Sensitivity Analysis of Predicted Pavement Performance

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A sensitivity analysis of a performance model is conducted. The performance model evaluated was developed from AASHO Road Test data, and it uses pavement surface roughness as the distress criterion. In order to evaluate the sensitivity of predicted pavement performance to various design factors, a factorial experiment was established assuming a three-layer model of the pavement structure. Eight different factors were considered in the development of the factorial experiment: (1) initial Present Serviceability Index (PSI), (2) asphalt concrete modulus, (3) asphalt concrete thickness, (4) granular base thickness, (5) coefficient k_1 of the base resilient modulus-bulk stress relationship, (6) exponent k_2 of the base resilient modulus-bulk stress relationship, (7) coefficient m_1 of the subgrade resilient modulus-deviatoric stress relationship, and (8) exponent m_2 of the subgrade resilient modulus-deviatoric stress relationship. Predictions of service life from the model evaluated were found to be sensitive to asphalt concrete thickness, initial *PSI*, asphalt concrete modulus, and the constants m_1 and m_2 defining the stress dependency of the resilient modulus of the subgrade soil. In addition, because of the influence of the stress dependency of unbound pavement materials, there is strong indication that optimum values for base-related variables exist for different pavement conditions. The results obtained showed the importance of a sensitivity analysis for evaluating the behavior of a performance model over a range of conditions considered to be of practical interest. The information generated from a sensitivity analysis is of value in evaluating the most effective pavement design for a given set of conditions and in developing guidelines for the proper application of a performance model.

A sensitivity analysis is an important tool for evaluating the behavior of a performance model over a range of conditions considered to be of practical interest. Such an analysis would indicate whether the model behaves realistically, and it would show the pavement design factors that significantly influence the performance predictions. Thus, a sensitivity analysis would identify pavement design factors which, for practical purposes, may require more careful laboratory characterization and/or control during field construction.

As related herein, a sensitivity analysis of a performance model was conducted to illustrate how such an analysis may be accomplished. There were two specific objectives: first, to evaluate the sensitivity of performance predictions to various pavement design factors (i.e., asphalt concrete modulus, layer thicknesses, and coefficients defining the stress dependency of the resilient modulus of unbound pavement materials), and, second, to evaluate the effects of these pavement design factors and their interactions on predicted pavement performance. The results from the analysis are certainly useful for determining the most effective pavement design for a given set of conditions.

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PERFORMANCE MODEL FOR THE SENSITIVITY ANALYSIS

The performance model selected for the sensitivity analysis was developed by Fernando et al. (*1*). The model, which predicts the trend in pavement surface roughness with a cumulative number of load applications, was developed using performance data collected from flexible pavement sections at the AASHO Road Test. The performance model is given in Table 1.

In developing the model, pavement failure was assumed to be a function of the response to vehicle loadings, and it was hypothesized that the variation in pavement performance can be explained from the corresponding variation in the theoretical structural response.

While maximum asphalt tensile strain and maximum subgrade compressive strain are the most frequently used variables for predicting pavement performance, strain basin indices, developed from an evaluation of theoretical strain basins, were also examined to evaluate their usefulness as performance-prediction variables. These quantities are analogous to such deflection basin indices as Surface Curvature Index (SCI), Base Curvature Index (BCI), or Base Damage Index (BDI), defined in Figure 1, that are used as indicators of pavement structural integrity. Strain basin indices are therefore related to theoretical strains at different locations within a pavement structure. Figure 2 presents a subgrade compressive strain basin for an 18,000-pound single-axle load.

The importance of strain basins in the evaluation of pavement performance is illustrated conceptually (Figure 3) by plotting the longitudinal distribution of subgrade compressive strains for two different pavements. If only the maximum subgrade compressive strain is considered, then the two pavements would be characterized as having the same pavement response under load. However, it is apparent from an examination of these strain basins that such is not the case. The load distribution across the subgrade for Pavement A is different from the load distribution for Pavement B. Inasmuch as pavement performance is logically related to how the pave-

TABLE 1 PERFORMANCE MODEL FOR SENSITIVITY ANALYSIS

$$\log_{10}(1 + SV) = (C_0 + C_1\log_{10}N)/(1 + C_2\log_{10}N)$$

$$C_1 = -0.035 - 0.220\ C_0 - 0.035\ \log_{10}V_3 - 0.050\ \log_{10}(1 + H_1)$$

$$C_2 = -0.354 + 1.232\ C_1 + 0.269\ \sqrt{C_0} - 31.958\ V_5 - 0.026\ \log_{10}T_2 + 0.007\ \log_{10}(1 + H_2)$$

where,

SV = slope variance

N = cumulative number of load applications

C_0 = initial pavement surface roughness $[\log_{10}(1 + SV)]_i$

H_1 = thickness of the asphalt concrete layer, inches

H_2 = thickness of the base layer, inches

$V_3 = \epsilon_{sg3} - \epsilon_{sgmax}$

$V_5 = \epsilon_{sg2} - \epsilon_{sg1}$

$T_2 = \epsilon_{acmax} - \epsilon_{ac2}$

ϵ_{sgmax} = maximum vertical compressive strain at the top of the subgrade directly underneath the tire load

