What an Overlay Design Procedure Should Encompass

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•A COMPREHENSIVE EXAMINATION of what an overlay design procedure should encompass is not possibile because of the lack of knowledge in this area. Therefore, the scope of this paper is restricted to a conceptual examination of what an overlay design procedure should encompass, and a consideration of the present procedures of overlay design.

CONCEPTUAL DISCUSSION OF DESIGN

A crude attempt to portray the problems that must be faced in an overlay design procedure is shown in Figure 1. First, the truck represents the mechanical stress and strain caused by wheel loads and complicated by the dual tandem-axle configuration and repetitive loads by various trucks. Furthermore, there are the environmental factors, represented by the rain and the sun, that result in thermal changes in the material as well as in certain chemical reactions. To complicate the problem even further, the supporting materials of the pavement, represented by the nonuniform materials of the subgrade and the various layers of the pavement structure, must be characterized and evaluated. Another complicating factor is the existing pavement structure. To be economically feasible, the procedure must consider the load-carrying capacity of existing pavement and the effects that this may have on the overlay layer.

A systematic approach to general pavement design is shown in Figure 2, but the concepts are also fully applicable to an overlay design procedure. Performance variables are shown in the upper portion of the figure. The inputs of load, environmental, constructional, and maintenance variables at the left in Figure 2 result in the system outputs of deflection, stress, and strain that lead to the distress manifestations of rupture, distortion, and disintegration. These are combined to give a wear-out parameter for the system.

The decision criteria—safety, economics, reliability, riding quality, and maintainability—are the factors used in applying a weighting function to determine whether or not the distress parameters in a pavement have progressed to a point at which the pavement is considered to be a failure. These factors are considered by most engineers in judging the performance of pavement, but at the present time there are no quantitative functions available that account for all of the parameters and their relative interdependence.

The failure parameters may be examined more closely in Figure 3. Rupture, distortion, and disintegration are expressed in terms of time with each one increasing by some given amount. Ideally, the methods used to design a pavement should encompass all three parameters to prevent failures. From a realistic standpoint, however, the present pavement research and pavement design have progressed only to a point at which the rupture mode of failure can be quantitatively examined.

The two factors of distortion and disintegration represented at the bottom of Figure 3 are not well defined even though much work is currently being conducted in areas such as soil suction. At the present time, these two distress manifestations are guarded against by specification requirements. Unfortunately, this type of approach does not

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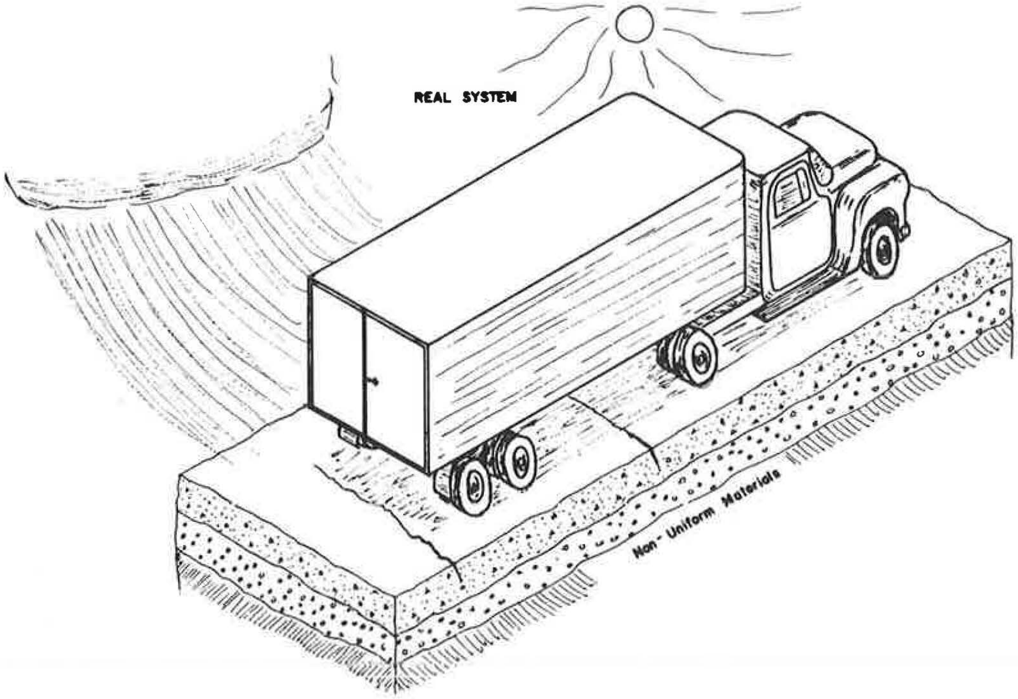

Figure 1. Problems faced in an overlay design procedure.

