MECHANICAL PROPERTIES OF GAP-GRADED ASPHALT CONCRETES

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ABRIDGMENT

•THIS report presents the results of a laboratory study that compared well-graded and gap-graded aggregates used in asphalt concrete paving mixtures. There was a total of 424 batches of asphalt concrete mixtures involving 3,960 Marshall and Hveem specimens and 33 gradations of which 27 were gapped.

MATERIALS

Two crushed limestones, 1 natural gravel, and 1 crushed gravel were included in this study. The Ferguson aggregate (L_1), a dolomitic limestone, was used in series B and C. The Moscow aggregate (L_2), a lithographic limestone, was used in series D. The crushed and pit-run gravels were used in series F. To improve workability, a concrete sand was added to the major aggregates in all series for fractions retained on a No. 30 sieve and a No. 50 sieve at a 50-50 ratio.

Seventeen aggregate gradings were examined for ¾-in. (19.1-mm) maximum-size aggregates, including a gradation following Fuller's maximum density curve (A-F); a Federal Highway Administration (FHWA) curve, $P = 100(d/D)^{0.45}$ (A-P)(1); a midpoint Iowa type A grading (A-1)(2); and 14 gap gradings as shown in Figure 1. Eight aggregate gradings were examined for ½-in. (12.7-mm) maximum-size aggregates: a FHWA maximum density grading (B-P), a British Standard 594 grading (B-B), and 6 gap gradings as shown in Figure 2. Eight aggregate gradings were studied for ⅜-in. (9.5-mm) maximum-size aggregates for all crushed limestones, including a FHWA grading (C-P), 6 gap gradings, and a midpoint Iowa type A grading (C-I) as shown in Figure 3.

Three asphalt cements of 2 penetration grades were studied in conjunction with the aforementioned aggregate gradings. Asphalt A (65 penetration grade) was used in series C and D; asphalt B (94 penetration grade) was used in series B; and asphalt C (91 penetration grade) was used in series F.

METHODS AND PROCEDURES

Oven-dried crushed aggregates were first separated by ¾-in. (19.1-mm), ½-in. (12.7-mm), ⅜-in. (9.5-mm), No. 4, No. 8, No. 30, No. 50, No. 100, and No. 200 sieves. Concrete sand was separated and added to retain No. 30 and No. 50 fractions at a 50-50 ratio. Required weights of each fraction were then combined to produce the gradation curves shown in Figures 1 through 3. Asphalt concrete mixtures were made in a 50-lb (22.7-kg) laboratory pugmill mixer at asphalt contents from 3 to 7 percent. Nine specimens were prepared from each batch. Six specimens were compacted by the 50-blow Marshall method and 3 specimens by the Hveem method. Of the 6 Marshall specimens, 3 were tested by the standard Marshall method, 2 were tested by the Marshall immersion compression method (3), and 1 was tested for indirect tensile strength (4).

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Figure 1. Grading curves for $^{3}/_{4}$-in. maximum-size aggregates (0.45 power).

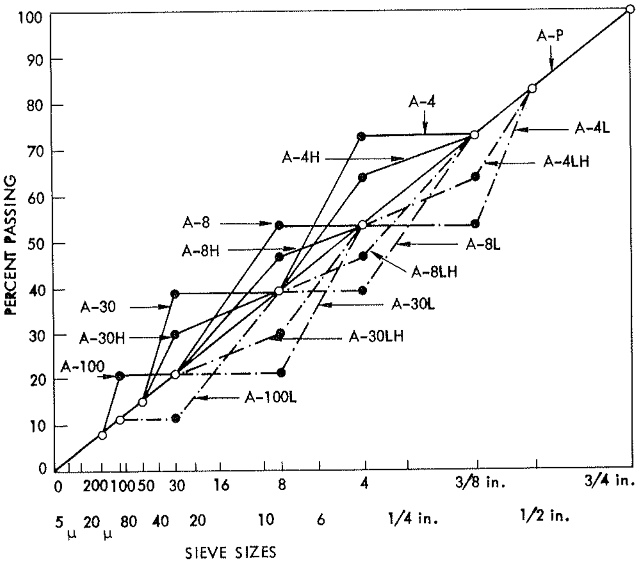


Figure 2. Grading curves for $^{1}/_{2}$-in. maximum-size aggregates (0.45 power).

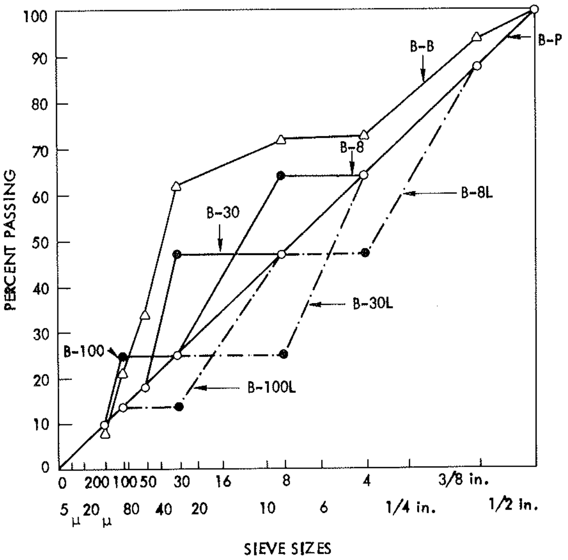


Figure 3. Grading curves for $^3/_8$-in. maximum-size aggregates (0.45 power).