ϵ_{sgi} = vertical compressive strain at the top of the subgrade located along the longitudinal direction at a distance of 'i' feet from the maximum

ϵ_{acmax} = maximum tensile strain at the bottom of the asphalt concrete layer and directly underneath the tire load

ϵ_{ac2} = tensile strain at the bottom of the asphalt concrete layer located along the longitudinal direction at a distance of 2 feet from the maximum

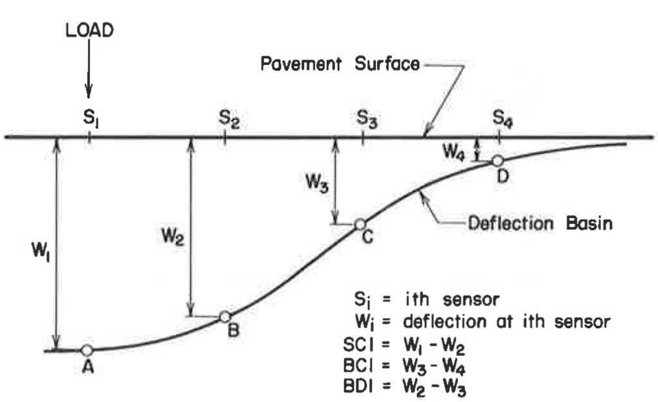

FIGURE 1 Example surface deflection basin.

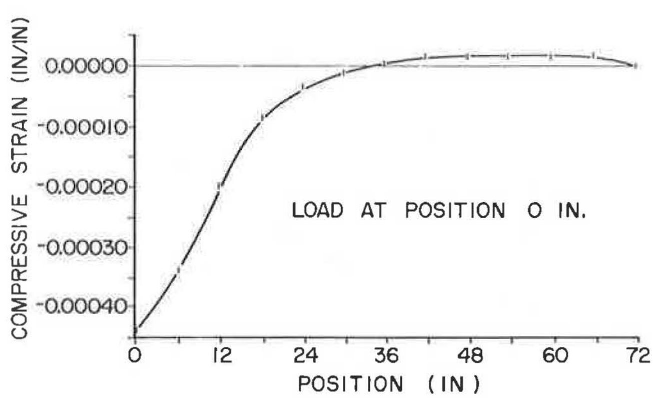

FIGURE 2 Subgrade compressive strain basin for an 18-kip single-axle load.

ment responds under load, indices developed from an evaluation of strain basins may provide a better explanation of the variation in performance for different pavement structures. A detailed discussion of the development of the performance model is presented elsewhere (*1*). It was found that a hyperbolic equation adequately modeled the observed trends in flexible pavement performance at the AASHO Road Test. In developing the model, pavement surface roughness, as quantified by slope variance (*SV*), was selected as the pavement condition indicator.

A performance model (Table 1) was evaluated by comparing observed versus predicted performance trends. When predictions from the model were plotted with the observed values for pavement roughness (Figure 4), the predictions generally compared favorably with observed roughness data as reflected by the dark region around the line of equality. The root-mean-square (RMS) statistic for the performance predictions was found to be 0.24 with 5,895 observations. A similar statistic calculated from the observed performance data for the replicate sections at the AASHO Road Test was found to equal 0.19 with 767 observations. Replicate sections were identical pavement sections constructed at the AASHO Road Test. Thus the RMS statistic for the performance model compares favorably with the RMS statistic for the replicates, which gives a measure of the pure error in observed pavement performance.

In addition, the correlation coefficient between the predicted and observed $\log_{10}(1 + SV)$ was determined to be 0.59. In contrast, the correlation coefficient for the observed $\log_{10}(1 + SV)$ between replicates was found to equal 0.44. The higher correlation coefficient obtained from the model's predictions reflects the smoothing effect of the curve fitting that was done as part of the model development. In addition, the higher coefficient further indicates that a performance model with reasonable predictive ability has been developed.

SENSITIVITY ANALYSIS OF THE PERFORMANCE MODEL

In order to evaluate the sensitivity of predicted performance from the model presented, a factorial experiment was established assuming a three-layer pavement structure (Figure 5). The following factors were considered in developing the

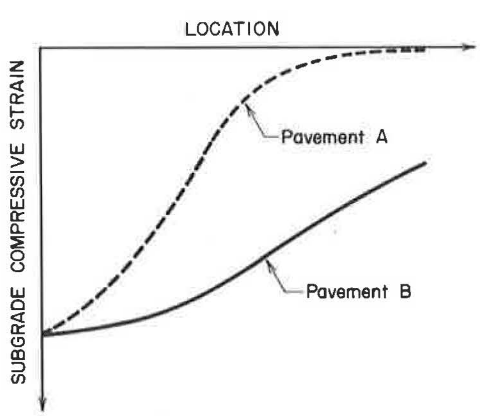

FIGURE 3 Conceptual subgrade compressive strain basins for Pavements A and B.