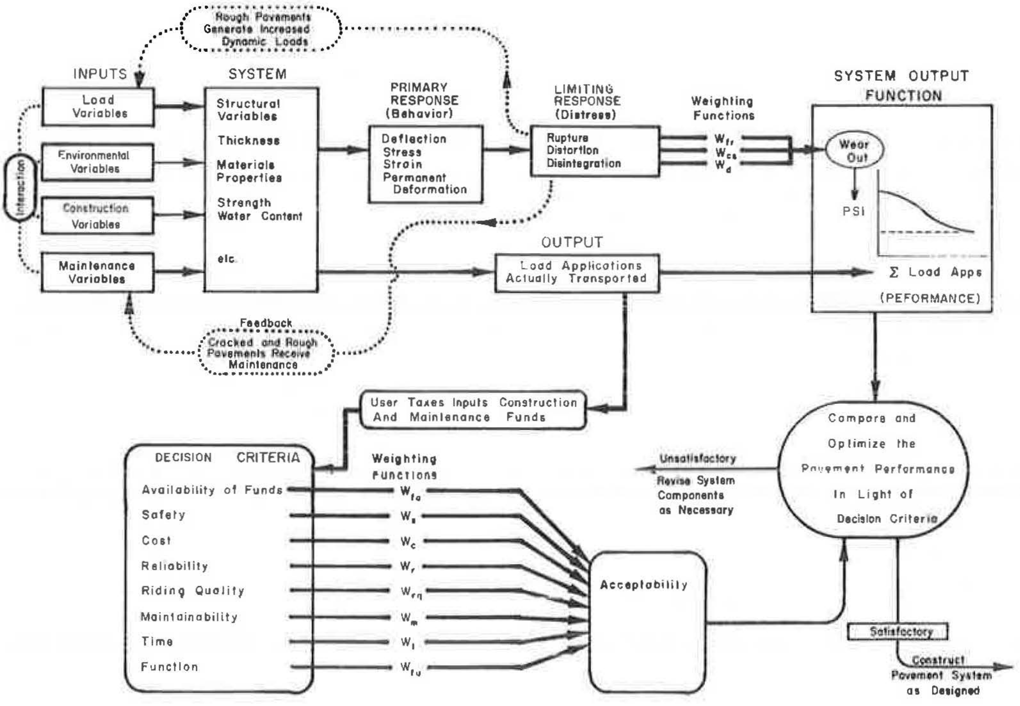

Figure 2. Pavement design system.

