Moisture Damage Cutoff Ratio Specifications for Asphalt Concrete

ROBERT P. LOTTMAN AND STEPHEN BREJC

Moisture susceptibility of asphalt concrete (AC) mixtures is identified by performing laboratory tests on dry- and wet-accelerated conditioned specimens. Excessive moisture susceptibility is associated with low ratios of wet-to-dry mechanical properties. Highway agencies use values of cutoff wet-to-dry ratios for resilient modulus and for indirect tensile strength as specifications. Mixtures having wet-to-dry ratios lower than the cutoff ratios have excessive moisture susceptibility and require treatment before paving. Currently, most highway agencies apply either a resilient modulus cutoff ratio of 0.70 or an indirect tensile strength cutoff ratio of 0.75. The University of Idaho AC moisture damage analysis system (ACMODAS) programs on field performance are applied to predict cutoff ratios, compare predicted cutoff ratios to currently used ratios, classify AC mixture moisture susceptibility, and recommend cutoff ratios to be used in practice. Two cutoff ratios are necessary to control moisture susceptibility both for fatigue cracking and for wheelpath rutting field distresses. These cutoff ratios are 0.80 for resilient modulus and 0.85 for indirect tensile strength, and both should be applied simultaneously. [Simultaneous application of the (lower) currently used cutoff ratios may only control fatigue cracking.] Applying individual cutoff ratio values to each material, about 25 percent of mixtures, which cannot be treated by conventional additives or other means to obtain desired fatigue cracking performance because of water-induced brittleness, have cutoff ratios >1. However, the other mixtures can be treated, if need be, to obtain desired performance; their cutoff ratios are <1. Identification of these mixtures is discussed.

Moisture damage in asphalt concrete (AC) mixtures as pavements occurs in many locations and results in loss of performance life. Application of related control specifications is a strong factor in AC mixture design for highway agency laboratories. Cutoff ratios will continue to be used in the near future as moisture damage specifications.

Controlling fatigue cracking distress in the design of AC mixes is based on a resilient modulus cutoff ratio as well as a tensile strength cutoff ratio. In addition, a resilient modulus cutoff ratio is necessary to control wheelpath rutting distress. Each mixture and pavement situation provides specific values and a unique relationship between these cutoff ratios.

Most highway agencies currently use only one cutoff ratio to control moisture damage. A two-ratio control method is necessary to minimize field damage from the occurrence both of fatigue cracking and of rutting when pavements become wet. Routine ability is needed to perform both the indirect tensile strength and resilient modulus tests in highway agencies. Fortunately, these test activities are increasing steadily because of awareness of other uses for these test data for the evaluation of AC mixtures.

The objective is to predict cutoff ratios and to combine them in a practical form that will provide rational specifications to control the field distresses of fatigue cracking and wheelpath rutting.

Cutoff ratios obtained through the ACMODAS prediction models are related to ratios currently in use that have been based on experience. The simpler approach to specifications is the application of universal cutoff ratio values rather than of specific cutoff values associated with each type of AC mixture.

Use of cutoff ratios implies that decisions of satisfactory field performance are based on comparative or relative behavior. A cutoff ratio defined for AC moisture sensitivity is the value of the mechanical property of the wet specimen divided by the value of the mechanical property of the dry specimen. Ratios much lower than 1.0 indicate high moisture sensitivity and a potential for severe loss of field life when the AC becomes wet.

Magnitudes of cutoff ratios should be independent of the laboratory wet-accelerated conditioning test used. These ratios are specifications that set a standard for limiting moisture-induced damage in the field to a predetermined level. Separately, the laboratory test procedure is developed on the merits of producing adequate moisture damage potential for AC mixtures. The test-obtained mechanical property ratios are compared to the cutoff ratios.

