Development of Rational Pay Adjustment Factors for Asphalt Concrete

PRACHUAB PUANGCHIT, R. G. HICKS, JAMES E. WILSON, AND C. A. BELL

The effect of variations in asphalt concrete mix properties on pavement performance life is a crucial factor in highway pavement construction. In this study, data from laboratory-prepared samples from the North Oakland-Sutherlin, Castle Rock-Cedar Creek, and Warran-Scappoose projects were analyzed by using the Statistical Interactive Programming System. Regression analysis techniques were used to develop predictive models of pavement performance life based on each of the mix characteristics. The asphalt concrete mixture properties evaluated in this study were percentage of air voids, asphalt content, gradation, and aggregate type used. Percentage of air voids or mix density is found to be the most dominant factor and most highly significant in controlling both fatigue cracking and rutting failure. The mix that had low void content showed remarkably long fatigue life and high performance deformation resistance. The best performance life was obtained when the asphalt content and the amount of fines were at an optimum level. Deviation from optimum content in either of these properties causes a reduction in pavement life. The amount of voids and the optimum asphalt content appeared to be a function of the aggregate type used. The analysis indicates that, for the mix deviations considered, fatigue cracking is more critical to reduction in life than rutting. Therefore, the pay adjustment factors were developed based on fatigue performance life as opposed to a proposed standard pavement life. Summary tables of recommended pay adjustment factors as well as comparisons with others currently used are also included.

One of the major difficulties in asphalt concrete pavement construction is the control of materials and the subsequent payment to contractors. Quite often material quality does not meet specification requirements. The effect of this noncompliance on pavement serviceability is not fully established; however, it frequently results in reduced payments to contractors, which in turn causes controversy between the client and the contractor.

Some agencies reject construction and materials that do not meet specifications and do not pay the contractor. A majority of agencies, however, accept percentages of compaction, asphalt content, asphalt properties, and mix gradation that are outside of the specification tolerance limits, but apply a pay adjustment factor that penalizes the contractor by reducing his compensation (1). The pay adjustment factor relies heavily on the experience and judgment of project engineers. Therefore, there is a wide disparity in the pay adjustment factors currently used.

Several approaches have been used to establish pay factors for each material, but they have not always been based on sound engineering principles. Thus, pay adjustment factors are not always a reliable measure of reduced serviceability and the agencies do not have a uniform procedure for accepting or rejecting noncompliance work. For these reasons, contractors object to the use of pay adjustment systems. This leads to administrative and legal problems that cause the agencies to lose considerable time and money every year.

Past practices indicate that the extent to which the quality of work should be accepted or rejected is inconclusive. In addition, the properties that can be lower than the standard and the amount compensation should be reduced for substandard quality are not well defined.

PURPOSE

The purpose of this paper is to develop a rational procedure for establishing pay adjustment factors for asphalt concrete mixtures by finding a relation between asphalt concrete quality and pavement serviceability that would indicate whether the work should be accepted or rejected and how much compensation should be paid. The specific objectives are as follows:

1. To determine the most important factors that affect the properties of asphalt concrete mixtures,
2. To evaluate the effect of variations in these factors on pavement life for projects in Oregon,
3. To develop pay adjustment factors consistent with the latest engineering principles, and
4. To compare these values with those currently used by other agencies in the Pacific Northwest.

LABORATORY TESTS

This section presents the results of a search of the literature on asphalt concrete mix performance characteristics. In addition the results of an Oregon Department of Transportation (DOT) study of three projects--North Oakland-Sutherlin, Castle Rock-Cedar Creek, and Warren-Scappoose--which were analyzed by regression analysis techniques, are discussed. The effect of each mix property on pavement performance is studied to provide better understanding for developing pay adjustment factors.

The expected serviceability or performance of the finished product is of great concern in all pavement construction. The serviceability of asphalt pavements is a function of factors such as expected loads, mixture, and environmental variables. Failure of asphalt concrete pavement is the result of (a) rutting or washboarding caused by stability problems, (b) progressive cracking caused by fatigue problems, and (c) fracture caused by strength failure. Fatigue cracking is probably the most destructive mode of distress and, therefore, of most concern to highway engineers and researchers (2).

Fatigue is the phenomenon of cracking due to a repeated stress or strain level with a maximum value less than the tensile strength of the material when subjected to a single load application (3). The fatigue life of asphalt concrete is governed by many factors: loading, base and subbase support, climatic and environmental factors, and asphalt concrete mixture variables. Of these factors, the asphalt mix plays an important role in the ultimate life of asphalt pavements. Asphalt content, aggregate gradation and type, air void content (density), and asphalt viscosity are all mix variables that have been shown to be related to fatigue resistance. Many of these variables are interrelated so that a change in one is comparable to a change in another.

Typical Fatigue Prediction Models

The fatigue response of asphalt paving mixtures throughout the world has been investigated for a number of years (4-9). Studies (4-7) have indicated that there is a relation between the fatigue performance of asphalt mixes and initial tensile strain that could be considered linear when plotted on a logarithmic basis. This relation can be expressed as follows:

$$N_f = K(1/\epsilon_t)^C \quad (1)$$

where

N_f = number of load repetitions to failure,
ϵ_t = horizontal elastic tensile strain, and
K,C = regression constants.

Factors K and C depend on the composition and properties of the mix and are also affected by the testing method and temperature (8). The mix variables that affect fatigue life are type and gradation of aggregate, filler, binder type, viscosity and content, degree of mix compaction, and resulting air void content. Pell (4) stated that the most important variables are binder content and void content.

The results of research (4,5,9) indicate that mixes that have a high void content exhibit comparatively short fatigue lives. Increasing the asphalt content of a mix results in increases in fatigue life up to an optimum (9). Further increases of asphalt content result in a decrease in fatigue life. Other mix variables, such as aggregate type and gradation, also affect mix performance. The Oregon DOT undertook this study to evaluate the effect of mix variations on pavement life.

Results of Oregon DOT Study

The Oregon DOT and Oregon State University (OSU) initiated a laboratory study to establish the relation between asphalt concrete pavement performance and level of compaction, asphalt content, percentage passing the No. 200 sieve, and aggregate quality. Laboratory samples of asphalt concrete mix from the North Oakland-Sutherlin, Castle Rock-Cedar Creek, and Warren-Scappoose projects were prepared and tested at the Oregon State University laboratory (10-12).

Fatigue cracking and rutting were the main types of pavement failure considered during the test program. Conventional tests and improved dynamic tests were performed to determine stiffness, fatigue life, and permanent deformation characteristics for the mix. The percentage of reduction in pavement life, based on fatigue and/or permanent deformation characteristics from the standard mix, was used as a criterion in developing pay adjustment factors.