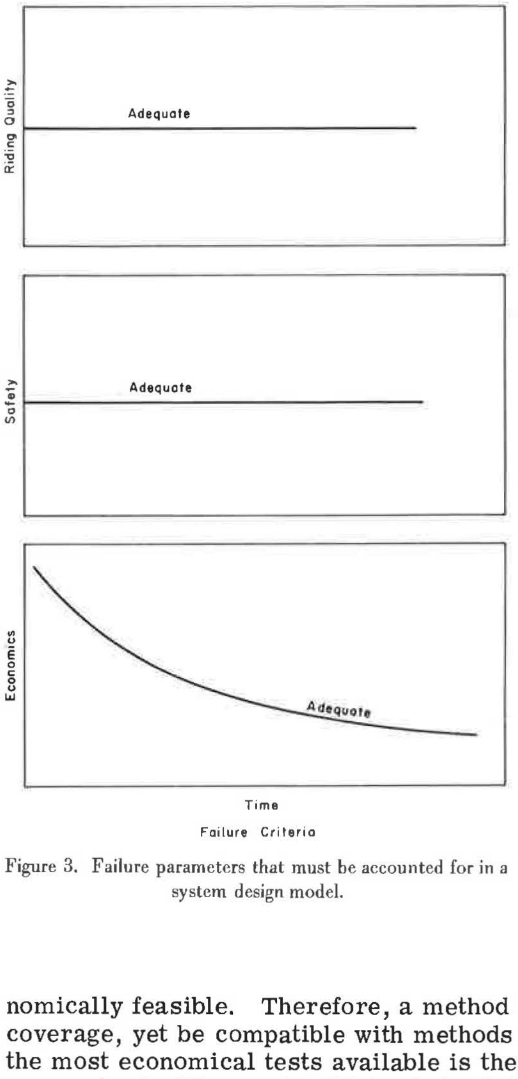

Figure 3. Failure parameters that must be accounted for in a system design model.

take into account the interaction of the various parameters. In the future, considerable amount of research will be required to investigate these latter parameters, i.e., distortion and disintegration.

To prevent the rupture-distress manifestation, the designer must be able to predict the stress and strain in the total pavement structure and be able to judge this stress and strain in terms of the limiting factors or strength of the materials. Although a considerable discussion may be developed as to which is the best theory for characterizing materials, the only practicable approach at the present time is to assume that the material is linear-elastic and to develop the elastic constants in the most appropriate manner (Fig. 4). For example, the upper layer may be most appropriately described by a nonlinear-elastic approach, but the solution of boundary value problems has not been developed to the point where this type of characterization can be used practically.

The question of what test to use in characterizing these materials as linear-elastic is subject to discussion. Two possible approaches are to use (a) the resilient modulus test developed at the University of California, or (b) the complex modulus concept being pursued at Ohio State University. One problem with these types of tests is that they are expensive to perform, and, thus, to get a good statistical sampling of the properties along an existing facility, the design cost soon expands beyond that economically feasible. Therefore, a method is required that will give better statistical coverage, yet be compatible with methods for predicting the stress and strain. One of the most economical tests available is the surface deflection test, with which good coverage of a facility can be obtained at relatively minor expenditure.

Figures 5 and 6 may be used to clarify the statement that deflection is a means to an end and not the end itself. In essence, these figures show that deflection alone will not tell the complete story, and that an estimate of the stress and strain in the existing pavement structure is required.

Figure 5 shows the percentage of reduction in deflection for a given increase in pavement thickness. The two lines are curves computed by using an elastic-layered theory. For this particular case, an existing pavement with a 2-in. surface thickness was overlayed with various thicknesses of asphalt concrete, and the resulting deflections were computed by layered theory. These deflections were then compared with those originally computed for the facility to attain a percentage of reduction. One line is for a base thickness of 6 in. with a resilient modulus of 30,000 psi, and the other line is for a base thickness of 12 in. with a resilient modulus of 15,000 psi. The line for the 6-in. subbase is very close to the curve for an existing design method, but it differs considerably from the other line. For a 40 percent deflection reduction, if the layered theory is applied,

