Open-Graded, Plant-Mixed Seals

J. W. HEWETT, Office of Engineering and Operations, U.S. Bureau of Public Roads

•AN OPEN-GRADED, plant-mixed seal is essentially a chip-seal aggregate, contains some additional sand-sized material, is premixed in a plant, and has a relatively high asphalt content. This type of seal provides an exceptionally smooth riding surface. A good seal is produced that is durable and has good skid resistance qualities.

A number of western states are now constructing open-graded, plant-mixed seals as a standard on nearly all high-quality asphalt pavements. Other states and the U.S. Bureau of Public Roads have constructed substantial mileages. At least 12 states have constructed some projects of this type.

A common gradation that is used has $^3/_8$- to $^1/_2$-in. maximum size aggregate with 30 to 50 percent passing the No. 4 sieve and 10 to 30 percent passsing the No. 8 sieve. The asphalt content is usually $5^1/_2$ to 8 percent. It is placed $^1/_2$ to $^3/_4$ in. in depth or 55 to 70 lb per square yard. This seal has most of the good qualities of a chip seal without many of the bad qualities. As with a chip seal, a thick film of asphalt covers the underlying surface forming a seal; there are large voids between the exposed coarse surface particles. Aggregate particles are coated with a film of asphalt 3 to 4 times thicker than that for a dense-graded mix. This provides durability and resistance to moisture in spite of the high void ratio.

In contrast to the extremely wide range of skid resistance values of chip-seal surfaces, a uniformly good skid-resistant surface is produced. In the four states where tests were made in 1967 with the Bureau of Public Roads skid trailer, open-graded, plant-mixed seals had the highest average skid resistance of all surfaces tested in all states but one. In that state, the average skid number for open-graded, plant-mixed seals was 51 and for chip seals it was 54.

The loss of skid number with speed is relatively small because of the voids at the surface. The average loss in skid resistance from 40 to 50 mph was only $^9/_{10}$ of a skid number for 15 projects tested with the Bureau of Public Roads skid trailer in the summer of 1967. This would give a skid number speed gradient of about 0.1 of a skid number per mile per hour. The low value of the skid number speed gradient would result in considerably better skid-resistance properties at higher speeds, when compared with surfaces with higher skid number speed gradients, than shown by the skid number values at 40 mph alone. As an example, to meet the tentative minimum recommendation (1, Table 18) for an average traffic speed of 60 mph, a plant-mixed seal surface with a skid number speed gradient of 0.1 would require a skid number of 33 measured at 40 mph compared with a required skid number of 41 for a surface with a gradient of 0.5. Based only on this criterion, the plant-mixed seal with a skid number equal to 33 at 40 mph would be equal to the pavement with a skid number equal to 41 at 40 mph for a design speed of 60 mph. In other words, the plant-mixed seal would be far superior to the other pavement at a design speed of 60 mph if both had the same skid number measured at 40 mph. The difference in requirements would be even more at higher speeds. The skid number speed gradient of 0.1 is admittedly based on data from only 15 projects. However, this type of material would be expected to have a relatively low gradient because of the open nature of the surface.

The rate of water distribution was not varied when the speed of test was increased from 40 mph to 50 mph to obtain the measurements from which the speed gradients were calculated. Water-film thickness would be decreased by 20 percent because of the higher

Paper sponsored by Committees on Salvaging Old Pavements by Resurfacing, Maintenance of Bituminous Pavements, and Maintenance of Portland Cement Concrete Pavements and presented at the 48th Annual Meeting.

speed. This would be less than the 25 percent tolerance allowed by ASTM designation E 274-65T, Tentative Method of Test for Skid Resistance of Pavements Using a Two-Wheel Trailer. Even if the variation were two or three times this amount, it should have little if any effect on the skid number for this type of surface (1, Fig. 36).

A chip seal adds roughness to a smooth pavement, but an open-graded, plant-mixed seal greatly reduces the roughness. The roughness is 10 to 30 in. per mile less than that on a good asphalt pavement as measured by the Bureau of Public Roads roughometer. This results in an increase to the present serviceability index of 0.13 to 0.50. Besides providing better service to the highway users, the higher serviceability index should result in longer pavement life. Additional serviceability must be lost before reaching a given level; lower strains in the pavement would be expected from moving wheel loads on the smoother pavement.