The results of all projects indicated that the level of compaction was the controlling factor for all dynamic properties of the mix. Increasing the mix density increased the fatigue life and resistance to permanent deformation. The effects of changes in asphalt content and gradation were not always so clear and varied from project to project. Some of these effects are discussed later in this paper.

Statistical Computer Analysis of Data

All samples were tested in the diametral mode at initial strain levels of 50, 100, and 125 microstrain. The number of repetitions to failure was recorded for both fatigue cracking and rutting and used in statistical regression analyses (13) to develop predictive models of pavement performance.

Regression analysis was performed for each project and for all projects together at each microstrain level. Mix properties such as gradation, percentage of voids, asphalt content, and aggregate type are considered in the development of a pavement performance model by means of regression analysis techniques. Search procedures used to find the best set of mix variables are forward selection, backward elimination, and t-directed search of the Statistical Interactive Programming System at Oregon State University. The best possible sets of all mix properties at each level of microstrain are given by Puangchit and others (13).

Effect of Mix Properties on Fatigue Life

The effect of each mix property on fatigue life was determined separately by scatter of data versus number of repetitions to obtain the trend of the relation. Then the regression equation of fatigue life as a function of each property was set at levels of 50, 100, and 125 microstrain. The effect of each mix characteristic on fatigue life is discussed below.

Density

Density (or percentage of air voids) is the most dominant factor for all mix properties. Fatigue life is primarily affected by the level of compaction; increasing the density or decreasing the percentage of voids increases the fatigue life of the pavement. In mix design, when considering other variables, the void content should generally be minimized; i.e., binder content, aggregate gradation, density, and the use of fillers are selected to obtain the smallest void space possible so that bleeding will not occur.

The results of regression analysis for the effect of percentage of voids on fatigue life for one project and all projects combined are shown in Figure 1. The results of the analysis indicate that the amount of air voids controls the number of repetitions to failure of asphalt concrete pavements. Small increases in air voids content cause substantial decreases in fatigue life. The decrease in fatigue life is also affected by the traffic load level and aggregate type when all other factors are fixed. At the low level of microstrain or a heavy-traffic-load level, fatigue life decreases sharply with increasing voids content of the mix.

Asphalt Content

Binder content is one of the critical factors that regulate all mix properties. Not only is the binder the most expensive constituent of the mix but it also directly controls the stiffness (or flexibility) of the asphaltic concrete. As the binder content in the mix fluctuates, the amount of void space filled by the binder in the aggregate gradation is also altered. This modification in void space filled affects aggregate interparticle friction, which in turn affects the stability, durability, strength, and fatigue of the mix.

The effects of asphalt content on fatigue life for one project and all projects combined are shown in Figure 2. As asphalt content increases, fatigue life increases to the point where the optimum asphalt content corresponds to the maximum fatigue life obtainable. This is caused by the binder filling the aggregate void space. As the voids become filled, the binder cements aggregate particles together, which causes an increase in the strength of bonding. As the voids become overfilled, the aggregate friction decreases and the binder takes more of the load. In this situation, the stiffness decreases as more and more binder is added.

Table 1 gives the optimum asphalt content related to fatigue life at each traffic load or strain level. These asphalt percentages are an optimum for the particular aggregate type, binder type, gradation of aggregate used, and level of traffic load. Changes in fatigue life caused by changes in asphalt content are greater at the low strain level (heavy traffic load). A comparison of the two projects

Figure 1. Effect of percentage voids on fatigue life at three microstrain levels.

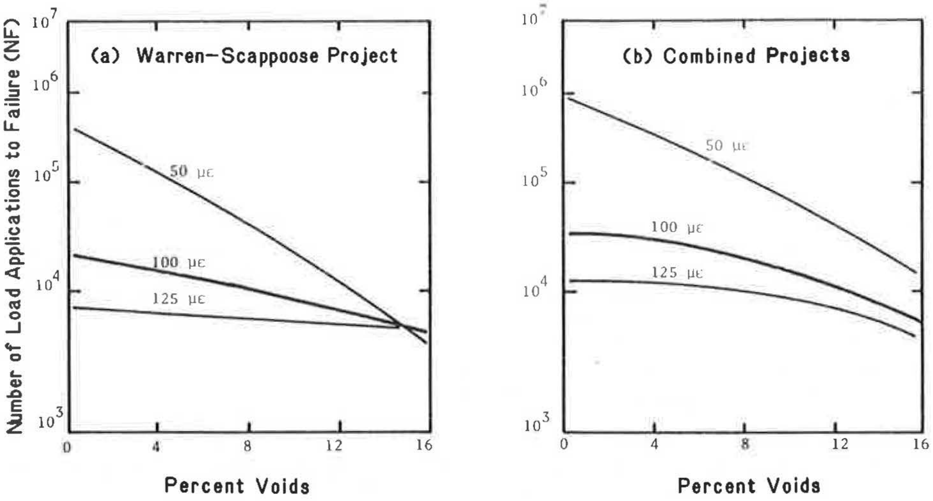


Figure 2. Effect of asphalt content on fatigue life at three microstrain levels.

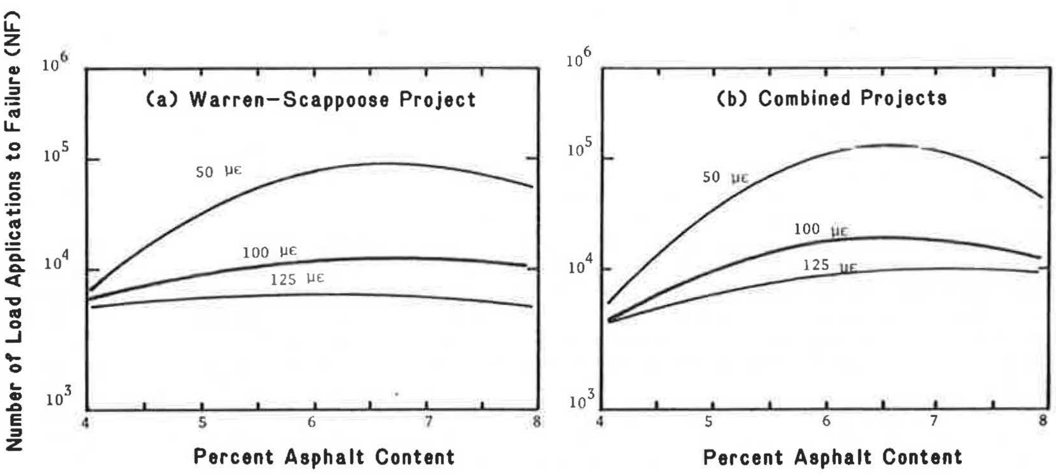


Table 1. Relation between optimum asphalt content and fatigue life.

