

CONCEPTS FOR RIGID PAVEMENT OVERLAY DESIGN

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SUMMARY

The overlay design concepts presented in this paper were developed by Austin Research Engineers Inc under FCP Research Project 5D, Structural Rehabilitation of Pavement Systems, sponsored by the Federal Highway Administration. An actual working design procedure has been developed from these concepts and is being packaged into a computer program with a user's manual.

Efforts were made to use and improve the most up to date concepts and theories available for rigid pavement overlay design in developing a universal design procedure for implementation. Work done by McCullough (Ref 1) and McComb (Ref 2) provided useful information on review of existing overlay design concepts. The new procedure developed accounts for rehabilitation of existing Portland cement concrete pavements by overlaying with either Portland cement concrete or asphaltic concrete.

Three basic steps are required: 1) evaluation of the existing pavement, 2) determination of design inputs, and 3) overlay thickness analysis. These are illustrated in flow chart form in Figure 1. Evaluation of the existing pavement is accomplished by a condition survey and deflection measurements. This information enables the designer to distinguish between different segments of the existing pavement based on their condition. Each segment becomes a "design section" and is analyzed separately. Thus, the most economical rehabilitation is accomplished by varying overlay thickness along the roadway according to the existing pavement condition. This same concept has been applied to design of overlays for flexible pavements (Ref 3) and airfield pavements (Ref 4, 5).

Determination of the design inputs includes both past and projected future traffic, environmental considerations, and materials testing and analysis. Results of the deflection measurements also serve as an aid in establishing properties of the subgrade material.

The overlay thickness analysis is based on the concepts of failure by fatigue cracking and reflection cracking. Stresses in the pavement are computed using elastic layered theory (Ref 6). The fatigue life is determined by entering these stresses into a fatigue equation that relates stress magnitude and stress repetitions to failure. Reflection cracking is reduced or minimized by including a stress relief layer in the overlay analysis. The overlay thickness that satisfies both the fatigue and reflection cracking criteria is selected as the design thickness.