With an open-graded, plant-mixed seal, there is practically no loss of material as with a chip seal, and there are no flying particles to damage windshields. Surface water can escape through the voids instead of flowing over the surface. This eliminates or greatly reduces tire splash and hydroplaning possibilities. Painted stripes are more visible and more durable because of the surface voids. No curing time is required so that the road can be opened to traffic immediately following rolling. Cost is largely dependent on aggregate availability. Recent prices range from $6.00 to $8.74 per ton or 20 to 30 cents per square yard. The price compares favorably with chip seals on a ton basis, but, because of heavier placement, the square yard price is two to three times higher.

A high-quality aggregate, which has a large percentage of crushed surfaces, is not subject to degradation, has good resistance to polishing, and is not subject to stripping, is necessary for this mix. Crushed surfaces and nonpolishing characteristics are essential for good skid resistance because the tire contact area consists of exposed coarse aggregate surfaces separated by voids. Crushed surfaces also contribute to more voids and high stability. Because stability depends on aggregate interlock, good resistance to degradation is essential to maintain the necessary void ratio. The mix must resist extreme exposure from water and air entering the large voids, and a high-quality asphalt is essential.

The construction procedure is to mix in a plant at a relatively low maximum temperature of about 260 F and place with a regular laydown machine. Mixing is easily done at these low temperatures because of the open gradation. The low mix temperature is necessary because of the tendency of asphalt to separate from the aggregate at higher temperatures and to drain to the bottom of the haul trucks, especially on long hauls. This can result in unsightly fat spots. If fat spots occur, they can be eliminated by handraking ahead of the roller. The Colorado Division of Highways has found that the addition of 1 ounce of silicone per 5,000 gallons of asphalt minimizes this tendency.

Either surface or atmospheric temperature is usually required to be above 60 to 70 F at the time of laydown. The thin lift loses heat rapidly. One or two passes with a steel-wheel roller immediately following laydown is usually specified. Additional rolling is ineffective, because of the rapid heat loss, and may cause degradation.

An error that is almost always committed by project personnel who are not familiar with this type of construction is cutting down the asphalt content. The mix has a very dark appearance compared with a dense-graded mix. The appearance may cause project personnel inexperienced with this type of seal to think that there is an excessive amount of asphalt. A too low asphalt content results in raveling. Because the mix is so open, however, this condition can be corrected, if recognized, by a light application of liquid asphalt after construction. One case of raveling was attributed to bad weather conditions at the time of construction.

Bleeding has occurred at high traffic volumes when the asphalt content was too high or gradation was such that voids were inadequate. It has been found in Phoenix, Arizona, that the percentage passing the No. 8 screen is critical with respect to bleeding, and it has been suggested that a maximum be established of 15 percent passing the No. 8 screen. The Colorado Division of Highways has developed a procedure in which one sample is compacted in the kneading compactor at 125 blows and a companion sample is compacted at 470 blows. The gradation is adjusted until the additional consolidation resulting from

the increased compactive effort is minimized. This test also shows that the amount passing the No. 8 screen should be limited to about 15 percent to eliminate additional consolidation with the increased compactive effort. An analysis of gradation data taken in other states from projects that have been under traffic for some time shows that bleeding is usually associated with mixes in which the percentage passing the No. 8 screen is relatively high or the asphalt content is excessive.

A recommendation from the Denver office of the Bureau of Public Roads is that, for heavy traffic and high ambient temperatures, the material passing the No. 8 screen be limited to less than 15 percent and the asphalt be limited to 7 percent. No cases of bleeding have been observed where these two conditions were met.

The seal cannot be expected to correct large, underlying structural deficiencies of a poor pavement, such as excessive deflection or low stability. The structural qualities of the seal, however, are normally taken into account in pavement design by using a structural value that is equal to the thickness of dense-graded asphalt concrete.

Because of the high voids of the mix, some troubles have been expected from freeze-thaw and tire-chain damage. When construction began in 1961 with this type of seal, some projects were in areas subject to severe freezing and logging-truck traffic. No unusual damage has occurred on these projects. Since then a number of states have projects in locations where there is considerable exposure to freezing, and no unusual damage has been observed. The Maine State Highway Commission has one section constructed that is now going through its second winter with no distress from freeze-thaw.

Stripping of overlays placed over open-graded, plant-mixed seal has occurred in one state apparently because of water trapped in the voids of the underlying seal. This may be caused by weather conditions at the time of overlay or the use of aggregates subject to stripping. An objection to the use of this seal is its susceptibility to oil drippings, especially at an early age. This can be a major problem at signalized intersections, where large accumulations of oil drippings occur.

