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16. Abstract

This report demonstrates that a bonded concrete overlay (BCO) can be a viable and economical rehabilitation strategy for an in-service PCC pavement. In addition, it provides a review of state-of-the-art methods and guidelines for design, construction, and maintenance of BCOs. Although the information and experience has been primarily developed for CRCP, the concepts are applicable to all types of portland cement concrete (PCC) pavements.

The report first reviews the advantages and limitations associated with BCOs, followed by a detailed summary of Texas' experience with BCOs. It surveys Texas projects, evaluates in-service behavior and performance characteristics, and emphasizes the steps taken in the first 10-72 hours after concrete placement. Next, the report describes the criteria for selecting the conditions that maximize BCO performance. It then outlines the process used for designing thickness, reinforcement, and interface (a user-friendly automated process is furnished in the appendix). Finally, the report describes specifications, BCO construction control, and the maintenance procedures to follow when repairing distress on an existing PCC pavement scheduled to receive an overlay.

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BONDED CONCRETE OVERLAY (BCO) PROJECT SELECTION, DESIGN, AND CONSTRUCTION

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Research Report Number 920-6F

Research Project 3-12D-84-920
Evaluation of the Performance of the Bonded Concrete Overlay on Interstate Highway 610 North, Houston, Texas

conducted for the

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research

THE UNIVERSITY OF TEXAS AT AUSTIN

November 1994

IMPLEMENTATION STATEMENT

This report summarizes the experiences, observations, field measurements, and evaluation of three bonded concrete overlays (BCOs) of continuously reinforced concrete pavement (CRCP) constructed in the Houston District. Although the discussion focuses exclusively on CRCP, the concepts are applicable to BCOs of any type of portland cement concrete pavement. It is recommended that the report findings be incorporated into the Texas Department of Transportation's Design and Operation Procedures. Specifically, the following steps are recommended:

1. Convert the material into a user-manual that is a part of standard TxDOT procedures.
2. Implement the user-friendly, automated process developed in this project (the procedure is provided in the appendix).
3. Develop and conduct a seminar for all interested users in the state. This step is essential for maximizing the benefits of this research.

Prepared in cooperation with the Texas Department of Transportation.

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DISCLAIMERS

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

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TABLE OF CONTENTS

SUMMARY

This report demonstrates that a bonded concrete overlay (BCO) can be a viable and economical rehabilitation strategy for an in-service PCC pavement. In addition, it provides a review of state-of-the-art methods and guidelines for design, construction, and maintenance of BCOs. Although the guidelines have been primarily developed for CRCP, the concepts are applicable to all types of portland cement concrete (PCC) pavements.

The report first reviews the advantages and limitations associated with BCOs, followed by a detailed summary of Texas' experience with BCOs. It surveys Texas projects, evaluates in-service behavior and performance characteristics, and emphasizes the steps taken in the first 10-72 hours after concrete placement. Next, the report describes the criteria for selecting the conditions that maximize BCO performance. It then outlines the process used for designing thickness, reinforcement, and interface (a user-friendly automated process is furnished in the appendix). Finally, the report describes specifications, BCO construction control, and the maintenance procedures to follow when repairing distress on an existing PCC pavement scheduled to receive an overlay.

CHAPTER 1. INTRODUCTION

As a rehabilitation strategy, bonded concrete overlays (BCO) have been the subject of increasing interest in Texas and other states. Reflecting this growing interest, this report outlines the development of a BCO project — from initial project selection through design, construction, and maintenance. This introductory chapter provides general information and background on BCOs, looking in particular at their various advantages and disadvantages.

1.1 BACKGROUND

The rehabilitation of highways and airfields constructed of portland cement concrete (PCC) has increasingly involved bonded concrete overlays. These 10.16- to 15.24-cm (4- to 6-in.) overlays provide a thicker monolithic pavement, one able to provide increased structural capacity. A recent U.S. Department of Transportation survey of state transportation agencies (Ref 1) shows that many are using bonded overlays (some more successfully than others). What these agencies have found is that cost-effective and long-term performance of this type of pavement rehabilitation requires that the overlay be applied before the original concrete has suffered excessive deterioration. Thus, pavements showing cracking, loss of slab support, and a significant number of joint failures are not good candidates for this type of rehabilitation, owing to their need for costly repairs prior to overlay placement. The U.S.DOT study (Ref 1) provides considerable guidance on the selection of suitable rehabilitation strategies for jointed concrete pavements.

Given the state's substantial network of continuously reinforced concrete pavements (CRCP), the Texas Department of Transportation (TxDOT) has made an effort to expand its understanding and use of bonded concrete overlays, gaining over the years extensive experience with asphalt concrete and unbounded portland cement concrete overlays on these pavements (Refs 2, 3). Because of their low maintenance requirements and light reflective surface, the thinner bonded concrete overlay provides an attractive rehabilitation alternative.

1.2 BCO CONSIDERATIONS

Even on the best existing slabs, however, bonded overlays will not perform as expected if the bond is not maintained. That is, the design process assumes that the placement of the overlay yields a monolithic structure. If the substrate and overlay act independently, then the overlay will fail in a short time as a result of the high stress of traffic on the relatively thin overlay. Thus, an additional criterion for the successful use of bonded concrete overlays is establishing and maintaining the necessary bond. This bond must be sufficiently strong to resist environmentally induced stresses immediately after placement, as well as environmental and traffic loadings throughout the service life of the overlay.

Nor are BCOs appropriate for all conditions of portland cement concrete pavement. Accordingly, a pavement engineer considering whether to use a BCO must look at the advantages and the limitations. Table 1.1 lists the factors to be considered in BCO evaluation, while the following sections describe the advantages and limitations.

Table 1.1 Factors to be considered in BCO evaluations

Advantages	**Limitations**
Provides optimum investment protection	Reflects condition of existing surface
Expedites construction	Not optimum solution when extensive repairs required
Minimizes clearance problems	Critical timing required
Improves riding quality	Not applicable with "D" cracking in pavement
Maximizes visibility	
Minimizes reconstruction problems	

1.2.1 Advantages of BCOs

The primary advantage of a BCO is that, if applied at the proper time, it can cost-effectively extend pavement life and load-carrying ability, thereby protecting infrastructure investment. Another advantage is that the strategy expedites construction, since the overlay requires only a minimum number of operations (e.g., it may be possible to return traffic to the overlay within 24 to 36 hours after placement). And because the overlay is thin, pavement engineers can use a BCO in areas where there are clearance problems.

The first three items in Table 1.1 pertain uniquely to BCOs, while the latter three are applicable to both bonded and unbonded PCC pavement overlays. Of these last three advantages, the first, improvement of riding quality, is obvious; and as mentioned above, the overlay's bright surface can improve night visibility. The last factor, minimizing reconstruction problems, covers several facets. For example, any rehabilitation that requires the original subgrade to be uncovered can create numerous problems (saturated soils, etc.) and can increase the time needed for project completion, especially if the original pavement was constructed over poor subgrades. An overlay represents a time-saving alternative to such reconstruction. Another factor is the risk of reconstruction work exposing a swelling clay subgrade to drying and/or moisture (this assumes that the existing pavement vertical movement has stabilized). Exposing such a subgrade may reinitiate a cycle of extreme soil movements. Again, an overlay strategy will avoid such problems. In addition, because an overlay does not require the existing surface to be removed, the traffic can be safely maintained on adjacent lanes and shoulders during construction.

1.2.2 Limitations of BCOs

There are several limitations of a BCO that should be weighed during the selection process. First, a BCO will reflect the condition of the existing surface (i.e., cracks, failures, etc.). Although the reflection of cracks presents no problem in CRCP, for other concrete pavement types it may be necessary to restore the slab continuity by using epoxies or polymers. Thus, a BCO is not an optimum solution if the existing surface requires extensive repairs.

The need to time the construction can also be a limitation. If there is a 3- to 4-year delay between design and construction of the overlay, then the condition of the existing pavement could deteriorate to the point where extensive repairs (especially for "D" cracking) would be required.

Thus, the planner and designer should weigh the advantages and limitations of a BCO before selecting the design type to use. But decisionmakers must realize that, because these factors are qualitative, there are no weighting variables that can be applied in the decision-making process.

1.3 OBJECTIVES

This report summarizes a series of studies that undertook to develop effective BCO design and construction procedures. These studies, conducted over an eight-year period at The University of Texas at Austin by the Center for Transportation Research, were sponsored by the Texas Department of Transportation. This report summarizes the results of the following projects:

1. Project 920 – "Evaluation of Thin Bonded Concrete Overlays on IH 610 (South Loop) in Houston, Texas"
2. Project 457 – "Thin Bonded Overlay Implementation"
3. Project 1205 – "Finite-Element Analysis of Bonded Concrete Overlay"
4. Project 357 – "Thin Bonded Concrete Overlay"

The objectives of this report are to provide state-of-the-art criteria, procedures, and techniques for:

1. selecting a project for detailed cost analysis;
2. designing the BCO thickness and reinforcement for the anticipated traffic and environmental conditions;
3. developing specifications, quality assurance, and quality control for use during the construction operation; and
4. performing proper maintenance before and after the construction operation.

1.4 SCOPE

This report describes primarily the Texas experience with BCOs on CRCP. The intent is to provide guidance for the evaluation, design, and construction of a BCO on an existing PCC pavement. Although the study involved CRC pavements, the concepts and guidelines are applicable to all BCO pavement types. And finally, though the specific critical information required to accomplish the appropriate task is presented, we sought to minimize the length of this particular document by referencing, rather than reiterating, detailed background information.

CHAPTER 2. REVIEW OF BCO EXPERIENCE

This chapter describes BCO projects undertaken on IH-610 in the Houston area. The first part summarizes the in-service performance of these pavements, while the last section discusses the early-age, quality-control measures that should be implemented to ensure the long-term performance of a BCO.

2.1 PROJECT LEVEL

Although bonded concrete overlays were first constructed in the U.S. around 1900, not until mid-century did pavement engineers began to investigate ways of consistently applying these overlays. During the 1950s, Gillette (Ref 4) and Felt (Ref 5) both began to report the results of their laboratory and field testing of bonded overlays. These studies concluded that clean, dry surfaces were required for good bond-strength development. They also found that the use of grout increased the bond strength. Gillette reported in 1965 (Ref 4) that an interface bond strength of 1,378.9 kPa (200 psi) was adequate for successful overlay bonding and that, if a loss of bond did occur, it probably developed soon after the overlay was placed.

With most transportation agencies now moving away from new infrastructure construction to the rehabilitation of existing facilities, bonded concrete overlays have emerged as one of the most promising (though still infrequently employed) rehabilitation options available. Among all state transportation agencies, the Iowa Highway Department leads the nation in the use of bonded overlays, having constructed many lane kilometers of BCO since 1976. Indeed, current design and construction practice is based in part on the experiences of the Iowa Highway Department. The success of the bonded overlay projects in Iowa was such as to prompt the Texas Department of Transportation (TxDOT) to construct an experimental overlay in 1983; this successful application, in turn, led to the construction of a BCO on two projects on IH-610 in Houston (described below and hereafter designated the North and South Loop experimental sections).

2.1.1 South Loop Experimental Sections

TxDOT's first use of bonded concrete overlays to rehabilitate continuously reinforced concrete pavements (CRCP) was on a four-lane, 304.8-m (1000-foot) experimental section constructed in 1983 on Interstate Highway 610 (South Loop) in Houston (Figure 2.1). The section, still in service, consists of five test areas, each approximately 60.96 m (200 feet) long. Overlay thicknesses of 5.08 and 7.62 cm (2 and 3 inches) were placed with and without reinforcement. Neat portland cement grout was used throughout the experimental section as a bonding agent, except on a short four-lane section (6.096 m, or 20 feet), which was placed without a bonding agent. The existing surface was prepared first by cold-milling and then by sandblasting. A factorial indicating the variables investigated is shown in Table 2.1 (Refs 6, 7).

These overlayed test sections have been in service for more than 10 years, carrying approximately 150,000 vehicles per day. Shortly after the overlay was placed (1983), engineers performed deflection tests that indicated the pavement's expected life was 20 years (Ref 6).

Condition surveys conducted in the spring of 1990 support this estimate, while sounding surveys conducted at the same time showed, in addition, that some debonding of the overlay had occurred. The results of the sounding surveys are shown in Table 2.2. The majority of the delamination was found near the longitudinal construction joint at the center of the 14.63-meter-wide (48-foot) pavement. It is not known whether this delamination occurred shortly after construction, or if it developed over time (no record can be found of soundings prior to February 1990). The early success of these experimental sections prompted TxDOT to construct a second, more ambitious bonded overlay project.

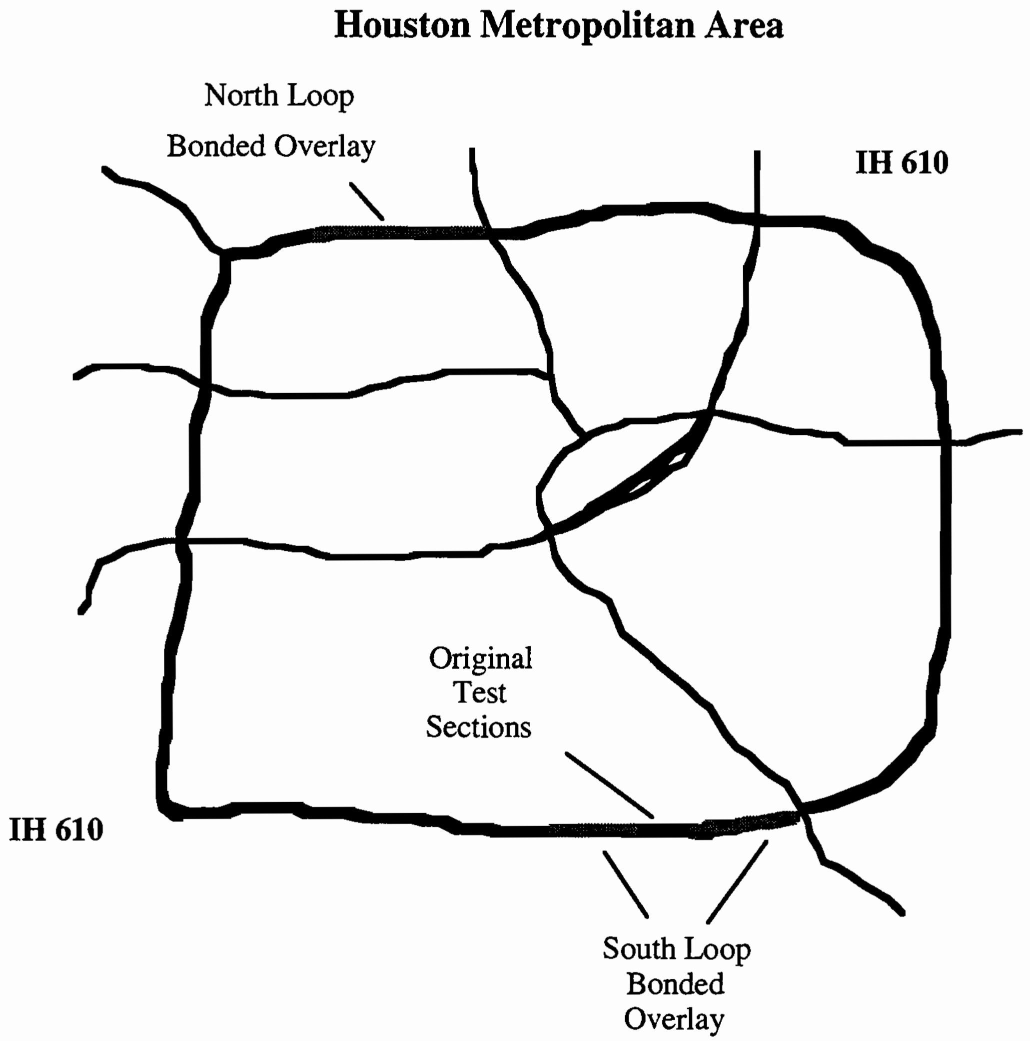


Figure 2.1 Locations of three bonded concrete overlays in the Houston, Texas, area

Table 2.1 Main factors investigated in the IH-610 South experimental BCO test sections

Reinforcement Type	**Thickness (mm / in.)** 50 / 1.95	 75 / 2.92
Plain	X	–
Wire Mesh	X	X
Steel Fibers	X	X

Table 2.2 Delamination in the IH -610 South experimental sections (as of March 1990)

Test Section ID	**Thickness mm / in.**	**Reinforcement Type**	**Section Length, m / ft**	**Percent of Total Area Delaminated**[1]
A	50 / 1.95	None	49 / 160	0.0
B [2]	50 / 1.95	Welded Wire Fabric	61 / 200	0.01
C	75 / 2.92	Welded Wire Fabric	55 / 180	0.6
D	75 / 2.92	Steel Fiber	55 / 180	0.01
E	50 / 1.95	Steel Fiber	49 / 160	0.0

[1] Includes all four lanes.

[2] Section B includes a 6-meter (19.68-foot) length of overlay placed without grout. This no-grout area contains the delamination in the section.

