The basic premise of this symposium is the assumption that fatigue cracking in an asphalt pavement is "bad" and that such cracking reduces the long-term performance capability of the pavement. Probably without exception, engineers, particularly maintenance engineers, would agree with that conclusion. However, how much cracking is bad, what kinds of cracking are bad, and what happens to a pavement after cracking occurs are all questions that need to be answered before cracking predictions are undertaken. This paper attempts to relate fatigue cracking to performance. It is hypothesized that one of the objectives of any structural design system is to provide a pavement that will resist fatigue cracking to such an extent that premature maintenance will not be required.

Relation Between Cracking and Performance

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In December 1970, the Highway Research Board conducted a special workshop dealing with the structural design of asphalt concrete pavements. The primary goal of the workshop was to review the current status of structural design and to evaluate and assimilate ways of applying research findings to future design procedures. Emphasis was placed on the need for relating distress to performance and performance in turn to the present serviceability index (riding quality) of a pavement.

One of the workshop groups was charged with responsibility for discussing distress and pavement performance. The report (1) from that group indicated unanimous agreement that a present serviceability rating or present serviceability index evaluation system is the most satisfactory method currently available for evaluating pavement performance.

However, it would appear that cracking alone does not correlate well with riding quality as quantified by the present serviceability index (PSI) equation developed by the AASHO Road Test staff (2). For example,

$$PSI = 5.03 - 1.91 \log (1 + sv) - 1.38\, \overline{RD}^2 - 0.01\, (C + P)^{1/2}$$

where

sv = slope variance, a measure of longitudinal roughness,
$\overline{RD}$ = average rut depth, and
$C + P$ = area of class 2 + class 3 cracking plus patching, per 1,000 ft^2.

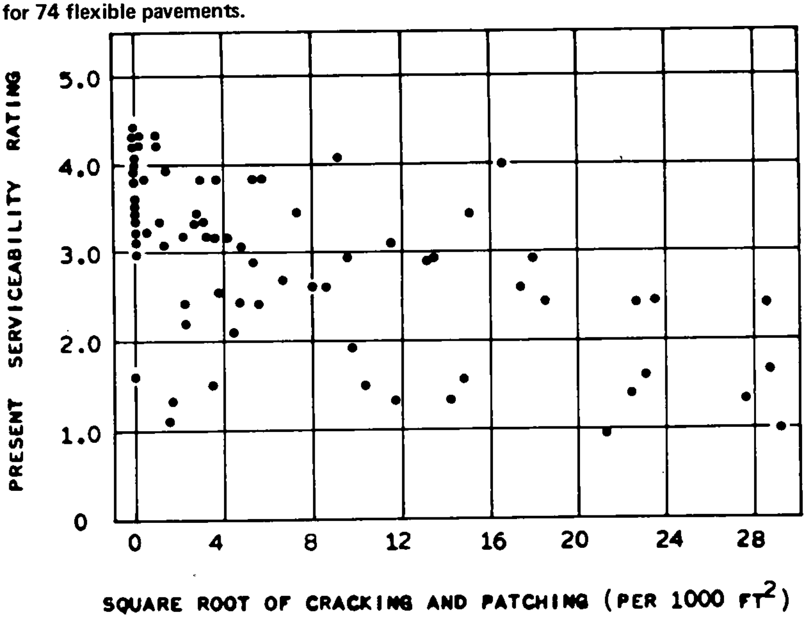
A numerical evaluation of that relation will indicate that when there is 100 percent cracking, that is, 1,000 ft^2 of cracking per 1,000 ft^2 of pavement, the serviceability is reduced by 0.33. The suggestion here is that cracking may not influence riding quality in a particularly significant amount. Longitudinal roughness, which would logically be expected to be the most significant single parameter in the evaluation of riding quality, has simply overwhelmed other factors such as rut depth and cracking plus patching. It was suggested at the HRB workshop that a high correlation exists between the present serviceability rating and the amount of cracking and patching on a given pavement. Specifically, it was indicated that present serviceability ratings obtained by the use of only cracking and patching would give a correlation coefficient of about 0.8 and those obtained by the use of roughness would give a correlation coefficient of 0.9. However, the AASHO Road Test report (2) does not appear, at least in this particular example, to give that reliable a coefficient of correlation. Figure 1 (2) does suggest that, when the amount of cracking exceeds approximately 40 percent (400 ft^2 per 1,000 ft^2) of the total area, none of the pavements would have an acceptable riding quality of 2.5.

In all probability, the subjective opinions of most engineers would be that 40 percent of class 2 or class 3 structural cracking in an asphalt pavement would be highly excessive and totally unacceptable in terms of the adequacy of a particular pavement structure. It is pertinent to note that the PSI includes cracking plus patching. The specific area of cracking included in the equation cannot be distinguished from patching. Hence, the areas of cracking shown in Figure 1 could be relatively small, and good quality patches would not contribute to increased roughness. Thus, efforts to analyze the PSI equation could be misleading.