Project	Design Percentage	Level of Microstrain[a] (με)	Optimum Asphalt Content (%)	Max Fatigue Life (cycles to failure)
North Oakland-Sutherlin	6	50	6.36	4.23×10^5
		100	6.20	3.95×10^4
		125	6.39	1.61×10^4
Castle Rock-Cedar Creek	6	50	6.41	9.23×10^4
		100	6.41	2.38×10^4
		125	6.41	1.32×10^4
Warren-Scappoose	5.5	50	6.71	9.53×10^4
		100	6.70	1.30×10^4
		125	6.01	6.627×10^3
All		50	6.58	1.79×10^5
		100	6.60	2.19×10^4
		125	7.21	1.21×10^4

[a] Strain levels are associated with types of highway facilities as follows: 50 = Interstate type, 100 = primary type, and 125 = low-volume road.

shows that a change in fatigue is affected somewhat by aggregate type. Figure 2 shows these effects.

Aggregate Gradation

The gradation of an aggregate also determines the amount of void space available to be filled with asphalt binder. The degree to which the voids are filled with binder greatly influences the stiffness and fatigue life of a mix. In the same regard, the amount of void space provided by the aggregate also controls the stiffness and fatigue life. Figure 3 verifies that fatigue is related to the percentage passing the No. 200 sieve at each microstrain level; the amount of this material that is present increases fatigue life until an optimum is reached.

For the Warren-Scappoose project (Figure 3a) at 100 microstrain, an increasing amount of fines increases the life of the pavement; maximum fatigue life is approached at about 10 percent fines. In general, for all three projects together, the optimum amount of material passing the No. 200 sieve required to obtain maximum fatigue life at 100 microstrain is 9 percent, as shown in Figure 3b. However, the optimum percentage of fines is considerably lower in the case of permanent deformation, as will be discussed later.

Aggregate Type

In an asphalt concrete mix, the aggregate provides the primary load-carrying mechanism and thus is expected to have some effect on fatigue life. Shape, surface texture, durability, and chemical properties are of interest in investigating aggregate types. Probably the most important is durability. In Oregon, pavement performance has been drastically reduced by aggregate breakdown. The effect of aggregate type on fatigue life for each project and all projects combined is shown in Figure 4. The regression equations used for the effect of aggregate type on fatigue are given below for all three projects together. Equation 2 represents the model

Figure 3. Effect of percentage passing the No. 200 sieve on fatigue life at three microstrain levels.

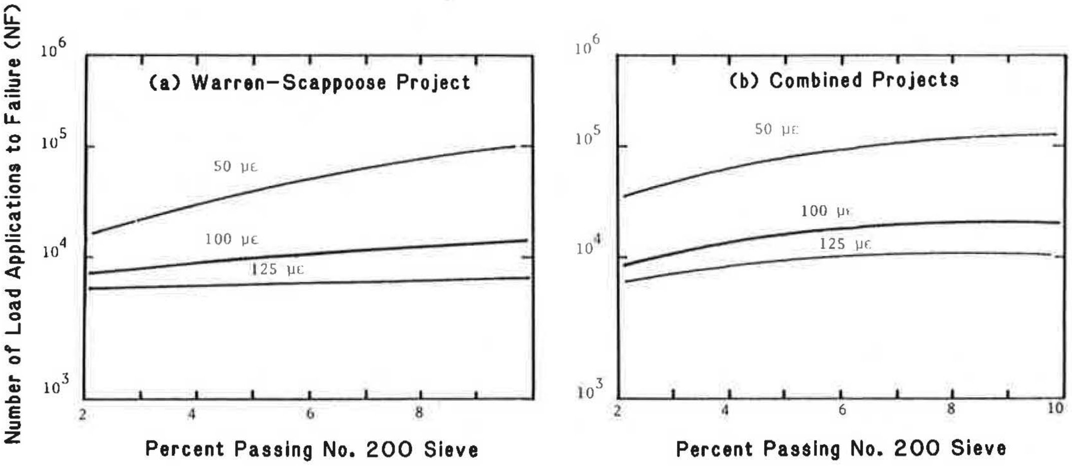
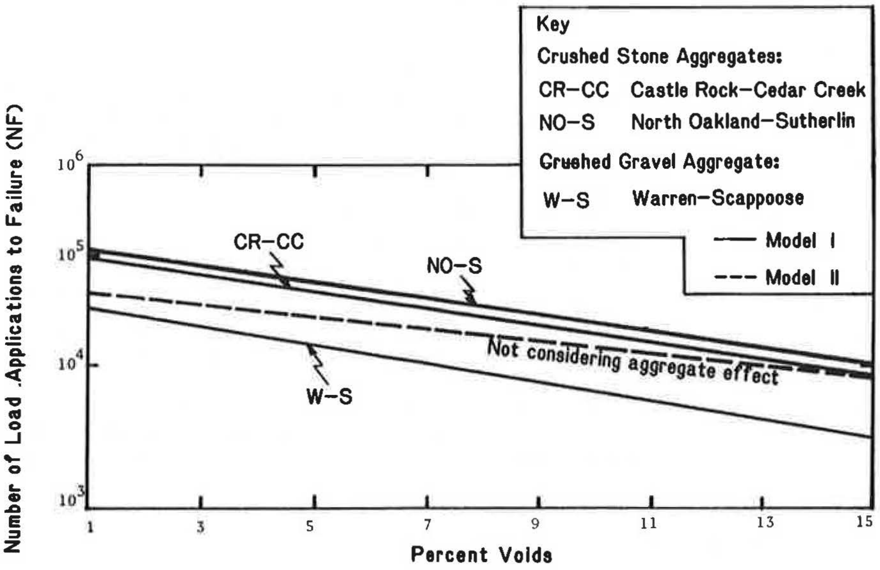


Figure 4. Effect of aggregate type on fatigue performance of asphalt concrete mixtures.



in which the effect of aggregate type is not considered and Equation 3 the model in which it is considered:

$$\log NF = 4.6875 - 0.05103\,(\mathrm{VOIDS}) \qquad R^2 = 0.3300 \qquad (2)$$

$$\log NF = 4.5732 - 0.0744\,(\mathrm{VOIDS}) + 0.5325\,(\mathrm{AG.T1}) + 0.4585\,(\mathrm{AG.T2}) \qquad R^2 = 0.8266 \qquad (3)$$

where

NF = number of repetitions to failure,
AG.T1 = 1 for marginal quality aggregate and 0 for good quality aggregate, and
AG.T2 = 1 for crushed stone and 0 for crushed gravel.