2.1.2 North Loop

TxDOT next constructed a much larger bonded overlay section in Houston on the IH-610 North Loop in 1985 and 1986 (Ref 8). This section, about 103 km (64 lane-miles) long, has a nominal thickness of 10.16 cm (4 inches) on the roadways; bridge decks were overlaid to a thickness of 5.08 cm (2 inches). After repairing the existing CRCP, engineers prepared the surface by light shotblasting, followed by air blasting immediately prior to placement of the grout. Most of the section (85.3 km, or 53 lane-miles) was constructed using wire mesh reinforcement and a siliceous river gravel similar to that used in the existing pavement (Refs 11, 12). (TxDOT engineers believed that using similar aggregates would reduce the thermal incompatibility between the overlay and substrate; see Refs 9, 10.) Other test sections used the siliceous aggregate with steel fiber reinforcement (12.9 km, or 8 lane-miles) and limestone aggregate with mesh reinforcement (5.1 km, or 3.2 lane-miles).

Through sounding surveys, debonding was located in one area shortly after the project was placed in service. TxDOT, in response, undertook a project to assess the extent of the delamination and to determine, through subsequent surveys, whether the debonding was progressing (Refs 13, 14). Ultimately, one-half of the total project length was sounded on three occasions over four years. These survey results (Refs 11, 12, 13, 15) established that:

1. all debonded areas were located adjacent to cracks or joints;
2. although some areas had as much as 20 percent delamination, the debonding areas in a specific area did not increase in four years of monitoring;
3. the overlays with limestone aggregate concrete had significantly less debonding than the siliceous aggregate concrete, suggesting that thermal compatibility of the substrate and overlay concretes is not critical;
4. there was a positive correlation between the presence of delamination and adverse environmental conditions (i.e., high evaporation rates and large ambient temperature drops) at the time of placement; and
5. all analysis and correlations of debonding to various variables and factors associated with the project indicated the delamination occurred early in the life of the pavement, perhaps during the first 12-48 hours following placement.

The third overlay project originally planned for 1987 was postponed until after the completion of the delamination investigation of the North Loop project. After careful consideration of the North Loop study results, TxDOT decided to proceed with the third overlay project in 1989.

2.1.3 South Loop

The third overlay project was recently completed (1990) in Houston on the South Loop (Figure 1). This 180.2-km (112 lane-mile) project consists of a 10-cm (3.9-inch) thick, wire-mesh-reinforced, limestone aggregate concrete overlay. After repairs were made, the surface of the existing CRC pavement was prepared by cold milling and sandblasting. Portland cement grout was used as the bonding agent, except in certain experimental areas discussed below.

The specifications used on the previous job were revised to incorporate the findings from the North Loop project. These revisions included limits on the allowable evaporation rate (≤ 0.1 kg/m^2/hr, or 0.2 lb/yd^2/hr) and on the ambient temperature drop during the 24 hours following placement of the overlay (≤ 14° C, or 25° F). Limestone aggregate was recommended for use, in part, based on the relative lack of delamination on the North Loop test section (Refs 11, 15, 16). Also, finite element analyses showed that the use of concrete with a lower thermal coefficient in the overlay (compared with the substrate) reduces the interface stress (Refs 17, 18). To date, the only delamination found in this project occurred in one of the experimental sections (described below).

The eight experimental sections, each 304.8 m x 14.6 m (1000 ft x 48 ft), were constructed in 1989 on the eastbound lanes. The section variables included bonding agent type, surface preparation, and reinforcement type (Table 2.3). Delamination was discovered within the first 12 hours after placement in the test sections that used latex-modified portland cement grout (the delamination was similar to that occurring in the first 12-48 hours on the North Loop). Debonding progressed to such an extent that the latex grout test sections were removed and replaced with the project control standard overlay method within 30 days following construction. Despite considerable investigation, the exact cause of this extensive delamination was not determined (though it was perhaps the result of the interforce stresses increasing faster than the bond strength).

Table 2.3 Experimental factors considered in the South Loop IH-610 sections

Test Section Identification	Bonding Agent	Reinforcement	Surface Preparation
1	PC Grout	Steel Fibers	Cold Milling
2	None	Welded Wire Fabric	Cold Milling
3	PC Grout	Welded Wire Fabric	Cold Milling
4	Epoxy	Welded Wire Fabric	Light Shotblasting
5	Latex-Modified PC Grout	Welded Wire Fabric	Light Shotblasting
6	Latex-Modified PC Grout	Welded Wire Fabric	Heavy Shotblasting
7	PC Grout	Welded Wire Fabric	Heavy Shotblasting
8	None	Welded Wire Fabric	Heavy Shotblasting

These three overlay projects have provided extremely valuable information on the factors that effect the construction and performance of bonded concrete overlays. In conjunction with these projects, researchers at The University of Texas at Austin conducted laboratory and analytical investigations to determine the importance of a variety of factors on the early-age and in-service performance of bonded overlays. These studies are discussed below.

2.2 IN-SERVICE PERFORMANCE

The evaluation of BCO in-service performance, as used herein, is based on the overlay's ability to maintain an adequate bond throughout its service life. That is to say, the bond must resist traffic-induced stress and environmental loadings caused by seasonal and diurnal temperature and moisture fluctuations. The interface must also be sufficiently strong to resist the fatigue induced by the long-term cyclic loading of traffic and the environment. Gillette (Ref 4) concluded from his research that a limiting value of interface shear strength of 1,378.9 kPa (200 psi) was sufficient to resist the applied stresses. Research conducted in Texas indicates that this value is sufficient and, in fact, exceeds the expected in-service stresses by a factor of 4 to 5 under normal conditions (Refs 14, 15, 17). However, it should be understood that the buildup of this strength value (relative to the cycling stress value) is much more important than an ultimate value.

Bagate et al. (Ref 19) analyzed the overlay-substrate interface under in-service conditions to determine the magnitude of the shear stresses present as a result of wheel loading. The pavement system was investigated using layered elastic analyses and a simple finite-element method program. A variety of overlay and existing slab thicknesses and support conditions were examined. The maximum shear stress was found to be less than 193 kPa (28 psi) under a standard 80-kN (18-kip) axle. Because of the limitations of the analysis tools used by Bagate, thermally-induced stresses could not be evaluated.

Work by van Metzinger (Ref 17) greatly extended the work of Bagate. Using an improved finite element method of analysis, he incorporated slip elements into model cracks, which allowed non-linear thermal gradients to be analyzed. The investigation included evaluations of the influence of overlay and base slab thicknesses, moduli, and thermal coefficients. Van Metzinger also investigated reflective and non-reflective cracking in overlays. He concluded that the tension and shear stresses caused by wheel and thermal loads are generally too low to produce debonding in in-service pavements. Furthermore, he states that, because the calculated stresses were considerably less than 50 percent of the interface strength, long-term, fatigue-induced delamination is unlikely.

The work of van Metzinger (along with the lack of debonding propagation found on the North Loop project) suggests that in-service stresses generated after the initial construction period are relatively low compared with reasonably obtainable interface strengths. However, the total delaminated area on the South Loop latex-modified test sections under mild temperature fluctuations and without traffic loading demonstrates the importance of adequate initial interface strength. The occurrence of debonding within 24 hours after placement supports the hypothesis of both Felt (Ref 5) and Gillette (Ref 4), who suggest that debonding most likely forms soon after the overlay is placed.

2.3 EARLY-AGE CONSIDERATIONS

Field experience (along with the work of van Metzinger) allowed analytical and laboratory investigations to be developed that focus on several factors related to early-age bond strength development (Ref 17). The finite element method was used to analyze recently placed bonded overlays subjected to a variety of adverse environmental conditions. The laboratory phase of the project investigated the effect of bonding agent, surface texture, and placement delay on the interface bond strength. The bond strength was determined using a variety of test methods. The analytical and laboratory phases are described below.

The finite element method was utilized to determine the stress regime at or near the interface between the overlay and the substrate. Slip elements with user-specified shear and normal strength limits were then used to model the interface between the overlay and the substrate. If the calculated stress exceeded the limiting value, then debonding of the overlay was modeled by setting the slip element stress to zero. The stress regime throughout the system was then recalculated. Iterations continued until the limiting strengths in the slip elements were reached. Interface strength inputs for this program were taken from the laboratory tests (discussed below) and from field testing. Temperature gradients with depth in the overlay and the substrate slab were input for early morning and late afternoon overlay placements. Winter and summer placements were also modeled. These inputs were generated from field measurements, weather service data, and from additional heat transfer modeling. A variety of material properties was used for the overlay and existing pavement. Cracks in the substrate and overlay and steel reinforcement were also included in the analyses.

After investigating a comprehensive series of early-age conditions, it was found that, even under the most severe environmental conditions, the interface shear stresses were less than 300 kPa (43.5 psi). Only at very early ages would shear strength values be less than 300 kPa (43.5 psi). These results, coupled with the work of van Metzinger, indicate that once the overlay has cured, the sum of all likely stresses, even under extreme conditions, are not adequate to cause delamination. Early debonding problems seem to occur only when environmental conditions generate a significant combination of stresses at the interface very early (i.e., before the overlay has achieved any appreciable strength; Ref 16). One method of minimizing the occurrence of delamination is to avoid placing overlays when adverse conditions exist or are anticipated. This type of control was used on the recent South Loop project to limit early interface stress by limiting the allowable temperature drop and evaporation rate.

Another method of assuring adequate bond strength at early ages is to use specialized materials or techniques that achieve higher strengths. These concepts were investigated in another phase of the research that examined the effects of different substrate temperature, types of bonding agents, rates of application, times of application, and surface textures on the bonding of portland cement concrete overlays and the concrete substrate. More than 150 base slabs, 0.91 m x 0.91 m x 27.94 cm (3-ft x 3-ft x 11-in), were constructed, prepared, and overlaid (Ref 15). The variables investigated are shown in Table 2.4. Comparisons of bond strengths were made using the direct shear, direct tension, and 5.08- and 10.16-cm (2- and 4-inch) core diameter pullout tests. A prototype torsional testing device was also developed in this phase of the project (Refs 14, 15).

The strength data showed that the epoxy bonding agent gave the highest bond strength for all surface textures; they also showed that high substrate temperatures adversely affect the bond strength, regardless of the bonding agent used in the surface preparation. These results were consistent across all types of strength testing, with no other definitive relationships emerging among the other variables. It should be noted that the strength tests were run on specimens seven days after placement. Only the prototype torsion test device was able to provide bond strength data within less than 24 hours of curing. However, this device cannot be considered practical for field construction control in its present state.

2.4 SUMMARY

The implementation of the information presented in this chapter will significantly increase the probability of achieving a rehabilitated pavement that will continue to provide an excellent service record with minimum maintenance during and beyond the intended design life. Because the information in the chapter is presented in summary form, the reader is encouraged to examine the references given for more detailed background information.

Table 2.4 Laboratory factorial for early-age bond characteristic study

		Surface Temp.	Low (10-15)		Medium (20-40)		High (50-60)	
		Application Time	<2 min.	> 5 min.	<2 min.	> 5 min.	<2 min.	> 5 min.
Texture	Bonding Agent	Application Rate						
Light Shot Blast	Latex	Low						
		High						
	Epoxy	Low						
		High						
	PC Grout	Low						
		High						
Cold Mill	Latex	Low						
		High						
	Epoxy	Low						
		High						
	PC Grout	Low						
		High						
Heavy Shot Blast	Latex	Low						
		High						
	Epoxy	Low						
		High						
	PC Grout	Low						
		High						

*Note: Specimen prepared for each cell of the matrix with a 50-percent replication.

CHAPTER 3. PROJECT SELECTION

By definition, a BCO implies that the overlay is uniformly attached (bonded) to the pavement, and that the entire unit acts as a single, integral unit to reduce stresses. It is distinguished from an unbonded PCC or ACP overlay, which provides a series of *independent* component layers that, together, act as a unit to reduce the stresses imposed by wheel loads.

The successful implementation of a BCO depends much on the existing pavement condition; that is, a BCO applied as a remedy to a distressed pavement will result in poor BCO performance. For such overlays, any distress, including wide cracks or joints and/or punchouts, will reflect through the upper layer to the surface. As a result, the old problems will soon be manifested in the surface of the new pavement, with the overlay merely delaying slightly the inevitable failure of the original pavement. Accordingly, proper application of a BCO requires the repair, prior to overlay, of all severe failures and wide cracks. The problem with such a requirement, of course, is that it forces subjective judgments regarding a pavement's condition.

Figure 3.1 outlines a method for determining the acceptability of existing conditions. The following sections discuss each of the items.

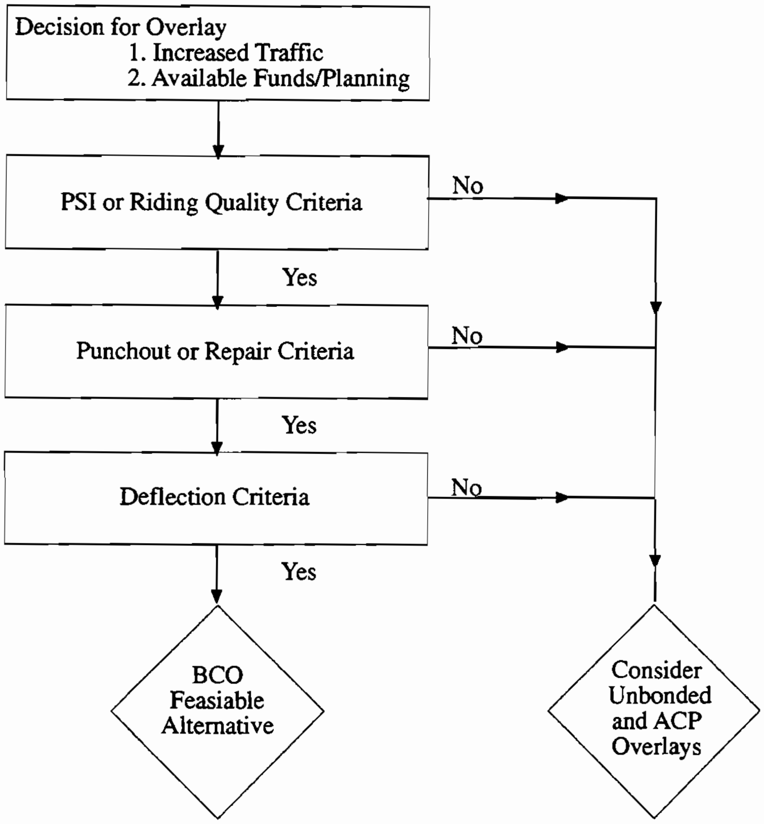


Figure 3.1 Criteria for determining if an in-service CRCP will accept a BCO

3.1 OVERVIEW AND CONCEPTS

First, the process illustrated in Figure 3.1 assumes that a decision to overlay has been made. This decision could come in response to either actual or anticipated traffic increases, measured in terms of greater ESALs. Or the decision to overlay could come as the pavement approaches the end of its intended performance period.

Figure 3.2 illustrates the time element involved in overlay decisions. As suggested in that figure, at some point it is more economical to construct an *un*bonded overlay (or to reconstruct), while at another point it is more economical to construct a *bonded* concrete overlay. The point at which it is no longer feasible to construct a bonded concrete overlay should be determined to ensure cost-effective rehabilitation.

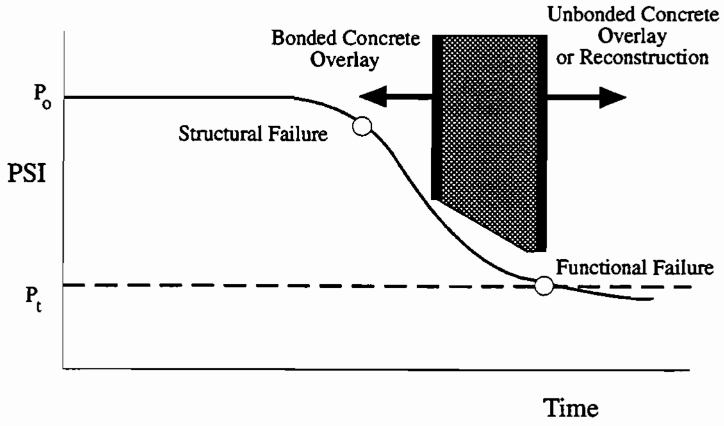


Figure 3.2 PSI performance curve illustrating structural and functional failure and the criteria for bonded or unbonded overlays

In Figure 3.2, the term *functional failure* describes a pavement that has become unsafe or uncomfortable, while the term *structural failure* describes a pavement that has reached a preselected level of distress (e.g., cracking or punchouts). As indicated in the graph, a BCO can be applied after *structural* failure has occurred, but it is generally not feasible after *functional* failure has occurred. Again, subjective judgment must be used to determine the type of failure.

If functional failure has not occurred, then the designer must consider whether the advantages of a BCO outweigh the limitations outlined in Table 1.1. If this is the case, then the designer moves through the project selection process by first considering the ride quality, the punchout, the repair criteria, and, finally, the deflection criteria. If the project successfully meets these criteria, then a BCO overlay is probably the optimum solution. If at any point the criteria are not met, then a BCO is probably not the optimum solution, and other methods should be used.