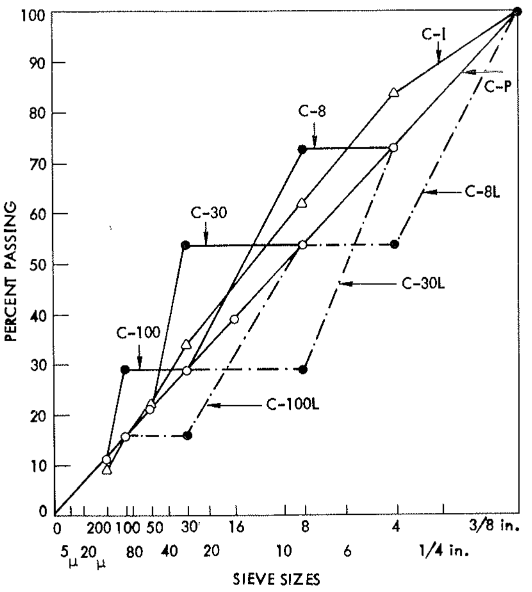


Figure 4. High and low Marshall unit weights, Series B, $^3/_4$-in.

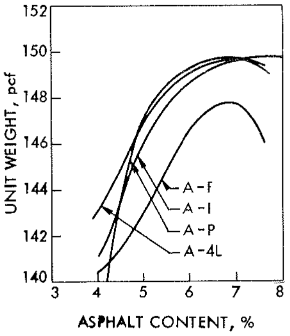


Figure 5. High and low Marshall unit weights, Series B, $^1/_2$-in.

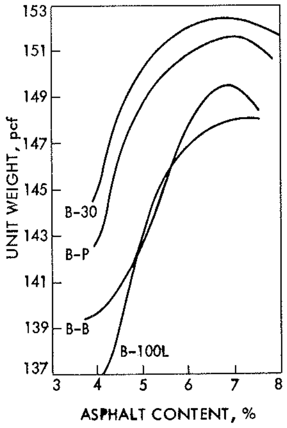


Figure 6. High and low Marshall unit weights, Series B, $^3/_8$-in.

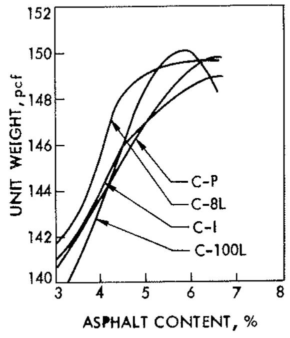
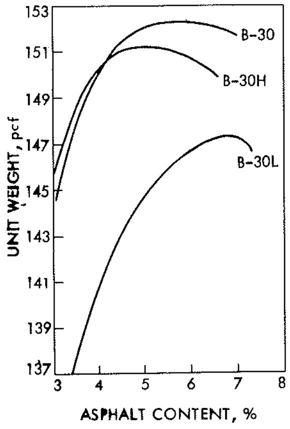


Figure 7. Comparison of Marshall unit weights among B-30, B-30H, and B-30L.



RESULTS AND DISCUSSION

Density and Gradation

By comparing the maximum densities for each gradation determined from unit weight-asphalt content plots within each series we noted the following:

1. In general, softer asphalt and harder limestone resulted in higher compacted density;
2. In most series, the well-graded gradings (F) were not among the gradings that give the highest maximum density; and
3. Gradings that consistently yielded mixtures of higher maximum density were A-4L, A-8L, B-30, and C-8L; gradings that consistently yielded lower maximum density were A-100L, B-30L, B-100L, C-I, C-30, and C-100L.

Some of these features are shown in Figures 4, 5, 6, and 7 for Marshall mixes in series B ($L_1 \times 94$ penetration grade).

Stability and Gradation

When the maximum Marshall stability (determined from stability versus percentage of asphalt plots) of various gradings was compared within each series and between series, we observed the following:

1. All mixes studied (gap or well-graded) yielded mixtures with maximum Marshall stability far exceeding the minimum of 750 pounds (3.34 kN) required of mixes designed for heavy traffic.
2. The best gaps for high-stability mixes appeared to be different for different maximum aggregate sizes and aggregate-asphalt combinations. The well-graded Iowa type A and FHWA gradings (I and P) were usually among the gradings that yielded high Marshall stability. The best gap gradings for Marshall stability were A-I, A-P, A-8, A-30, B-30, B-B, and C-100.

The Hveem stability at 3 percent air void content was determined for each grading within each series and was used as a basis for comparison. It was observed that

1. More than 50 percent of the gap-graded mixtures yielded stability at 3 percent air void content exceeding the minimum required stability of 35 as recommended by the Asphalt Institute method; and
2. The best gap gradings by this criterion were A-F, A-I, A-8, A-4H, A-4L, A-100L, B-100L, B-8L, C-I, and C-30.

Voids in Mineral Aggregate and Gradation

The purpose of minimum voids in mineral aggregate (VMA) requirements is to ensure sufficient air voids to prevent flushing and sufficient intergranular void space for enough asphalt for durability. As had been expected by many as one of the disadvantages of well-graded aggregates, the well-graded mixtures in this study produced mixtures of low VMA. However, data also indicated that gapping the grading may or may not increase the VMA values. For example, although all gap-graded mixtures gave VMA values higher than that of I or P gradings, gap-graded A-100, A-8, and C-100 mixtures had VMA values lower than corresponding well-graded mixtures. Further, the effects on VMA of the location of the gap and method of gapping were also different for different maximum sizes.

CONCLUSIONS

With proper combinations of type of aggregate, aggregate size, type of asphalt, and asphalt content, numerous gap-graded aggregates can be made into satisfactory paving mixtures. Therefore, it appears that rigid requirements of grading conforming to a certain constant mathematical relationship such as Fuller's curve, $P = 100(d/D)^n$, are not justified.

Because of the attractiveness of the cost (in certain areas), fatigue resistance, durability, compactibility, and skid and wear resistance of gap-graded asphalt concrete, more research and experiments, especially in the field, should be conducted.

ACKNOWLEDGMENTS

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