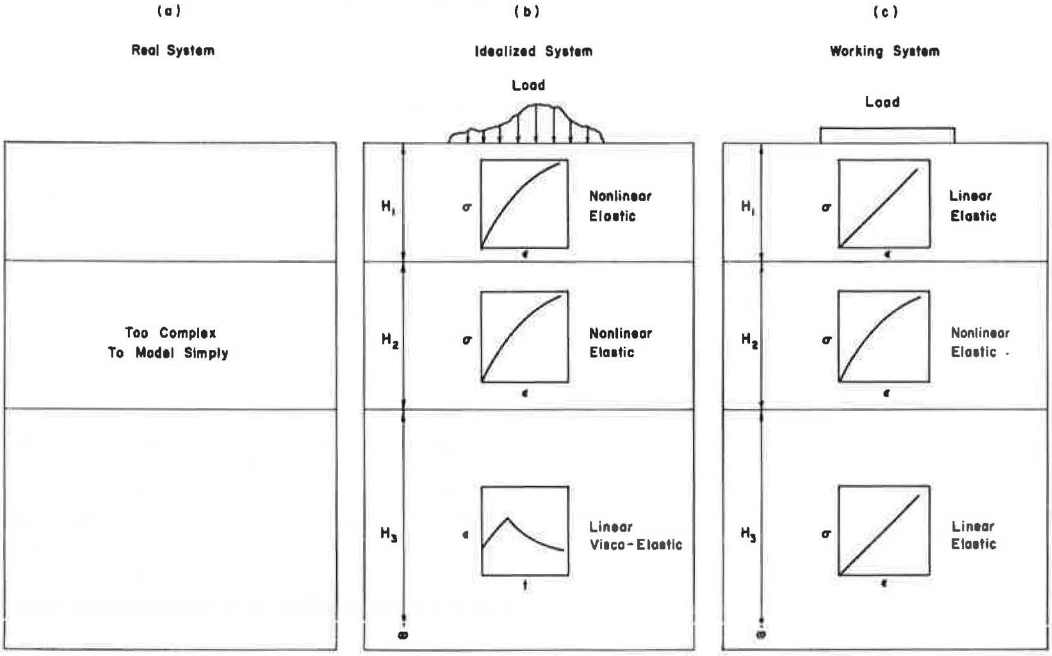

Figure 4. Characterization of a system using engineering judgment and currently available models to estimate the stress and strain in a pavement structure.

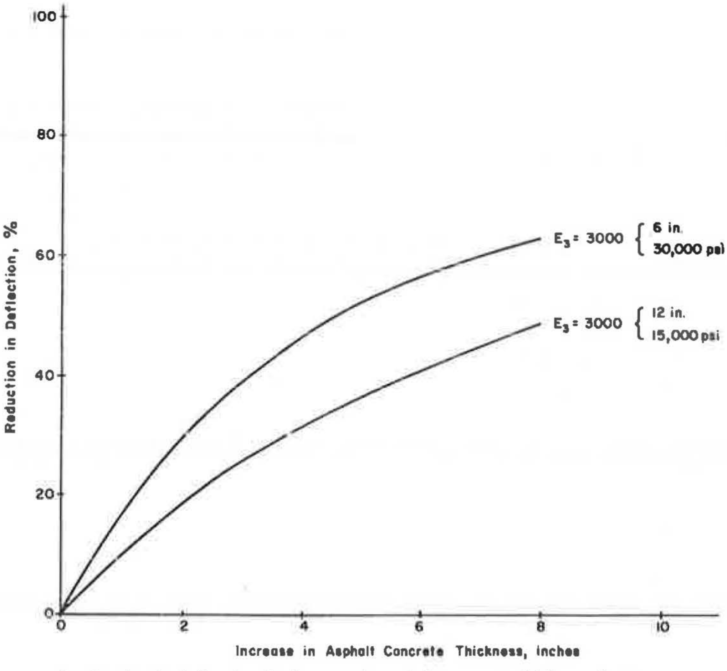

Figure 5. Computed reduction in deflection for increase in asphalt concrete thickness for two pavement structures.

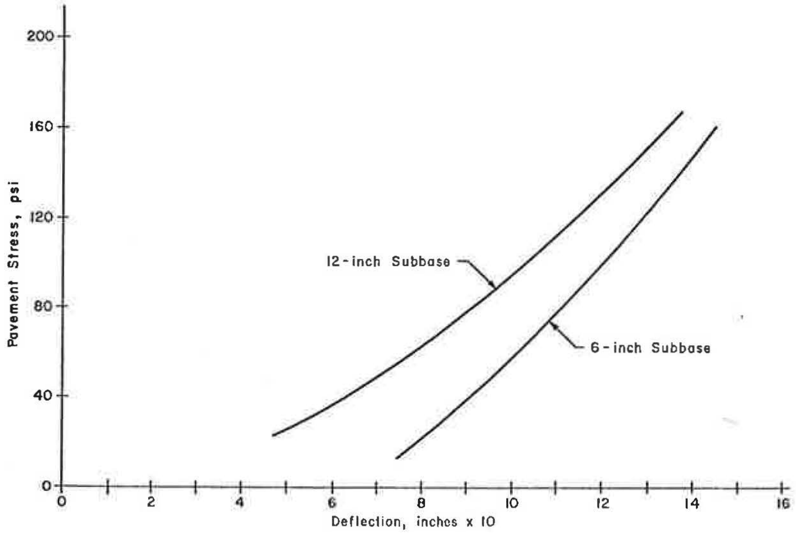

Figure 6. Computed pavement stress in terms of deflection for two pavement structures with different subbase thicknesses.