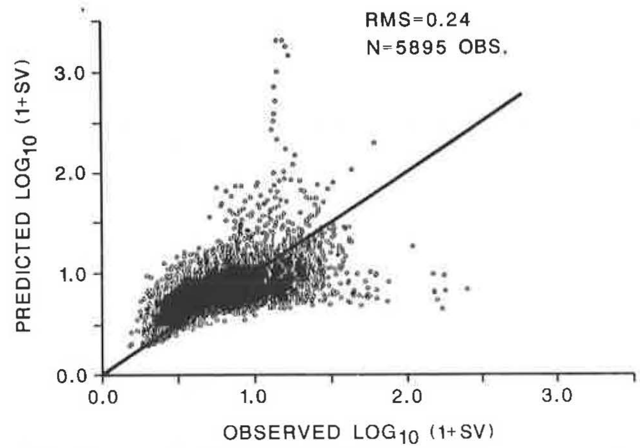

FIGURE 4 Comparison of predicted $\log_{10}(1 + SV)$ from the hyperbolic model with the observed $\log_{10}(1 + SV)$.

experiment: (1) initial Present Serviceability Index (PSI_i), (2) asphalt concrete modulus, (3) asphalt concrete thickness, (4) granular base thickness, (5) coefficient (k_1) of the base resilient modulus-bulk stress relationship, (6) exponent (k_2) of the base resilient modulus-bulk stress relationship, (7) coefficient (m_1) of the subgrade resilient modulus-deviatoric stress relationship, and (8) exponent (m_2) of the subgrade resilient modulus-deviatoric stress relationship. The factors k_1, k_2, m_1, and m_2 define the stress dependency of the resilient modulus of unbound pavement materials, as given by the following equations:

For granular materials:

$$M_r = k_1 \theta^{k_2} \quad (1)$$

For fine-grained soils:

$$m_r = m_1 \sigma_d^{m_2} \quad (2)$$

where,

M_r = resilient modulus
θ = bulk stress (sum of principal stresses: $\theta_1 + \theta_2 + \theta_3$)
θ_d = applied deviatoric stress ($\theta_1 - \theta_3$)
k_1, k_2, m_1, m_2 = experimental constants

Fixed values for the Poisson ratios of the various layers, ν_1, ν_2, and ν_3, were assumed as pavement response is not

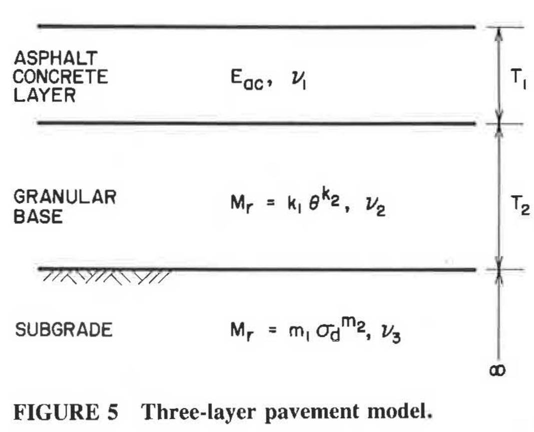

FIGURE 5 Three-layer pavement model.

sensitive to changes in this variable. Specifically, Poisson's ratios of 0.30, 0.40 and 0.45 were assumed for the asphalt concrete, granular base, and subgrade layers respectively.

Each factor included in the factorial experiment (Table 2) was varied over a wide enough range of practical applications to allow the given factor to demonstrate significant effects, if any, on predicted pavement performance. As shown, three levels were selected for each factor resulting in a 38 or 6,561 different pavement designs. Levels for the initial *PSI* were established using the following equation:

$$PSI = 4.96 - 2.01 \log_{10}(1 + SV) \quad (3)$$

$$R^2 = 0.80 \qquad N = 74 \text{ obs.}$$

where,

PSI = Present Serviceability Index
SV = slope variance

The above equation was developed from the same data set used in the development of the AASHO *PSI* equation (*2*). In determining levels for PSI_i, the values of 0.38, 0.53, and 0.68 were assumed for initial surface roughness, i.e., initial $\log_{10}(1 + SV)$.

For each pavement design represented in the factorial experiment, the allowable number of 18-kip single-axle load applications was determined. An 18-kip single-axle load is commonly used as a reference load for design purposes. A terminal serviceability index of 1.5, corresponding to a final pavement surface roughness of 1.72, was used as the failure condition for predicting the allowable number of 18-kip single-axle load applications. Multilayer linear elastic theory was used to calculate the appropriate strain basin indices for a given pavement design. An iterative application of linear elastic layer theory was conducted to get stress compatible moduli. The same pavement response analysis procedure was used in the development of the performance model presented herein.

