EVALUATION OF PERCENT FRACTURE AND GRADATION ON BEHAVIOR OF ASPHALT CONCRETE AND AGGREGATE BASE

Executive Summary

by

R. G. Hicks
Stuart Albright
James R. Lundy

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TRANSPORTATION RESEARCH INSTITUTE
OREGON STATE UNIVERSITY
CORVALLIS, OREGON 97331-2302

for

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
RESEARCH SECTION
2301 Peger Road
Fairbanks, Alaska 99701-6394

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1.0 INTRODUCTION

Problem Statement

At the present time (1985), crushed aggregates are specified differently in Alaska depending on whether they are intended for highway or airfield applications. Except for the minus No. 200 (fines) content in highway base courses, crushed aggregate specifications are not directly related to Alaska's present pavement design methods; therefore, there is no way to determine effects of design variabilities on the actual load-bearing capabilities of nonspecification materials. The crushed aggregate specifications used at present by Alaska DOTPF need to be evaluated along with relation of aggregate properties to their expected performance in pavement sections.

Objectives

The objectives of this study are to:

1) develop a soundly based approach for the utilization of crushed aggregates in highway and airfield pavements, and
2) provide a rational link between highway and airfield pavement designs and their utilization of crushed aggregates.

Study Approach

To satisfy the project objectives a series of tasks were undertaken. The first task consisted of a detailed literature review of current specifications used in Alaska and the Pacific Northwest of the United States followed by reviews of the literature pertaining to the effect of aggregate fracture and gradation on the behavior of both aggregate base and asphalt concrete materials. The next task consisted of developing a detailed laboratory plan to evaluate the effect of aggregate fracture and graduation (minus No. 200) on the properties of aggregate base and asphalt concrete. Aggregate base materials were tested using the repeated load triaxial test (AASHTO T-274) while asphalt concrete specimens were tested using the repeated load triaxial test (ASTM D-4123).

All laboratory results were then evaluated in terms of the effect that percent fracture and/or fines have on pavement behavior, specifically on material properties such as modulus, resistance to permanent deformation, and fatigue life. In addition, these properties were analyzed using layered elastic theory (PSAD2A and ELSYM5) to evaluate the effect of fracture and gradation on pavement life. These results were then used to develop a design methodology and/or guidelines which can be used to evaluate the use of crushed aggregate materials in highway and airfield pavement structures.

2.0 RESULTS

Literature Review

An extensive review of the literature was conducted to identify current specifications for fracture and the effects of fracture level and gradation on the properties of asphalt concrete and aggregate base. The results of the literature review are summarized as follows:

1) The literature supports the theory that an increase in fracture level leads to an increase in internal friction and to increased shear strength in most asphalt concretes and aggregate bases. In this respect, fracture specifications fulfill their intended purpose.
2) The extent to which fracture level affects performance in a pavement structure is still unclear. Test track data show no clear benefits from the use of crushed material but resilient testing indicates some definite benefits.
3) A need exists for further study into dynamic modeling of the use of fractured particles in pavement structures.
4) The presence of fines in asphalt concrete aggregate causes an appreciable increase in the stiffness of the mix. The effect this has on field performance is unclear.
5) The presence of fines in aggregate base material is necessary to obtain the optimum density and strength of an aggregate. A maximum limit must be set since an excess of fines is detrimental to pavement behavior.
6) Saturation of an aggregate is detrimental to the strength properties of the aggregate base materials. Resilient modulus values decrease and permanent deformation values increase when the base is saturated. This illustrates the need for well

drained base course layers to be used and the importance of considering moisture conditions when designing or evaluating pavements.

Laboratory Test Program

Both aggregate base and asphalt concrete mixtures were tested using dynamic load test procedures to determine the effect of percent fines and percent crushed aggregate on their behavior. Variables considered in the study included:

1)	Aggregate source:	Crushed river gravels from Anchorage, Fairbanks, and Juneau
2)	Level of fracture, %:	50, 70, and 90
3)	Gradation (% minus No. 200):	
	aggregate base	0, 3, and 6
	asphalt concrete	3, 6, and 10

For the aggregate base study, the mean grading for Alaska D-1 was used. The mean grading for Alaska Type II aggregate was used for the asphalt concrete. An AC-5 was used in all the asphalt mixtures. Properties of the aggregates and asphalt cement are given in Tables 1 and 2.