3.2 RIDING QUALITY

Having obtained PSI measurements from such instruments as the Mays Meter, Siometer, and/or a profilometer, the engineer may use Figure 3.3 to determine whether a BCO should then be applied to an existing PCC pavement. If the PSI is less than 2.5, then structural failure has probably occurred or is imminent, and thus a BCO would not be recommended. For a PSI range of 2.5 to 3, the construction of an overlay is marginally advisable, with the success or failure of the overlay depending much on how long after the PSI measurement the actual construction is undertaken. If there is a long delay, then a high probability exists that the pavement will deteriorate rather rapidly and move into the "poor" zone (and thus a BCO should not be applied). If it is to be a short duration, the BCO reliability improves greatly. Finally, from PSI 3.0 to 3.5, the reliability is very good; above 3.5 it is excellent (approaching 100 percent reliability). The only problems within this last range will be those resulting from poor construction (see Chapter 5).

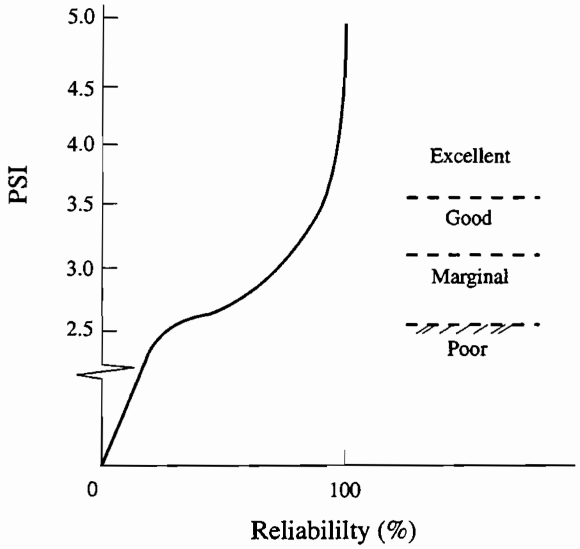
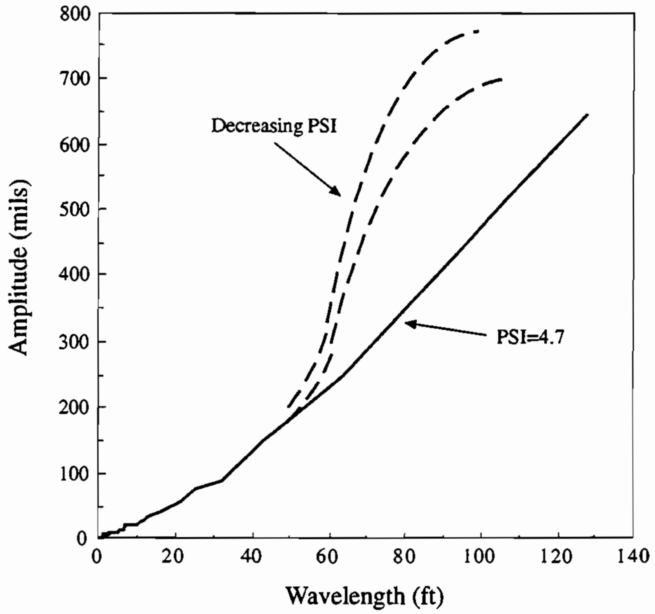


Figure 3.3 Reliability of a successful BCO application estimated in terms of PSI (riding quality)

The use of Figure 3.2 criteria is not recommended for those special cases in which the loss of riding quality (i.e., PSI) is due to deep soil movements (e.g., swelling clay or differential settlement). In most of these cases, the pavement is still structurally sound, even though the riding quality may be low. Thus, the application of a BCO may still be an acceptable activity and would be a very reliable choice. Such a special case is illustrated by Figure 3.4, a diagram obtained from a GM profilometer analysis that shows the amplitude as a function of the wavelength. The solid line represents a pavement in good shape, in this case a PSI equal to 4.7. If swelling clay action occurs, it generally occurs with the longer wavelengths and, hence, deterioration occurs, as shown by the dashed lines. Short wavelengths, less than 6.096 m (20 feet), will probably remain the same, indicating the pavement structure is still in excellent shape. The plot of the data obtained from the profilometer will indicate the degree of swelling action.

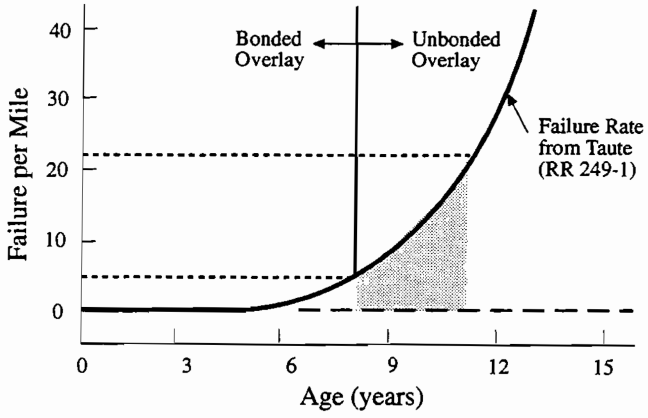


1 mil = .025 mm
psi=6.89476 kPa
feet=0.3048 meters

Figure 3.4 Roughness vs. wavelength showing PSI deterioration with swelling clay action

3.3 PUNCHOUT AND REPAIR CRITERIA

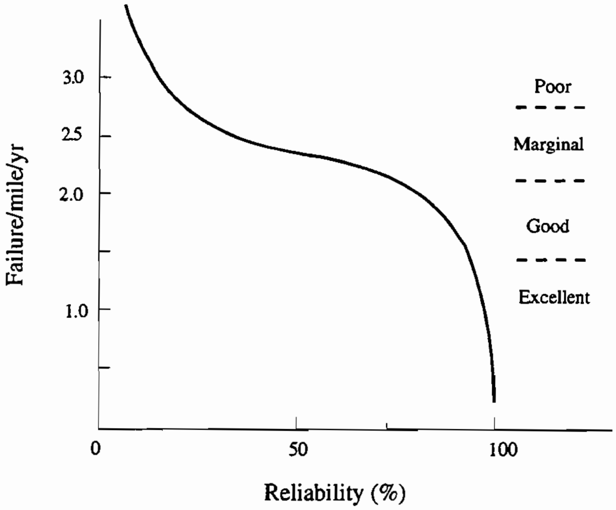
Gutierrez has shown that PSI measurements are not the most appropriate method of establishing failure within CRC pavements (Ref 20). His study found that, owing to excellent riding quality after repairs were made, the districts were overlaying the pavements well before a PSI value of 2.5 was experienced. The districts were basing decisions on the cost of the repairs. A follow-up study by Taute examined the failure history of all the CRCPs in Texas using plots of failure per mile versus age, with a typical example shown in Figure 3.5. (Ref 21) The study found that, when the slope of the line reached three failures per mile per year, the district generally overlaid the pavement, since the failure rate (i.e., cost of repairs) was considered excessive. In Figure 3.5, the "elbow" of the graph occurs at approximately 8 years. Depending on circumstances, this may occur anywhere from 6 to 30 years. As indicated in the figure, this is probably a breakpoint for selecting between bonded and unbonded overlays. If the failure rate is substantially below this value, then a successful BCO application is highly probable.



1 mile =1.609344 km

Figure 3.5 Use of repairs and punchout performance curve as criteria for bonded or unbonded overlays

Figure 3.6 shows the reliability of a successful BCO application in terms of an annual failure rate. As shown in the figure, anything greater than 3 is rated poor, whereas a rate of less than 1.5 is excellent. The marginal area shows a rapid change in reliability, since the annual failure rate may increase rapidly from year to year; any delay in the overlay will put the project in the "poor" range of reliability. This concept may be applied by simply counting the failures per mile on a project over a couple of years and monitoring it to establish the general rate. Another method is to count the total failures per mile and then plot them in terms of age and with one year's estimate of the repair rate.



1 mile =1.609344 km

Figure 3.6 Reliability of successful BCO application estimated in terms of annual failure rate

3.4 DEFLECTION CRITERIA

Van Metzinger et al. (Ref 17) equated different deflections at the crack and at the midspan for various pavement stiffnesses at the midspan. The deflection ratio at the crack versus that at midspan was obtained and plotted against the stress ratio between the maximum tensile stress in the overlay divided by full interlock transverse stress in the existing pavement. The results are shown in Figures 3.7 and 3.8, which depict concrete with limestone and siliceous river gravel coarse aggregates, respectively.

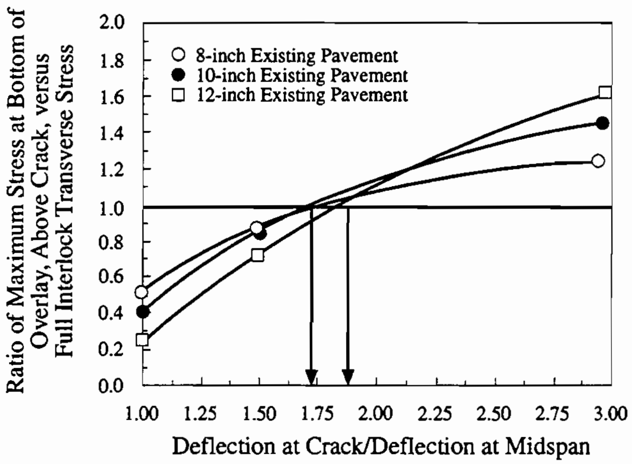


Figure 3.7 Use of the crack midspan deflection ratio as criteria for bonded or unbonded overlay–limestone coarse aggregate concrete (1 in.=2.54 cm)

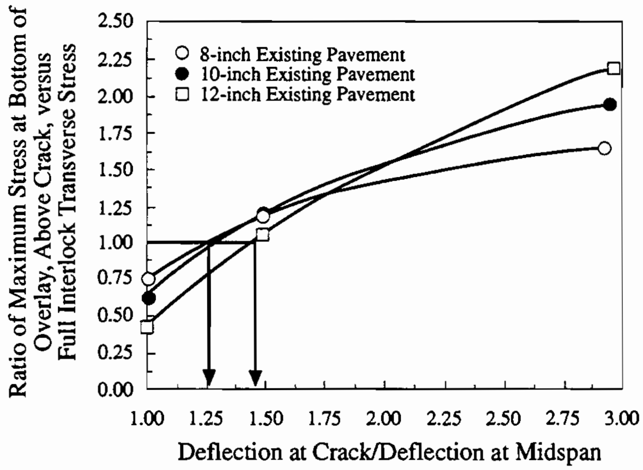


Figure 3.8 Reliability of successful BCO application estimated in terms of annual failure rate–SRG coarse aggregate concrete (1 in.=2.54 cm)

The figures illustrate that, if the deflection ratio for limestone aggregate is between 1.5 and 1.75 for 20.32 to 25.4 cm (8 to 10-inch) pavements, and between 1.6 and 1.85 for 30.48 cm (12-inch) pavement, then the BCO falls into either the "marginal" or "good" condition. The ratios for the siliceous river gravel aggregate are 1.25 and 1.4 for the same thicknesses of pavement. Thus, if the criteria presented in Figures 3.3 and 3.6 are used, any deflection ratio at the crack between crack stress ratios of around 1.0 falls into the "excellent" category.

3.5 SUMMARY

If the engineer determines the pavement condition meets the criteria outlined in this chapter, then the project is an acceptable candidate for a bonded concrete overlay, and in all probability that particular method will be the optimum solution. If any of the tests fail to meet the criteria, then an unbonded concrete overlay may be more applicable.

CHAPTER 4. THE DESIGN PROCESS

The objective of the BCO design process is to develop a pavement structure that, first, reduces critical stresses to an acceptable level and, second, acts as a single integral unit to provide consistent performance throughout the design life. To accomplish this twofold objective, the pavement engineer constructing a BCO must identify the overlay thickness that is appropriate to the existing pavement's condition; additionally, material properties, projected 80-kN (18-kip) ESALs, and the environmental conditions experienced both during the life of the facility and during the initial construction phases must also be considered. This chapter describes the three phases of the BCO design process, namely, the determination of the thickness of the portland cement concrete overlay, the development of the reinforcement, and the specification of an adequate interface condition. Chapters 5 and 6 will consider additional factors that must be included in the specifications and in the construction process.

4.1 THICKNESS DESIGN

The primary assumption implied in the design process is the existence of a structurally sound pavement (as described in Chapter 3). Thus, the overlay thickness is a function of the layer thicknesses, material properties, projected traffic, and an estimate of the remaining life. Figure 4.1 illustrates the various thicknesses considered, as well as the material properties (in terms of the stiffness or modulus of elasticity of each layer).

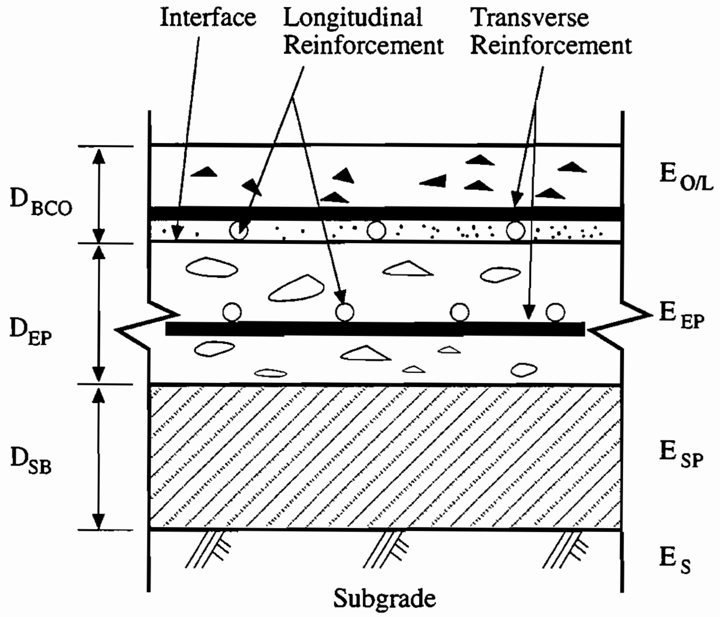


Figure 4.1 Typical section of BCO with essential design elements

The thickness design procedure is reported as a part of the computer program in Appendix A and is illustrated in Figure 4.2. These design steps may be briefly summarized as follows:

1. The primary factor in design criteria is the design life anticipated, which, for practical purposes, should be between 20 and 35 years. If other major rehabilitation is anticipated, the design life should be on the low side; if the facility is expected to operate as is, then the longer design life should be selected. After determining the design life, the projected 80-kN (18-kip) ESALs should be obtained from the Planning Division.
2. A detailed condition survey should be conducted to record any punchouts or longitudinal cracks that should be repaired (as described in Chapter 7). The reinforcement for wide longitudinal cracks is discussed in the next section.
3. The deflection test should be performed at 30.48-m (100-foot) intervals using the FWD or the Dynaflect. The deflection at midspan and at the crack should be plotted separately as a function of distance. In addition, the ratio of the deflection of the crack to midspan should be plotted (as described in Chapter 3).
4. The deflection plots are evaluated to determine areas of approximately equal response or deflection. Statistical testing may be used to ascertain if the areas are statistically different. Each of these areas is then labeled as a design section. The condition survey information is superimposed on this to determine if these areas should be treated in a different manner (i.e., nonbonded, different overlay thicknesses, etc.). This will depend on existing conditions and length of the project.
5. The deflection information is then used to compute the modulus properties for each of the existing layers. For the overlay, the modulus of elasticity may be developed using the procedures described by Dossey (Ref 23).
6. The remaining life of the existing pavement may be determined using the program developed by CTR for CRCP (Ref 30), the procedures outlined in the *AASHTO Pavement Design Guide* (Ref 23), or the procedures developed by Taute (Ref 13). The CTR program (Ref 30) uses a combination of crack spacing distribution, observed punchouts, 80-kN (18-kip) ESALs, and the deflection behavior to predict the consumed and remaining life. (See Appendix B for a more detailed description of the process.)
7. Using the computer program in Appendix A, the overlay thickness can be developed for each design section, as illustrated in Figure 3.3. This figure is obtained by first assuming an overlay thickness; then, computing the allowable traffic after plotting this life curve, the projected 80-kN (18-kip) ESALs may be entered and the minimum overlay thickness selected. This process is repeated for each design section.
8. Selection of design thicknesses will depend on the project length. With current slip form pavement equipment, adjustments in overlay thickness can be made, though the practical aspects of this must be considered along with the need to maintain riding quality.

4.2 REINFORCEMENT DESIGN

A structurally sound pavement generally has adequate reinforcement. Thus, the designer should reinforce the BCO in a way that simulates the reinforcement of the existing pavement, as shown in Figure 4.1. To expedite construction, the reinforcement may be placed at the interface between the overlay and the existing pavement, since laboratory studies have shown that reinforcement placed at the interface develops the same bond capabilities as reinforcement placed in the middle of the overlay. Placement of the reinforcement at the interface also eliminates the risk of concrete honeycombing and poor consolidation beneath the steel. (The field projects described in Chapter 2 verify these laboratory studies.)

