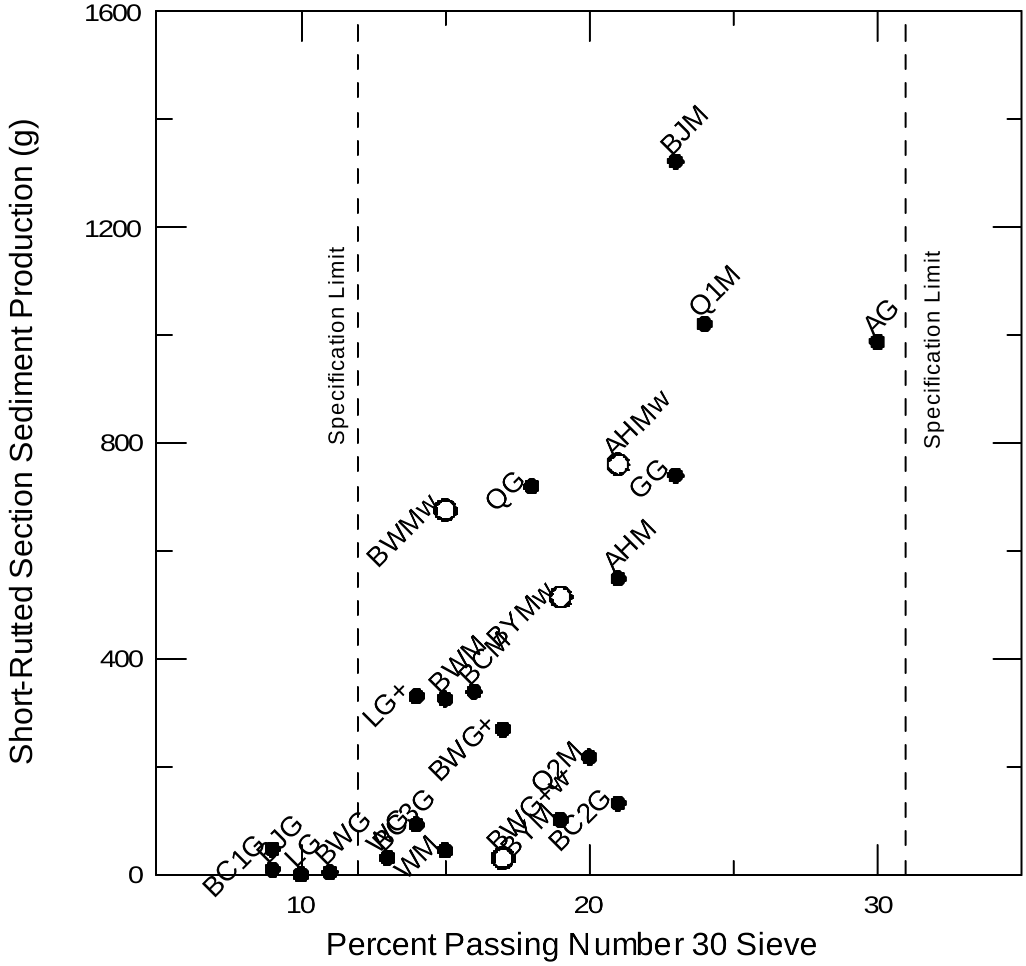

Figure 1 - Relationship between sediment production and percent passing number 30 sieve for the short, rutted condition. Closed circles represent base conditions. Open circles represent near saturated conditions.

Table 1 - Parent material, locations, and sediment production for the 18 aggregates. Sediment production from the short, rutted road section.

Parent Material and Abbreviation	Source Name	Forest	Sediment Production (g)
Limestone (LG)	Black Hills	Black Hills, SD	0
Western Cascades basalt (BWG)	Springfield Quarry	Willamette, OR	3.6
John Day basalt (BJG)	Highland	Ochoco, OR	8.8
Columbia River basalt (BC3G)	Umatilla B	Umatilla, WA	31.0
Welded tuff (WM)	Montane	Wallowa-Whitman, OR	44.4
Columbia River basalt (BC1G)	Harvard Pit	Clearwater, ID	46.7
Welded tuff (WG)	Fir Tree	Ochoco, OR	91.9
Yahats basalt (BYM)	Saddle Mountain	Siuslaw, OR	101.3
Columbia River basalt (BC2G)	Top of the World	Clearwater, ID	131.9
Quartzite (Q2M)	Stage	Nez Perce, ID	217.3
Western Cascades basalt (BWM)	Lowell	Willamette, OR	325.1
Columbia River basalt (BCM)	Twin Ravens	Nez Perce, ID	339.1
Alluvial High Cascades (AHM)	Recycled Surfacing	Willamette, OR	548.7
Quartzite (QG)	Tyler Ridge	Panhandle, ID	719.0
Glacial outwash (GG)	Johnson Creek	Panhandle, ID	740.1
Alluvial (AG)	Strawberry Pit	Unita, UT	986.8
Quartzite (Q1M)	Forage Mountain	Panhandle, ID	1020.6
John Day basalt (BJM)	Sherwood Saddle	Ochoco, OR	1322.2

Table 2 - Analysis of variance (ANOVA) of the difference between aggregate quality and aggregate performance tests. Tests are listed in decreasing order of statistical significance.

Test Value	Typical Specification	Average of Good Aggregates	Average of Marginal Aggregates	p-value
Oregon Air - P20	35 max	8.5	19.6	0.0004
Sand Equivalent	35 min	36.7	22.8	0.002
Durability - Fine	35 min	60.1	38.3	0.007
Sodium Sulfate - Fine	12 max	1.6	9.3	0.012
DMSO	12 max	9.0	27.3	0.015
Sodium Sulfate - Coarse	12 max	1.7	6.5	0.017
Oregon Air - H	3.5 max	1.1	3.8	0.038

Table 3 - Sediment production by aggregate quality for each road condition. P-value tests the hypothesis that there is no difference between the means.

Road Condition	Sediment Production (g)		p-value
	Marginal	Good	
Short section	601.4	208.8	0.041
Short, rutted section	489.8	279.8	0.255
Long, rutted section	4095.5	3309.2	0.597

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