Application of cutoff ratios as specifications is several decades old. Early tests screened AC mixtures in the laboratory before paving by using unconfined compressive strength. Specimens were wet-accelerated conditioned by soaking for 24 hr at 140°F. On the average, the specific AC mixture was satisfactory if its wet-to-dry ratio or cutoff ratio was equal to or greater than 0.85. Currently, indirect tension tests are being used from which wet-to-dry resilient modulus ratios (MrR) and tensile splitting strength ratios (TSR) are applied for control before paving. These biaxial stress tests bring out adhesion effects more readily than the unconfined compressive strength tests. Also, the wet-accelerated conditioning is a forced saturation by vacuum on which is superimposed a freeze-thaw cycle or a 24-hr, 140°F water soak, or both, producing somewhat more severe conditioning than in the unconfined compressive strength test. These factors have led highway agencies to establish cutoff ratios of 0.70 for MrR and 0.75 for TSR, lower than the 0.85 value for the unconfined compressive strength test. These cutoff ratios vary by ±0.05 around the country, depending on the experience of the highway agency.

Highway agencies use only one cutoff ratio, either an MrR or TSR value. The approach of this study is based on the simultaneous application of both ratios.

Department of Civil Engineering, University of Idaho, Moscow, Idaho 83843.

Further discussion of cutoff ratios, including quantitative relationships, has been provided by Lottman et al. (*1*).

PERCENTAGE ALLOWABLE REDUCTION

The universal acceptance of using cutoff ratios lower than 1 by highway agencies implies a philosophy that there is an acceptable loss of pavement performance life (i.e., AC mixture durability) caused by moisture damage. The acceptable loss of life can be translated into percentage allowable reduction (of all-dry performance life) (PAR). At present, PAR is determined subjectively, but results of life cycle cost and performance determination procedures will improve the selectivity of PAR. The average highway agency PAR is 10 percent, with range from 0 to 20 percent. For example, suppose PAR is 10 percent and an all-dry performance life is assumed to be 12 years, then the maximum allowable wet performance life of the AC must be no less than 10.8 years.

The cutoff ratio is a function both of PAR and of the association of the field performance life relationship with AC mechanical properties.

Evaluation of PAR with cutoff ratios indicates that

1. Efficient programming for pavement life cycle costing will require that PAR be small;
2. Practicalities, including imperfect treatments of moisture-sensitive AC mixtures, will keep PAR greater than zero; and
3. Severity of the laboratory specimen wet-accelerated conditioning is independent of establishing values for the cutoff ratios when considering the application of PAR.

In this study, PAR = 10 percent is used to develop the cutoff ratios.

ANALYSIS PROGRAM

The ACMODAS programs were developed several years ago by the University of Idaho for predicting relative wet-pavement performance life of moisture-sensitive AC. The programs are mechanistically based. The program inputs are wet and dry mechanical properties of resilient modulus and tensile splitting strength for a specific AC mixture, PAR, and pavement climate factor. The mechanistic models in the programs translate the laboratory-determined mechanical properties to performance life, in years. They are also used to predict the MrR and TSR cutoff ratios. Technical background and application of the programs were described by Lottman and Frith (*1*,*2*).

ACMODAS C consists of two programs, one each for the two prominent field distresses related to moisture sensitivity:

1. ACMODAS 2, for effect of moisture on wheel load (or fatigue) cracking; and
2. ACMODAS 3, for effect of moisture on wheelpath permanent deformation or rutting.

The Idaho Research Foundation, Moscow, Idaho, provides the ACMODAS C diskette and operator manual in response to inquiries.

Using ACMODAS C, cutoff ratios are obtained for MrR and TSR for fatigue cracking, and for MrR for wheelpath rutting. Values of the three ratios are usually not the same, even for a specific AC mixture.

For fatigue cracking, both cutoff ratios of MrR and TSR are required to control or limit the moisture sensitivity because the ACMODAS 2 model incorporates relative fatigue strength and toughness as a measure of moisture resistance, which, in turn, is related to both stiffness and strength. For wheelpath rutting, an MrR cutoff is used without a TSR cutoff because the ACMODAS 3 model incorporates relative shear strain permanent deformation, which, in turn, is related to stiffness. Because these field distresses are different physically, the MrR cutoff ratios from ACMODAS 2 and 3 have different values.

The ACMODAS 2 and 3 programs of ACMODAS C were applied to develop cutoff ratios for specific AC mixtures containing different asphalt binders and aggregates. These mechanistic-based, predicted cutoff ratios are independently determined.