An equation relating the predicted allowable 18-kip single-axle load applications to the different factors considered in the study was determined through multiple linear regression using the model given below:

$$N_{18} = \beta_0 + \sum_{i=1}^{8} \beta_i X_i + \sum_{i=1}^{8} \beta_{i+8}(3X_i^2 - 2) + \sum_{i=1}^{7}\sum_{j=i+1}^{8} \beta_{p(i,j)} X_i X_j + \sum_{i=1}^{7}\sum_{j=i+1}^{8} \beta_{q(i,j)}(3X_i^2 - 2) \cdot (3X_j^2 - 2) + \sum_{i=1}^{7}\sum_{j=i+1}^{8} \beta_{r(i,j)} X_i (3X_j^2 - 2) + \sum_{i=2}^{8}\sum_{j=1}^{i-1} \beta_{s(i,j)} X_i (3X_j^2 - 2) \quad (4)$$

where,

N_{18} = predicted number of allowable 18-kip single-axle load applications
β = model parameters
X_i, X_j = pavement design factors
$p(i,j) = 8 + 7.5i - 0.5i^2 + j$
$q(i,j) = 36 + 7.5i - 0.5i^2 + j$
$r(i,j) = 64 + 7.5i - 0.5i^2 + j$
$s(i,j) = 101 - 1.5i + 0.5i^2 + j$

The functions $p(i,j)$, $q(i,j)$, $r(i,j)$ and $s(i,j)$ provide the appropriate subscripts for the β's for different values of the summation indices *i* and *j*. The eight different factors of Table 2 and their two-way interactions were used as the independent variables, while the predicted logarithm (base 10) of the allow-

TABLE 2 LEVELS OF FACTORS IN SENSITIVITY ANALYSIS

Factor	Levels	Units
1. Initial present serviceability index (PSI_i)	3.6; 3.9; 4.2	-
2. Asphalt concrete modulus (E_{ac})	300,000; 450,000; 600,000	psi
3. Asphalt concrete thickness(T_1)	3; 5; 7	inches
4. Granular Base thickness (T_2)	4; 7; 10	inches
5. Granular Base k_1	3000; 6000; 9000	-
6. Granular Base k_2	0.20; 0.50; 0.80	-
7. Subgrade m_1	10,000; 20,000; 30,000	-
8. Subgrade m_2	-1.00; -0.60; -0.20	-

able 18-kip applications was used as the dependent variable. In order to evaluate the relative importance of each factor, standardized regression coefficients were determined by coding the levels of each factor in Table 2. Specifically, the low, middle, and high levels for each factor were coded as −1, 0, and +1 respectively. In addition, each main effect was decomposed into linear and quadratic components, while each interaction effect was decomposed into linear by linear, linear by quadratic, quadratic by linear, and quadratic by quadratic components. The quadratic effect is associated with the square of the level of a particular factor. In equation 4, the polynomial ($3X^2 - 2$) is used to generate orthogonal contrast coefficients for the evaluation of quadratic effects. Inasmuch as the low, middle, and high levels of a particular factor have been coded as −1, 0, and +1 respectively, orthogonal contrast coefficients of +1, −2, and +1 are obtained from the polynomial ($3X^2 - 2$). The use of orthogonal contrast coefficients in the regression analysis leads to model parameter estimates (β_i's) that do not vary as independent variables are added to or taken out of equation 4. Using the eight pavement design factors of Table 2 and their respective two-way interactions as independent variables in the regression analysis, a coefficient of determination (R^2) of 0.99 was obtained. Thus, most of the variation in the predicted allowable number of 18-kip applications was accounted for by the set of independent variables considered. In addition, approximately ninety percent of the total variation in the performance predictions was explained by the main effects. Table 3 shows standardized model parameter estimates for the linear and quadratic components of main effects. By comparing the magnitudes of the parameter estimates, the relative importance of each factor can be evaluated. It can be seen in the table that the linear effects are more important than the quadratic effects. In particular, the linear effects associated with the following factors are relatively important: (1) asphalt concrete thickness, (2) initial *PSI*, (3) asphalt concrete modulus, and (4) the coefficients m_1 and m_2 defining the stress dependency of the resilient modulus of the subgrade.

In order to illustrate the relative importance of the different factors, each was varied from the low to the high level, while the other factors were fixed at one level (low, middle, or high). The effect of each of the eight factors on predicted pavement performance appear in Figures 6, 7, and 8. The arrows in the boxes indicate whether the factor in question had a positive (pointing right) or negative (pointing left) effect on the predicted allowable number of 18-kip applications. The vertical line in each figure indicates the value for predicted performance when all variables are held at one level (low, middle, or high). By adding to this value the calculated root-mean-square for the observed performance of AASHO replicate sections, the box labeled REP has been constructed. The width of this box gives a measure of the unexplained variation in pavement performance, thereby providing a comparative value with which to evaluate the relative importance of the various pavement design factors. By comparing the widths of the boxes for the different factors with the width of the box for the replicates, the relative importance of each design factor and the sensitivity of predicted performance to a particular factor can be evaluated.