Aggregate base samples were tested at optimum water content (AASHTO T-180) for modulus and resistance to permanent deformation using the repeated load triaxial test (AASHTO T-274). Asphalt concrete mixtures were tested at optimum asphalt content and at 10°C for modulus, permanent deformation and tensile strength using diametral test equipment similar to that described in ASTM D-4123.

Laboratory Tests - Aggregate Base

Tests on aggregate base materials included: 1) compaction tests, 2) modulus tests, and 3) permanent deformation tests. An evaluation of these results is presented in this section.

Compaction Tests. The results of the compaction tests were consistent with those reported in the literature, namely, maximum dry density decreases with increasing fracture level and increases with increasing fines content. From a physical standpoint, the results are also consistent. The increased particle angularity associated with a high fracture aggregate produces a

Table 1. Aggregate Properties.

Materials	Specific Gravity App.	Specific Gravity Bulk	Specific Gravity SSD	Sod. Sul. Soundness,	L.A. Abrasion Percent Wear, % Loss	L.A. Abrasion Percent Wear, Grade	Degradation %
Anchorage Fine	2.77	2.54	2.66	1	-	-	-
Anchorage Coarse	2.80	2.77	2.78	1	15	A	68
Fairbanks Fine	-	-	-	3	-	-	-
Fairbanks Coarse	2.70	2.64	2.66	1	29	A	87
Juneau Fine	2.78	-	-	3	-	-	-
Juneau Coarse	2.75	-	-	1	33	A	77
Alaska Specifications				12 max	40 max		45 min

Table 2. Asphalt Properties.

Property	Actual	Specification
Viscosity, 140°F, poises	458	500 ± 100
Viscosity, 275°F, centistokes	161	110 min
Penetration, 77°F, dmm	147	120 min
Flashpoint, COC, °F	595	350 min

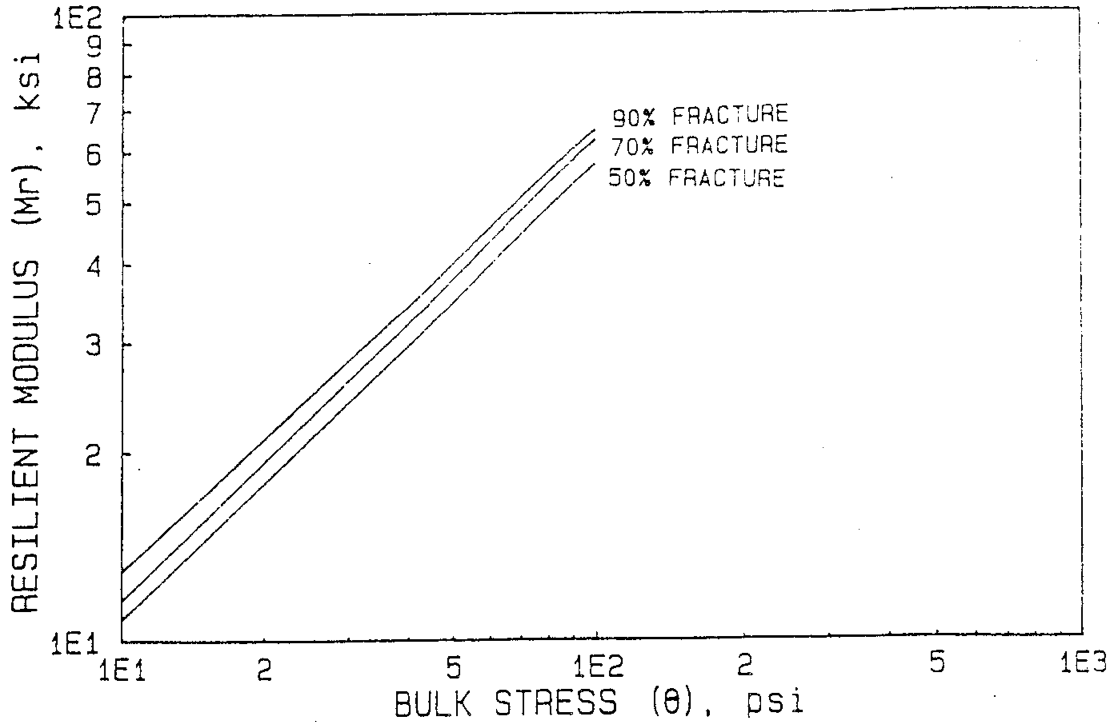
higher level of particle interlock and therefore increases the forces which resist densification and interparticle movement. A high fracture aggregate would then be expected to have a lower dry density than a low fracture one for the same compaction effort.

