Prediction of Flexible Pavement Performance from Deflection Measurements

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- This paper deals primarily with the fifth Road Test objective: "To develop instrumentation, test procedures . . . and formulas which will reflect the capabilities of the various test sections and which will be helpful in future highway design and in the evaluation of the load carrying capabilities of existing highways. . . ." An attempt was made to develop correlation equations whereby a flexible pavement could be tested at a given point in time and its future performance or capability predicted.

Early in the planning stages of the Road Test, it was reasoned that the curvature or bend in an asphaltic concrete surfacing under moving wheel loads might be highly correlated with pavement performance. Considerable effort was expended in the development of instrumentation to measure directly curvature under dynamic loading. Over 100 so-called curvature strips or gages were installed in the surfacing of selected sections of pavement. It was found that the output of these gages was erratic. They failed to reveal any well-defined effect of the magnitude of the applied load or of its position on the pavement with respect to the location of the gages. As a result attempts to obtain information from them were ultimately discontinued. However, further studies along these lines with improved instrumentation might well be worthwhile.

Far more encouraging results were obtained in studies in which deflection under moving load was used as the predictor of pavement performance. There was ample reason to believe this would be so, because work at the WASHO Road Test indicated high correlation between dynamic deflections and pavement performance. Similar findings have been reported by Hveem of California, Helmer of Oklahoma, Campbell of the Canadian Good Roads Association, and others.

The deflections used in the Road Test analyses were measured with the Benkelman beam with the outside wheels of the test vehicle positioned about 3 ft from the pavement edge. Average values from tests in both wheelpaths were used.

The basic premise was that the deflection of a given pavement under a particular load would serve as a better measure of that pavement's ability to survive many applications of the load than knowledge of its structural design alone; *i.e.*, the magnitude of the deflection may be expected to reflect the strength of the embankment soil and the strength of the surfacing, base, and subbase as they were actually constructed, regardless of how they may have been specified. After several alternatives were considered, a mathematical model was found from which the life of a pavement to a given level of serviceability could be estimated satisfactorily provided both load and deflection were included in the function. The model was of the form

$$W_p = \frac{A_0 L_1^{A_1}}{d^{A_2}} \qquad (1)$$

in which

W_p = applications of axle load L_1 to serviceability level p;
L_1 = single-axle load, in kips; and
d = deflection under wheel load = $L_1/2$.

The constant terms, A_0, A_1 and A_2, were determined by regression analysis. To perform the analysis by linear regression techniques, logarithms of both sides of the equation were taken:

$$\log W_p = A_0 + A_1 \log L_1 - A_2 \log d \qquad (2)$$

The data for this analysis consisted of simultaneous sets of values for W_p, L_1 and d.

Two independent studies were made. In the first, data were used that had been obtained from deflections measured in the fall of 1958 immediately after construction and before the start of test traffic. Data for the second study were obtained from deflections measured in the spring of 1959 during the so-called critical spring period. The axle loads used in all of these deflection tests were those normally assigned to the single-axle lane of the loop involved. The performance or life data for these relationships in most cases were observed values of W at the level of p specified. In cases where the serviceability of the section remained above the specified level, estimates for W were obtained from the performance equations shown in Road Test Report 5.

The two separate studies were made for the following reasons. Many pavements are constructed in the summer and are opened to traffic in the fall, particularly in northern areas. The spring deflection tests were made during the critical period because it is the time when the highest deflections are found and the greatest range in deflections between thin and thick pavements is noted. Furthermore, if some weakness inherent in the base or embankment soil is going to cause trouble it is most likely to show up during the spring period.

Inasmuch as loads were confounded with design (that is, the lighter loads operated over pavements in loops with thinner designs) and since only one load was used for the determination of deflection in each loop, there was no way of knowing at the outset whether or not a design-load interaction was present. Consequently, two separate rationales were used in the analysis of each set of data.

In the first, log W was regressed on log d one loop at a time; then the coefficients for log d for the individual loops were averaged, and an adjusted loop mean for log W was determined for each loop. These adjusted means were then regressed on log L_1 to obtain a coefficient for log L_1 and the constant term A_0.

In the second analysis, the coefficients A_0, A_1 and A_2 were all determined in one step by multiple regression techniques. There were very small differences between the two sets of coefficients obtained from the two analyses. This served to indicate that significant design-load interactions were not present. Therefore, the multiple regression analysis in which all coefficients were obtained in one step was chosen as the more appropriate analysis of the two.

The analyses were made for terminal serviceabilities of 2.5 and 1.5, *i.e.*, data were analyzed for log $W_{2.5}$ and log $W_{1.5}$ matched with appropriate L_1's and d's. In Eqs. 3 through 6, d_f refers to fall deflections and d_s to spring deflections.