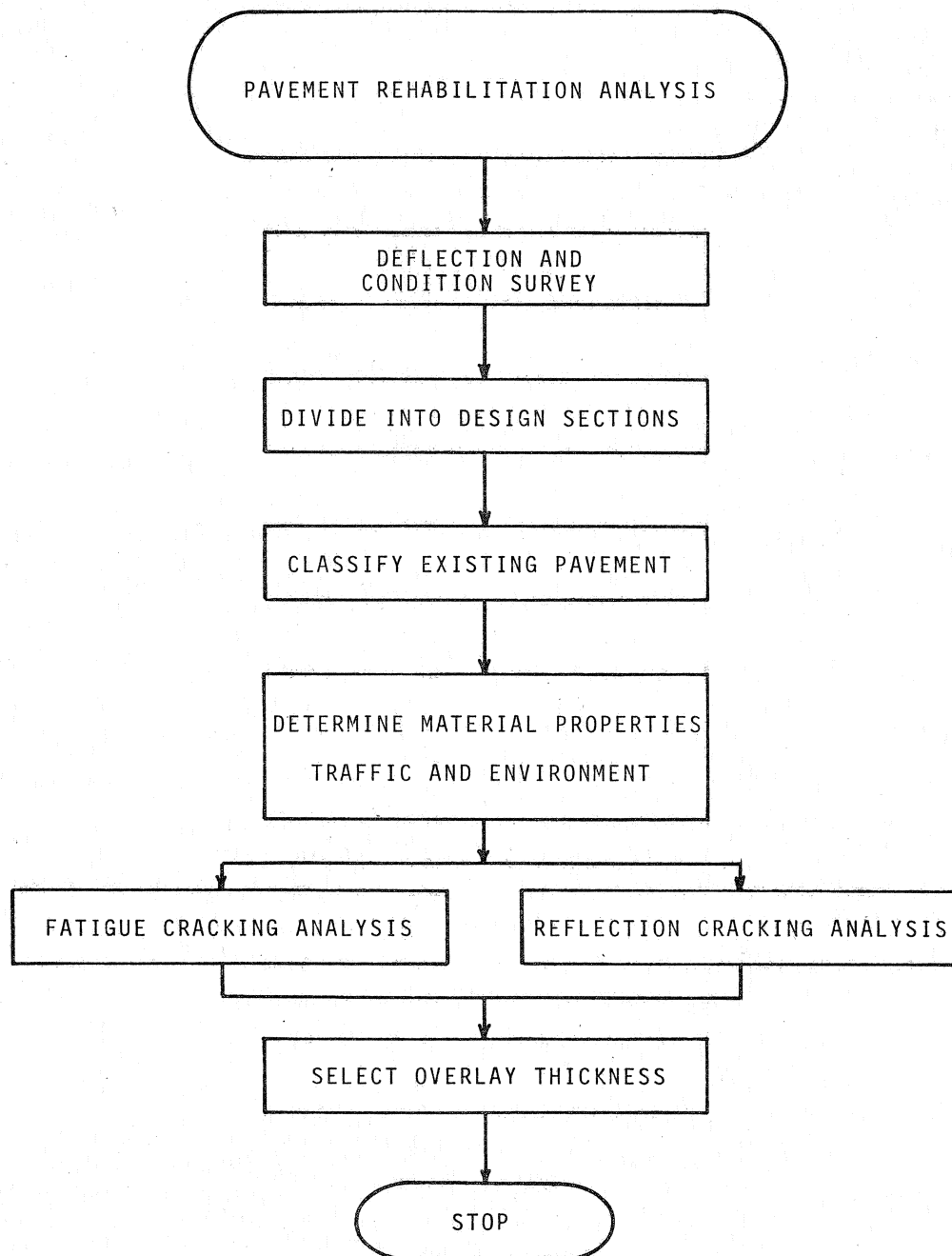


Figure 1. Flow chart of pavement rehabilitation procedure.

EVALUATION OF EXISTING PAVEMENT

Evaluation of the existing pavement is accomplished by a condition survey and deflection measurements.

Condition Survey

The main purpose of the condition survey is the determination of the type and amount of cracking present. The cracking is classified as Class 1, 2, 3, or 4 according to the definitions adopted during the AASHO Road Test (Ref 7). This information becomes decision criteria relative to the method of characterization of the existing pavement and the kind of overlay analysis performed. The condition survey should also include other relevant information such as drainage areas, soil changes, and cut-fill transition areas.

Deflection Analysis

The deflection measurements provide data necessary for dividing the pavement into segments that behave differently under load. These are termed "design sections" and each is analyzed separately for overlay thickness. The deflections may be measured with any conventional device and should be spaced along the pavement at intervals that will adequately describe its behavior. The deflection measurements are input as data to a computer program that plots deflection versus distance along the pavement, as shown in Figure 2. The designer must then visually divide the plot into sections of different performance, such as those designated as Section 1 and Section 2 in Figure 2. These sections are then evaluated for significant difference by a computer program that uses the Student "t" test for comparison. If they prove to be significantly different they are analyzed separately for overlay thickness, but if they are not significantly different they are analyzed as one section.

The deflection measurements also serve another purpose by aiding in characterization of the subgrade material. The subgrade can be characterized more thoroughly by using deflections along the entire roadway in conjunction with laboratory tests, than it can by using laboratory test values alone. This is discussed in more detail under DESIGN INPUTS.

Classification of Existing Pavement

Based on the condition of the existing pavement, it must be classified according to one of the following categories:

1. Uncracked or Class 1 and 2 cracking,
2. Class 3 and 4 cracking,
3. Mechanically broken up.

Each of these categories is treated differently in the overlay analysis. If the pavement is uncracked or has Class 1 and 2 cracking it is checked for remaining fatigue life. If there is any remaining life it is accounted for in design, thus allowing some reduction in the overlay thickness. If the existing pavement contains Class 3 or 4 cracking it is said to have reached failure and has no remaining life. It is therefore assigned a reduced surface modulus to help model this deteriorated condition. If the designer decides it is best to break up the pavement mechanically, this condition is modeled by an even lower surface modulus for use in the overlay analysis. The overlay analysis performed in each of these three classifications is discussed in more detail under OVERLAY ANALYSIS.

DESIGN INPUTS

The design inputs consist primarily of traffic, environment and material properties.