The following mix compositions were used in the projects:

Project	Mix Composition
North Oakland-Sutherlin	Crushed stone with good and marginal-quality aggregate
Castle Rock-Cedar Creek	Crushed stone with good-quality aggregate
Warren-Scappoose	Crushed gravel with good-quality aggregate

Equation 2 shows that the effects of aggregate type are statistically significant and also indicates the influence of aggregate type on fatigue life (i.e., mixes composed of crushed stone have better fatigue resistance than those composed of crushed gravel).

RECOMMENDED PAY ADJUSTMENT FACTORS

To isolate the most critical pavement performance conditions for use in developing pay adjustment factors, the estimated fatigue and permanent deformation performance of the mix are compared for each mix variable. Pay adjustment factors are developed based on the fatigue distress mode, as explained below. The pay adjustment factors developed in the study are summarized and compared with existing local pay factors.

Approaches

The predictive models were evaluated at three levels of tensile strain. The models corresponding to 100 microstrain were considered the most representative of general traffic-load conditions in Oregon. The model of 50 microstrain represents a thick pavement carrying heavy traffic loads, whereas the models of 125 microstrain represent light traffic loads or private roads. Therefore, the predictive models of 100 microstrain were used to determine pavement life in this study. The effects on pavement performance of variations in percentage of voids, asphalt content, and percentage passing the No. 200 sieve were evaluated for both fatigue and permanent deformation criteria. The predictive models of fatigue and permanent deformation life were obtained and evaluated. The results are given below.

Pavement performance life as a function of air voids for both fatigue and rutting is shown in Figure 5 for all projects combined. An increasing percentage of voids results in reducing pavement life for both permanent deformation and fatigue cracking. As void content increases, its effect on the occurrence of rutting is greater than its effect on cracking. It should be noted that the fatigue and deformation results are for the same temperature, and, although the number of repetitions to failure is greater for deformation at this temperature, changes in temperature could alter the relative performance. It should also be noted that the laboratory results have not been adjusted to field performance curves; therefore, the same relations are assumed between laboratory and field performance for both fatigue and deformation.

The permanent deformation and fatigue curves as a function of asphalt content are shown in Figure 6 for all projects combined. The change in asphalt content from the design optimum significantly changes the pavement life because of permanent deformation. The effect on reductions of fatigue life was less critical.

The impact of the amount of fines on fatigue and permanent deformation for the Warren-Scappoose project and all projects combined at the 100-microstrain level is shown in Figure 7. The results indicate that the effect of fines on mix behavior is similar to that of asphalt content. When the optimum value is exceeded, the number of repetitions to failure for permanent deformation drops sharply. The variation in the amount of fines appears to have minimal effect on fatigue life.

Development of Pay Adjustment Factors

The fatigue life predictive models at 100-microstrain were used in this study to develop pay adjustment factors for two reasons:

1. The 100-microstrain level represents an average condition typical of most roads in Oregon.
2. Fatigue criteria were used because fatigue is the most prevalent type of distress found in Oregon. Had permanent deformation criteria been used, the resulting penalties would have been much greater.

The predictive models given in Table 2 have been used to estimate the performance life of the pavement in this study. For given mix properties (asphalt content, voids, percentage passing the No. 200 sieve, and aggregate type), the design fatigue life (N_f) can be found from the predictive model. At three different confidence intervals (90, 95, 99 percent) for mean response of fatigue life models, the estimated fatigue life of a proposed pavement is obtained and evaluated to determine the reduction in pavement performance.

The proposed pay adjustment factors are based on the concept that pavements constructed within design mix specifications are accepted with full payment or a pay adjustment factor of 100. A deviation for the mix specifications causes a change in pavement fatigue life. Therefore, the pay adjustment factor is

Figure 5. Permanent deformation and fatigue curves as a function of percentage voids for all projects at 100 microstrain.

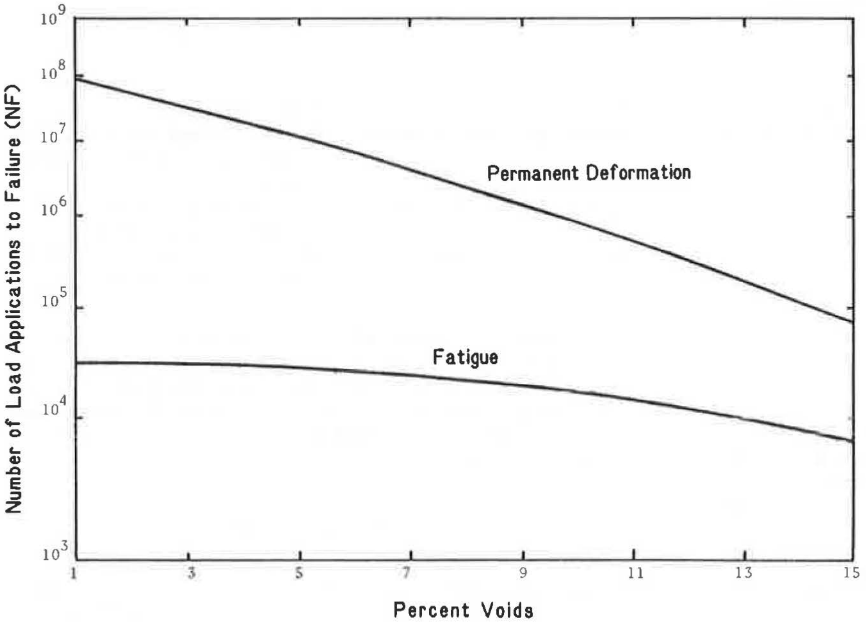


Figure 6. Permanent deformation and fatigue curves as a function of asphalt content for projects at 100 microstrain.