3 in. of asphalt concrete are adequate for the pavement structure represented by one line, whereas 6 in. are required for the pavement structure represented by the other line. This is a difference of 3 in. Therefore, if one of these two lines represents the design curve, the design could be as much as 3 in. in error under certain conditions. This, of course, indicates that an overlay design procedure requires more finesse than a design curve.

Figure 6 shows the possible sources of error in using an all-encompassing maximum deflection. In this graph of a stress-deflection relationship for different pavement structures, the design pavement used is a 6-in. concrete pavement over a poor subgrade; the only variables are the thicknesses of subbases. Each curve was developed by varying the elastic modulus of the subbase from that of a granular material to one simulating a cement-stabilized granular material.

There is a considerable difference in the positions of the two curves. Recalling that this much difference is developed for pavements with equal surface thickness and subgrade modulus, one can easily envision the difficulties in establishing an all-encompassing maximum deflection. If a maximum allowable deflection for a 6-in. pavement is established as 0.010 in., then it is evident from Figure 6 that the stress levels of the two pavements are considerably different. For example, the pavement with the 6-in. base would have a stress of approximately 60 psi compared to the stress of approximately 100 psi in the pavement with the 12-in. base. Therefore, it is possible to conclude that an acceptable deflection for one pavement structure, from the standpoint of stress, may be unacceptable for another.

This discussion of Figures 5 and 6 may lead to the question of the purpose for measuring deflections. This, of course, is not the intention because deflection represents the best method for obtaining an integrated measure of the load-carrying capacity of the in-place pavement structure. The measurement of the deflections in the field makes it possible to determine the actual load-carrying capacity without the use of a computer. If the measured deflection can be simulated by theory, then a fairly good indicator of the true stress and strain in the pavement structure may be obtained. Thus, the effect of adding layers of material to increase the load-carrying capacity of the facility may be evaluated. The stress and strain at every point in the structure, as well as on the surface, are obtained. Therefore, the weak areas of the pavement structure may be ascertained for design purposes.

Four broad areas of data required to obtain a rational pavement design procedure previously discussed are as follows: statistical deflection parameter, samples for material properties, estimate of traffic, and temperature changes. The first requirement is a good measure of statistical deflection for a given section of roadway in which conditions are relatively uniform. This measure of statistical deflection is greater than an average value for the reasons discussed in another paper (1). The second set of parameters are measurements of material properties at random locations along a project. Also required are estimates of traffic and temperature changes. These data supply the initial input for the program and give a starting point from which to work.

PRESENT UTILIZATION OF OVERLAY DESIGN

Figure 7 shows a cross section of a typical pavement structure and the parameters required for making the stress computations. The thicknesses and the modulus of elasticity of each layer are required, as is the wheel load for the equipment used in the deflection measurements. With these properties, the deflections can be computed and may then be compared with the measured deflections. If the properties are varied slightly, the deflections can be recomputed; this process can be reiterated until the computed and measured deflections are compatible. At this point, the properties used in the deflection computation are truly representative of the materials in the pavement structures. This method can then be expanded into areas in which properties were not measured simply by using the deflection measurements and engineering judgment. The use of this process makes it possible to expand a few measured material properties, which are expensive to obtain, into a wide sampling of the pavement structure; this would be economically unfeasible without such a process. It is now possible to investigate the effect of adding thicknesses of material in terms of the existing facilities and the loading conditions expected in the future.

Another factor that must be considered in the design procedure in order to prevent the rupture mode of failure is the fatigue aspect. Figure 8 shows a typical fatigue curve, which is representative of most materials. The curve shows that the allowable stress in a material decreases as the number of applications increases. For example, assume that the criterion of design is X applications of a given wheel load. First, a given thickness of overlay would be added to the existing facility. Then, through the use of layered theory, the stress level in the pavement structure, represented by σ_1 would be projected across to the fatigue curve and downward to determine the allowable number of applications of this load. If there were less than the required number of applications, the procedure would have to be reiterated by adding the thickness of asphalt concrete and computing the stress level. This might be represented by σ_2 on the curve. The allowable number of applications of this load represented by N_2 is obtained by projecting the new stress level across to the fatique curve. If this value is greater than X, then an acceptable design is achieved.