AC MIXTURE VARIABLES

AC mixtures from the following two categories were investigated:

1. Highly strippable aggregate from a constant source with variable asphalt binders [three asphalt sources, approximately 25 asphalt treatments (antistripping additives, i.e., liquid chemicals and lime), polymeric modifiers, and combinations of additives and modifiers]. The total amounted to 58 different AC mixtures. Further description of the variables and properties was provided by Lottman and Mesch (*3*). The wet-accelerated conditioning in NCHRP Report 246 (*4*) (90 percent saturation by vacuum plus freeze and 24 hr, 140°F water soak) was used.
2. Variable strippable aggregate from a nonconstant source with specific asphalt for each aggregate. Mixtures were made with and without additives. Further description of the variables and properties was provided by Brent Rauhut Engineering (*5*). Both NCHRP Report 246 (*4*) wet-accelerated conditioning and AASHTO T-283 wet-accelerated conditioning (67 percent saturation by vacuum plus freeze and 24 hr, 140°F water soak) were used.

Specimens representing each of these AC mixtures, having different input wet and dry mechanical properties, provided a varied-population data base from which to predict and evaluate cutoff ratios using ACMODAS C. The variation of proportionality between modulus and strength properties in both wet and dry conditions affected the magnitude of cutoff ratio predicted for a specific mixture. The type of wet-accelerated conditioning test used did not seem to be a factor in changing the proportionality; the test mainly is responsible for the magnitude of these input mechanical properties.

GROUPING OF RESULTS AND EXAMPLES

Moisture Effect Categories

As previously mentioned the cutoff ratios determined by the ACMODAS C program are related to specific field distresses of fatigue cracking and wheelpath rutting. The results, therefore, are separated as follows:

Distress	*Cutoff Ratios*
Fatigue cracking	MrR, TSR
Wheelpath rutting	MrR

Also, the cutoff ratios obtained by the ACMODAS C program can be separated into three mixture-moisture effect categories, each with a specific relationship to specifications and control. These categories are as follows:

1. Cutoff Ratios >1.0. No conventional routine mixture improvement, e.g., additive application, will make MrR and TSR >1.0. Thus, mixtures requiring cutoff ratios >1.0 will not perform in the field to the level of the designated PAR.
2. Cutoff Ratios <1.0 with MrR Cracking Cutoff Larger Than MrR Rutting Cutoff. When quality additive application is necessary, ratios equal to or larger than the cutoff ratios can be produced so that these mixtures will perform at PAR in the field for both distresses. Control set by the MrR and TSR cracking cutoffs becomes the specification; the MrR rutting cutoff is automatically achieved.
3. Cutoff Ratios <1.0 with MrR Rutting Cutoff Larger Than MrR Cracking Cutoff. Quality additive application should also produce input ratios equal to or larger than cutoff ratios to perform at PAR for both distresses. A cutoff-setting procedure is required. The TSR cracking cutoff is increased to retain relative wet-mixture toughness because the larger MrR cutoff, the one for rutting, controls. The MrR cracking cutoff is increased to equal the MrR rutting cutoff, thus the TSR cracking cutoff is also increased.

Figure 1 is a specification chart giving example cutoff ratios for a specific AC with given mechanical properties and a PAR