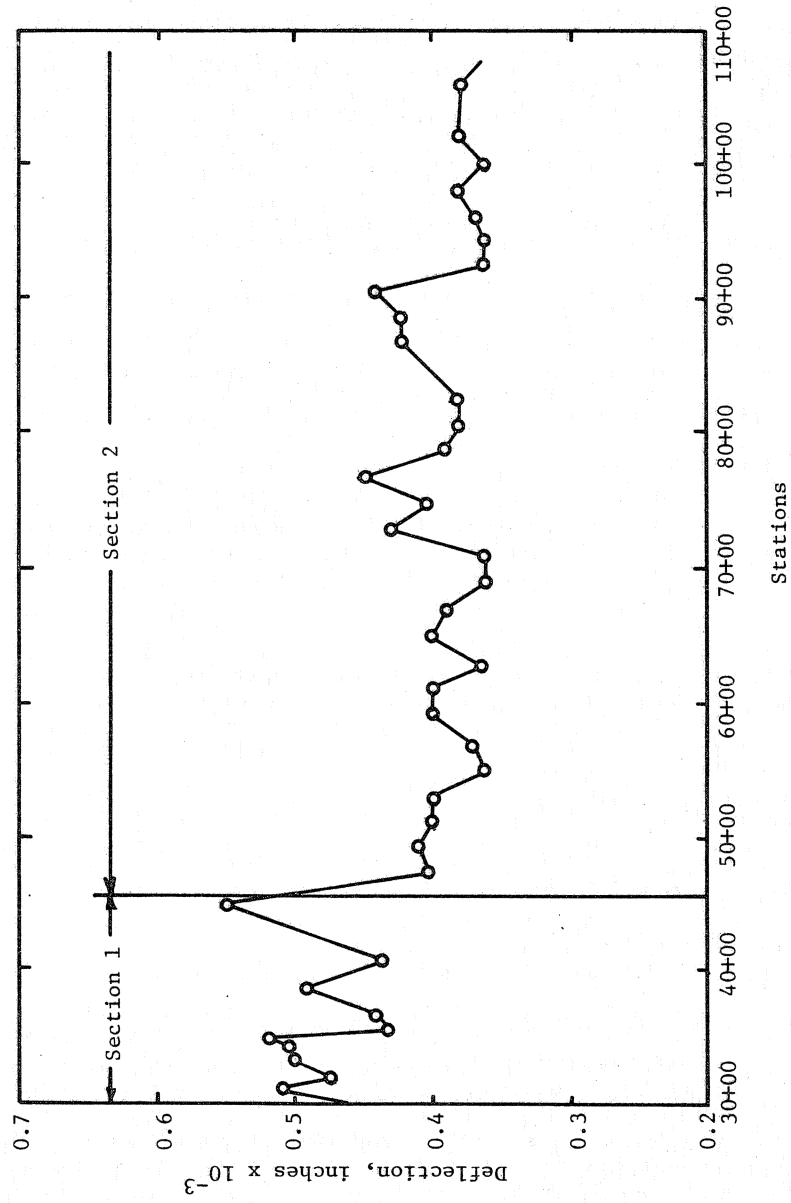


Figure 2. Sample deflection profile

Traffic

The design load used in the procedure is an 18-kip single axle. Thus mixed traffic must be converted to 18-kip equivalent axle load applications using AASHO equivalency factors. The traffic prior to the overlay should be determined for use in remaining life computations and the projected future traffic should be determined for the overlay thickness analysis. The traffic analysis should also determine the distribution between directions and lanes. The following equation is used in traffic computations:

$$N_{\text{design}} = N_{\text{total}} \times \text{DDF} \times \text{LDF}$$

where:

N_{design} = design traffic

N_{total} = total traffic for both directions and all lanes

DDF = directional distribution factor

LDF = lane distribution factor

Environmental Considerations

It is desirable to consider the rainfall for the area and drainage for the highway being overlaid, since moisture can have significant effects on material properties. In some cases the material strengths should be reduced due to excessive rainfall or poor drainage. The designer should also consider environmental effects in selecting the season for making deflection measurements. They should be made during the season that produces the highest deflections. This will insure a conservative approach when characterizing the subgrade material.

Material Properties

Material properties in the form of elastic moduli must be established for each layer in the pavement system as inputs to the linear elastic layered theory analysis. Some of these values are determined directly from laboratory tests, some are derived from deflection measurements, and some have been permanently set based on stress analyses.

The modulus for an asphaltic concrete or Portland cement concrete overlay, an existing uncracked or Class 1 and 2 cracked PCC, and a base or subbase material is determined directly from laboratory tests.

The modulus for the subgrade is based on deflection measurements in conjunction with laboratory tests. The process is shown in flow chart form in Figure 3. Linear elastic layered theory is used to develop a relation between subgrade modulus and surface deflection as shown in Figure 4. The deflection measured in the field is entered into this relation and the corresponding modulus is selected. If the deflection measurement load is different than the design load, the modulus must be adjusted for stress sensitivity. This is done by developing a relation between deviator stress and modulus and adjusting the laboratory test results as shown in Figure 5. The deviator stress for the design load is then used in conjunction with the adjusted laboratory curve to determine the final subgrade modulus.

The modulus of an exiting PCC pavement is automatically set up at 500,000 psi if it exhibits Class 3 or 4 cracking or 70,000 psi if it will be mechanically broken up. These values were established from a stress and deflection analysis of AASHO Road Test rigid pavements using discrete element theory (Ref 8).