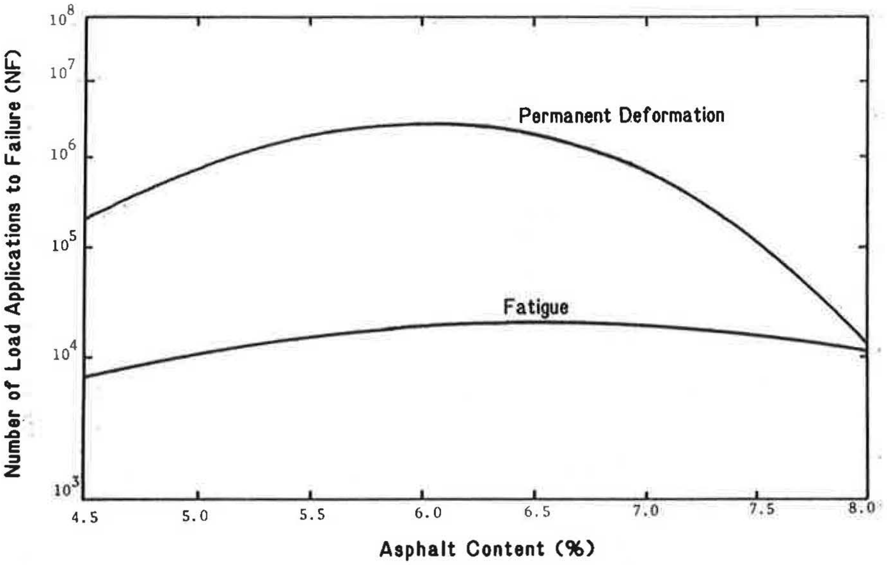
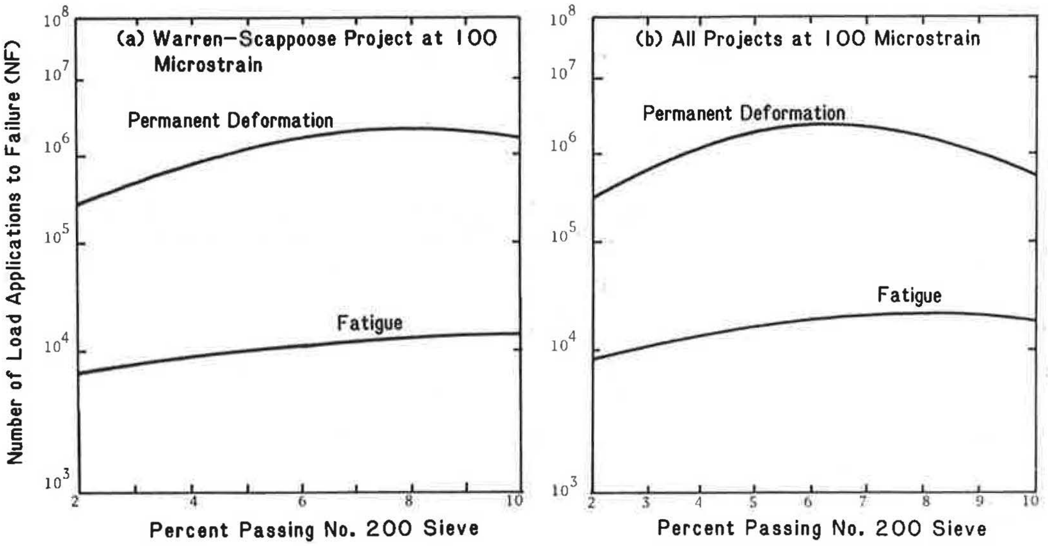


Figure 7. Permanent deformation and fatigue curves as a function of percentage passing the No. 200 sieve.



defined as the ratio of the fatigue life of the constructed pavement to the fatigue life of the standard proposed pavement:

$$\text{Pay adjustment factor} = [N_f \text{ (of constructed)}/N_f \text{ (of design standard)}] \times 100 \qquad (4)$$

The payment would be increased for a greater fatigue life and reduced for a shorter life than the design standard pavement life.

The pay adjustment factors developed for each mix variable and for the combined effects of all three variables in each project were derived from the models given in Table 2. The effect of aggregate type has been considered in developing the pay adjustment factor in all projects. It can be seen that for each project the models for density (voids) have a much higher R^2 than those for asphalt content or percentage passing the No. 200 sieve.

R^2 indicates the dependence of fatigue life on the voids variable and thus shows the significance of density. Even when all of the variables are considered together for each project with various regression models, voids is often the only variable of significance. When all of the projects are combined, the R^2 values drop for all models; however, those that contain only a voids term and exclude aggregate effects have the highest values.

Pay adjustment factors based solely on void content, asphalt content, and the amount of fines are given in Tables 3-5, respectively. Table 6 gives the pay adjustment factors obtained when all mix properties are considered, not including the effect of aggregate type. The model as given in Table 6 explains only 33 percent of the variation in the logarithm of fatigue life as controlled by void content. Hence, all of these predictive models clearly illustrate the effect of aggregate type on variation of mix characteristics. Differences in the aggregate type result in different mix characteristics, which directly affect fatigue life and, of course, pay adjustment factors. Unfortunately, it is not

Table 2. Regression models of repetitions to failure as a function of mixture properties for fatigue criteria at 100-microstrain level.