If it is necessary to change the longitudinal percentage, or if wide longitudinal cracks are present in the pavement, then the longitudinal steel and/or the transverse steel should be redesigned.

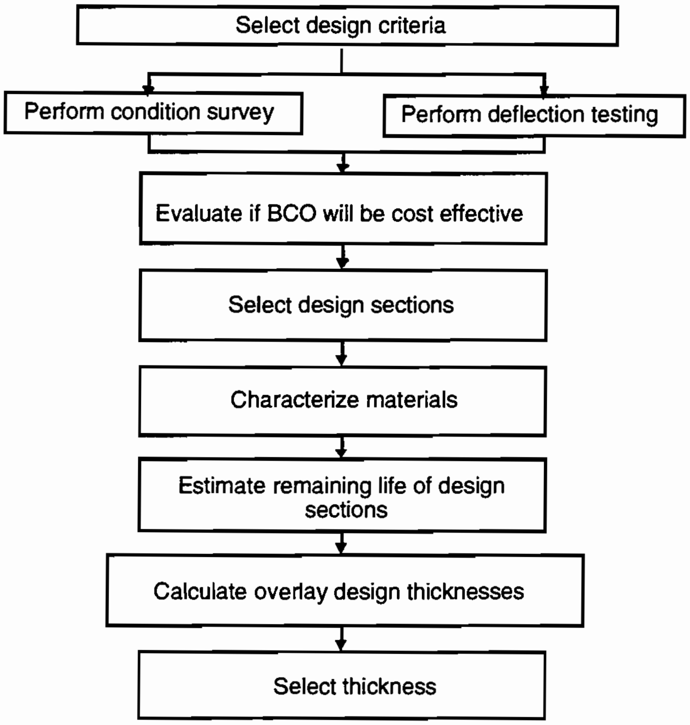


Figure 4.2 Outline of the thickness design procedure (see Appendix C)

4.2.1 Longitudinal Reinforcement

The CRCP program analysis should be performed as described by Won et al. (Ref 24) and by Suh et al. (Ref 25). First, the designer uses the program to replicate the existing crack spacing by inputting the existing steel percentage, past concrete properties, and past environmental conditions. Then, the total pavement structure considering the overlay should be investigated by varying the percentage steel design input in the program. The result in crack spacing will be similar to the combination of the reflective crack of the existing pavement and the new pavement.

4.2.2 Transverse Reinforcement

If longitudinal crack widths or longitudinal joint widths are excessive, then the transverse reinforcement should reevaluated. While the reinforcement procedure described in the *AASHTO Pavement Design Guide* may be used, it would be better to use the friction values developed by Wimsatt et al. (Ref 26), since these more realistically portray Texas conditions. Once the steel percentage is developed, this additional steel must be placed across the transverse crack to firmly tie it together; the crack is then filled using techniques described in Chapter 7. A similar technique should be used for longitudinal joints if failure has occurred.

4.3 INTERFACE DESIGN

Researchers at CTR found that early-age stresses are relatively low compared with the normal range of tensile stresses thought to cause failure in concrete. However, superimposing these stresses and comparing them with the available strength at the interface can reveal a potential for delamination (Refs 17, 27). The CTR studies concluded that shear and tension stresses are generally low at the interface, and that delamination should not occur if proper controls are applied. For example, if the change in temperature from the high during placement to the low following placement is less than 14° C (25° F), then the bond should be adequately strong. If the change in temperature is greater than 14° C (25° F) and the construction cannot be suspended, then the stress conditions used in the program developed by CTR (Ref19) should be applied for proper criteria. Since the drop in temperature causes higher stresses in concrete placed during the middle of the day, night placements will reduce the total temperature decrease and minimize the problem.

4.4 LIFE-CYCLE COST ANALYSIS

The user guide for the computer program outlined in Appendix A will provide a life-cycle costs analysis. Other design combinations can be made with the program (i.e., unbonded concrete overlays, etc.) to ensure that the optimum design is achieved over the analysis period.

CHAPTER 5. SPECIFICATIONS

This chapter recommends specifications to be included in BCO construction guidelines. These specifications, based on work by CTR (Refs 11, 15, 27), will be reported in terms of materials and mixtures, surface preparation, bonding agents, placement conditions, curing, and quality control/quality assurance tests.

5.1 MATERIALS

This section discusses the coarse aggregate, cement, and admixtures recommended for use in a BCO.

5.1.1 Coarse Aggregates

The coarse aggregate used in a BCO should have a coefficient of thermal expansion no higher than that used in the existing pavement. For example, while it is acceptable to place a limestone coarse aggregate concrete over an existing siliceous river gravel concrete, the reverse arrangement would render the pavement susceptible to delamination.

The maximum size coarse aggregate should be compatible with the overlay thickness. It is generally recommended that the size of the coarse aggregate be no greater than 1/3 the thickness of the overlay.

5.1.2 Cement

The concrete should be Type 1 portland cement. This cement develops less heat from hydration and, hence, avoids many of the problems associated with hydration heat. If it is necessary to expedite the placement, then Type 3 cement may be used (though placement of this concrete during the summer should be avoided; if summer placement is necessary, then it should be placed at night).

5.1.3 Admixtures

While it is acceptable to specify admixtures (e.g., superplasticizers) to increase workability and strength, any admixtures that *retard* strength development should be avoided. In all cases, preliminary bond tests should be conducted with similar concretes — both with and without the admixtures — to ensure that comparable strengths are obtained at early ages.

5.2 SURFACE PREPARATION

For substrate surface preparation, equipment capable of heavy shotblasting should be specified. This equipment should remove a significant amount of mortar matrix around the aggregate, leaving the coarse aggregate itself intact (except in cases where the coarse aggregate is softer than the mortar matrix). Cold milling is acceptable, though since it cracks and breaks the coarse aggregate, neither good texture nor overall pavement soundness is achieved with the heavy shotblasting; bond strengths are, consequently, typically lower.

The designers should specify that the depth of the cut and texture required must expose clean, sound substrate. Typical cuts should be 0.63-cm (1/4-inch) deep into the coarse aggregate. Typical texture readings from the Texas Sand Patch Method (Ref 15) are between 0.127 cm (0.050 in.) and 0.24 cm (0.095 in.).

Even with a clean, sound substrate, additional precautions may be required to ensure the best performance for BCO (especially when placed under adverse environmental conditions). Among these additional precautions are the following:

1. use of epoxy bonding agents for any substrate texture (especially effective on surfaces where less expensive light shotblasting only is to be used), or for heavy texture in the substrate surface resulting from severe shotblasting (for non-epoxy bonding agents or no bondings agents); and
2. the use of power nails or other shear reinforcement at the edge of the pavement to provide a resistance to delamination of the pavement.

5.3 BONDING AGENTS

Under normal conditions, it is recommended that the pavement surface be dry and that the BCO concrete be placed without a grout boundary agent. If the existing pavement is wet, then a grout should be used. These combinations will provide the optimum shear strength at the interface. For special conditions (discussed in section 5.2 above), epoxies may also be used to improve strength.

5.4. PLACEMENT CONDITIONS

Paving should be avoided — or conditions should be artificially improved — whenever the following environmental conditions exists:

1. high surface temperature (over 51.67° C or 125° F) on the substrate immediately prior to placement of the overlay;
2. ambient temperature variations of more than 13.89° C (25° F) during the 24-hour period immediately following the placement of the overlay; and/or
3. water evaporation rates that exceed 0.1 $kg/m^2/hr$ (0.2 $lb/ft^2/hr$), when calculated according to the ACI procedure (Ref 28).

5.5 CURING

The curing requirements associated with conventional concrete pavement specifications should be revised to ensure that excessive evaporation of bleed water from the surface does not occur. Studies of new concrete pavements and BCO placement conditions found that, with excessive water evaporation conditions, there is a high probability that crack spalling will be excessive and that delamination of the BCO from the existing surface will occur within the first 24 hours. Thus, it is imperative that the curing compound be placed immediately after the initial sheen of water evaporates from the surface. It is also recommended that a double application of the curing compound be used. Under extreme environmental conditions, the use of cotton batting should be considered and provisions provided for keeping the batting wet through the first 48 hours.

5.6 QUALITY CONTROL AND QUALITY ASSURANCE TESTS

To maintain BCO strength, it is recommended that the splitting tensile test be used (as an alternative to the flexural test). The specifications used should be in accordance with the values used in the design analysis outlined in Chapter 4.

It is difficult to specify a bond test, since studies have shown that most debonding is induced at relatively low stresses (under 3.45 kPa, or 50 psi), while the overlay is still in its early curing stage. Fortunately, the curing bond is adequate under most conditions. *Un*fortunately, once the overlay has obtained sufficient cohesive strength to be cured and tested, either it has performed satisfactorily or it has debonded because of insufficient strength. At the present time, the best method for monitoring the bond strength in the field is a modified ACI 503 pullout test. Hopefully, the maturity method will provide for better monitoring of bond strength.

The maximum surface water evaporation rate should be limited to 0.1 kg/m^2/hr (0.2 lb/ft^2/hr) and calculated according to the ACI procedure previously described.

CHAPTER 6. CONSTRUCTION CONTROL

This chapter describes the procedures and monitoring steps required in BCO construction control. Such monitoring involves taking measurements, recording field information, calculating certain construction parameter limits, maintaining records, and informing TxDOT when environmental limits are exceeded. Technicians charged with monitoring should also be responsible for running computer programs in the field, in order to keep the engineer apprised of critical problems. The following sections cover the procedures for construction monitoring.

6.1 PROCEDURES FOR CONSTRUCTION MONITORING

Paving operations require close communication and cooperation between the contractor and the TxDOT engineer. Particular procedures required for monitoring ambient temperature differentials, evaporation, and other data as required by the specification and the design have been discussed in previous chapters.

6.1.1 Ambient Temperature Differential

When paving operations are underway, the technician should each day obtain the official National Oceanic and Atmospheric Administration (NOAA) daily low temperature forecast for the next 24 hours. The predicted low should be compared against the ambient temperature recorded during paving. Whenever the ambient temperature approaches a reading 13.89° C (25° F) higher than the expected low for the next 24 hours, the engineer should be advised.

6.1.2 Evaporation Monitoring

Because of the complexity of the evaporation computation, a microcomputer with the appropriate software should be available so that field data can be continuously entered and the desired information obtained. The technician should have available a small weather station that records ambient temperature, relative humidity, and wind speed. In addition, the temperature of freshly placed concrete should be obtained and input. Using this information and a proprietary program, the computer can calculate the evaporation rate in lb/ft^2/hr. When the evaporation rate approaches 0.1 kg/m^2/hr (0.2 lb/ft^2/hr), the engineer should be notified. When conditions exceed the evaporation rate limit early in the day, the contractor should shut down paving operations for the rest of the day. Later in the day, special precautions can be taken (as described in section 5.5).

6.1.3 Additional Required Data

The technician should also record texture measurements and substrata temperatures to ensure that the maximum values are not exceeded. If possible, the technician should also conduct interface bond tests and other quality assurance tests.

6.2 MONITORING EQUIPMENT

Microcomputers should be used for storing data, computing the evaporation rate during curing, and generating daily reports for the engineer and for project files. Some information can be obtained through the use of a thermocoupler installed in the pavement; a field logger capable of transmitting data via modem to a remote personal computer should also be considered. Telemonitoring equipment eliminates the roadway clutter created by cables and wires.

CHAPTER 7. MAINTENANCE PROCEDURE

The implementation of a BCO requires that certain pavement distresses be corrected before actual placement; otherwise, these distresses will be reflected through the new surface to create similar failures. Problems that require special attention are wide longitudinal and transverse cracks, and opened longitudinal joints that threaten the integrity of the transverse reinforcement across the joint. The following sections address these particular items.

7.1 PREPARATION TECHNIQUE FOR WIDE CRACKS

A polymer or monomer system may be used to repair the PCC. Longitudinal cracks may be routed or blasted to allow placement of polymer mortar. A single-piston pneumatic crack router is the best equipment available for enlarging the crack. The 1.905-cm (0.75-inch) diameter bit can enlarge the crack to a width of 2.54 cm (1 inch) in a single pass. Depth should not be greater than 1.905 to 2.54 cm (0.75 to 1 inch).

The polymer is placed by first filling the enlarged crack with a clean, dry concrete sand, and then pouring the methyl methacrylate (MMA) monomer system over the sand until it (the sand) is completely saturated. The monomer system should consists of 95 percent of MMA and 5 percent trimethylol propane trimethacrylate (TMPTMA). Benzoyl peroxide (BzP) initiator in dispersion form may be added at a level of 1 percent by weight of monomer for ambient temperature conditions.

The monomers should be reapplied to keep the sands saturated (since some monomer will be lost as a result of evaporation and leakage through the cracks). The primary objective is to have the monomer penetrate the crack to bond the concrete.

7.2 REOPEN LONGITUDINAL JOINT

Load transfer must be reestablished between slabs when the longitudinal joint is opened excessively. This may be achieved by stitching the two sides of the crack together. In this context, stitching refers to cutting slots in the pavement perpendicular or diagonal to the joint. The open joint should then be filled with a fibrous cement grout or epoxy, as indicated earlier in this report. The slots are necessary for placing reinforcing bars across the joint; the slots are then filled with an epoxy concrete (Ref 20).

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Appendix A

Design and LCC Analysis Procedure

USER'S GUIDE
FOR
PROGRAM RPRDS-1

A DESIGN SYSTEM FOR RIGID PAVEMENT REHABILITATION

by

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conducted for

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

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TABLE OF CONTENTS

1. INTRODUCTION

PRDS-1 incorporates a number of pavement design and analytical models for the generation, analysis, and comparison of numerous pavement design strategies. Only structural rehabilitation, specifically overlay construction, is considered. The design model used is an improved and extended version of the ARE, Inc./FHWA and Texas State Department of Highways and Public Transportation rigid pavement overlay design procedure. The development of this version is described in Research Report 249-2,"A Design System for Rigid Pavement Rehabilitation", by S. Seeds, B. F. McCullough, and W. R. Hudson. This improved and extended version was developed at the Center for Transportation Research at The University of Texas at Austin.

Provision is also made within the program to consider Asphalt Concrete Pavements (ACP), Continuously Reinforced Concrete Pavement (CRCP), and Jointed Concrete Pavement (JCP) type overlays; concrete shoulder construction; and variable concrete flexural strengths and variable overlay thicknesses.

A number of feasible overlay design strategies, based on user input, are generated and a present value cost analysis is performed on each of these strategies. The optimal economical strategies are then presented, based on the net present value cost of construction maintenance, rehabilitation, user delay, and salvage value.

The program also uses the following design and analytical models to perform the analysis: a distress/maintenance prediction model, a traffic delay cost model to calculate cost of delay during overlay construction, and a model for the prediction of overlay cost.

2. USING THE PRDS-1 PROGRAM

The program can be used with any standard IBM or IBM compatible personal computer with a mathematical co-processor. On the XT models the program will run approximately 45 minutes, whereas AT and PS/2 models reduce the running time to 20 minutes.

The program uses only one 360k floppy disk. Prior to using the program a second copy should be made by the user as a back-up copy to the original. This is done as follows:

Making Back-up Copies of the Original:

(a) For a duel disk drive PC:

When the computer is switched on with the system disk in Drive A, it will give an A> prompt. Put a new double sided, double density disk in Drive A and type the command

```
A>FORMAT A:
```

Press ENTER and the computer will format the new disk. After the formatting process is finished, put the formatted disk in Drive B and the original disk in Drive A and type the command

```
A> DISKCOPY A: B:
```

All information on the disk in the Drive A will now be copied to Drive B.

(b) For a single disk drive PC with a hard drive.

The same formatting process is used as in (a) above. Put the original disk in Drive A. Type the command

```
C>DISKCOPY
```

The computer will ask you to put the original copy in the drive and to press ENTER. It will then ask you to put the empty formatted disk in the drive and will then copy the original to the disk.

The back-up copy should be stored in a safe place and not used except if problems with the original are found.

Starting the Program

Type the command

```
C>A:PRDS
```

This will start the program and ask for certain input values. The file PRDS.BAT on your program disk is configured as if the computer is connected to a printer. If no printer is connected an error message will be displayed. The PRDS.BAT file can be edited so that the program will run without a printer. This is, however, not advisable due to the length of the output. Also on the program disk is a file called REHAB.DAT. This file is an example input file and could be edited. If the user wants to keep the REHAB.DAT file he should save the edited version under another filename.

Default values for each variable are fixed in the program. The values used, such as construction costs, are estimated costs for Texas in 1988. These default values are listed in the screens shown in this guide. There are, however, values needed for program execution, which does not have default values. These values should be entered by the user.