It can be observed (Figure 6) that, at the low levels, predicted pavement performance is very sensitive to asphalt thickness, asphalt concrete modulus, initial *PSI*, and the parameters m_1 and m_2 defining the stress dependency of the subgrade resilient modulus. The effect of asphalt thickness is particularly important, and it can be inferred that for pavements constructed with weak materials and on poor subgrade,

TABLE 3 STANDARDIZED REGRESSION COEFFICIENTS FOR THE LINEAR AND QUADRATIC COMPONENTS OF MAIN EFFECTS

Factor	Standardized Regression Coefficient	
	Linear Component	Quadratic Component
1. Initial PSI (PSI_i)	0.414	-0.045
2. Asphalt concrete modulus (E_{ac})	0.306	-0.009
3. Asphalt concrete thickness (T_1)	0.568	0.016
4. Granular base thickness (T_2)	0.095	0.015
5. Granular base k_1	0.055	0.004
6. Granular base k_2	0.109	0.030
7. Subgrade m_1	0.255	-0.019
8. Subgrade m_2	0.290	0.017

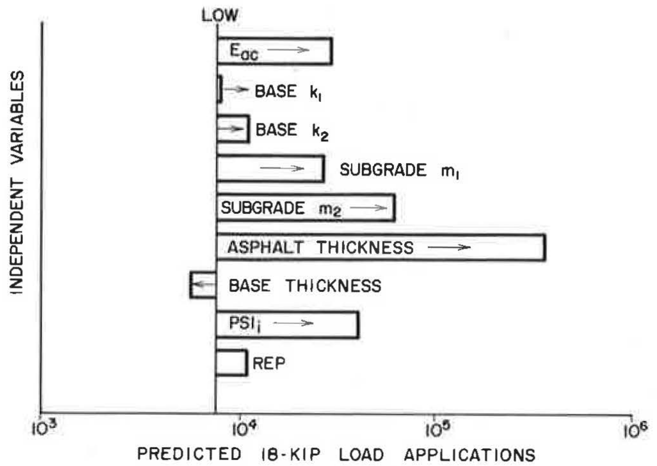

FIGURE 6 Change in applications to failure when each factor is varied from low to high levels, with all other factors at low levels.

performance can be significantly improved by increasing the asphalt thickness. It can also be observed from Figure 6 that the effects of base-related factors are relatively less important. The effect of base k_1 for the conditions considered is relatively minor, especially when viewed in relation to the unexplained variation in pavement performance indicated by the REP box. The effects of base k_2 and base thickness are relatively larger in comparison with the effect of base k_1. However, the widths of these boxes are about the same as the width of the REP box indicating that these factor effects are still less significant than those exhibited by factors associated with other pavement layers.

It is interesting to observe that for the conditions considered in Figure 6, the base thickness has a negative effect on predicted pavement performance. Increasing the base thickness from the low to the high level while keeping the other factors at their low levels led to a decrease in predicted service life. Although it can be argued that this decrease may not be significant when viewed in relation to the unexplained variation in pavement performance, it is still worthwhile to find possible reasons that would explain or justify the result obtained.

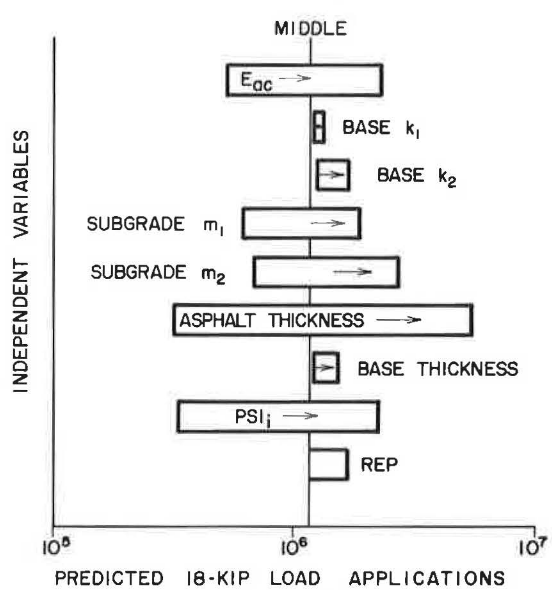

FIGURE 7 Change in applications to failure when each factor is varied from low to high levels, with all other factors at middle levels.

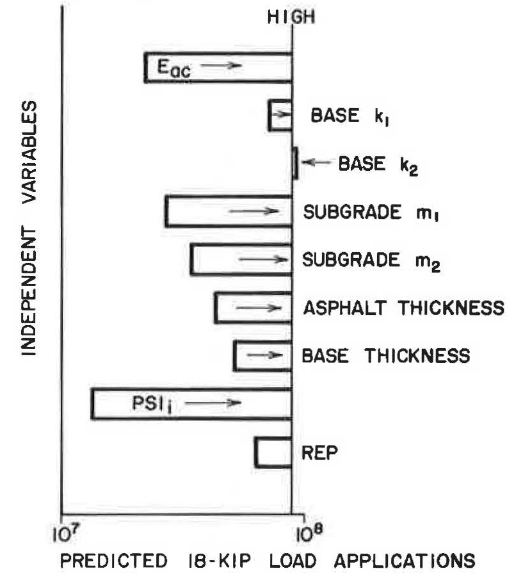

FIGURE 8 Change in applications to failure when each factor is varied from low to high levels, with all other factors at high levels.