Modulus Tests. Increases in resilient moduli were consistently associated with increases in fracture values. The resilient modulus-bulk stress relationships tended to converge at high bulk stress levels but at stress levels associated with pavement loading (5-30 psi) the effect of fracture is measurable. The increases in moduli associated with fracture increases are on the order of 5-10% over a range of bulk stresses of 5-30 psi. An example of this increase is shown in Figure 1a for Juneau aggregates. The moduli increases associated with increases in particle interlock as represented by high fracture levels were anticipated. However, since small strain levels are associated with pavement loadings, the strain levels necessary to reach a full interlocking condition may not have been realized. This may account for the relatively small effect of fracture on modulus values.

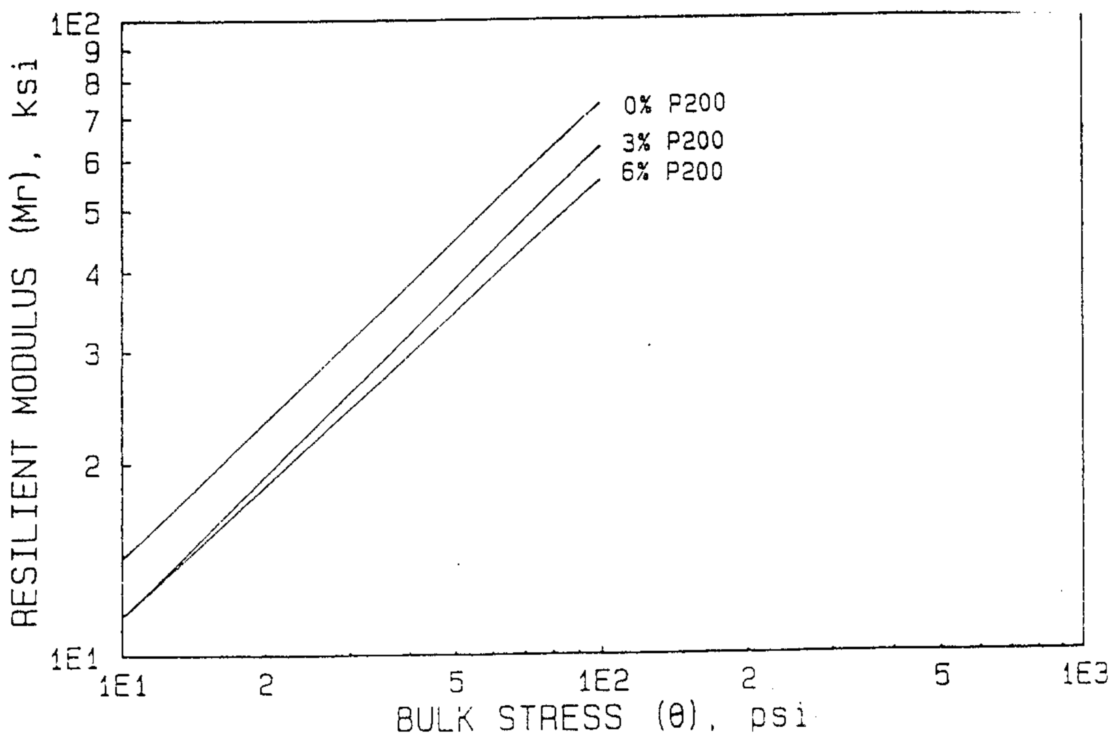
The modulus values decreased with increases in fines content. With the exception of the totally clean (0% passing No. 200) samples, the effect of fines content on modulus is very small at bulk stress levels from 5-30 psi. The effect of fines content on modulus for Juneau aggregate is shown in Figure 1b. As with the effects of fracture results, it is likely that pavement stress and strain levels do not allow full development of particle interlock and surface friction. Therefore while fines between the coarse-grained particles in an aggregate may interfere with the development of interlock and friction forces the effect does not appear to be significant at these stress levels.