In 1963, Rogers et al. (3) reported results of a nationwide survey of pavements that were scheduled to be rehabilitated. Efforts to correlate PSI with the amount of class 2 and class 3 cracking plus patching indicate that little, if any, correlation exists between those 2 factors. Examination of the data included in that report is limited because areas are reported as the sum of cracking and patching. However, the data indicate that (a) for pavements with less than 5 percent cracking plus patching, the PSI was above 2.0; and (b) for pavements with more than 45 percent cracking plus patching, the PSI was below 2.5. A limiting amount of cracking and patching would be between 5 and 45 percent of the pavement area. Admittedly, that is a very loose association, but, when added to other bits of information, it may be useful.

Those at the HRB workshop were unable to postulate a specific method by which distress could be related to performance. They were in agreement that the occurrence of cracking can be damaging to the continued performance of the pavement. They also agreed that when cracking occurs, water will enter through the pavement into the base

Figure 1. Present serviceability rating versus square root cracking and patching for 74 flexible pavements.



and subgrade and cause increased roughness because of heaving or consolidation. Pell (10) indicates that a considerable amount of crack propagation will have to occur over a wide area before any serious deterioration of the pavement structure results from the possible penetration of water or from the increase in stresses in the underlying layers or from both of these.

On the other hand, Terrel (9) indicates,

> Fatigue cracks were frequently developed during the summer and autumn months when test pavements received the first phase of loading. Provided there was no accompanying change in subgrade or base courses, the number of load repetitions supported were surprisingly large....Intrusion of water through the cracked surface and the usual spring thaw tended to weaken the underlying material. When testing was resumed in the spring, total failure quickly resulted. That was a result not of further fatigue distress but of subgrade failure.

Apparently, Terrel found that with cracking local failure will be accelerated by water. Pell considers that this will not necessarily propagate areally and, therefore, could be controlled or would not significantly influence the total pavement.

During the AASHO Road Test, the occurrence of class 2 cracking was observed at approximately 50 percent of the traffic volume necessary to reduce the riding quality to a level of 2.5 (2). Clearly then, it can be expected that a certain amount of cracking is acceptable in terms of riding quality but not acceptable in terms of structural integrity. On the Zaca-Wigmore Test Road in California, maintenance engineers established the terminal amount of cracking to be 10 percent. That is, after the pavements exhibited 10 percent cracking based on the total area, it was determined that maintenance was necessary in order to hold that pavement together and to reduce the eventual need for expensive rehabilitation.

Examination of some pavement condition survey forms may be useful in attempting to equate cracking to performance. In Washington (3), a system is used of negative values for various types of structural deficiencies. The negative values for alligator cracking are as follows:

Percentage of Area/Station	Hairline	Spalling	Spalling Plus Pumping
1 to 24	2	5	10
24 to 49	5	10	15
50 to 74	10	15	20
75+	15	20	25

It is perhaps significant that the first percentage division is set at 24 percent. Riding quality is combined with distress to summarize pavement ratings on a scale of 0 to 100. The reduction in overall rating associated with 1 to 24 percent cracking would be comparable to one-half point on the PSI scale of AASHO. That seems to suggest fairly significant sensitivity to cracking by that method.

Another evaluation of the Washington method is to compare the total amount of reduction by cracking to the total allowable deduction for various classes of flexible pavements. For example, the limiting rating for Interstate and principal pavements has been set at 60. Assume that the riding quality is good (equivalent to a PSI of 4.0). With no cracking, the rating would be 84; with 75 percent of the area exhibiting cracking, the rating would be 72. Assume that riding quality is fair (equivalent to a PSI of 2.5). With 75 percent cracking, the rating would be 62. It appears that, if only riding quality and cracking are considered, extensive cracking would be permitted and still be acceptable. In all probability, that is a somewhat questionable conclusion because other forms of distress (e.g., rutting) have probably occurred in practice to cause the pavement rating to fall below 60 long before cracking reached 75 percent of the area.

Forbes (5) has suggested a similar classification for cracking except that the first separation on the amount of cracking is 15 percent. Azarnia (6) in evaluating maintenance criteria for county roads indicates that alligator cracking at less than 5 percent of the area should not require maintenance; however, maintenance could be required for 15 percent cracking depending on the level of severity. Hughes (7) has also reported on some of the problems related to structural deficiencies. Although this report was issued in 1971, several of the comments are still very pertinent.

> 1. The subject of pavement deficiencies has received the most attention since the initiation of the structural rating system. There are, of course, obvious deficiencies which affect pavement performance and develop a need for resurfacing. The main difference of opinion among engineers is the relative seriousness of these deficiencies.
> 2. The first step in the development of the rating system, then, was to hold discussions with individuals knowledgeable about pavement deterioration to enumerate and define the deficiencies which indicate the structural condition of a roadway. In addition, the relative seriousness of the deficiencies were discussed and numerical factors indicating the same were assigned.