Project	Model No.	Mix Properties Included	No. of Samples	Regression Model Equation	t	R^2
N. OAKLAND-SUTHERLIN	1	VOIDS	10	log NF = 5.1758 – 0.07973 (VOIDS)	–5.805	0.8082
	2	AC	10	log NF = –0.1173 + 1.1435 (AC) – 0.00997 (AC) – 0.00997 (AC)^3	–0.925	0.1327
	3	No. 200 sieve	10	log NF = 3.9938 + 0.1031 (No. 200) – 0.00042 (No. 200)^3	–0.687	0.2199
	4	No. 10 sieve	3	log NF = 4.5129 – 0.00855 (No. 10)	–1.467	0.6827
	5	No. 200, AC, VOIDS	10	log NF = 6.0333 – 0.1199 (AC) = 0.0943 (VOIDS)	–2.528	0.8997
	6	Polynomial	10	log NF = 5.6699 – 0.0937 (VOIDS) – 0.0099 (AC)^2	–2.533	0.8999
	7	Interactions	10	log NF = 5.3093 – 0.01596 (AC) (VOIDS)	–7.935	0.8873
	8	All effects	10	log NF = 5.3093 – 0.01596 (AC) (VOIDS)	–7.935	0.8873
CASTLE ROCK-CEDAR CREEK	9	VOIDS	10	log NF = 4.9118 – 0.00514 (VOIDS)^2	–13.562	0.9583
	10	AC	10	log NF = –6.8514 + 3.5035 (AC) – 0.2733 (AC)^2	–1.266	0.3804
	11	No. 200 sieve	10	log NF = 3.5307 + 0.1583 (No. 200) – 0.00094 (No. 200)^3	–1.128	0.2263
	12	No. 200, AC, VOIDS	10	log NF = 5.4439 – 0.1099 (VOIDS)	–11.385	0.9419
	13	Polynomial	10	log NF = 4.9118 – 0.00515 (VOIDS)^2	–13.652	0.9583
	14	Interactions	10	log NF = 5.4439 – 0.1099 (VOIDS)	–11.385	0.9419
	15	All effects	10	log NF = 4.9118 – 0.00515 (VOIDS)^2	–13.562	0.9583
WARREN-SCAPPOOSE	16	VOIDS	10	log NF = 4.3154 – 0.0401 (VOIDS)	–5.041	0.7605
	17	AC	10	log NF = 1.9253 + 0.6535 (AC) – 0.04879 (AC)^2	–0.503	0.3561
	18	No. 200 sieve	10	log NF = 3.7795 + 0.0429 (No. 200) – 0.00007 (No. 200)^3	–0.20	0.3108
	19	No. 200, AC, VOIDS	10	log NF = 4.3154 – 0.04010 (VOIDS)	–5.041	0.7605
	20	Polynomial	10	log NF = 4.3154 – 0.04010 (VOIDS)	–5.041	0.7605
	21	Interactions	10	log NF = 3.8729 – 0.0011 (VOIDS) + 0.0098 (No. 200) (AC) – 0.0042 (No. 200) (VOIDS)	–5.620	0.9789
	22	All effects	10	log NF = 3.8729 – 0.0011 (VOIDS) + 0.0098 (No. 200) (AC) – 0.0042 (No. 200) (VOIDS)	–5.620	0.9789
ALL	23	VOIDS	30	log NF = 4.5072 – 0.00295 (VOIDS)^2	–3.975	0.3608
	24	AC	30	log NF = 0.7705 + 0.8131 (AC) – 0.00625 (AC)^3	–1.225	0.2248
	25	No. 200 sieve	30	log NF = 3.6938 + 0.1456 (No. 200) – 0.00863 (No. 200)^2	–1.191	0.1543
	26	No. 200, AC, VOIDS	30	log NF = 4.6875 – 0.05103 (VOIDS)	–3.714	0.3300
	27	No. 200, AC, VOIDS, AG.T	30	log NF = 4.5732 – 0.0744 (VOIDS) + 0.5525 (AG.T1) + 0.4585 (AG.T2)	6.329	0.8266
	28	Polynomial	30	log NF = 4.5072 – 0.00295 (VOIDS)^2	–3.975	0.3608
	29	Polynomial + AG.T	30	log NF = 4.3039 + 0.5382 (AG.T1) + 0.4797 (AG.T2) – 0.00426 (VOIDS)	7.147	0.8539
	30	Interactions	30	log NF = 4.3801 – 0.0045 (VOIDS) + 0.8429 (AG.T1) + 0.0048 (AG.T2) (No. 200)	–2.162	0.9148
	31	All effects	30	log NF = 4.3217 + 1.2297 (AG.T1) + 0.4998 (AG.T2) – 0.1139 (AC) (AG.T1) – 0.0045 (VOIDS)	–2.162	0.8769

Table 3. Pay adjustment factors for percentage of voids of three projects determined by using fatigue criteria.

Design Target Value (%)	Specifications Limits (%)	No. of Repetitions (log NF)	Pay Adjustment Factor (%)
10	<7.38	>4.3467	136
	8.14-7.38	4.3119-4.3467	131
	8.48-8.14	4.2951-4.3119	123
	11.31-8.48	4.1298-4.3119	100
	11.57-11.31	4.1129-4.1298	81
	12.06-11.57	4.0783-4.1129	76
	>12.06	<4.0783	73
8	<3.29	>4.4754	144
	4.96-3.29	4.4348-4.4754	137
	7.79-4.96	4.3282-4.4348	116
	8.20-7.79	4.3089-4.3282	100
	10.16-8.20	4.2024-4.3089	87
	10.82-10.16	4.1618-4.2024	74
	>10.82	<4.1618	70
5	<4.54	>4.4464	103
	5.41-4.54	4.4207-4.4464	100
	8.82-5.41	4.2781-4.4207	82
	9.81-8.82	4.2238-4.2781	66
	>9.81	<4.2238	62

Note: Based on model 23 from Table 2.

Table 4. Pay adjustment factors for percentage of asphalt content (optimum value 6.6 percent) of three projects determined by using fatigue criteria.

Specifications Limits (%)	No. of Repetitions (log NF)	Pay Adjustment Factor (%)
7.84	<4.1317	62
7.67-7.84	4.1858-4.1317	66
7.10-7.67	4.2121-4.1858	72
6.10-7.10	4.2121-4.2121	100
6.10-5.43	4.2121-4.1858	72
5.43-5.23	4.1858-4.1317	66
<5.23	<4.1317	62

Note: Based on model 24 from Table 2.

practical to consider the effect of aggregate type in developing pay factors for general use unless the aggregate types used in a given area are extremely uniform.

Comparison with Existing Pay Adjustment Factors

The successful implementation of pay adjustment factors depends on their reliability, fairness, ease of use, and accuracy in representing true pavement performance. The format should be relatively simple, but it must be based on sound engineering and statistical principles to ensure general acceptance. The pay adjustment factors developed in this study are compared with those currently in use in Tables 7-9.

The pay adjustment factors relating to density are given in Table 7. The following target density values are used in the various specifications cited in Table 7:

Specification	Voids (%)
Oregon standard	1-3
Washington DOT	0.0
OSU-Oregon DOT study	0.0
Oregon quality assurance	
R = 1	1-3
R = 2	1-3
R = 4	1-3

The pay factors given in Table 7 are comparable to those of the Oregon quality assurance specification

(R = 4) except that a higher bonus is recommended for good compaction and a greater penalty is recommended for poor compaction, which reflects the substantial effect of compaction on pavement life. Density was shown to be the most significant variable and is regarded as the only one to which a bonus payment should be applied. The Oregon quality assurance specifications allow a small bonus payment when the constituents of the mix are close to the target values.

The pay factors developed in this study for asphalt content (Table 8) are significantly more severe than the others shown with the exception of the FHWA specification, which appears to penalize material within the normally accepted range of ±0.5 percent of the target value and allows for rejection outside that range. This is because the FHWA specification recognizes that when a mean value from five tests results is used, there is less probability of that value differing from the target value by a given amount than if fewer tests were used. The pay factors based on percentage passing the No. 200 sieve (Table 9) are slightly more severe than the others shown with the exception of the FHWA specification for reasons similar to those stated above for asphalt content.

CONCLUSIONS AND RECOMMENDATIONS

The impacts of variations in material quality, construction, and environment cause uncertainty in the performance of asphalt concrete pavements. The influence of variations in asphalt concrete mix characteristics on mix performance was studied for the North Oakland-Sutherlin, Castle Rock-Cedar Creek, and Warren-Scappoose projects in Oregon. The results from a computer statistical analysis led to the following conclusions:

1. Mix density (or air voids content) shows highly significant influence on mix performance. An increase in air voids content is associated with a decrease in performance life. Thus, a mix with low air voids content is most desirable in asphalt concrete pavement construction.
2. The results of the analyses suggest that maximum performance life occurs at an optimum asphalt content. It is interesting to note that the optimum asphalt content required on all projects for maximum permanent deformation resistance is always less than that required for highest fatigue life. It is also obvious that performance life decreases as asphalt content deviates from an optimum value.