3. PROGRAM INPUT

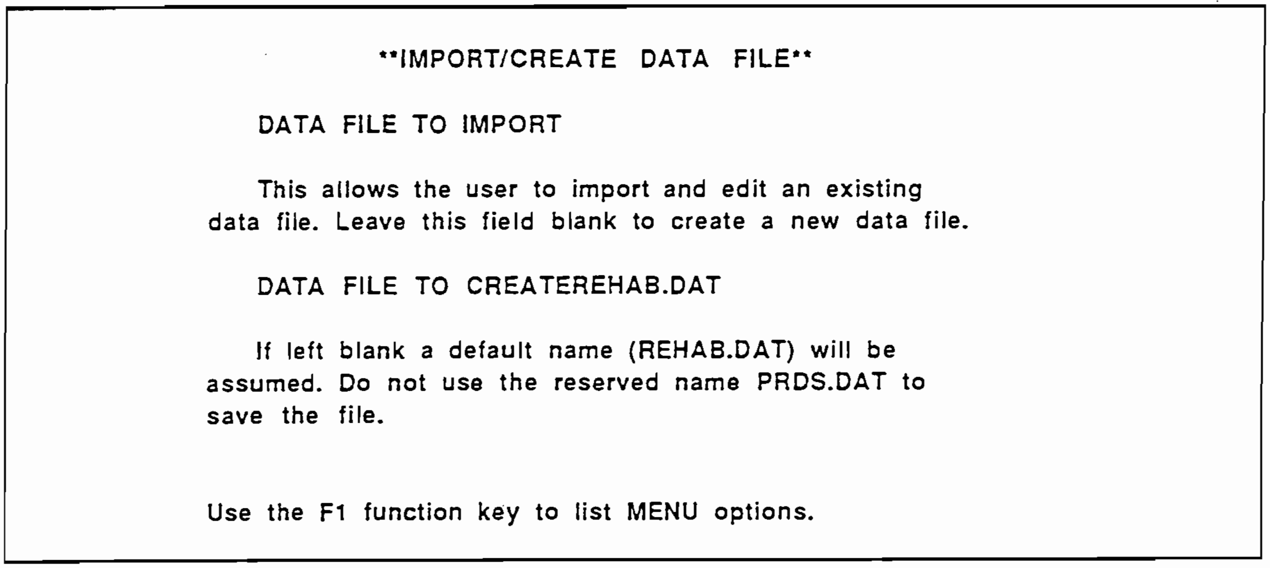
As soon as the execute command is given, the program will prompt the user for certain information and input values. The first screen page shows the program name and developers. From then on, each screen will ask for some input data. The following paragraphs describe the needed input, and the computer input screens are shown with the different input categories. Some of the input values are not necessary, depending on the strategies analyzed. The user should ascertain that all necessary input values are completed before the analysis is started. If the user is changing only one section of the input data of the file REHAB.DAT, or if he created a new file, completed the necessary input values, and wants to use the default values, such as cost values, for the rest of the program, he could terminate the edit session by pressing F1, which will prompt the program MENU. The input data are divided into 11 broad categories, namely:

A. Project Description,
B. Original Pavement, (2-3; 7-8; 4-6)
C. Traffic Variables, (9)
D. Time Constraints, (10)
E. Remaining Life Variables,(11-12)
F. Overlay Characteristics, (13-41)
G. Overlay Construction Cost Variables, (42-49)
H. Traffic Delay Cost Variables, (50-54)
I. Distress/Maintenance Cost Variables, (55-58)
J. Cost Returns, (59) and
K. Combined Interest and Inflation Rate (60).

Figures 1 show flowcharts of the specific input variables with relation to program execution, and the input screens.

The first input the user should give is either the name of an existing file or a name for a new file. If an old filename is used, the file can be edited and reused in the analysis. To create a new dataset, a new filename should be used. Screen 1 shows the input screen for the filenames. The filename should consist of not more than eight letters or numbers and an extension of not more than three, as shown in the example name:

PAVEMENT.DAT



```
                **IMPORT/CREATE  DATA  FILE**

        DATA  FILE  TO  IMPORT

        This  allows  the  user  to  import  and  edit  an  existing
     data  file.  Leave  this  field  blank  to  create  a  new  data  file.

        DATA  FILE  TO  CREATEREHAB.DAT

        If  left  blank  a  default  name  (REHAB.DAT)  will  be
     assumed.  Do  not  use  the  reserved  name  PRDS.DAT  to
     save  the  file.

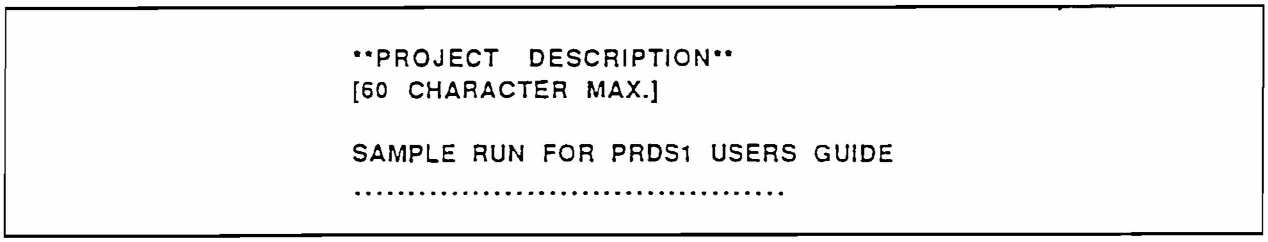

     Use  the  F1  function  key  to  list  MENU  options.
```

Screen 1: Data File Input

One or more data variables are required for each of the categories mentioned above and are discussed in the following paragraphs.

A. Project Description

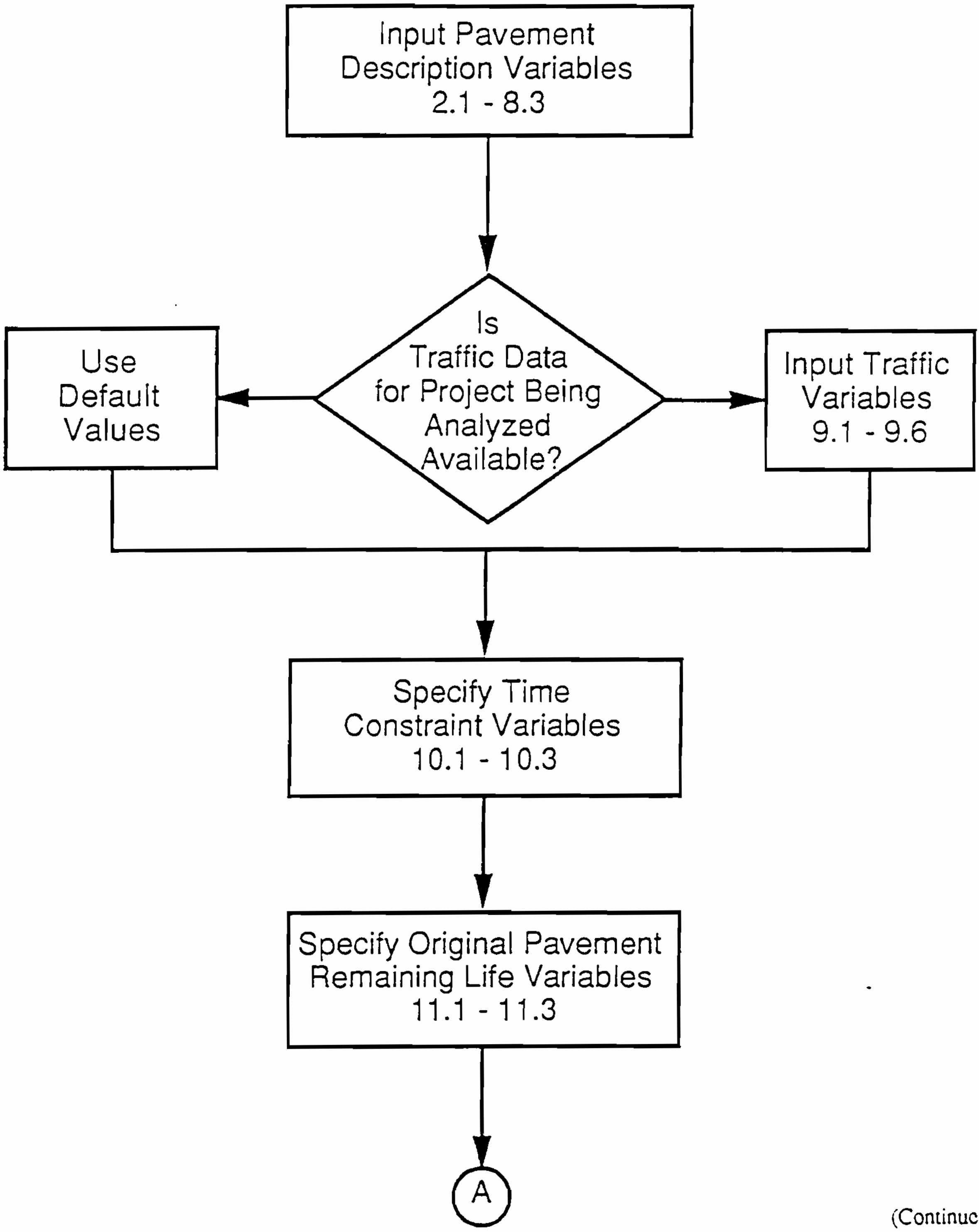
The project description, shown on Screen 2, should consist of not more than 60 characters and should provide information about the type, location, and date of the project, as well as the initials of the user, if possible.



```
**PROJECT  DESCRIPTION**
[60  CHARACTER  MAX.]

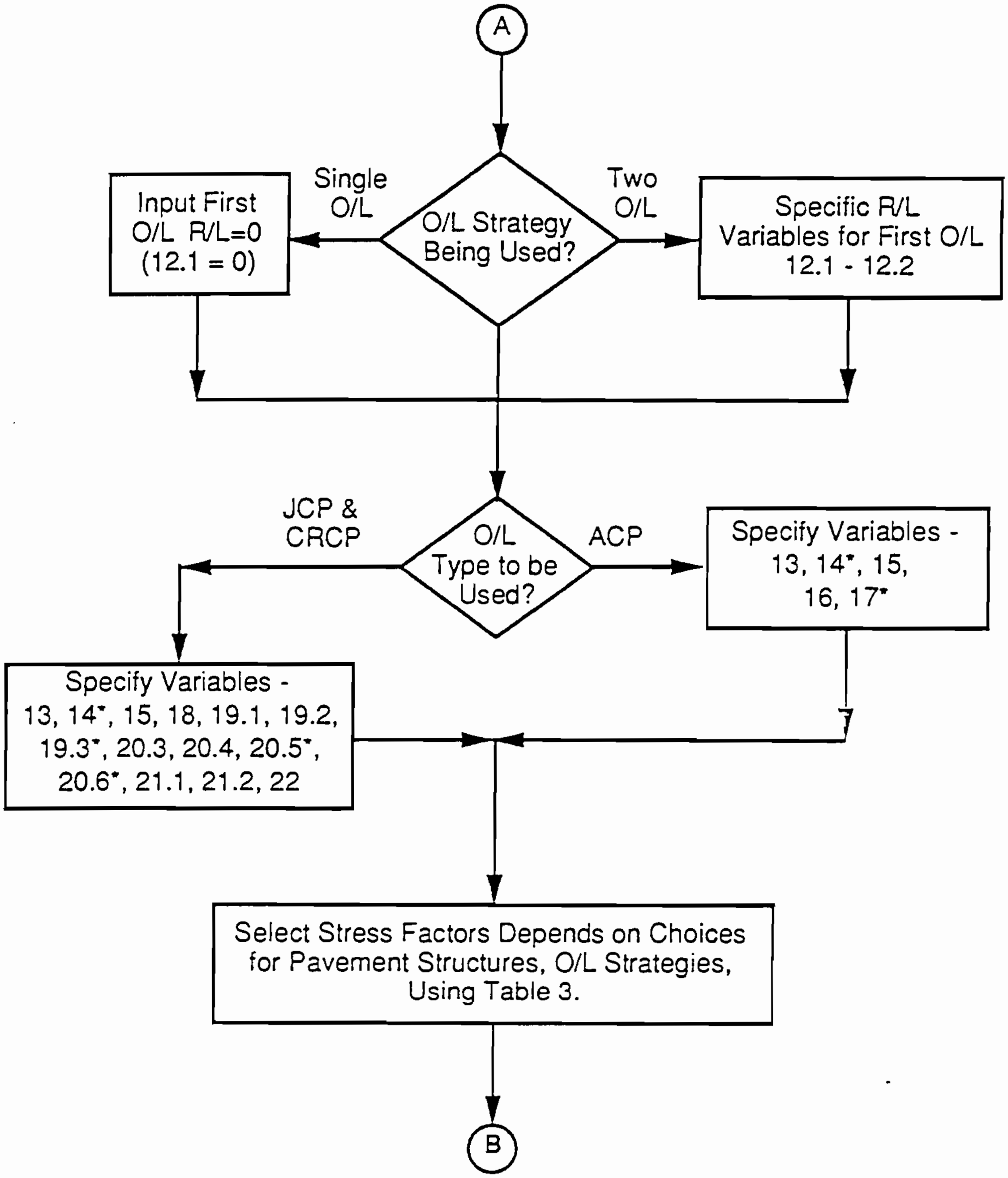
SAMPLE  RUN  FOR  PRDS1  USERS  GUIDE
........................................
```

Screen 2: Project Description



(Continued)

Fig 1. Flowchart of program execution.



(Continued)

Fig 1. (Continued).

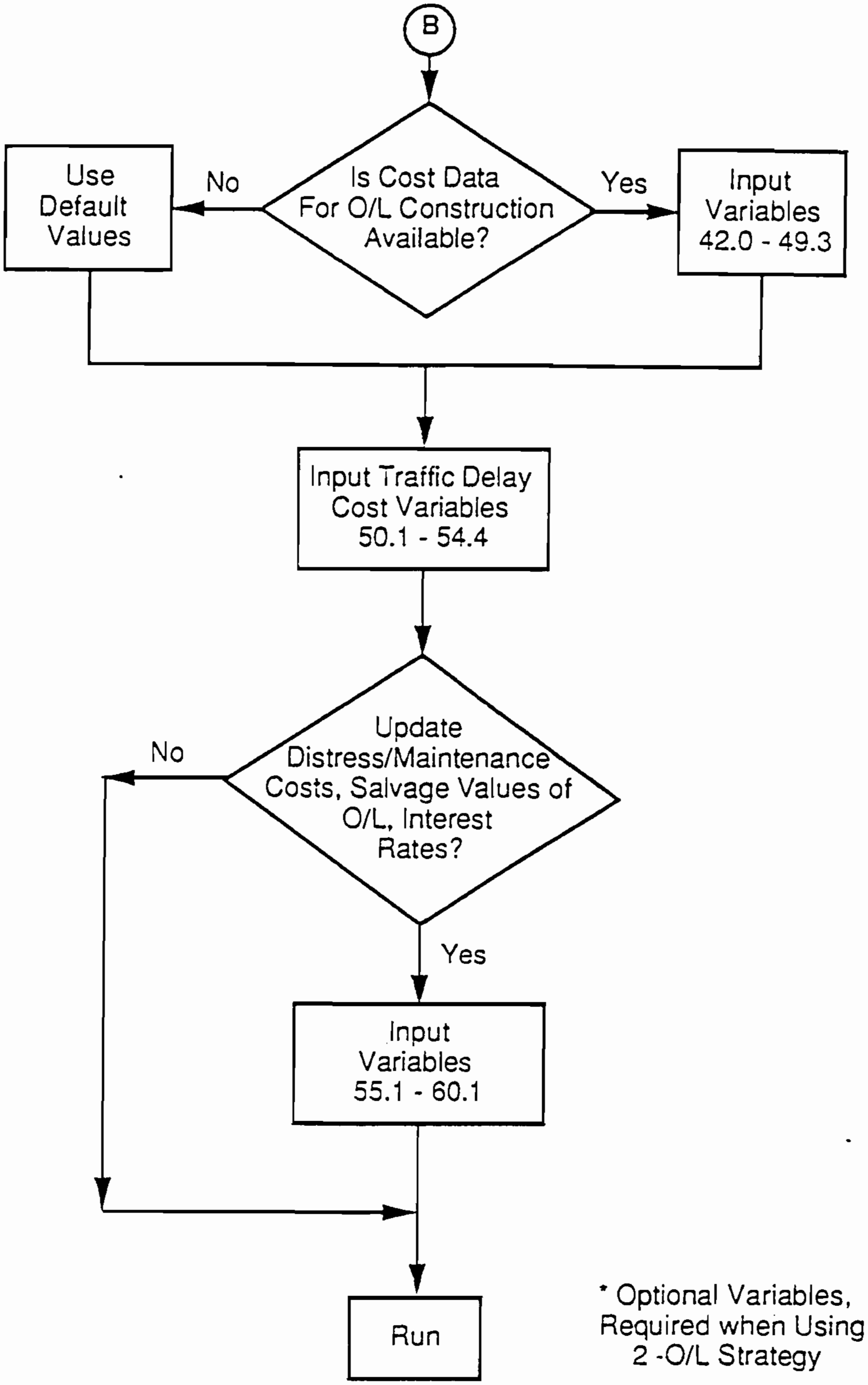


Fig 1. (Continued).