Table 4 lists thirty-eight different effects for which the standardized regression coefficients are equal to or greater than 0.01. The effects have been ordered according to the absolute magnitudes of the regression coefficients. From the table, it can be seen that, relative to the linear component of the base thickness effect T_2, the interactions between base thickness and base k_2, and between base thickness and base k_1, are significant. These interactions have standardized regression coefficients of 0.100 and 0.055 respectively compared with a coefficient of 0.095 for the base thickness. Because low, middle, and high levels were coded as -1, 0, and $+1$ respectively, it can be seen that when the base thickness is at the high level $(+1)$, and the base k_1 and base k_2 are at the low levels (-1), each of the interactions between these variables and base thickness has a negative effect on predicted pavement performance (i.e., $0.095(+1) + 0.100(.1) + 0.055(.1) = 0.060$). However, when all of these factors are at the high levels, a positive effect results. The practical implication of this finding is that in order to obtain any benefit to increasing base thickness, the factors k_1 and k_2 also have to be increased as a consequence of the stress dependency of the base resilient modulus. Other conditions being equal, an increase in base thickness could lead to a decrease in base modulus as a result of a reduction in bulk stress within the layer. Increasing the levels of k_1 and k_2 could help counteract this negative effect of base thickness on base resilient modulus.

At the middle levels, predicted service life (Figure 7) is also very sensitive to asphalt thickness, initial *PSI*, asphalt concrete modulus, and the factors m_1 and m_2 defining the stress dependency of subgrade resilient modulus. In contrast, predicted service life is not as sensitive to the base-related factors,

TABLE 4 THIRTY-EIGHT DIFFERENT EFFECTS SORTED ACCORDING TO ABSOLUTE MAGNITUDE OF REGRESSION COEFFICIENT

Effect	Component	Standardized Regression Coefficient
1. T_1	Linear	0.568
2. PSI_i	Linear	0.414
3. E_{ac}	Linear	0.306
4. m_2	Linear	0.300
5. m_1	Linear	0.255
6. $k_2 * T_1$	Linear by Linear	-0.170
7. $m_2 * T_1$	Linear by Linear	-0.125
8. $E_{ac} * T_1$	Linear by Linear	0.118
9. k_2	Linear	0.109
10. $k_1 * k_2$	Linear by Linear	0.102
11. $k_2 * T_2$	Linear by Linear	0.100
12. T_2	Linear	0.095
13. $k_1 * T_1$	Linear by linear	-0.094
14. $T_1 * T_2$	Linear by Linear	-0.075
15. $m_1 * m_2$	Linear by Linear	0.055
16. $k_1 * T_2$	Linear by Linear	0.055
17. k_1	Linear	0.055
18. PSI_i	Quadratic	-0.045
19. $E_{ac} * k_2$	Linear by Linear	-0.042
20. $m_1 * T_1$	Linear by Linear	-0.039
21. $k_2 * m_2$	Linear by Linear	-0.033
22. k_2	Quadratic	0.030
23. $k_2 * m_1$	Linear by Linear	-0.024
24. $E_{ac} * k_1$	Linear by Linear	-0.023
25. $k_2 * T_1$	Linear by Quadratic	0.022
26. $E_{ac} * m_2$	Linear by Linear	-0.021
27. m_1	Quadratic	-0.019
28. $k_1 * m_2$	Linear by Linear	-0.018
29. m_2	Quadratic	0.017
30. T_1	Quadratic	0.016
31. $E_{ac} * T_2$	Linear by Linear	-0.016
32. $k_1 * m_1$	Linear by Linear	-0.015
33. T_2	Quadratic	0.015
34. $k_2 * T_1$	Quadratic by Linear	-0.014
35. $k_2 * T_2$	Quadratic by Linear	0.013
36. $T_1 * T_2$	Quadratic by Linear	0.012
37. $m_2 * T_1$	Linear by Quadratic	0.011
38. $m_1 * T_2$	Linear by Linear	0.011

particularly when the effects of these factors are compared with the variation in the performance of AASHO replicate sections. It is interesting to note, however, that the boxes for the base-related factors are to the right of the vertical line, indicating the value of predicted service life when all factors are at the middle levels. This implies that for the conditions considered in this figure, the middle level of each base related factor is a point where predicted service life is a minimum. The occurrence of this condition again reflects the influence of the stress dependency of unbound pavement materials. Because the base resilient modulus is stress stiffening, whereas the subgrade resilient modulus is stress softening, conditions at which predicted performance is a maximum can exist.

At the high levels, predicted service life (Figure 8) is influenced significantly by (1) initial *PSI*, (2) asphalt concrete modulus, (3) the factors m_1 and m_2 defining the stress dependency of subgrade resilient modulus, (4) asphalt concrete thickness, and (5) base thickness. The effect of initial *PSI* is particularly important, and one can infer from the results that a pavement constructed with good materials in thick layers would have a predicted service life significantly lower if the initial riding quality were poor than if it were good. One can also infer that two pavements with levels of initial surface roughness that are substantially different will yield different service lives even though the two pavements have identical layer thicknesses and material properties. The difference in service lives may be explained by the effect of pavement surface roughness on the magnitudes of axle loadings that are applied to the pavement. The base thickness effect shown in Figure 8 is also consistent with a finding made previously concerning the need for increasing the levels of the base factors k_1 and k_2 for an increase in base thickness to have a positive effect on predicted pavement performance.