Table 5. Pay adjustment factors for percentage passing the No. 200 sieve (optimum value 8.5 percent) of three projects determined by using fatigue criteria.

Material Passing No. 200 Sieve (%)	No. of Repetitions (log NF)	Pay Adjustment Factor (%)
>13.50	<4.0867	60
12.80-13.50	4.1441-4.0867	64
8.67-12.80	4.3074-4.1441	83
8.67-8.33	4.3074-4.3078	100
8.33-4.08	4.3078-4.1441	83
4.08-3.37	4.1441-4.0867	64
<3.37	<4.0867	60

Note: Based on model 25 from Table 2.

Table 6. Pay adjustment factors for mixture properties of three projects determined by using fatigue criteria.

Design Target Value Loads (%)	Required Value (%)	No. of Repetitions (log NF)	Pay Adjustment Factor (%)
10	<7.29	>4.3155	138
	7.99-7.29	4.2797-4.3155	132
	8.33-7.99	4.2623-4.2797	124
	11.67-8.33	4.0919-4.2623	100
	12.01-11.67	4.0919-4.1771	91
	12.71-12.01	4.0388-4.0746	76
	>12.71	<4.0388	73
8	<5.08	>4.4280	147
	5.84-5.08	4.3895-4.4280	135
	7.82-5.84	4.2886-4.3895	115
	8.19-7.82	4.2698-4.2886	100
	10.16-8.19	4.1680-4.2698	87
	10.92-10.16	4.1303-4.1688	74
	>10.92	<4.1303	71
5	<0.70	>4.6521	166
	1.87-0.70	4.5920-4.6521	155
	4.73-1.87	4.4462-4.5920	122
	5.27-4.73	4.4184-4.4462	100
	8.19-5.27	4.2694-4.4184	82
	9.31-8.19	4.2125-4.2694	64
	>9.31	<4.2125	60

Note: Based on model 26 from Table 2.

Table 7. Pay factor comparison based on density.

	Pay Factor					
				Oregon Quality Assurance Specification		
Compaction (%)	Oregon Standard	Washington DOT	OSU-Oregon DOT Study	R = 1[a]	R = 2[a]	R = 4[a]
≥95.0	-	-	110	-	-	-
92.0-94.9	-	-	100	-	-	-
≥94.0	-	-	-	102	102	102
≥92.0	-	100	-	100	100	100
≥91.5	100	-	-	-	-	-
91.0-91.9	-	95	94	96.7[b]	95.4[b]	92.7[b]
91.0-91.4	99.8[c]	-	-	-	-	-
90.0-90.9	99.6[c]	90	87	92.7[b]	91.4[b]	88.7[b]
89.0-89.9	99.3[c]	80	80	88.7[b]	87.4[b]	84.7
<89.0	-	50[d]	70[e]	-	-	-
88.0-88.9	98.8[c]	-	-	84.7	83.4	80.7
87.0-87.9	98.2[c]	-	-	80.7	79.4	76.7
<87.0	Less pay	-	-	76.7	75.4	72.7

[a] R is the difference between the highest and lowest values in the group of several test results from the lot.
[b] Values calculated at the midpoint of the percentage compaction range.
[c] Values calculated by using current guidelines for pavement with 16-ft width, 2-in. thickness, 0.5-mile length, 140-lb/ft^3 density, and $23/ton cost.
[d] Maybe.
[e] Reject.

Table 8. Pay factor comparison based on asphalt content.

Tolerance for Percent Asphalt	Pay Factor					
				Oregon 1982 Quality Assurance Specification		
	Oregon Standard[a]	FHWA[b]	OSU-Oregon DOT Study[c]	R = 0.1[d]	R = 0.2[d]	R = 0.4[d]
±0.35	100.0	100.0	100.0	100.0	100.0	100.0
±0.40	100.0	95.0	100.0	100.0	100.0	100.0
±0.45	100.0	85.0	100.0	100.0	100.0	100.0
±0.50	100.0	-	100.0	100.0	100.0	100.0
±0.60	99.2	-	96.5	97.1	96.3	94.9
±0.70	98.4	-	93.0	94.9	94.1	92.7
±0.80	97.6	-	89.0	92.7	91.9	90.5
±0.90	96.8	-	85.5	90.5	89.7	88.3
±1.00	96.0	-	80.5	88.3	87.5	86.1
±1.10	95.2	-	76.0	86.1	85.3	83.9
±1.20	94.4	-	71.0	83.9	83.1	81.7
±1.30	93.6	-	66.0	81.7	80.9	79.5
±1.40	92.8	-	60.0	79.5	78.7	77.3

[a] For an individual field test with testing of a backup sample for failing samples to confirm results.
[b] May be accepted at a pay factor of 70% or rejected. For an average of 5 tests.
[c] Based on fatigue criteria on specimens outside the ODOT tolerance of ±0.5%. For an average of 5 tests.
[d] R is the difference between the highest and lowest values in the group of several test results from the lot.

Table 9. Pay factor comparison based on percentage passing the No. 200 sieve.

Tolerance for Percent Passing No. 200 Sieve	Pay Factor					
				Oregon 1982 Quality Assurance Specification		
	Oregon Standard[a]	FHWA[b]	OSU-Oregon DOT Study[c]	R = 0.1[d]	R = 0.2[d]	R = 0.4[d]
±1.7	100.0	100.0	100.0	100.0	100.0	100.0
±1.8	100.0	95.0	100.0	100.0	100.0	100.0
±1.9	100.0	95.0	100.0	100.0	100.0	100.0
±2.0	100.0	85.0	100.0	100.0	100.0	100.0
±2.1	99.9	85.0	99.1	99.2	98.6	97.0
±2.2	99.8	-	98.1	98.6	98.0	96.4
±2.3	99.6	-	97.0	98.0	97.4	95.8
±2.4	99.5	-	95.8	97.4	96.8	95.2
±2.5	99.4	-	94.5	96.8	96.2	94.6
±2.6	99.2	-	93.1	96.2	95.6	94.0
±2.7	99.1	-	91.6	95.6	95.0	93.4
±2.8	99.0	-	90.0	95.0	94.4	92.8
±2.9	98.9	-	88.3	94.4	93.2	92.2
±3.0	98.8	-	86.5	93.8	93.2	91.6

[a] For an individual field test with testing of a backup sample for failing samples to confirm results.
[b] May be accepted at a pay factor of 70% or rejected. For an average of 5 tests.
[c] Based on fatigue criteria on specimens outside the ODOT tolerance of ±2.0%. For an average of 5 tests.
[d] R is the difference between the highest and lowest values in the group of several test results from the lot.