Permanent Deformation Tests. The effects of fracture and gradation on the permanent deformation results were more pronounced than the effects of the two properties on the resilient modulus results. The effect of fracture on permanent deformation was fairly consistent for all fines contents. Increase in fracture from 50-70% resulted in decreases in the permanent deformation rate in the range of 45-70%. A further increase in fracture from 70-90% resulted in decreases in the permanent deformation rate of only 15-30%.

The effect of fines content on permanent deformation was directly tied to fracture level. For the 90 and 70% fracture cases, an increase in fines



a) Effect of Fracture Level.



b) Effect of Fines Content.

Figure 1. Effect of Fracture and Gradation on Resilient Modulus of Juneau Aggregates.

content from 3% to 6% resulted in increases in the plastic strain rate in the range of 45-65%. For the 50% fracture case, the same increase in fines content resulted in a 200-300% increase in plastic strain rate. The combination of low fracture (50%) and high fines (6%) was shown to lead to permanent deformation rates which are two or three times greater than any other test condition studied. The combined effect of gradation and fracture on permanent deformation for Juneau aggregate can be seen in Figure 2.

Effect of Aggregate Type. While there were differences in results due to aggregate type, they were not very significant. In general, the variance in modulus results was less than 10% among the aggregates. This suggests that the currently specified test methods adequately assure that materials which are specified as being similar are in fact similar in performance.

Effect of Saturation on Test Results. The effect of saturation on the modulus and permanent deformation test results varied widely with the fracture level of the aggregate. In general, the saturated tests indicated consistently lower moduli than the corresponding optimum water content tests. For example, for tests on aggregates with the 50 and 70% fracture, the saturated moduli were approximately 40 and 35% lower respectively. On the other hand, the 90% fracture sample had saturated moduli values which were only 22% lower than for the corresponding optimum water content tests.

The permanent deformation results showed similar results. For example, for the 90% fracture sample, the accumulated plastic strain was approximately doubled by saturation. For the 70% fracture sample the strain increased by a factor of approximately 3. Most significant was the low fracture (50%) sample which deformed 4.7 times faster than the corresponding optimum water content sample.

Laboratory Tests - Asphalt Concrete Mixtures

Tests on asphalt concrete mixtures included: 1) mix design, 2) modulus, 3) fatigue, 4) permanent deformation, and 5) split tension. An evaluation of these results are presented in this section.

Mix Design. Examination of the optimum asphalt contents show the influence of gradation and fracture to be complex. At constant percent passing the 200 sieve, the asphalt content necessary to meet Alaskan mix design criteria generally increases with increasing percent fracture. This trend may