B. Original Pavement

The following input as shown on Screen 3 are required regarding the original project and original pavement structure:

```
**ORIGINAL PROJECT**

2.1  SURFACE TYPE.........................................................   JCP
2.2  CONCRETE SHOULDER....................................................    NO
2.3  NO. OF LANES (ONE DIRECTION).........................................     4
2.4  NO. OF PAVEMENT LAYERS...............................................     3
3.1  PROJECT LENGTH, MILES................................................  2.50
3.2  LANE   WIDTH,   FEET.................................................  12.0
3.3  TOTAL SHOULDER WIDTH, FEET...........................................   3.0

**ORIGINAL PAVEMENT STRUCTURE**

7.1  CONCRETE FLEXURAL STRENGTH, PSI......................................   600
7.2  CRITICAL  STRESS  FACTOR.............................................   1.4
7.3  CONCRETE STIFFNESS AFTER CRACKING, PSI...........................500000.0
8.1  NO. OF EXISTING DEFECTS PER MILE.....................................  10.0
8.2  COST OF REPAIRING A DEFECT, DOL...................................... 2000.0
8.3  RATE  OF  DEFECT  DEVELOPMENT,  NO./YR/MILE..........................   4.0
```

Screen 3: Original Project and Pavement Structure

2.1 **Surface Type.** This variable defines the type of original concrete pavement structure. The variable should either be CRCP (continuously reinforced concrete pavement) or JCP (jointed concrete pavement).

2.2 **Concrete Shoulder.** The input for this variable should be either "Yes" or "No". A pavement with a tied concrete shoulder provides for lower stress and better moisture condition than one without a shoulder. When a shoulder is used the program calculates a lower rate of deterioration.

2.3 **Number of Pavement Lanes.** This variable identifies the number of existing pavement lanes in one direction. It is used to calculate quantity and area of overlay as well as to estimate traffic delay costs during construction.

2.4 **Number of Pavement Layers.** This variable identifies the number of pavement layers (including subgrade) in the original pavement structure. A maximum of five existing layers may be considered.

3.1 **Project Length.** This variable defined the length of the overlay project and may range from one-half-mile sections up to 10-mile sections. It is used mainly to compute overlay quantities.

3.2 **Lane Width.** This variable describes the lane width in feet and is used to calculate overlay quantities.

3.3 Total Shoulder Width. This variable describes the total shoulder width (inside and outside) in feet. It is used to compare the cost of flexible shoulder versus concrete shoulder construction at the time of overlay.

Input value numbers 4, 5 and 6 are shown after input category 8.3.

7.1 Concrete Flexural Strength. This value, in psi, should be representative of the existing pavement's flexural strength over the remaining years of its service life. A value of 500 psi may be used if the existing pavement has less than 10 percent remaining life.

7.2 Critical Stress Factor. This value is used in the PCC fatigue equations to estimate the remaining life of the existing pavement. It represents the ratio of critical stress to the interior stress in the existing pavement. This value should always be specified. Table 1 provides a range of values for different types of existing pavements.

The low level for each category should be used if the results of the condition survey indicate that the existing pavement has performed well. Likewise, a high level should be used if poor performance has been observed..

7.3 Concrete Stiffness After Cracking. This value represents the elastic modulus of the existing PCC after it loses its load-carrying capacity. A value of 800,000 psi is recommended if the existing pavement is CRCP. A range of 300,000 to 500,000 psi is recommended for jointed pavements. The high level should be used normally, unless there is excessive pumping or a high joint to interior deflection ratio (greater than 1.5) has been observed. This variable should not be left blank.

TABLE 1. EXISTING PAVEMENT CRITICAL STRESS FACTORS

Existing Pavement Type	Existing PCC Shoulders	Range of Critical Stress Factor
CRCP	NO	1.20-1.25
	YES	1.05-1.10
JCP (with load transfer)	NO	1.25-1.30
	YES	1.10-1.20
JCP (without load transfer)	NO	1.50-1.60
	YES	1.40-1.50

8.1 Number of Defects. This value is the number of defects (per mile) which are present in the existing pavement. It is used to estimate the cost of repairs which are to be performed on the existing pavement prior to overlay and is not required if these repairs will not be performed.

8.2 Repair Cost. This value should be the total cost for repairing a defect in the existing pavement. It is not required if repairs will not be made prior to overlay.

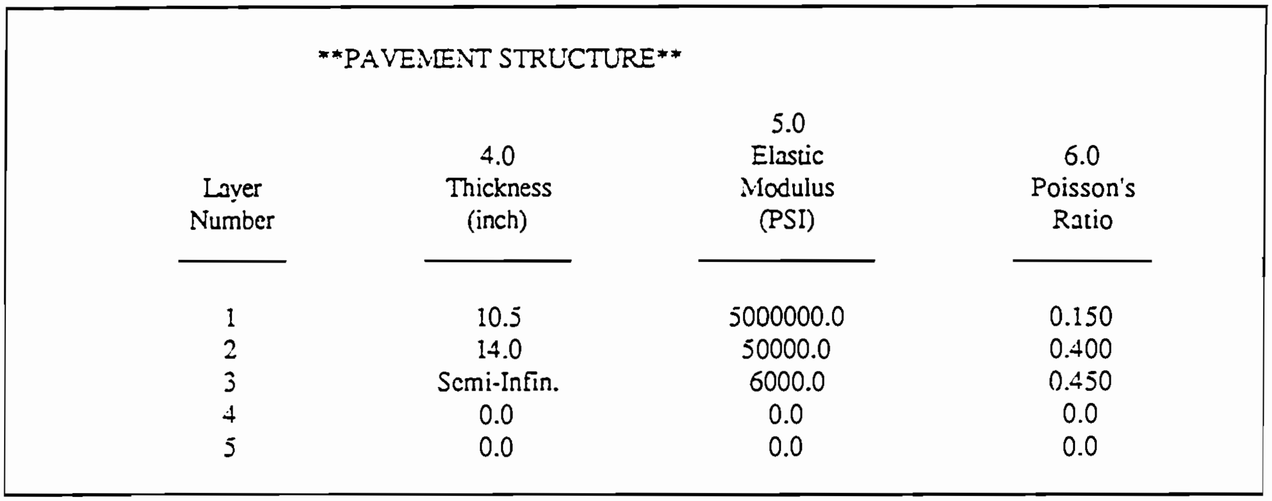
8.3 Rate of Defect Development. This value represents the rate of development of defects over the remainder of the service life of the existing pavement. A value recommended for CRC existing pavements is two per year per mile. This value is not required if repairs are not to be made prior to overlay.

4. THICKNESS, 5.ELASTIC MODULUS, AND 6. POISSON'S RATIO

As mentioned before, input values for categories 4, 5 and 6 are shown after variable number 8. Screen 4 is used for input of these values. The thickness (inches), elastic modulus(psi) and Poisson's ratio for each layer should be specified in the correct columns. The thickness of the bottom layer is always assumed to be semi-infinite, and, therefore, it may be left blank or SEMI-INFIN may be typed. Table 2 lists recommended values of Poisson's ratio for different pavement materials.

Traffic variables relate to truck and vehicles traffic that is to be carried by the facility over the analysis period. Screen 5 shows the input values concerning traffic.

9.1 Average Daily Traffic (ADT). This value should be the present average number of vehicles per day carried by the facility.



PAVEMENT STRUCTURE

Layer Number	4.0 Thickness (inch)	5.0 Elastic Modulus (PSI)	6.0 Poisson's Ratio
1	10.5	5000000.0	0.150
2	14.0	50000.0	0.400
3	Semi-Infin.	6000.0	0.450
4	0.0	0.0	0.0
5	0.0	0.0	0.0

Screen 4: Pavement Structure

C. Traffic Variables

9.2 Growth Rate of Average Daily Traffic . This value represents the yearly rate of growth of average daily traffic.

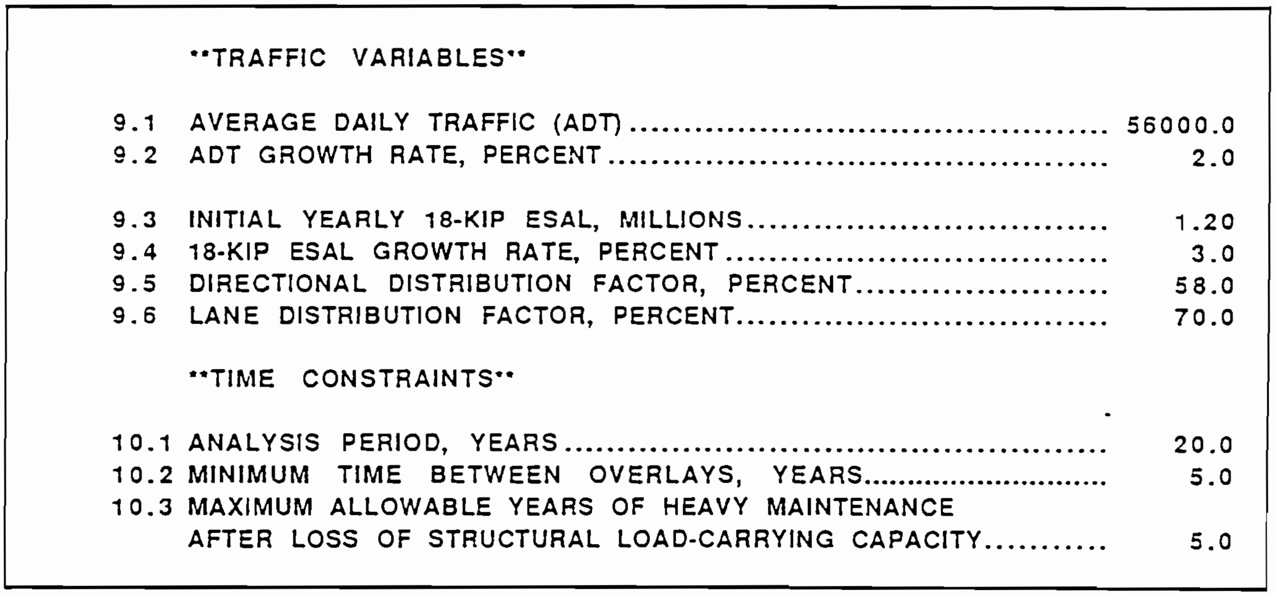
9.3 Initial Yearly 18-kip ESAL. This value is the number of yearly 18-kip equivalent single axle loads (18-kip ESAL) presently being carried by the facility in both directions. This value is always required.

9.4 18-kip ESAL Growth Rate. It projects the growth of 18-kip ESAL over the analysis period, which may be different than that of ADT.

TABLE 2. RECOMMENDED VALUES OF POISSON'S RATIO FOR DIFFERENT PAVEMENT MATERIALS

Material Type	Range of Poisson's Ratio
Portland cement concrete	0.15-0.20
Asphaltic concrete	0.25-0.35
Cement stabilized base	0.20-0.30
Asphaltic stabilized base	0.25-0.35
Unbound granular base	0.40
Granular subgrade	0.40
Clayey or silty subgrade	0.45

9.5 **Directional Distribution Factor.** Certain highways have shown a marked difference in distribution of traffic in one direction from another. The directional distribution factor, expressed as a percent of the total 18-kip ESAL traffic in both directions, is used to account for this possibility. If this value is not 50 percent, the optimum design generated by RPDS is only for the direction being considered.



```
         **TRAFFIC  VARIABLES**

9.1   AVERAGE DAILY TRAFFIC (ADT)........................................ 56000.0
9.2   ADT GROWTH RATE, PERCENT............................................     2.0

9.3   INITIAL YEARLY 18-KIP ESAL, MILLIONS................................    1.20
9.4   18-KIP ESAL GROWTH RATE, PERCENT....................................     3.0
9.5   DIRECTIONAL DISTRIBUTION FACTOR, PERCENT............................    58.0
9.6   LANE DISTRIBUTION FACTOR, PERCENT...................................    70.0

         **TIME  CONSTRAINTS**

10.1 ANALYSIS PERIOD, YEARS...............................................    20.0
10.2 MINIMUM TIME BETWEEN OVERLAYS, YEARS.................................     5.0
10.3 MAXIMUM ALLOWABLE YEARS OF HEAVY MAINTENANCE
     AFTER LOSS OF STRUCTURAL LOAD-CARRYING CAPACITY......................     5.0
```

Screen 5: Traffic Variables

9.6 **Lane Distribution Factor.** This factor accounts for the distribution of truck traffic across the facility (in one direction). Since most of the heavy traffic is carried by the inside lane, for rural conditions, it is generally the "design" lane. The location of the design lane will vary for urban conditions. The lane distribution factor then defines what percent of the 18-kip ESAL traffic is carried by the design lane. This factor usually has a value of 90 to 95 percent for four-lane facilities and may be as low as 70 percent for eight-lane facilities.

D. Time Constraints

Time constraint input variables are shown on Screen 5.

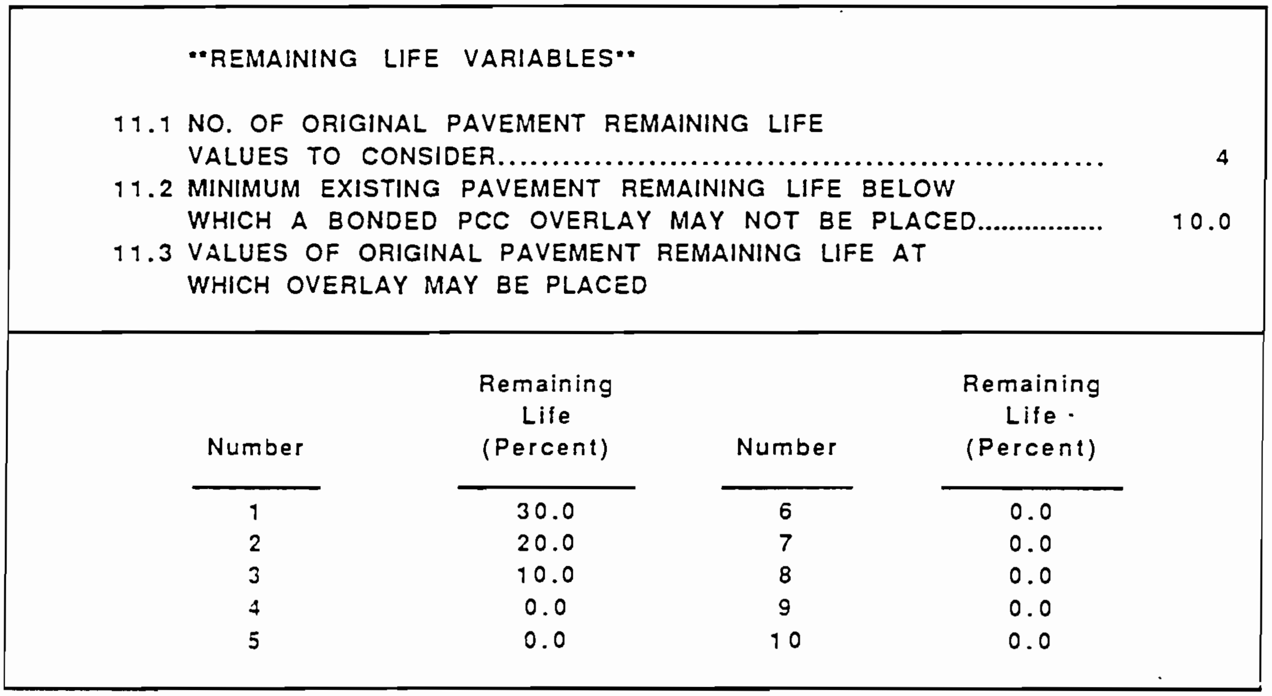
10.1 Analysis Period. This constraint defines how many years (from the present), the user desires the optimization of designs to be considered. The value will depend upon the facility type, but generally for rigid pavements the value should be greater than 20 and 30 years for rural and urban conditions, respectively..

10.2 Minimum Time Between Overlays. This constraint specifies the minimum number of years that can be allowed between two overlays. This value should not be greater than the analysis period. Also, if a second overlay will not be considered, this value is not required.

10.3 Maximum Number of Years of Heavy Maintenance. This value defines the maximum number of years of heavy maintenance (maximum of 10 years) the user may wish to consider to allow a strategy to last the analysis period. Note that for each additional year, distress increases rapidly, and therefore maintenance costs will increase correspondingly. It should also be noted that the user must provide data on these distress rates (in the Distress/Maintenance Cost Variables, Section I) for each additional year considered.