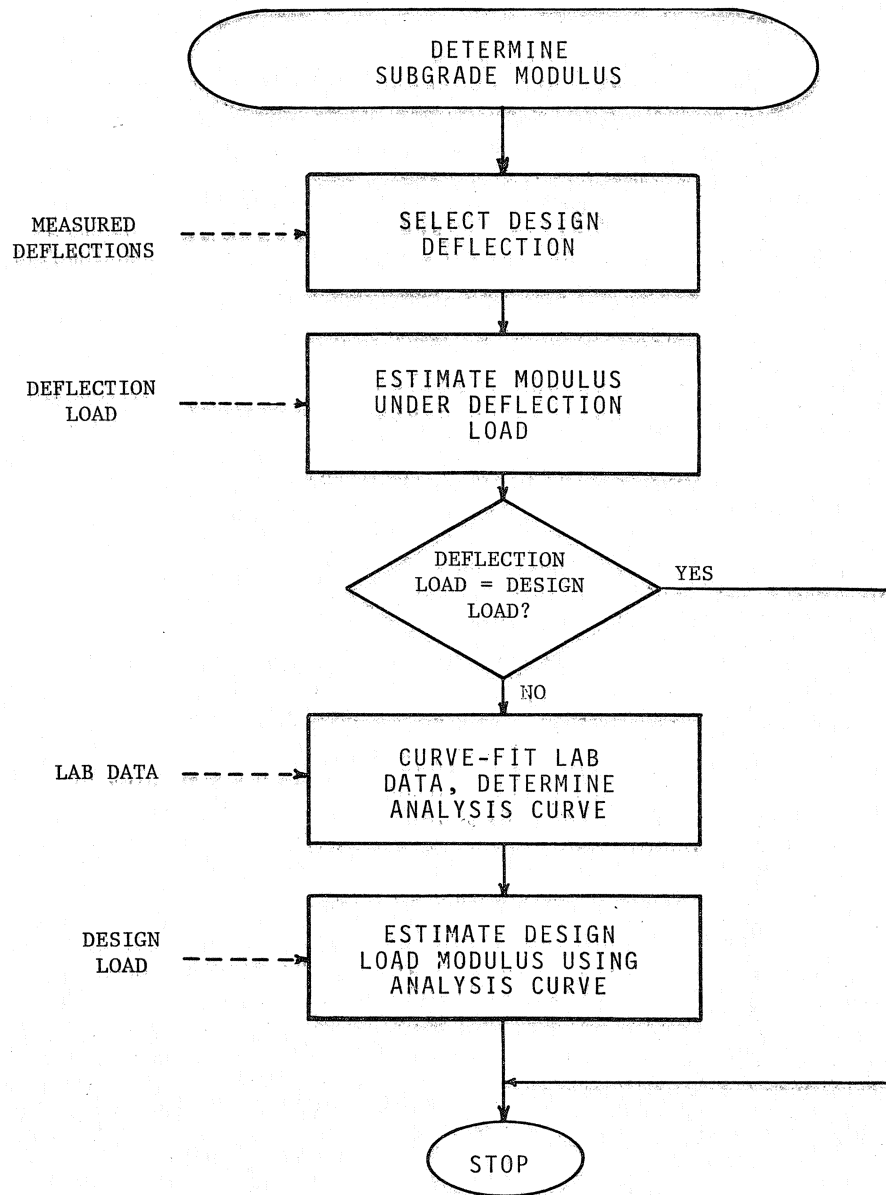


Figure 3. Determination of subgrade modulus.