EVALUATION OF THE EFFECTS OF INTERACTIONS ON PREDICTED PERFORMANCES

To further understand how predicted pavement performance is affected by the different factors considered in the sensitivity analysis, it is important to evaluate how these factors jointly affect the performance predictions. In view of the significant influence of the stress dependency of the resilient modulus of unbound pavement materials, it can be expected that predicted pavement performance will be significantly affected by some of the two-way factor interactions considered.

Figure 9 illustrates the interaction between base k_2 and asphalt concrete thickness T_1. The low, middle, and high levels of asphalt concrete thickness are represented by the circle, cross, and diamond symbols respectively. Solid lines, short dashed lines, and long dashed lines used to connect the different symbols represent conditions where pavement design factors other than base k_2 and T_1 are held at the low, middle, and high levels respectively. It can be observed that predicted pavement performance is significantly affected by asphalt concrete thickness. For any given level of base k_2, a thicker asphalt generally leads to a longer predicted service life. The effect of base k_2 is not very noticeable at the low levels of pavement design factors other than base k_2 and T_1. This is evident from the flatness of the solid lines. For these conditions therefore, it can be inferred that increasing the asphalt concrete thickness is the best alternative to improving the predicted pavement performance. At the middle and high levels, however, increasing base k_2 does have a positive effect on predicted performance. In particular, the effect of improving base k_2 is most significant at the low level of asphalt concrete thickness. At the high level of this particular variable, base k_2 has little effect on predicted performance. These observations again reflect the influence of the stress dependency of the resilient modulus of unbound pavement materials. At the high level of T_1, the bulk stress within the base layer would be relatively lower than that corresponding to the low level of T_1. In particular, it is possible that the bulk stress may not be sufficient to mobilize the base stiffness. Consequently, for pavements with thick asphalt layers, improving base k_2 may not bring any significant beneficial effect on predicted pavement performance.

Figure 10 illustrates the interaction between subgrade m_2 and asphalt concrete thickness. As may be expected, increasing the values of these two variables generally leads to improvements in predicted performance. This may be explained

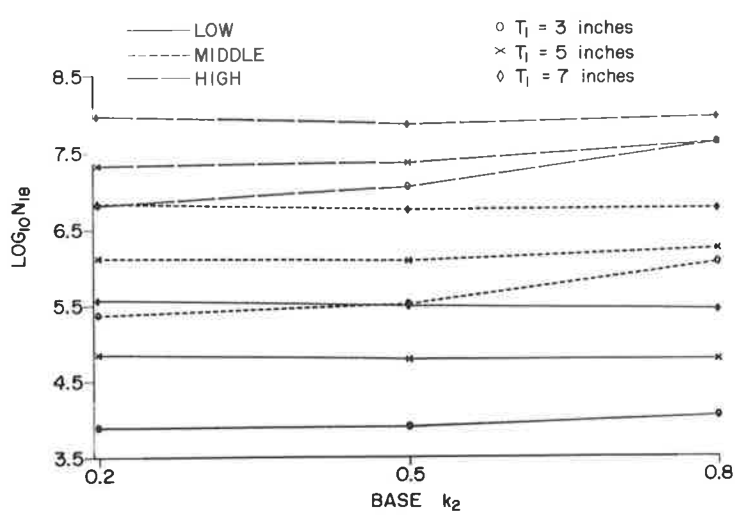

FIGURE 9 Effect of base k_2 on predicted service life for different levels of asphalt concrete thickness T_1.

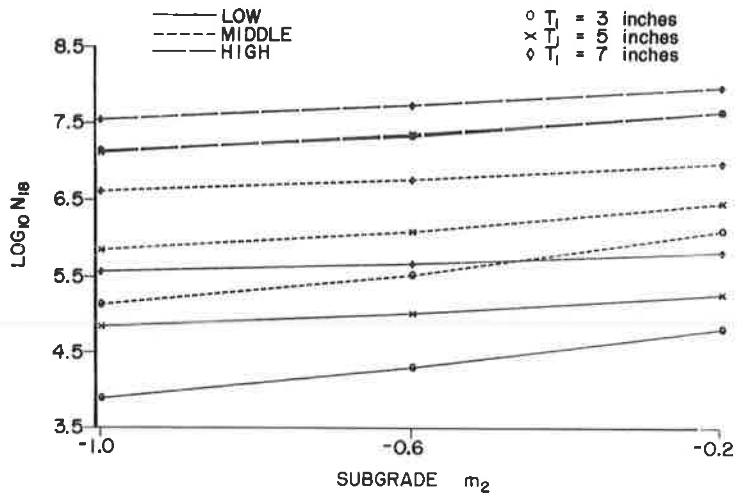

FIGURE 10 Effect of subgrade m_2 on predicted service life for different levels of asphalt concrete thickness T_1.

by considering that, for subgrade soils, the resilient modulus varies inversely with the deviatoric stress within the layer. Consequently, constructing a thicker asphalt surface would tend to have a beneficial effect on subgrade resilient modulus by lowering the deviatoric stress. Similarly, improving the quality of the subgrade soil by increasing the value of m_2 would have a positive effect on subgrade resilient modulus, and consequently on pavement performance.