E. Remaining Life Variables

The remaining life variables are used to define specific times at which an overlay may be placed. The specific variables are shown on Screens 6 and 7.



```
          **REMAINING LIFE VARIABLES**

   11.1 NO. OF ORIGINAL PAVEMENT REMAINING LIFE
        VALUES TO CONSIDER.........................................          4
   11.2 MINIMUM EXISTING PAVEMENT REMAINING LIFE BELOW
        WHICH A BONDED PCC OVERLAY MAY NOT BE PLACED...............       10.0
   11.3 VALUES OF ORIGINAL PAVEMENT REMAINING LIFE AT
        WHICH OVERLAY MAY BE PLACED

                    Remaining                       Remaining
                      Life                            Life
     Number        (Percent)         Number        (Percent)
    --------      -----------       --------      -----------
       1              30.0              6              0.0
       2              20.0              7              0.0
       3              10.0              8              0.0
       4               0.0              9              0.0
       5               0.0             10              0.0
```

Screen 6: Remaining Life Variables for Inputs 11.1-11.3

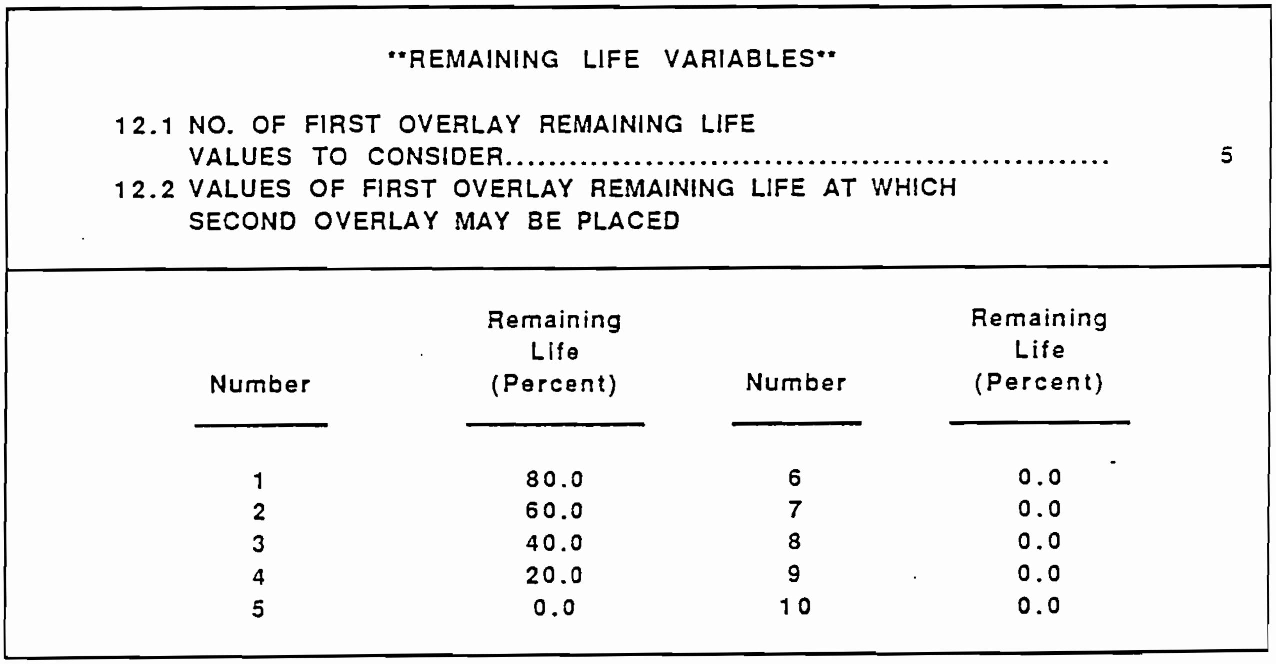
11.1 Number of Original Pavement Remaining Life Values. This number defines the number of different values of remaining life of the original pavement at which the first overlay may be placed.

This number should be at least one (otherwise an overlay will never be placed). The maximum limit on this number is 10.

11.2 Minimum Existing Pavement Remaining Life. Since it is not practical to bond a PCC overlay to an existing PCC pavement which has a very low level of remaining life (due to problems with reflection cracking), this constraint is provided. For user-specified values of remaining life below this value, bonded PCC overlays will not be considered. It does not affect ACP or unbonded PCC overlays. A practical range for this value is between 10 and 20 percent.

11.3 Original Pavement Remaining Life Values. The remaining life values of the existing pavement identify points during the life of the original pavement at which the first overlay may be placed in accordance with Variable 11.1. These values must be entered in order of decreasing magnitude, and the first is assumed to correspond to year zero of the analysis period. It is suggested that these values be entered in increments of not less than 10 percent, with the last value equal to zero.

12.1 Number of First Overlay Remaining Life Values. This number is similar to that used in Variable 11.1. It specifies the number of different values of remaining life in the first overlay at which the second overlay may be placed. The maximum limit is 10. This value should be zero if two-overlay strategies are not desired.



```
                    **REMAINING LIFE VARIABLES**

   12.1 NO. OF FIRST OVERLAY REMAINING LIFE
        VALUES TO CONSIDER.................................        5
   12.2 VALUES OF FIRST OVERLAY REMAINING LIFE AT WHICH
        SECOND OVERLAY MAY BE PLACED

                    Remaining                       Remaining
                       Life                            Life
        Number      (Percent)        Number         (Percent)
        ------      ---------        ------         ---------

          1            80.0             6              0.0
          2            60.0             7              0.0
          3            40.0             8              0.0
          4            20.0             9              0.0
          5             0.0            10              0.0
```

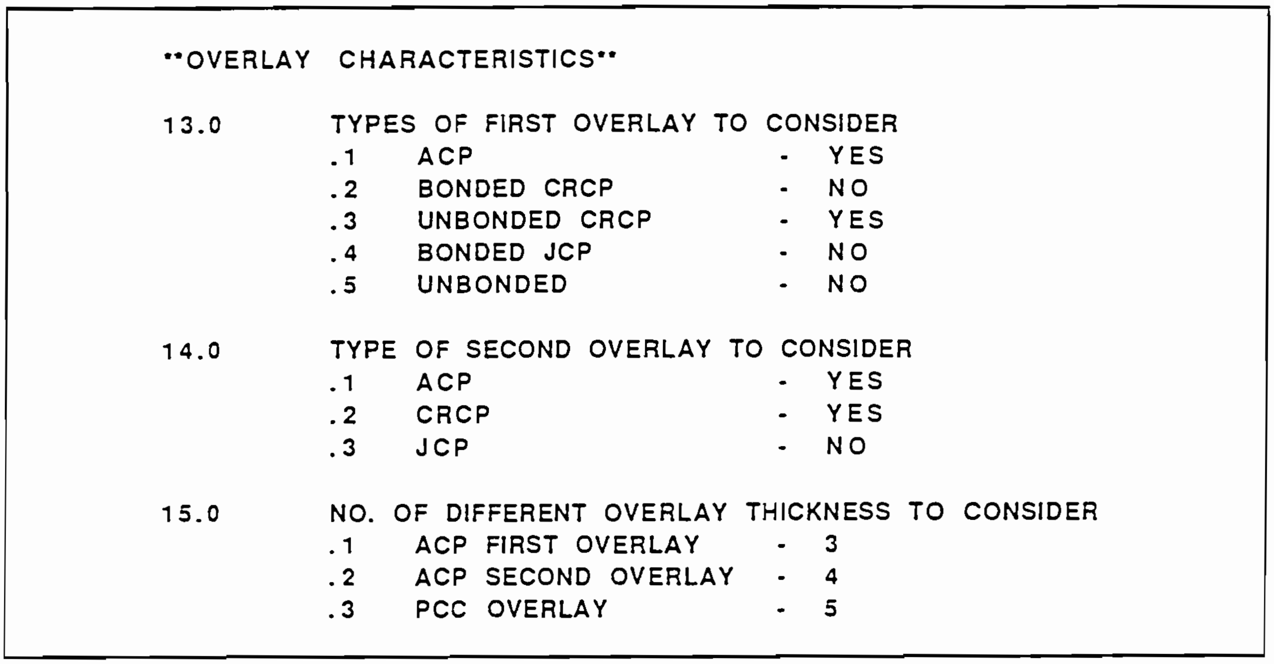
Screen 7: Remaining Life Variables for Inputs 12.1-12.2

12.2 First Overlay Remaining Life Values. These values of remaining life of the first overlay identify points during the life of the pavement structure at which a second overlay may be placed. Variable 12.1 defines how many of these values will be entered. As in 11.3, they must be entered in order of decreasing magnitude. It is suggested that, for practical design problems where a second overlay is to be considered, the list of these values should begin with 70 percent and decrease in 10-percent increments. For this example, 80 percent was used as a maximum, and it is decreased by 20 percent increments. This value may be left blank if no two-overlay strategies are to be considered.

F. Overlay Characteristics

The information required for the following variables is used to identify the types of overlay strategies to be considered and to define the pertinent properties for each alternative. Inputs are shown on Screens 8 to 11.

13.0 Types of First Overlay. This value identifies the types of first overlay that are to be considered. Five different types are available: (1) ACP, (2) bonded CRCP, (3) unbonded CRCP, (4) bonded JCP, and (5) unbonded JCP. Note that any or all combinations may be considered in a single run.



```
**OVERLAY  CHARACTERISTICS**

13.0      TYPES OF FIRST OVERLAY TO CONSIDER
          .1    ACP                    -  YES
          .2    BONDED CRCP            -  NO
          .3    UNBONDED CRCP          -  YES
          .4    BONDED JCP             -  NO
          .5    UNBONDED               -  NO

14.0      TYPE OF SECOND OVERLAY TO CONSIDER
          .1    ACP                    -  YES
          .2    CRCP                   -  YES
          .3    JCP                    -  NO

15.0      NO. OF DIFFERENT OVERLAY THICKNESS TO CONSIDER
          .1    ACP FIRST OVERLAY      -  3
          .2    ACP SECOND OVERLAY     -  4
          .3    PCC OVERLAY            -  5
```

Screen 8: Overlay Characteristics, Input values 13-15

In cases where the user desires to compare various type overlays but there is uncertainty about the relative costs between the options, it is recommended that separate RPRDS-1 runs be made for the different overlay types. This will allow the user to compare optimum overlay strategies of the various types considered, keeping in mind their cost uncertainty.

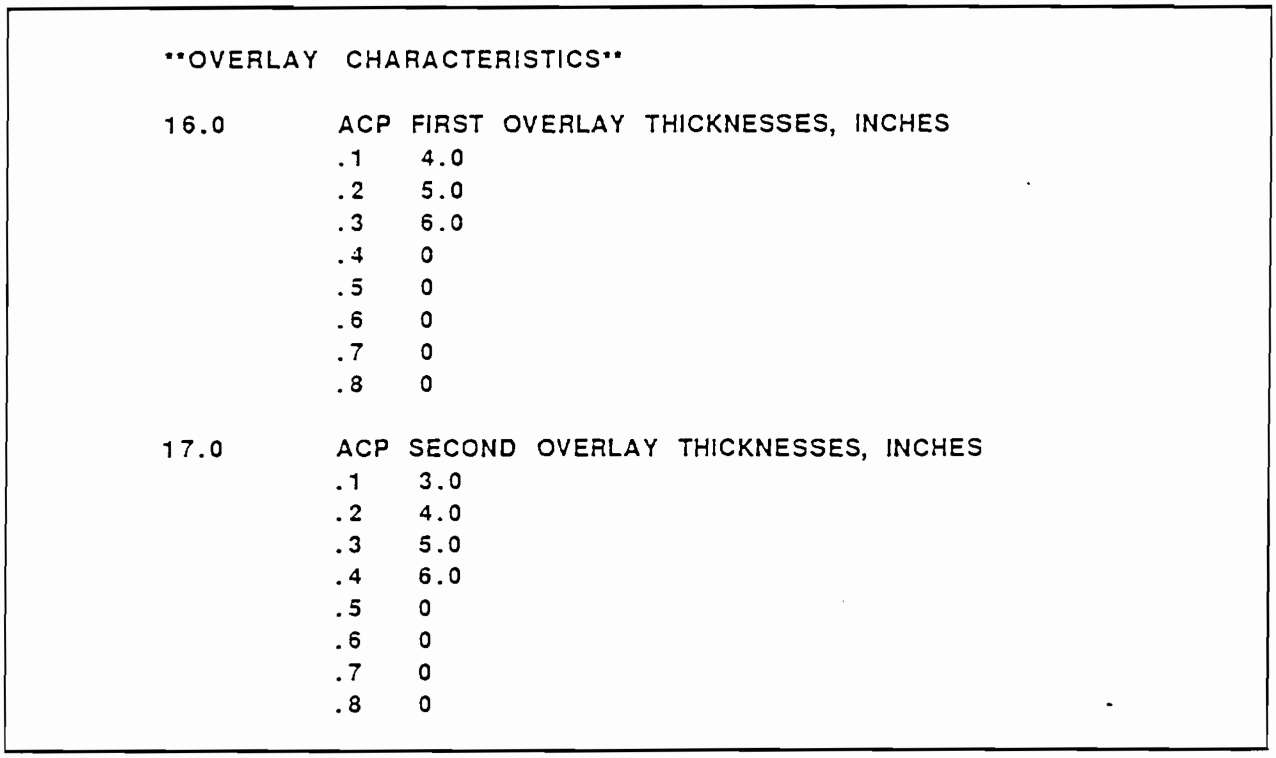
14.0 Types of Second Overlay. This value identifies the types of second overlay that are to be considered. There are three different types available: (1) ACP, (2) CRCP, and

15.1 Number of ACP First Overlay Thicknesses. This value defines how many different ACP first overlay thicknesses are due to be considered. A maximum of eight is allowed.

15.2 Number of ACP Second Overlay Thicknesses. RPRDS-1 allows the user to select an independent set of thicknesses to use for the second ACP overlay. (This provides flexibility, since the user may be constrained to one thickness for the first overlay.) This value defines how many second ACP overlay thicknesses are to be considered. A maximum of eight is allowed.

15.3 Number of PCC Overlay Thicknesses. This value defines how many PCC thicknesses are to be considered. The thicknesses apply to both CRCP and JCP overlays, whether they make up the first overlay or the second overlay. A maximum of eight is allowed.

16.0 ACP First Overlay Thicknesses. This value identifies what ACP thicknesses (in inches) to use for the first overlay. The number of these different thicknesses is set in Variable 15.1. These thicknesses should be entered in order of increasing magnitude. The first should be no less than 2 inches (a minimum for structural rehabilitation) and the largest thickness should not exceed 8 inches. This value may be left blank if an ACP first overlay is not to be considered.



```
**OVERLAY  CHARACTERISTICS**

16.0       ACP  FIRST  OVERLAY  THICKNESSES, INCHES
           .1   4.0
           .2   5.0
           .3   6.0
           .4   0
           .5   0
           .6   0
           .7   0
           .8   0

17.0       ACP  SECOND  OVERLAY  THICKNESSES, INCHES
           .1   3.0
           .2   4.0
           .3   5.0
           .4   6.0
           .5   0
           .6   0
           .7   0
           .8   0
```

Screen 9: Overlay Characteristics, Inputs 16-17

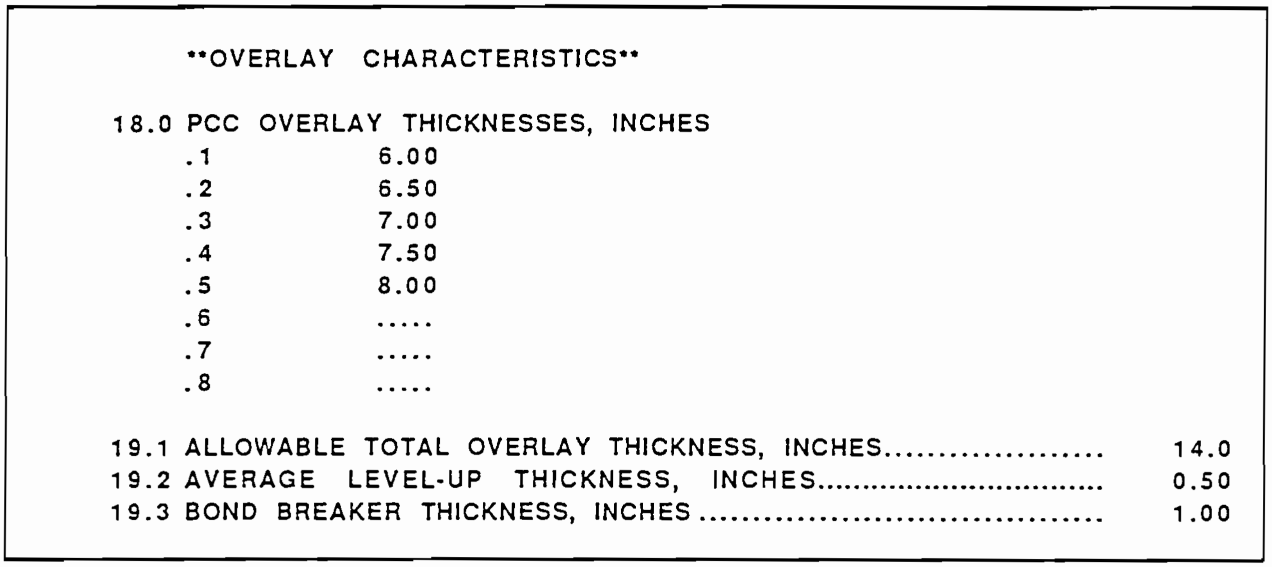
17.0 ACP Second Overlay Thicknesses. This value identifies what ACP thicknesses (in inches) to use for the second overlay. The number of these different thicknesses is set in Variable 15.2. Once again, these thicknesses should be entered in order of increasing magnitude with the first no less than 2 inches and the last no greater than 8 inches. This value may be left blank if an ACP second overlay is not to be considered.