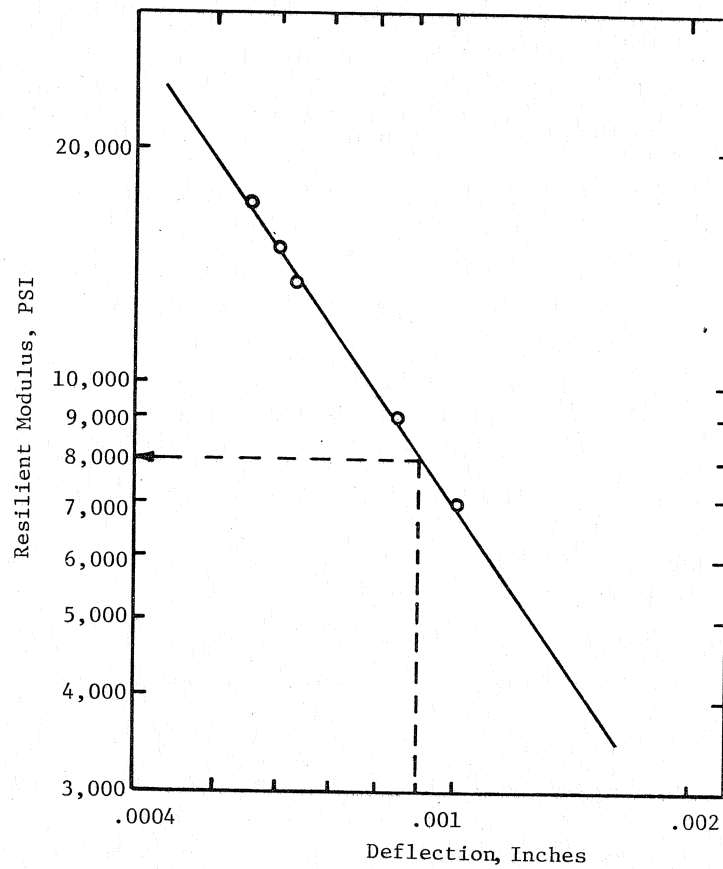


Figure 4. Relation of computed deflection and subgrade modulus.

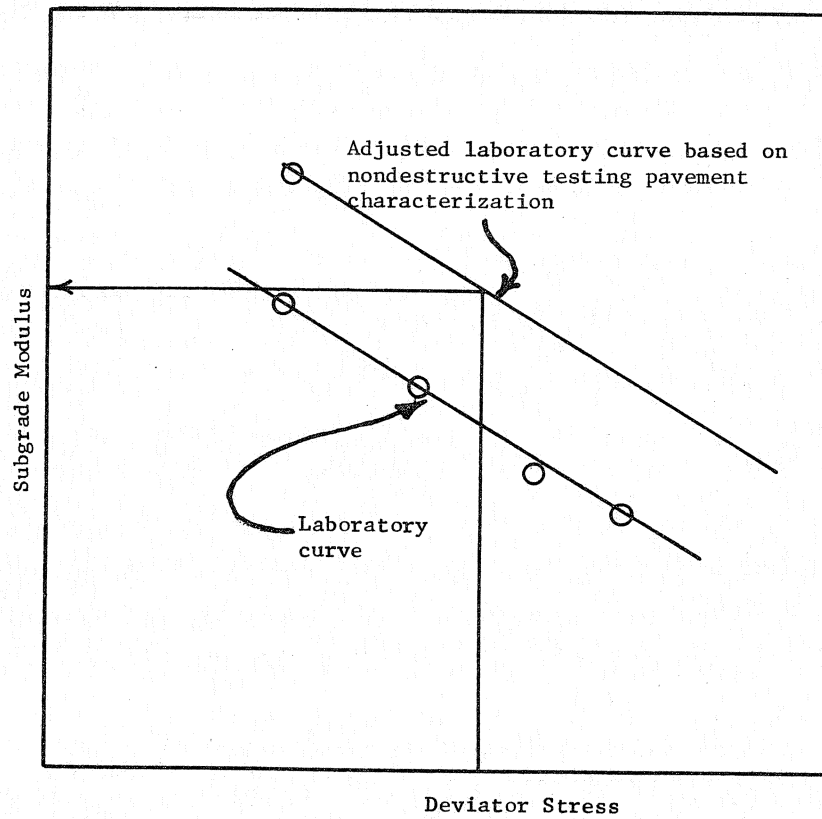


Figure 5. Relation of subgrade modulus and deviator stress used in determining subgrade modulus.

OVERLAY ANALYSIS

After evaluation of the existing pavement, designation of "design sections" and determination of design inputs the analysis for overlay thickness is performed. This includes designation of the existing pavement and overlay type, stress computations, and a fatigue analysis or reflection cracking analysis. The entire overlay analysis procedure is shown in flow chart form in Figure 6.

Pavement Type

Figure 6 indicates there are a total of 12 different analyses depending on the type of existing pavement, bond, and overlay. A distinction is made between jointed and continuous pavement because the stress computations differ in each case. A jointed pavement should be designed for a corner load condition, whereas a continuous pavement should be designed for an edge load condition. The fatigue analysis is performed for all 12 cases, but the reflection cracking analysis is performed only in cases where the existing pavement is jointed, badly cracked, or mechanically broken up. The proper analysis is keyed in the computer program by simply indicating in the input data the type of existing pavement, bond, and overlay.

Stress Computations

The stresses needed for the fatigue analysis are computed by the linear elastic layered theory program ELSYM5 (Ref 9), which is the primary subroutine in the overlay design computer program. Figure 7 shows that almost every phase of the design procedure is keyed to ELSYM5. A thorough review was made of elastic layer analysis programs before finally selecting this one as being best for the design procedure.