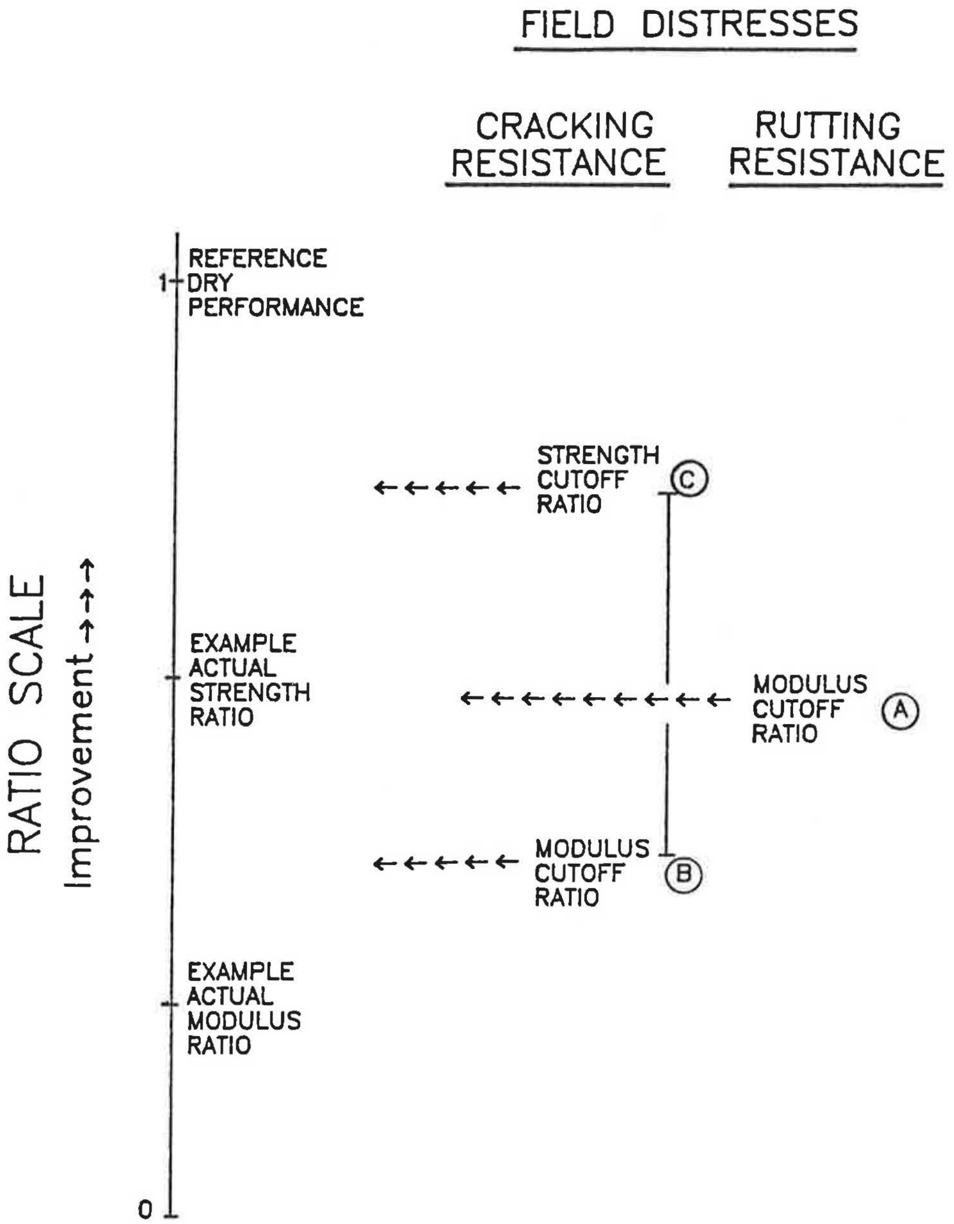

FIGURE 1 Interactive cutoff ratio specifications.

specified by a highway agency. Here, MrR and TSR obtained from the specimen tests reflect excessive moisture damage because the ratios are smaller than the corresponding cutoff ratios required for each distress. The change to be effected in this asphalt concrete before paving requires a specimen MrR increase to satisfy the MrR rutting cutoff *A*. The MrR cracking cutoff becomes equal to the MrR rutting cutoff (*B* increases to *A*), because the same mixture (i.e., specimen) cannot possess different values of the modulus ratio at the same time. The TSR cracking cutoff now must increase to a value >*C* to satisfy the required proportionality between cutoff ratios *B* and *C*. This *B*–*C* proportionality maintains satisfactory resistance against onset of cracking fatigue and crack propagation, which will be quantified in a following section. In order to meet the cutoff ratio specifications for both field distresses, the AC in this example will require a new mixture design, or inclusion of additives, to achieve the required MrR cutoff *A* and the new TSR cutoff value that is larger than *C*.

Examples of Categories

Table 1 contains examples of ACMODAS C predicted cutoff ratios for five different AC mixtures using a PAR value = 10 percent.