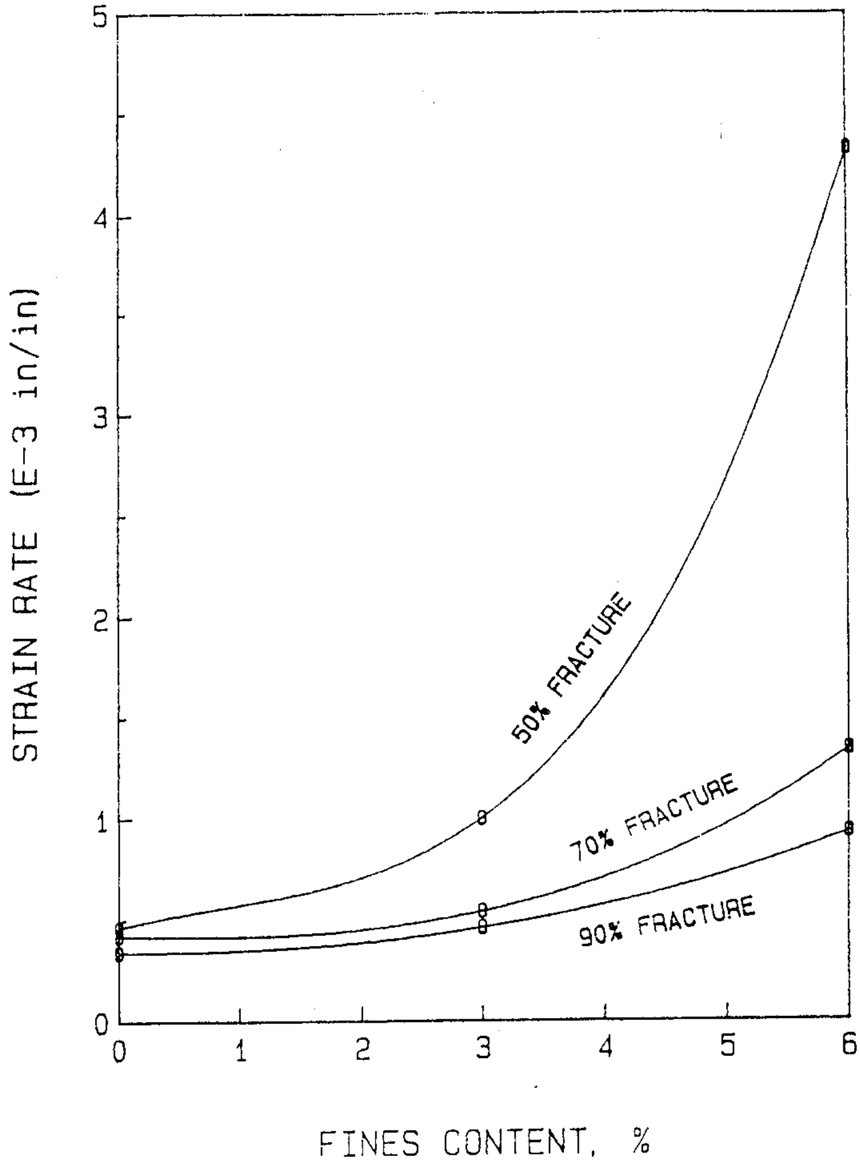


Figure 2. Combined Effects of Fracture and Fines on the Permanent Deformation Rate of the Juneau Aggregates.

reflect the increased roughness of the fractured aggregates when compared to the uncrushed particles.

The effect of increasing fines is not consistent. The optimum asphalt content decreases as the fines content was increased from 3 to 6%. The decrease in asphalt necessary to achieve optimum can be attributed to the criteria used to establish the optimum asphalt content. In particular, total voids are used as the primary parameter for optimum asphalt content determination. Voids may be decreased by adding asphalt or by increasing fines content. As the fines content was increased from 3 to 6%, the total voids decreased at lower asphalt contents. However, as the fines were increased from 6 to 10%, the surface area increase necessitated an increase in binder.

Resilient Modulus. Examination of modulus data (10°C) show few consistent trends in modulus variability with either gradation or fracture change. The differences in optimum asphalt contents among sample sets apparently masked the influence of fracture and gradation. Modulus data for the Juneau aggregate are included in Table 3.

The Fairbanks data does allow limited comparative evaluation of the effects of gradation and fracture at common binder contents. Optimum asphalt contents at the 90% fracture level for both 3 and 10% fines are the same. The increase in fines results in a 15% increase in resilient modulus. This increase in modulus has been attributed to the interaction of asphalt and P200 material to produce a more viscous binder.