The horizontal tensile stress due to the design load, an 18-kip single axle, is computed at either the bottom of the overlay or the bottom of the existing pavement depending on which analysis is being performed. If the existing pavement has remaining life, the critical stress is at the bottom of this layer, whereas if the existing pavement has no remaining life the critical stress is at the bottom of the overlay. The stress is automatically computed at the proper location in the pavement system, depending on what analysis has been designated in the program input data.

The stress computed by ELSYM5 is adjusted so that it is equivalent to the stress resulting from the design load position, that is an edge or corner load. A continuous pavement is designed for edge loading and a jointed pavement for corner loading. When the designer makes deflection measurements on jointed pavements, he makes them at the interior and corner of the same panel. The ratio of these deflections is calculated and used in selecting the exact stress adjustment factor. This concept allows the actual condition of joints in the existing pavement to be considered in the design procedure.

An extensive investigation of stresses and deflections led to the development of a stress-deflection relation as shown in Figure 8. The ratio of corner deflection to interior deflection is entered on the abscissa, projected to the curve, and then to the ordinate to determine the stress adjustment. For an edge load stress adjustment a constant value is used. These adjusted stresses are then used as the design stresses in the fatigue analysis.

Fatigue Analysis

The fatigue analysis consists of the development of a relation between axle applications to failure and overlay thickness. The number of axle loads to failure is computed using a fatigue equation of the following form:

$$N = A \left(\frac{f}{\sigma} \right)^B$$

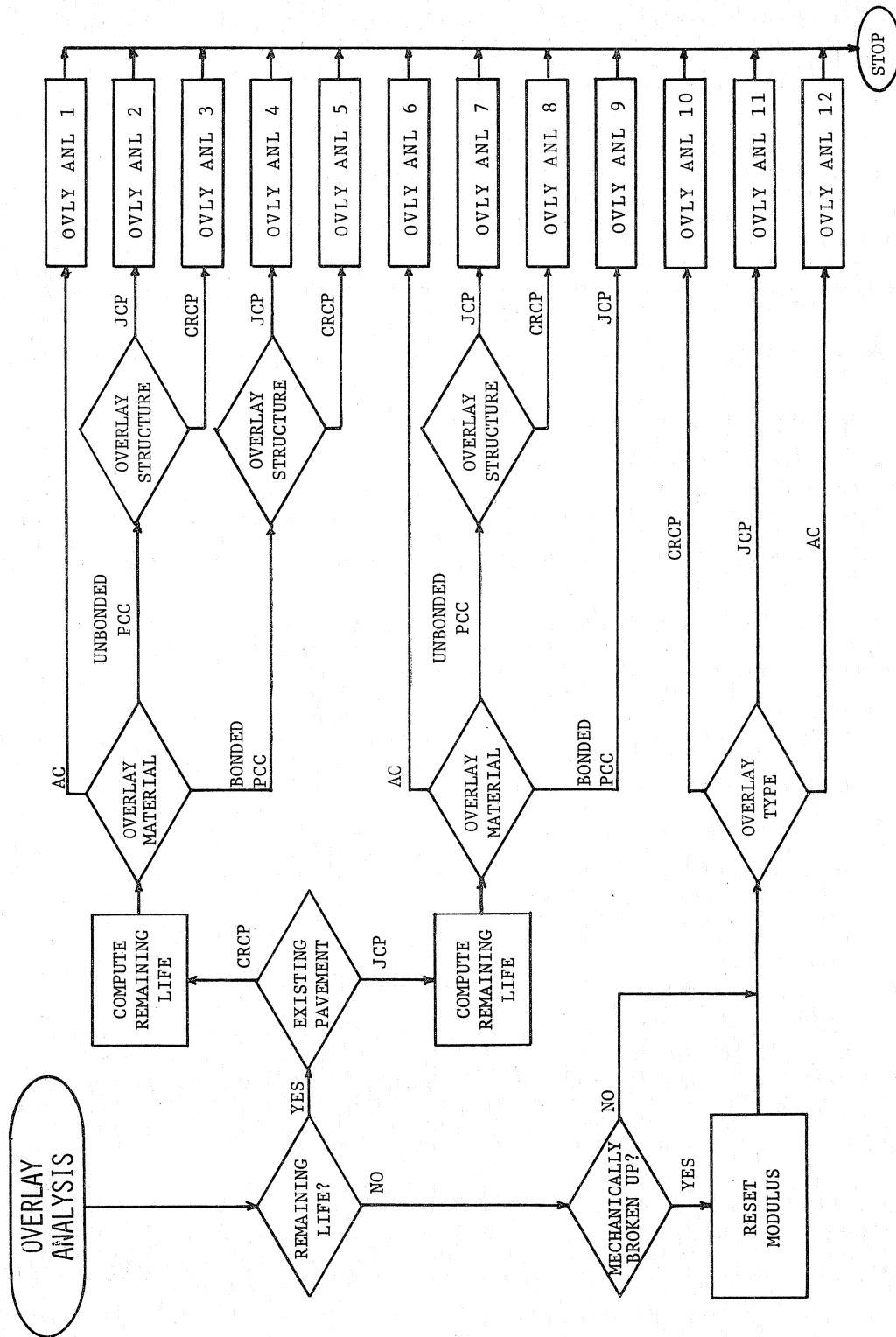


Figure 6. Overlay analysis system.