The interactive requirements when using the cutoff ratios as specifications are illustrated by the following brief evaluation, in detail, for each pavement mixture specified in Table 1:

- Pavement *C*. To meet the MrR cutoff for rutting of 0.88, the standards for cracking must increase, so that MrR cutoff for cracking increases from 0.45 to 0.88; the associated TSR cutoff of 0.65 must increase in proportion. The net result on the pavement will be that the AC will perform better than PAR for cracking and equal to PAR for rutting.
- Pavement *M*. To meet the MrR cutoff for cracking of 1.09, the standard for rutting must increase so that MrR rutting cutoff increases from 0.69 to 1.09. In the pavement, this increase will result in the AC having a better performance than PAR for rutting and equal to PAR for cracking. (This situation is theoretical, because an MrR cutoff of 1.09 cannot practically be met because it is larger than 1.)
- Pavement *T*. Because both MrR cutoff values are about the same, PAR for both rutting and cracking will be met by achieving an MrR cutoff of 0.77 and a TSR cutoff of 0.83.
- Pavement *V*. Similar evaluation to Pavement *C*.
- Pavement *W*. Similar evaluation to Pavement *M*.

The AC for pavements *M* and *W* will have a wet life smaller than the allowable 10 percent life reduction because of moisture damage (or PAR). This result follows from the problematic wet-to-dry strength-modulus relationships that exist in these ACs that cannot be easily remedied without chemical modification.

TABLE 1 EXAMPLE OF ACMODAS PREDICTED CUTOFF RATIOS

Pavement	Fatigue Cracking		Wheelpath Rutting
	TSR Cutoff	MRR Cutoff	MRR Cutoff
C	0.65	0.45	0.88
M	0.95	1.09	0.69
T	0.83	0.76	0.77
V	0.80	0.72	0.85
W	0.97	1.03	0.72

VALUES OF CUTOFF RATIOS AND PRACTICAL IMPLICATIONS

Average values of cutoff ratios determined by the ACMODAS C program are listed by cutoff ratio category in this section, along with related findings.

Cutoff Ratios >1

Approximately 25 percent of the mixtures required cutoff ratios >1 for the control of fatigue cracking.

It is not practical to treat or improve these mixtures to get an MrR or TSR value >1 to achieve PAR = 10 percent. Unfortunately, one has to settle for PAR value >10 percent, perhaps 20 or 25 percent, for the reduction of dry life (determined by fatigue cracking) caused by moisture damage.

These mixtures should be screened out, especially if they are problematic regarding other performance criteria. They can be identified because their MrR values are larger than their TSR values. This effect seems to be caused by water-induced brittleness.

However, the value of the MrR cutoff for wheelpath rutting is almost always <1, which is always practically achievable, so that a PAR = 10 percent can be reached for controlling wheelpath rutting.

Cutoff Ratios <1, with MrR Cracking Cutoff Larger Than MrR Rutting Cutoff

Approximately 30 percent of the mixtures are in this category. Moisture sensitivity control is achieved through the fatigue cracking cutoff ratios of MrR and TSR. Because the MrR cracking cutoff is larger than the MrR rutting cutoff, wheelpath rutting is automatically controlled by using the larger MrR cutoff value, which is for fatigue cracking.

An example for a specific mixture is MrR cracking cutoff = 0.78, TSR cracking cutoff = 0.84, and MrR rutting cutoff = 0.74. In application, MrR cutoff = 0.78 and TSR cutoff = 0.84 would be used for the moisture sensitivity control of this mixture.

In this category, for all the mixtures tested the average cutoff ratios were found to be MrR cracking cutoff = 0.85, TSR cracking cutoff = 0.80, and MrR rutting cutoff = 0.75. The MrR cracking cutoff of 0.85 and the TSR cracking cutoff of 0.80 would be simultaneously applied for overall control in this category.

Cutoff Ratio <1, with MrR Rutting Cutoff Larger Than MrR Cracking Cutoff

Approximately 45 percent of the mixtures are in this category. They will require the B–C TSR cutoff shift as shown in Figure

1. In this case, the MrR cutoff is based on rutting. Because it is required that the value of the MrR cracking cutoff be equal to that of the MrR rutting cutoff, the TSR cracking cutoff is shifted to a larger value. The value of the larger TSR cutoff can be calculated from the following equation:

$$TSR_2 = TSR_1 \, (MrR_2/MrR_1)^{0.50} + 0.02 \qquad (1)$$

where

TSR_2 = new, larger required TSR cracking cutoff,
TSR_1 = original TSR cracking cutoff,
MrR_1 = original MrR cracking cutoff, and
MrR_2 = required MrR cutoff (= MrR rutting cutoff).