Fatigue. The fatigue results show that for the range of fracture level investigated in this study, little benefit can be ascribed to fracture in prolonging the fatigue life of laboratory specimens (see Table 3). Some benefit may seem to be present at lower strain levels ($<$ 75 microstrain); however, examination of the average optimum asphalt contents for each fracture level tested shows an increase in binder of 0.4% with each step in fracture. The increased binder content may have resulted in the increase in fatigue life at the lower strain levels. In addition, all testing was completed at 10°C. At higher temperatures, the reduced binder viscosity would probably allow for more aggregate displacements. These displacements tend to enhance the aggregate interlock feature of higher fracture levels.

Table 3. Modulus and Fatigue Results - Juneau.

Fracture	%P200	Strain (E-6)	Average Modulus, ksi	Average Fatigue Life
50	6	100	1395	2662
		75	1467	4561
		50	1461	10803
70	3	100	1151	2242
		75	1170	5148
		50	1227	11997
	6	100	1368	2940
		75	1251	5024
		50	1313	15422
	10	100	1249	3917
		75	1333	9034
		50	1450	23937
90	3	100	979	3942
		75	955	8272
		50	1049	16961
	6	100	1159	3634
		75	1224	6569
		50	1330	24215
	10	100	1024	5070
		75	1049	7709
		50	1233	18264

The effect of percent passing the No. 200 sieve on the fatigue lives show few consistent trends. The effect of binder content may be masking the importance of fines content particularly at the lowest P200 level. Generally, the 3% P200 mixes contained an average of 1% additional binder. This increased binder content may have increased the fatigue life of these samples.

Permanent Deformation. These results showed generally decreasing deformations with increasing fracture at a given initial stress level. The results, however, are not consistent across the aggregate types tested. Anchorage aggregates show the greatest reduction in permanent deformations with increasing fracture. These results may be attributed to the lower asphalt contents associated with all Anchorage variable combinations. Optimum asphalt contents of Anchorage aggregates averaged 0.6% lower than those from Juneau and Fairbanks. These lower binder amounts may allow interparticle interlock of the increasingly fractured aggregate which may more effectively resist deformation.

The effect of percentage passing the No. 200 sieve show a reduction in permanent deformation with the increase from 3-6% fines. This trend does not continue with the increase from 6-10% fines. Again, these trends may be attributed to the binder content of each of the variable combinations tested. Generally, as the asphalt content increases, the permanent deformation associated with a given initial stress level also increases.

Split Tension. Split tensile strength results show the influence of increasing fracture at both the 6-10% fines content. These large strain tests activate the aggregate interlock mechanisms in the sample. Increased interlock can be associated with the increased fracture. This aggregate interlock effect would also be activated by testing at increased temperatures.

3.0 EVALUATION OF RESULTS

This section describes the computer study used to analyze the results of the laboratory study to:

1) determine the effects of base course and asphalt concrete surface course fracture and gradation on the fatigue life of typical highway and airfield pavement structures.

2) determine the effects of base course and asphalt concrete surface course fracture and gradation on the surface thickness required to ensure a minimum fatigue life in typical highway pavements.

Layered elastic theory was used to determine the effect of changes in gradation and/or fracture on pavement life for typical highway and airfield pavement sections. The effects of these changes on both the fatigue life and permanent deformation life were evaluated.

Aggregate Base

The structural responses (stress and strain levels) of the pavement structures studied were not seriously affected by the fracture level of the base course aggregates. The fatigue life and required surface thickness results seem to be insensitive to modulus changes which are associated with varying fracture levels over the 50-90% range.

One benefit to increasing fracture level is in reducing the effects of excessive fines contents and saturation on base course performance. The reduction of modulus associated with saturation was markedly affected by fracture content. The reduction in modulus for the 90% fracture aggregate was roughly half that which was associated with the 50% fracture aggregate. The permanent deformation rates for the 50% fracture samples which were saturated or had a high fines content (6%) were 4 times larger than that for any other fracture level or test condition.