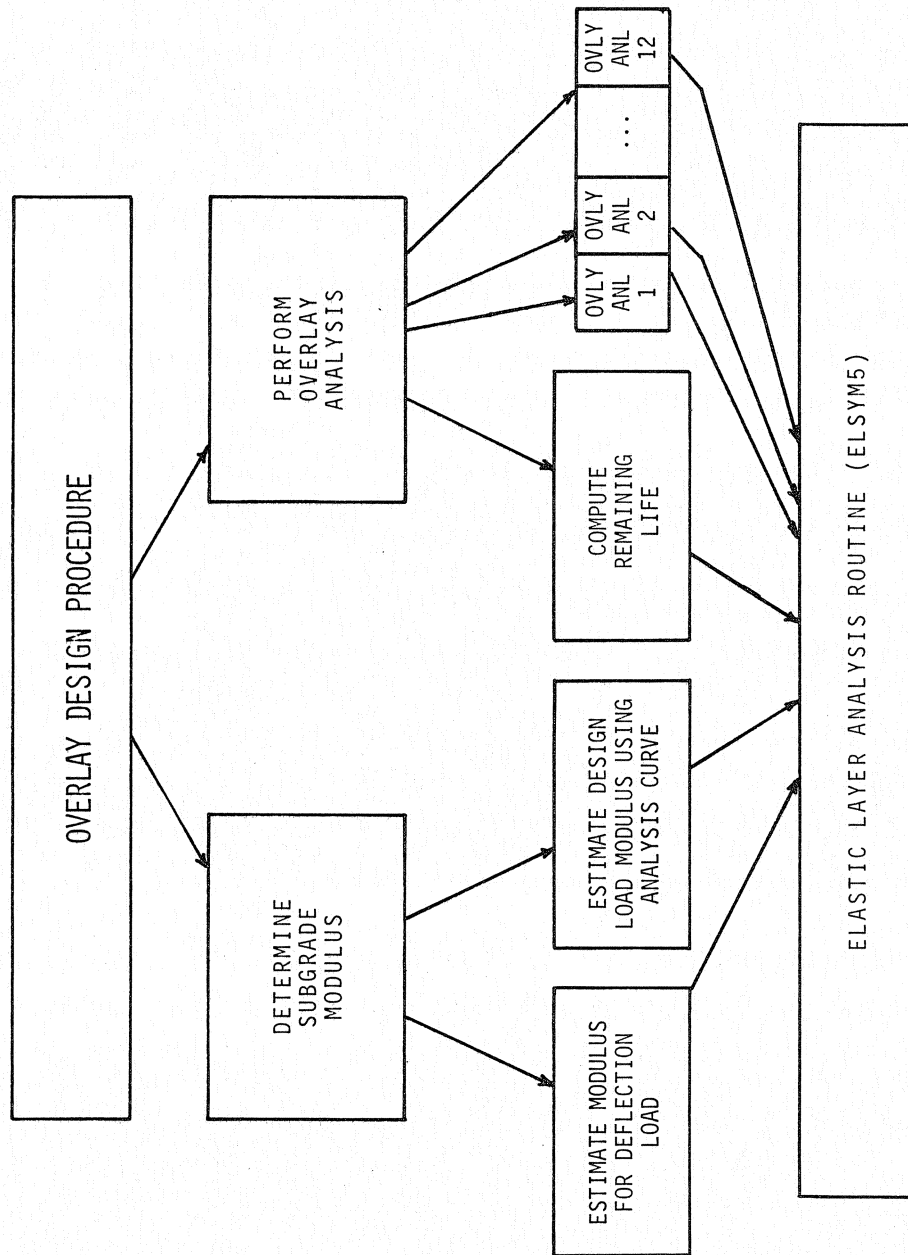


Figure 7. Overlay analysis program hierarchy.