Equation 1 has $r^2 = 0.95$. In the equation, MrR Subscripts 1 and 2 correspond to *A* and *B*, respectively, in Figure 1, and TSR Subscript 1 corresponds to *C* in Figure 1.

Average values of the cutoff ratios obtained for all mixtures in this study are (a) fatigue cracking cutoffs of $MrR_1 = 0.65$ and $TSR_1 = 0.75$ (corresponding to MrR_1 and TSR_1 in Equation 1), and (b) wheelpath rutting cutoff of $MrR_2 = 0.80$ (corresponding to MrR_2 in Equation 1).

If only the fatigue cracking cutoff ratios of MrR_1 and TSR_1 (0.65 and 0.75, respectively) are used for control, rutting will not be controlled to the desired level (10 percent) of PAR. The loss of rutting life will be greater than required. On the other hand, if the MrR_2 cutoff ratio is used with TSR_1 (0.80 and 0.75, respectively), cracking will not be controlled to the desired level of PAR because TSR_1 is now too low. Thus, a higher-strength cutoff ratio is required, i.e., TSR_2. Substitution of MrR_1, MrR_2, and TSR_1 into Equation 1 yields $TSR_2 = 0.85$. Therefore, the control of both cracking and rutting in this category to achieve PAR = 10 percent requires an MrR cutoff of 0.80 and a TSR cutoff of 0.85 to be simultaneously applied for overall control.

RECOMMENDATION

The preceding results of the evaluation of individual cutoff ratio categories obtained from the ACMODAS C program are now overviewed for current practice. This examination requires that MrR and TSR values obtained by laboratory test for a specific AC mixture be compared to overall predetermined cutoff ratios. The recommended approach is as follows:

1. Determine if the AC mixture is in the minority category, cutoff ratios >1. These mixtures can be identified by MrR $>$ TSR after wet-accelerated conditioning. Treatment may reduce the water sensitivity of these mixtures, but they still would remain more water sensitive to fatigue cracking than the limit set by PAR = 10 percent.

2. Remaining mixtures will have cutoff ratios <1. They can be conventionally treated and improved. The recommended approach is to make sure that the MrR and TSR values are equal to or greater than overall predetermined cutoff ratios to achieve control both of cracking and of rutting at PAR = 10 percent (10 percent loss of dry performance life). The values of these cutoff ratios are (a) MrR cutoff = 0.80, and (b) TSR cutoff = 0.85.

Both cutoff ratios should be simultaneously applied, i.e., at the same time for the same mixture. If MrR and TSR input values are smaller than the cutoff ratios, then treatment or different mixture constituents to reduce the water sensitivity will be required. Because of the need to control wheelpath rutting as well as fatigue cracking, the values of the recommended cutoff ratios are 0.10 higher than the values currently used by most highway agencies.

ACKNOWLEDGMENTS

This research study was one of three in the first series of research projects funded at University of Idaho under the TRANSNOW Northwest Transportation Center program in cooperation with the U.S. Department of Transportation. The authors appreciate the support of these agencies and also of the Idaho Transportation Department, which provided a portion of the local matching funds.

REFERENCES

1. R. P. Lottman, L. J. White, and D. J. Frith. Methods to Predict and Control Moisture Damage in Asphalt Concrete. In *Transportation Research Record 1171*, TRB, National Research Council, Washington, D.C., 1988, pp. 1–11.
2. R. P. Lottman, and D. J. Frith. Predicting the Effects of Moisture on Wheelpath Rutting in Asphalt Concrete. In *Transportation Research Record 1228*, TRB, National Research Council, Washington, D.C., 1989.
3. R. P. Lottman and K. A. Mesch. Effect of Microadditives on Asphalt Concrete. Final Project Report ECE-8411271, National Science Foundation, Washington, D.C., April 30, 1988.
4. R. P. Lottman. *NCHRP Report 246: Predicting Moisture-Induced Damage to Asphalt Concrete*, TRB, National Research Council, Washington, D.C., 1982.
5. Brent Rauhut Engineering. Development of Asphalt-Aggregate Mixture Analysis System: AAMAS. *Phase II Vol. II Preliminary Draft Final Report.* NCHRP Project 9-6(1). TRB, National Research Council, Washington, D.C., Sept. 1988.

Publication of this paper sponsored by Committee on Characteristics of Nonbituminous Components of Bituminous Paving Mixtures.