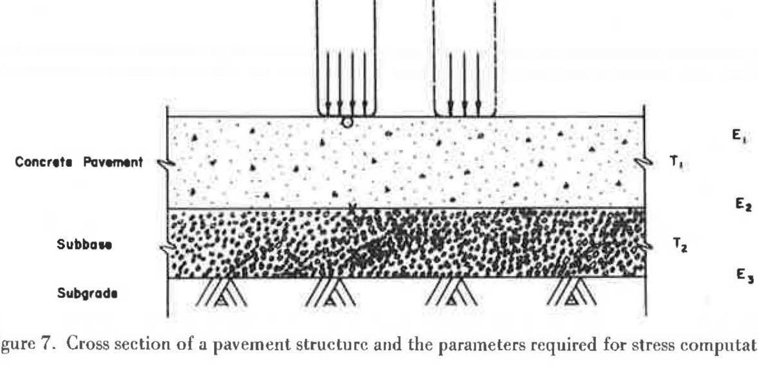

Figure 7. Cross section of a pavement structure and the parameters required for stress computations.

This is, of course, a simplified presentation of the procedure, but basically it illustrates the concept involved. In reality, there would be a number of load magnitudes that would give a certain fatigue effect. This could be handled as previously indicated, with the addition of a cumulative damage law required to combine the effect of the various applications of the fatigue life of the pavement structure. Minor's hypothesis or any one of a number of others that would be most representative of the material being investigated could be used by the highway designer.

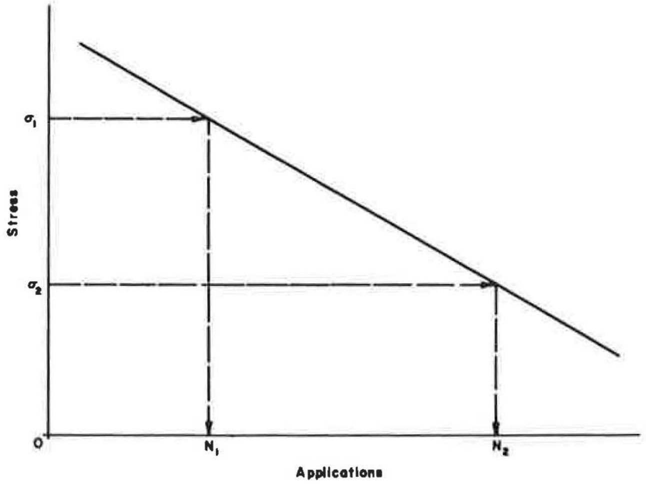

Figure 8. Typical fatigue curve for materials.

Other factors that must be considered in the design to prevent a rupture mode of failure are the thermal stresses induced into the material. These may be internal stresses developed by volume change or they may be thermal stresses induced into the overlay material by an underlying material. For example, a jointed concrete pavement will still fluctuate during the temperature changes. These fluctuations will result in thermal forces being induced into the overlay material. This is manifested many times by a reflection cracking over the joint. Several methods for handling this type of phenomenon have been developed, and the design procedure should include such a method to account for this factor.

RECOMMENDATIONS

The following recommendations are made:

1. A comprehensive overlay design procedure accounting for the interaction of all modes of failure is not feasible at the present time. This fact, however, is not justification for rule-of-thumb procedures, because the present design procedure is such that methods can be utilized to help prevent the rupture mode of failure. Thus, agencies should work toward developing a systematic approach to overlay design.
2. At the present time, the disintegration and distortion modes of failure must be controlled by independent specifications and design procedures. This fact emphasizes the need for future research regarding these factors.
3. Deflection is an excellent measure of load-carrying capacity of an existing facility, and its use is recommended in evaluating the mechanical stress and strain of a pavement structure.

REFERENCE

1. McCullough, B. F. Overlay Design: What Are the States Presently Doing? Paper presented at the 48th Annual Meeting and included in this Record.