The condition rating in Minnesota is obtained by averaging the PSR (riding quality) and the structural rating, each on a scale of 0 to 5. A weighting factor is applied to the various forms of structural distress, and information is corrected to a per-mile basis. By the suggested procedures, it would require almost 30 percent of the area to have alligator cracking before the pavement would be unacceptable. That is, if the riding quality is 2.5 or better, the area of cracking would need to be about 30 percent before the overall rating would drop below 2.5.

On the basis of the discussion given above, it is possible to draw the following conclusions:

1. Fatigue cracking in asphalt pavements is damaging to the continued successful performance of that pavement;
2. The initial occurrence of cracking may not be so crucial to the overall performance as some acceptable level generally indicative of a pending period of accelerated deterioration; and
3. The acceptable level of fatigue cracking could be between 10 and 30 percent depending on the amount of other types of structural distress and the riding quality.

Thus, to be helpful to the highway engineer, the output variable of cracking as predicted from research should include not only some estimate of initial cracking but also the rate of progression of cracking with time. McCullough et al. (8) indicated that it may be possible to predict the accumulation of cracking with time.

There are difficulties in using cracking as an output variable for field projects. That was probably best demonstrated on the WASHO Road Test in Idaho. On that project, cracking was considered the dependent variable or the performance rating factor. Design requirements were essentially based on the thinnest test sections considered not to have been damaged by the test traffic; in other words, those sections that basically had 0 percent distress or cracking. Examination of graphical representations of that information suggests that, if as little as 5 percent cracking had been tolerated, the allowable thickness requirements could have been reduced by approximately 3 in. for those sections surfaced with 2 in. of asphalt concrete and about 1 in. for those sections surfaced with 4 in. of asphalt concrete.

A second somewhat confounding aspect of the WASHO and AASHO data is that there were long periods at certain times of the year in which no cracking occurred in the pavement. Another problem is the ability to associate the various types (forms) of cracking with structural distress.

In summary, it would appear that the need to predict cracking is important and that most highway engineers agree that cracking is the first indication of the loss of load-carrying capacity of a given pavement construction. The initial occurrence of cracking is not so crucial to overall performance as the need to be able to predict some rate of propagation of cracking to some limiting amount.

At the present time, there does not appear to be any method of objectively quantifying cracking as a performance parameter. Performance data from the AASHO Road Test suggest that some cracking can be tolerated without serious loss in riding quality. Several papers in this Special Report and condition survey procedures indicate that some cracking is permissible. However, an upper limit needs to be established as a design criterion, and the further development of fatigue research needs to concentrate on some method for estimating the areal propagation of cracking as suggested by McCullough.

The only reasonable way to quickly determine the limiting amount of cracking is to ask the engineers who are responsible for the maintenance. Combining subjective evaluations of the future utility of a given pavement with objective measurements of the amount of cracking existing on the pavement with a well-planned performance feedback system should make it possible to develop useful cracking criteria. In this way, agencies can begin to establish a quantitative association between cracking and performance in terms of the need for specific maintenance strategies necessary to protect the basic investment.

REFERENCES

1. Structural Design of Asphalt Concrete Pavement Systems. HRB Spec. Rept. 126, 1971.
2. The AASHO Road Test: Report 5—Pavement Research. HRB Spec. Rept. 61E, 1962.
3. Rogers, C. F., Cashell, H. D., and Irick, P. E. Nationwide Survey of Pavement Terminal Serviceability. Highway Research Record 42, 1963, p. 26.
4. LeClerc, R. V., and Marshall, T. R. A Pavement Condition Rating System and Its Use. Proc., AAPT, 1969, pp. 280-295.
5. Forbes, C. E., and Currier, D. E. Surface Evaluation for Budgeting and Planning. 49th Annual Meeting of WASHO, 1970.
6. Azarnia, G. Development of Performance and Maintenance Criteria for County Roads. Univ. of Washington, Master's thesis, 1972.
7. Hughes, P. C. Development of a Rating System to Determine the Need for Resurfacing Pavements. Off. of Res. Coord., Minnesota Dept. of Highways, Invest. 189, 1971.
8. McCullough, B. F., Hudson, W. R., and Kher, R. K. Developing an Operational Pavement Design and Management System and Updating With Elastic Theory. Proc., 3rd Int. Conf. on Struct. Des. of Asphalt Pavements, 1972, p. 1061.
9. Terrel, R. L. Examples of Approach and Field Evaluation: Research Applications. Paper in this Special Report.
10. Pell, P. S. Characterization of Fatigue Behavior. Paper in this Special Report.