While fines content also had very little effect on the modulus and pavement life results, and may increase over the life of a pavement, permanent deformation results still show the need to at least attempt to control it. The threshold value for fines content is in the range of 3%. Decreasing fines from 3 to 0% only resulted in a decrease in permanent deformation of approximately 10%. Increasing fines from 3-6% percent on the other hand, resulted in increases in permanent deformation of 50-300%. An aggregate which is free of fines is difficult to handle; it is the fines which bind the aggregate and hold it together. Such an aggregate would also require additional processing after crushing to remove the fines. The 6% maximum currently specified is lower than that specified by all of the western states and is also lower than the Federal government or AASHTO and ASTM specifications. This is because the maximum fines content is based on frost action considerations.

Asphalt Concrete

Because there was little effect of fracture (50-90%) on modulus and fatigue life at 10°C, fracture did not affect pavement life. When determining the percent change in fatigue life associated with changes in fines content, the 6% P200 samples were assumed to represent the base condition. Percent changes in fatigue life associated with fines content changes seem to provide conflicting results. In general, the fatigue life of samples increases slightly when the P200 content is decreased to 3%. A somewhat greater increase in fatigue life corresponds to an increase in fines from 6 to 10%. This would indicate the minimum laboratory life is associated with 6% P200. However, examination of the standard errors associated with the regression coefficients show these percent changes in fatigue life to be statistically insignificant.

Though the results obtained in this analysis show laboratory fatigue lives to be unaffected by fracture level or fines content when tested at 10°C, additional testing at higher temperatures may show some effect of these factors on fatigue life.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions summarize the important findings of this study:

Base Course

1. Over the range of fracture levels studied (50 to 90 percent), increasing fracture level caused an associated increase in resilient modulus. The effect for the base course was small, a modulus increase of less than 10% was associated with a 20% increase in fracture. It appears that fracture level does not significantly affect the resilient modulus of crushed aggregates at optimum water content.
2. Over the range of fines contents studied (0 to 6 percent), increased fines content caused an associated decrease in resilient modulus for the base course. The effect was quite small, with a decrease in modulus of less than 10% associated with increasing fines contents from 0 to 6%. It appears that

fines content does not significantly affect resilient modulus for the conditions evaluated.

3. Permanent deformation rates for the base course increased dramatically when fines contents exceeded 3%. This was especially true for the 50% fracture samples where the deformation rates were approximately 3 times higher than for any other test condition. It appears that the effect of fracture and the effect of fines content on permanent deformation rates are tied together and that the case of high fines (> 3%) coupled with low fracture (50%) causes exceptionally high permanent deformation rates.
4. Saturating the aggregate base materials had the effect of lowering the resilient modulus significantly (25-40%) and noticeably increasing the permanent deformation rate (100-350%). As with the effect of fines content the effect of saturation on permanent deformation levels was tied to fracture level with the 50% fracture level sample showing particularly high deformation characteristics.
5. Since the layered system analysis performed on the aggregate base results was modulus based, the effect of fracture and gradation on the predicted pavement lives and required pavement thickness was negligible.

Asphalt Concrete

6. When tested at 10°C, asphalt concrete fatigue lives did not appear to be significantly affected by either fracture level between 50 and 90% or fines content from 3 to 10%.
7. Optimum asphalt contents as determined by Marshall mix design require minimum binder contents when fines content are between 6 and 8%. Increases in fines above 8% cause higher asphalt demand and increases the mix cost.
8. Variation in permanent deformation and modulus seems to be influenced more by asphalt content than by gradation and fracture.

Recommendations

The following recommendations concerning changes to the current design and specification procedures for the utilization of crushed aggregates are based on the results of this study:

1. The current specifications for fracture and fines content for base course aggregates appear to be the appropriate values for limiting pavement deformation and rutting. The 70% minimum fracture level and 6% maximum fines content should be retained.
2. In situations where base course saturation is unlikely and the aggregates being used are durable and will not degrade, the fracture level specification can be relaxed to at least 50% without any significant loss of base course performance.
3. The current specifications for fracture and fines content in asphalt concrete appear appropriate for highways. Changes cannot not be recommended based on this study. For airfields, a minimum fracture specification in excess of 70% cannot be justified for either asphalt concrete or aggregate base aggregates. A 70% minimum fracture specification appears appropriate for highway and airfield pavements.