3. The amount of fines has less effect in controlling mix behavior than density. As in the case of asphalt content, the best performance life is obtained at an optimum point. Beyond this value there is a reduction in mix performance life. A smaller amount of fines was required for permanent deformation to reach the highest performance level than for fatigue cracking.
4. Percentage passing the No. 10 sieve had an apparent effect on performance behavior, but the sample size was not adequate to draw a statistically valid conclusion.
5. Aggregate type exhibited an effect on mix performance. Aggregate type is important in that it determines the amount of asphalt and indicates the air voids that can be incorporated in the mix. With the same air voids and asphalt content, the mix performance still varies with the aggregate type used.
6. The pay adjustment factors are based on the concept that the performance life at the design target value derived from the predictive model is accepted with full payment. The other pay adjustment factors are derived by comparing the performance with that of a standard design mix.
7. The pay adjustment factors developed compare favorably with those used by other agencies in the Pacific Northwest.

Based on the analyses of data presented above, it is recommended that a compaction specification similar to Table 3, using 8 percent voids as a maximum value, should be adopted. The upper limit on the bonus should be 10 percent because an initial voids content lower than 5 percent may cause other problems. Furthermore, it is believed that, if higher compaction requirements are imposed, contractors will need better control of asphalt content and gradation to achieve tne higher density values.

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REFERENCES

1. M.R. Moore, J.E. Wilson, J.P. Mahoney, and R.G. Hicks. Impact of Variation in Materials Properties on Asphalt Pavement Life: Evaluation of a Questionnaire. FHWA, Interim Rept. FHWA-OR-81-5, May 1981.
2. Structural Design of Asphalt Concrete Pavement Systems. HRB, Special Rept. 126, 1971.
3. E.J. Yoder and M.W. Witczak. Principles of Pavement Design, 2nd ed. Wiley, New York, 1975.
4. P.S. Pell. Characterization of Fatigue Behavior. In Structural Design of Asphalt Concrete Pavements to Prevent Fatigue Cracking, HRB, Special Rept. 140, 1973, pp. 49-64.
5. P.S. Pell and K.E. Cooper. The Effects of Testing and Mix Variables on the Fatigue Performance of Bituminous Materials. Proc., Assn. of Asphalt Paving Technologists, Vol. 44, Feb. 1975.
6. M.W. Witczak. Fatigue Subsystem Solution for Asphalt Concrete Airfield Pavements. In Structural Design of Asphalt Concrete Pavements to Prevent Fatigue Cracking, HRB, Special Rept. 140, 1973, pp. 122-129.
7. J.H. Havens, R.C. Deen, and H.F. Southgate. Pavement Design Schema. In Structural Design of Asphalt Concrete Pavements to Prevent Fatigue Cracking, HRB, Special Rept. 140, 1973, pp. 130-142.
8. J.B. Rauhut and T.W. Kennedy. Characterizing Fatigue Life for Asphalt Concrete Pavements. TRB, Transportation Research Record 888, 1982, pp. 47-56.
9. J.A. Epps and C.L. Monismith. Influence of Mixture Variables on the Flexural Fatigue Properties of Asphalt Concrete. Proc., Assn. of Asphalt Paving Technologists, Vol. 38, Feb. 1969.
10. J.L. Walter and R.G. Hicks. Impact of Variations in Material Properties on Asphalt Pavement Life: North Oakland-Sutherlin Project. FHWA, Interim Rept. FHWA-OR-81-4, Nov. 1981.
11. J.L. Walter and R.G. Hicks. Impact of Variations in Material Properties on Asphalt Pavement Life: Castle Rock-Cedar Creek Project. FHWA, Interim Rept. FHWA-OR-81-6, Dec. 1981.
12. J.L. Walter and R.G. Hicks. Impact of Variations in Material Properties on Asphalt Pavement Life: Warren-Scappoose Project. FHWA, Interim Rept. FHWA-OR-81-7, Dec. 1981.
13. P. Puangchit, R.G. Hicks, J.E. Wilson, and C.A. Bell. Impact of Variations in Material Properties on Asphalt Pavement Life. FHWA, Draft Final Rept. FHWA-OR-82-3, June 1982.

Discussion

Richard M. Weed

The authors are to be commended for their efforts to relate quality measures to the actual performance of flexible pavement. If relations such as these can be firmly established, this will form the most rational basis for adjusted pay factors.

Their observation that there is a great disparity among the pay schedules used by different highway agencies is also right on target. This situation can hardly inspire the confidence or cooperation of the construction industry. Clearly, there is much to be done to establish a uniform pay adjustment system that is legally and technically sound.

In my opinion, the most logical way to do this is based on the legal principle of liquidated damages. Simply put, the highway agency should be entitled to withhold sufficient payment at the time of construction to cover the cost of future repairs made necessary by defective work. A valid fatigue relation would make it possible to predict when such repairs would be required; and by computing the present worth of these costs, an appropriate pay reduction could be determined. This approach has been developed for rigid pavement in two recent papers (1,2) and could also be applied to flexible pavement.

My one disagreement with the paper concerns the manner in which pay factors are defined. By computing them directly as the ratio of as-built load-bearing capacity to design load-bearing capacity, it is implied that a pavement that has no further load-carrying capability has no value. This is analogous to saying that an automobile with four flat tires is worthless, a position that would be extremely difficult to defend.

The liquidated-damages approach, on the other hand, recognizes that a pavement with no load-carrying capability still has considerable value as the subsystem on which the next generation of overlay will be placed. Pay reductions are based only on the expense necessary to restore the serviceability of the pavement throughout its intended design life. This represents the actual damage suffered by the highway agency and is the extent to which a contractor should properly be held responsible.

REFERENCES

1. R.M. Weed. Method to Establish Pay Factors for Rigid Pavement. TRB, Transportation Research Record 885, 1982, pp. 18-24.
2. R.M. Weed. Development of Multi-Characteristic Acceptance Procedures for Rigid Pavement. TRB, Transportation Research Record 885, 1982, pp. 25-36.

Authors' Closure

Weed's comment is certainly a valid one. The pay factors developed were based on fatigue criteria and assumed that asphalt surfaces that do not meet specifications would be subject to a penalty based on the reduction in life that results when a comparison is made with specification material. If no corrective action is taken, this approach is valid. If corrective action is taken, then the cost to restore the pavement to its intended life would be an appropriate action, as Weed points out. Both alternatives can exist. The fact that the developed factors compare favorably with those used by other agencies in the Pacific Northwest would indicate that the penalties developed in our paper are not unreasonable.

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