It is interesting to note however that the effect on performance of increasing subgrade m_2 is most significant at the low level of asphalt concrete thickness. It may be observed that when factors other than subgrade m_2 and T_1 are held at the low and middle levels, the lines corresponding to a 3-inch asphalt concrete thickness are relatively steeper than the lines for the other levels of this particular variable. In addition, at the high levels, there are no significant differences between the performance predictions for 3- and 5-inch thick asphalt layers. These observations again reflect the influence of the stress dependency of the base resilient modulus.

Insofar as the interaction between asphalt concrete modulus and asphalt concrete thickness is concerned (Figure 11), it is observed that predicted service life increases with increasing asphalt modulus and asphalt thickness. The beneficial effect of asphalt thickness on pavement performance is most significant when factors other than E_{ac} and T_1 are held at the low levels. This is apparent from observing that the solid line for a 7-inch thick asphalt layer overlaps short dashed lines representing predictions when factors other than E_{ac} and T_1 are held at the middle levels. At the high levels, the effect of increasing asphalt concrete thickness is not as significant as it is at the low and middle levels. Thus for pavements constructed with good base and subgrade layers, and with high values of initial *PSI*, one can infer that increasing asphalt concrete thickness would not yield as much benefit in percentage of improvement in predicted service life as it would for pavements with weak base and subgrade layers.

FINDINGS

This paper has presented the results of a research effort to evaluate the sensitivity of predicted pavement performance.

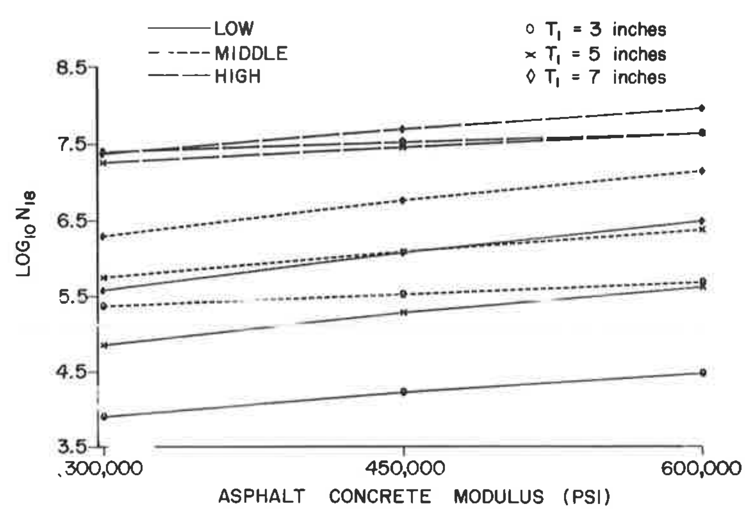

FIGURE 11 Effect of asphalt concrete modulus on predicted service life for different levels of asphalt concrete thickness T_1.

Based on the results of the research conducted, the following findings are noted:

1. Predictions of service life from the model evaluated were found to be sensitive to asphalt concrete thickness, initial *PSI*, asphalt concrete modulus, and the coefficients m_1 and m_2 defining the stress dependency of the resilient modulus of the subgrade soil. The effect of initial surface roughness on predicted service life is significant. Because the damaging effects of axle loads are logically influenced by the roughness of the pavement, it is conceivable for two pavements having identical layer thicknesses and material properties to yield different service lives if the levels of initial surface roughness were substantially different.
2. In general, if other factors are held constant, predicted service life improves with increases in the levels of the following factors: (a) asphalt concrete thickness, (b) initial *PSI*, (c) asphalt concrete modulus, (d) subgrade m_1, and (e) subgrade m_2. However, the amount of improvement in predicted service life is dependent on the levels at which the other factors are held constant.
3. In general, the effects of base-related variables (i.e., base thickness, base k_1, and base k_2) depend on the levels of the other pavement design factors considered. However, the effects of base-related variables are relatively small compared with the effects of the other design factors and to the unexplained variation in pavement performance.
4. Because of the influence of the stress dependency of unbound pavement materials, there is strong indication that optimum values for base-related variables exist for different pavement conditions.

CONCLUSIONS

The following conclusions are drawn from the information presented:

1. When designing pavements using the performance model evaluated, the consideration of the stress sensitivity of unbound pavement materials is important.
2. A sensitivity analysis is an important tool for evaluating the behavior or a performance model over a range of conditions considered to be of practical interest. In the application of the performance model presented herein, it is important to use the model consistent with the results of the sensitivity analysis conducted. This analysis identified pavement design factors that significantly influence the performance predictions.

It was found, for example, that the effects of base-related variables are small, especially when compared with an estimate of the unexplained variation in pavement performance. Whether this is reflected in pavement performance data for conditions other than those found at the AASHO Road Test is still subject to verification. However, as long as the performance model is to be used in its current form for pavement design, the model application must still be consistent with the model behavior. Very tight specifications for base course materials, for example, would not be warranted.

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