Figure 1 shows a gradation chart with sieve sizes raised to the 0.45 power. A maximum density line and typical gradation limits in use for open-graded, plant-mixed seals are plotted. The upper limit line would be lowered 10 to 15 percentage points at the No. 8 screen for high traffic density.

Figure 2 shows the drainage properties of this type of seal. The surface of the open-graded, plant-mixed seal (light material in the left half of the picture) appears dry, whereas water (dark splotches near the center of the picture) is draining through the voids of the seal and from the right of the seal onto the shoulder.

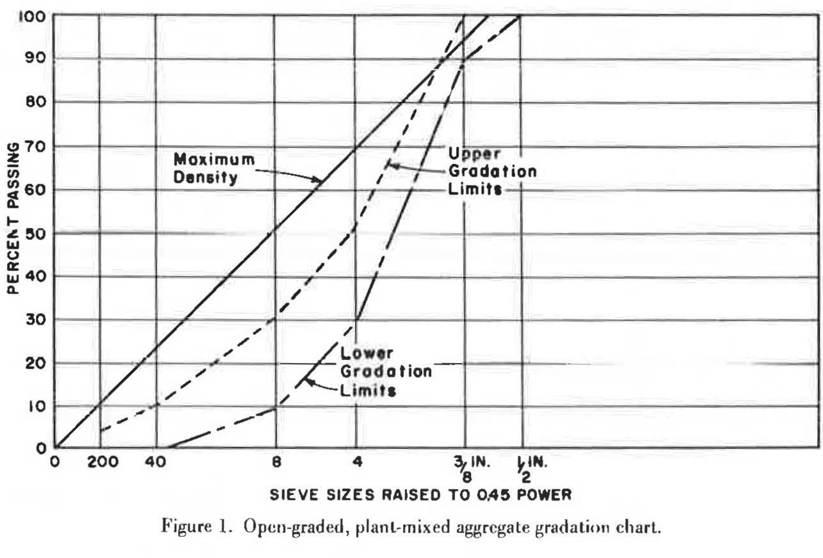

Figure 1. Open-graded, plant-mixed aggregate gradation chart.

Figure 3 shows a plot of skid resistance against traffic exposure for projects constructed in one state with crushed gravel. The skid resistance values shown are project averages as measured by the Bureau of Public Roads skid trailer in the summer of 1967. Traffic exposure is expressed here as ADT in one direction at the time of testing times the number of days open to traffic. No attempt is made to account for distribution of traffic between the driving and passing lanes. Traffic exposure as used in these figures is simply total ADT in one direction times the days open to traffic. The actual number of vehicle passes over a particular lane of pavement would be somewhat less than that shown, but values should be relative for pavements of a given width. The percentage of asphalt, age, and one-way ADT are shown at the point plotted for each project. The lower curve is for the right (travel) lane; another line is plotted for the left or passing lane. The difference in skid number between these two lines is an indication of the loss in skid resistance with traffic. These are all relatively young pavements, but there is an apparent trend of loss of skid resistance with traffic leveling off at higher traffic exposure.

Figure 2. Drainage properties of open-graded, plant-mixed seal.

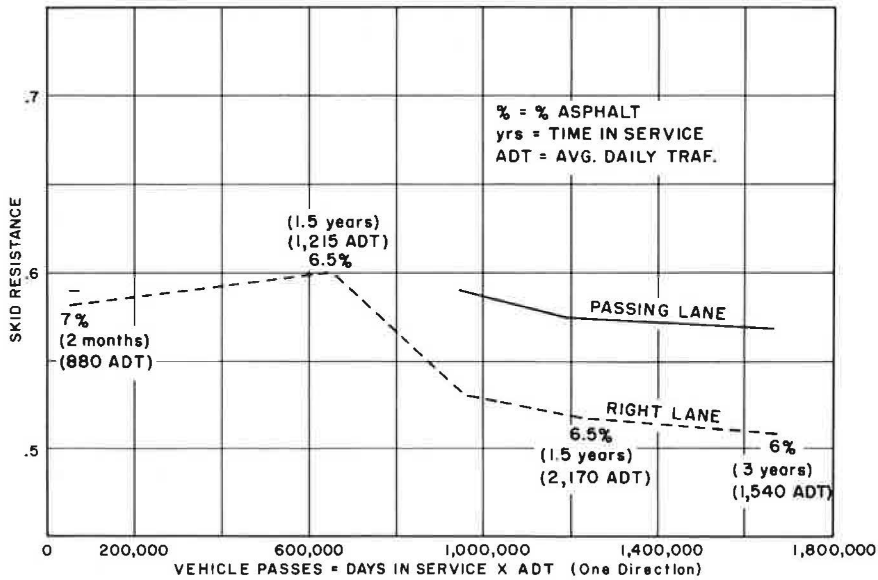

Figure 3. Skid resistance on crushed gravel pavement.