Fall

$$\log W_{2.5} = 7.98 + 1.72 \log L_1 - 3.07 \log d_f \tag{3}$$

$$\log W_{1.5} = 8.48 + 1.76 \log L_1 - 3.32 \log d_f \tag{4}$$

Spring

$$\log W_{2.5} = 9.40 + 1.32 \log L_1 - 3.25 \log d_s \tag{5}$$

$$\log W_{1.5} = 10.18 + 1.36 \log L_1 - 3.64 \log d_s \tag{6}$$

TABLE 1

CORRELATION INDEXES AND MEAN RESIDUALS FROM PERFORMANCE DEFLECTION EQUATIONS

p	Fall		Spring	
	C^2	F	C^2	F
2.5	0.47	0.33	0.78	0.21
1.5	0.39	0.34	0.66	0.24

The success with which these equations accomplished the objective of relating performance to deflection and load is given in Table 1. Here the terminal serviceabilities, 2.5 and 1.5 are given on the left, and correlation indexes C^2 and mean log residuals r are given for the fall and spring deflection equations. If the correlation were perfect C^2 would equal 1.0 and the mean residuals r would be 0. It is clear that the spring deflections correlate much more highly than the fall values with ultimate pavement performance. Furthermore, the residuals or errors in prediction from the spring equations are only about two thirds of those from the fall equations. Although it is true that the spring deflections are more effective than the fall deflections, this is not to say that the fall deflection relationships are meaningless. A correlation of 0.47 or 0.39 shows an unquestionably significant relationship, and the average residuals, although higher than those from the spring equations, are small even when compared with the residuals from laboratory controlled fatigue tests on supposedly homogeneous steel specimens. Therefore, it is concluded that deflection measurements made in the fall or in the spring are highly useful in the prediction of ultimate pavement performance.

In Road Test Report 5 curves computed from these equations are shown for each loop and each load along with the observations from which the equations were derived. By way of example, Figures 1 and 2 show the curves for the spring deflection versus log $W_{2.5}$ for the two

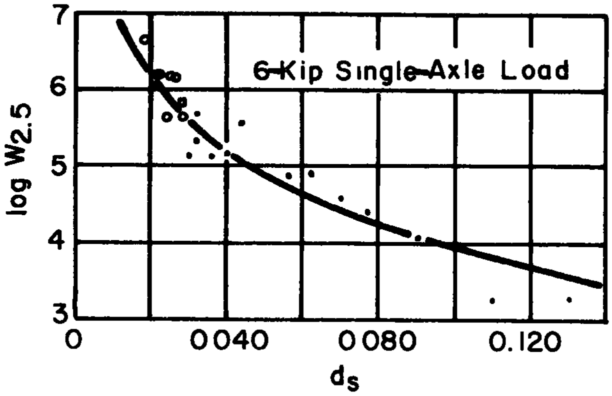

Figure 1. Example of fit of equations to data in Loop 2.

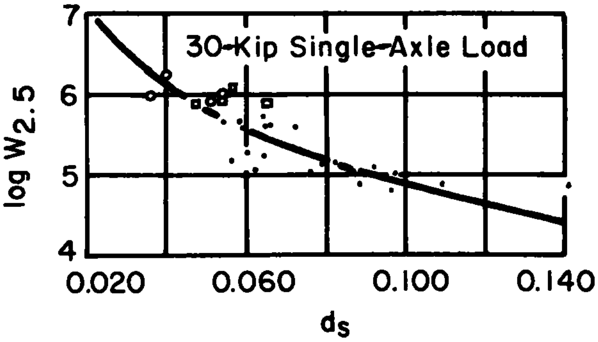

Figure 2. Example of fit of equations to data in Loop 6.

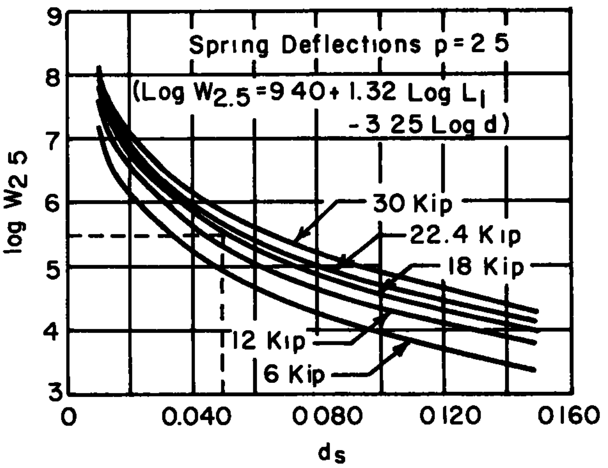

Figure 3. Plot of equations for all single-axle loads.

extremes of load used in this study, 6-kip single-axle load and 30-kip single-axle load. The points on these illustrations are observed data except where open circles are shown. The open circles are computed values from the performance equations since in these cases the final serviceability was greater than 2.5. The curves through the data are both drawn from Eq. 5. Similar curves for the fall deflection equations show much the same picture; however, the scatter of data points away from the curve is somewhat greater as would be indicated by the correlation index and residual values in Table 1.

Figure 3 shows curves computed from the spring deflection equation to $p = 2.5$ (without the supporting data) for all loads studied. The dashed lines show an example of possible use of such a family of curves. The deflection during the spring period in a particular pavement was measured to be 0.050 in. This value has been extended up to the 18-kip single-axle load curve. Reading from its intersection with the 18-kip curve, log $W_{2.5} = 5.5$. Taking the antilog it is shown that this particular section of highway whose deflection under an 18-kip load was 0.050 in. would survive 316,000 18-kip axle loads before its serviceability fell to 2.5. If the average residual (Table 1) is considered (in this case 0.21 in log W), the range in expected life encompassed by ±1 mean residual would be from about 200,000 to 500,000 applications.

It was demonstrated at the AASHO Road Test that performance in terms of applications to a given serviceability level may be predicted with satisfactory precision from measurements of deflection made in the fall on newly completed pavements or during the critical spring period provided that the nominal axle load that is going to use the pavement is known.