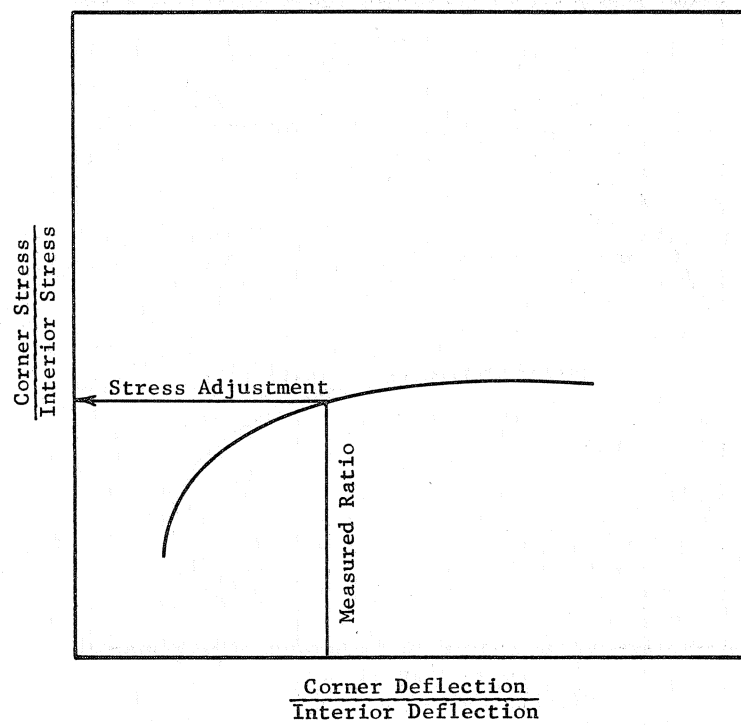


Figure 8. Selection of stress adjustment factor based on ratio of measured deflections.

where:

N = number of axle loads until failure (fatigue life)

f = flexural strength of concrete, psi

σ = computed stress due to design load, psi

A, B = constants

The fatigue life is computed for a range of overlay thicknesses and a plot is made of overlay thickness versus fatigue life as shown in Figure 9. The projected future traffic or desired life of the overlay is entered on the abscissa, projected to the curve and then to the ordinate to determine the overlay thickness. This concept allows the designer to evaluate the relation of overlay cost, as a function of thickness, to life of the overlay so that he can make tradeoffs between them if available funding requires it.

Reflection Cracking Analysis

A stress relief layer should be included between the overlay and existing pavement for any overlay that is subject to reflection cracking. This may be an asphaltic concrete cushion, crushed stone layer, thin fabric or any other material that has shown some promise in reducing reflection cracking. This stress relief layer is accounted for in the overlay thickness analysis.

Selection of Overlay Thickness

The final overlay thickness selected should be one that satisfies both the fatigue and reflection cracking criteria.

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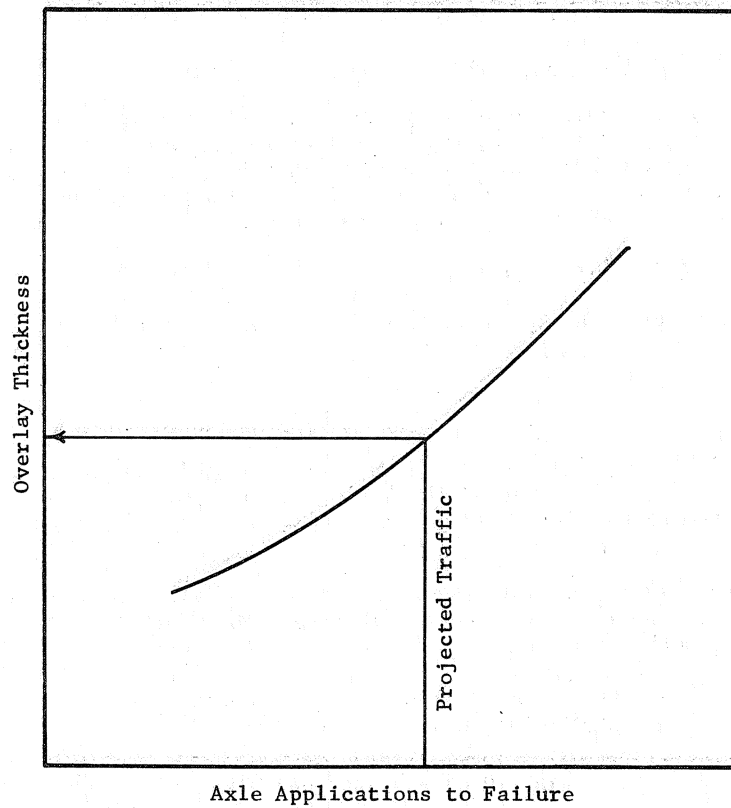


Figure 9. Relation of overlay thickness and fatigue life used in selecting overlay thickness.

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