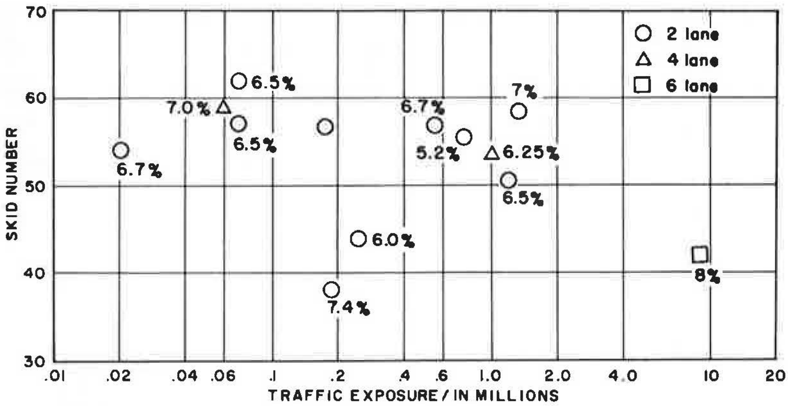

Figure 4. Average skid number of crushed gravel or granite aggregate pavement.

Figure 4 shows a plot of average skid number in the driving lane against traffic exposure plotted on a logarithmic scale for projects tested from the different states with the Bureau of Public Roads skid trailer during the summer of 1967. Only those projects reported to be constructed with crushed gravel or granite aggregate are shown. The asphalt content for each project is shown beside the point representing that project. There is no apparent trend of lower skid numbers with higher asphalt contents for projects with 7 percent or less asphalt content. However, the two projects with the lowest skid numbers are those with the highest asphalt content, 7.4 and 8 percent.

Figure 5 is similar to Figure 4, except that it shows a plot for projects constructed with limestone aggregate. Projects with the same symbol are from the same state. Each state is represented by a different symbol. All projects shown are two-lane pavements, except that the three with the lowest skid numbers are four-lane pavements. The asphalt content was not reported for the three projects with the highest skid numbers.

Although the projects with the lowest skid numbers also have the highest asphalt content for this type of aggregate, the asphalt content is considerably less than that which would appear to affect skid resistance for projects, shown in Figure 4, with crushed gravel aggregate. There is, however, an indication of loss of skid resistance with traffic exposure for the three projects with the lowest skid numbers. These three projects are all in one state. The other points shown represent projects in three other states. These projects do not appear to show a trend of loss of skid resistance with traffic exposure.

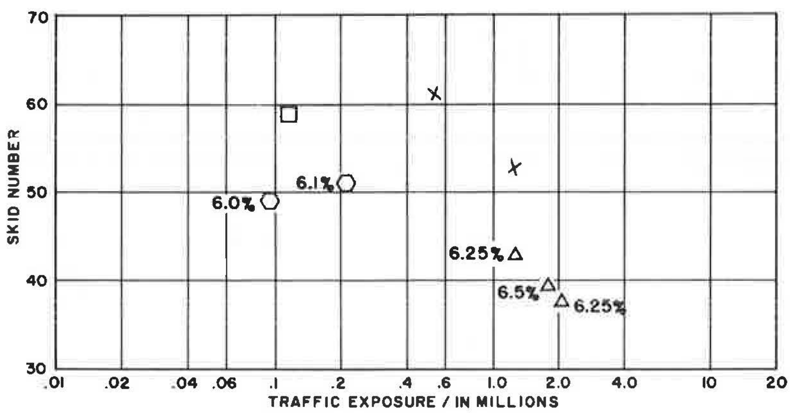

Figure 5. Average skid number on limestone aggregate pavement.

The skid resistance values shown on these plots were for pavements in place at the time of testing with the Bureau of Public Roads trailer. The lowest skid-resistance values can apparently be explained by insufficient voids, excess asphalt, or polishing aggregates. These deficiencies are now recognized and can be avoided.

An open-graded, plant-mixed seal has the qualities that are required for a good surface seal. Skid resistance, exceptional smoothness, and a durable seal are obtained. Material and construction control are essential to good performance.

REFERENCE

1. Kummer, H. W., and Meyer, W. E. Tentative Skid-Resistance Requirements for Main Rural Highways. NCHRP Report 37, 1967, p. 54.