18.0 PCC Overlay Thicknesses. This value identifies what CRCP and/or JCP thicknesses (in inches) to use for either the first or second PCC overlay. The number of these different thicknesses is set in

Variable 15.3. These thicknesses should be entered in order of increasing magnitude, with the first no less than 5 inches (a minimum practical construction thickness). The maximum practical thickness is left up to the designer.

19.1 Allowable Total Overlay Thickness. This variable acts as a constraint on those two-overlay strategies in which the combined thickness of both overlays may be too large for bridge clearance (or some other similar factor). Consequently, those strategies in which the combined thickness is greater than this allowable will not be considered. This value should not be left blank if two-overlay strategies are to be considered.

19.2 Average Level-up Thickness. This value is used to compute the cost of the additional overlay thickness required for level-up. It has no effect on the fatigue life calculations or the constraint on total overlay thickness. Also, it is assumed that this value applies to both first and second overlays, regardless of type.



```
          **OVERLAY  CHARACTERISTICS**

    18.0 PCC OVERLAY THICKNESSES, INCHES
          .1          6.00
          .2          6.50
          .3          7.00
          .4          7.50
          .5          8.00
          .6          .....
          .7          .....
          .8          .....

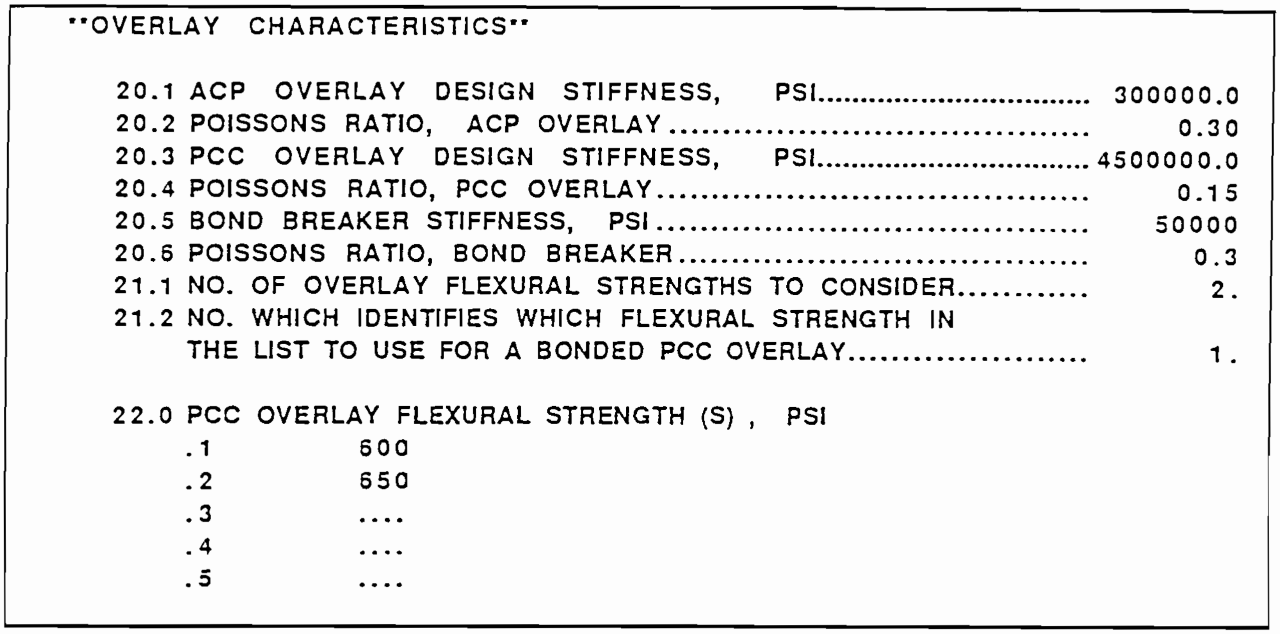
    19.1 ALLOWABLE TOTAL OVERLAY THICKNESS, INCHES....................   14.0
    19.2 AVERAGE  LEVEL-UP  THICKNESS,  INCHES.........................   0.50
    19.3 BOND BREAKER THICKNESS, INCHES...................................  1.00
```

Screen 10: Overlay Characteristics, Inputs 18-19

19.3 Bond Breaker Thickness. This variable is used in the fatigue life calculations for unbonded PCC overlays. A value of one inch is recommended. This value should not be left blank if an unbonded PCC overlay strategy is to be considered.

20.1 ACP Overlay Design Stiffness. This variable defines the ACP elastic modulus to use for pavement response calculations. Various methods are available for predicting what this value should be for given environmental conditions. The range on this value should be between 300,000 and 500,000 psi. A value of 400,000 psi is recommended for Texas conditions if no other data are available.

20.2 Poisson's Ratio, ACP Overlay. This variable is also used to predict pavement response. Its variation has very little effect on the predicted responses; however, it cannot be ignored. A value of 0.30 is recommended (see Table 2).



```
**OVERLAY  CHARACTERISTICS**

    20.1 ACP  OVERLAY  DESIGN  STIFFNESS,   PSI............................... 300000.0
    20.2 POISSONS RATIO,  ACP OVERLAY ........................................    0.30
    20.3 PCC  OVERLAY  DESIGN  STIFFNESS,   PSI...............................4500000.0
    20.4 POISSONS RATIO, PCC OVERLAY .........................................    0.15
    20.5 BOND BREAKER STIFFNESS,  PSI ........................................   50000
    20.6 POISSONS RATIO, BOND BREAKER ........................................     0.3
    21.1 NO. OF OVERLAY FLEXURAL STRENGTHS TO CONSIDER............               2.
    21.2 NO. WHICH IDENTIFIES WHICH FLEXURAL STRENGTH IN
         THE LIST TO USE FOR A BONDED PCC OVERLAY......................          1.

    22.0 PCC OVERLAY FLEXURAL STRENGTH (S) ,  PSI
         .1          600
         .2          650
         .3          ....
         .4          ....
         .5          ....
```

Screen 11: Overlay Characteristics, Inputs 20-22

20.3 PCC Overlay Design Stiffness. This variable defines the elastic modulus of the portland cement concrete for both CRCP and JCP overlays. The variation of this value has a significant effect on the prediction of pavement response, and, therefore, it should be estimated as accurately as possible. The factor which most affects this value is the aggregate type used in the mix. Table 3 shows values of the Modulus of Elasticity at 28 and 90 days, of two types of aggregate under certain conditions. These values are obtained from Research Report 422-2,"Design Recommendations for Steel Reinforcement of CRCP," by M. F. Aslam, C. L. Saraf, R. L. Carrasquillo, and B. F. McCullough. The report was produced at the Center for Transportation Research at The University of Texas at Austin in 1987.

20.4 Poisson's Ratio, PCC Overlay. This value is also used to predict pavement response. Like the Poisson's ratio for the ACP overlay, its variation has little effect on pavement response. Therefore, a value of 0.2 is recommended.

20.5 Bond Breaker Stiffness. A bond breaker is used for unbonded PCC overlays to help prevent reflection cracking. Consequently, a low stiffness asphaltic concrete layer is recommended for design (100,000 psi or lower).

20.6 Poisson's Ratio, Bond Breaker. Since this layer consists of a low stiffness asphaltic concrete, a value of 0.35 is recommended. Once again, its variation has little effect on the predicted pavement responses.

TABLE 3. MODULUS OF ELASTICITY(10^4 PSI) OF PCC

		Moisture Condition					
		40% Relative Humidity			100% Relative Humidity		
		Curing Temperature (°F)					
Aggregate	Days	50	75	100	50	75	100
Silicious	28	429.5	509.7	368.8	452.5	534.1	657.8
River gravel	90	573.5	480.3	486.1	898.6	453.4	1230.8
Limestone	28	603.5	507.3	508.4	211.2	473.0	447.1
	90	581.4	653.8	550.8	621.9	569.6	763.9

21.1 Number of Overlay Flexural Strengths. PRDS-1 allows the designer to consider up to five different concrete flexural strengths in the various PCC overlay design strategies. An increased flexural strength may make a significant difference in the predicted life of a strategy, and, therefore, it may be worthy of consideration. Since an increased cement content may be necessary to achieve a higher flexural strength, the designer must later input the cost associated with these different concrete strengths.

21.2 Number of Flexural Strength for Bonded PCC Overlays. Since, with small variation, flexural strength of bonded PCC overlays has little effect on the fatigue life of those strategies, only one strength need to be considered. This strength should be the 28-day concrete flexural strength. Consequently, this number identifies which flexural strength in the list (of those to be considered in 22.0) is to be used for a bonded PCC overlay. For example, if three flexural strengths are to be considered and the strength which would normally be used for a bonded PCC overlay is the second in the list, the user should enter a 2 for this variable.

22.0 PCC Overlay Flexural Strengths. These values should be entered in increasing order (in psi). As discussed under Variable 21.1, the limits of flexural strength that may be considered lie between 600 and 800 psi. These values may be left blank if no PCC overlays are to be considered.

Pavement Stress Factors After Overlay

This section of overlay characteristics deals with the selection of stress factors (ratios of critical stress to interior slab stress) for all possible overlay combinations selected by the user. Though there may be several of these combinations, the selection of the appropriate stress factors for each is simple. Basically, all the user must do is refer to the suggested values in Table 4, which identifies the inputs required for Values 23 through 40. Each value represents a particular overlay combination where the critical stress to be computed is located in either the

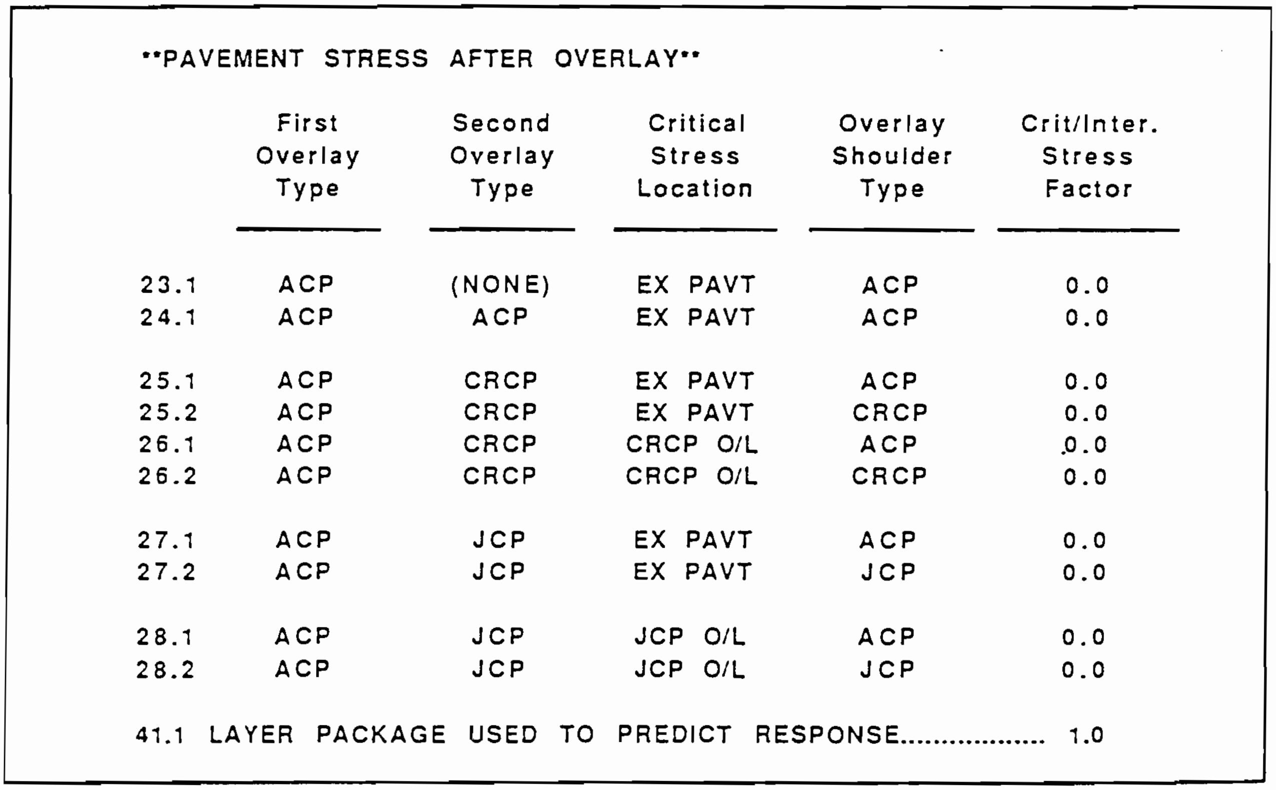
TABLE 4: CRITICAL STRESS FACTORS FOR THE VARIOUS EXISTING PAVEMENT-OVERLAY-SHOULDER COMBINATIONS CONSIDERED IN RPDS.

VARIABLE NO.	FIRST OVERLAY TYPE	SECOND OVERLAY TYPE	OVERLAY SHOULDER TYPE	LOCATION OF CRITICAL STRESS	RATIO OF CRITICAL TO INTERIOR STRESS EXISTING PAVEMENT TYPE CRCP	JCP
23.1	ACP	none	ACP	Exist. pavem.	1.25	1.45
24.1	ACP	ACP	ACP	Exist. pavem.	1.25	1.45
25.1	ACP	CRCP	ACP	Exist. pavem.	1.25	1.45
25.2	ACP	CRCP	CRCP	Exist. pavem.	1.08	1.25
26.1	ACP	CRCP	ACP	CRCP Overlay	1.25	1.35
26.2	ACP	CRCP	CRCP	CRCP Overlay	1.08	1.15
27.1	ACP	JCP	ACP	Exist. pavem.	1.4	1.4
27.2	ACP	JCP	JCP	Exist. pavem.	1.25	1.2
28.1	ACP	JCP	ACP	JCP Overlay	1.55	1.6
28.2	ACP	JCP	JCP	JCP Overlay	1.35	1.4
29.1	Bonded CRCP	none	ACP	Exist. pavem.	1.25	X
29.2	Bonded CRCP	none	CRCP	Exist. pavem.	1.08	X
30.1	Bonded CRCP	ACP	ACP	Exist. pavem.	1.25	X
30.2	Bonded CRCP	ACP	CRCP	Exist. pavem.	1.08	X
31.1	Bonded JCP	none	ACP	Exist. pavem.	X	1.4
31.2	Bonded JCP	none	JCP	Exist. pavem.	X	1.25
32.1	Bonded JCP	ACP	ACP	Exist. pavem.	X	1.4
32.2	Bonded JCP	ACP	JCP	Exist. pavem.	X	1.25
33.1	Unbonded CRCP	none	ACP	Exist. pavem.	1.25	1.4
33.2	Unbonded CRCP	none	CRCP	Exist. pavem.	1.08	1.2
34.1	Unbonded CRCP	none	ACP	CRCP Overlay	1.25	1.3
34.2	Unbonded CRCP	none	CRCP	CRCP Overlay	1.08	1.15
35.1	Unbonded CRCP	ACP	ACP	Exist. pavem.	1.25	1.35
35.2	Unbonded CRCP	ACP	CRCP	Exist. pavem.	1.08	1.2
36.1	Unbonded CRCP	ACP	ACP	CRCP Overlay	1.25	1.3
36.2	Unbonded CRCP	ACP	CRCP	CRCP Overlay	1.08	1.15
37.1	Unbonded JCP	none	ACP	Exist. pavem.	1.4	1.4
37.2	Unbonded JCP	none	JCP	Exist. pavem.	1.2	1.25
38.1	Unbonded JCP	none	ACP	JCP Overlay	1.3	1.4
38.2	Unbonded JCP	none	JCP	JCP Overlay	1.15	1.2
39.1	Unbonded JCP	ACP	ACP	Exist. pavem.	1.4	1.4
39.2	Unbonded JCP	ACP	JCP	Exist. pavem.	1.2	1.25
40.1	Unbonded JCP	ACP	ACP	JCP Overlay	1.4	1.4
40.2	Unbonded JCP	ACP	JCP	JCP Overlay	1.15	1.2

existing pavement or the PCC overlay. Most of these values also allow the specification of a second stress factor (for the same overlay combination) to simulate the effect of a PCC shoulder constructed along with the PCC overlay.

The user should use Table 4 to select the stress ratio required from the column corresponding to the type of existing pavement. Any stress factor left blank or specified to be zero will keep PRDS-1 from considering the corresponding overlay strategy. This is an important point because an error of this type will probably go unnoticed since these strategies will appear to be infeasible in the PRDS-1 program output. It is recommended, then, that the user pay close attention to selecting and recording these variables. Screens 12 to 14 show these input values. These values are suggested values. The user may want to do more exact calculations to obtain stress ratios.

41.1 Method of Response Prediction. This variable defines the method in which pavement responses are to be determined, either by the elastic layer submodel, LAYER(1), or the elastic layer regression submodel, REGRSP(2). Use of the REGRSP submodel allows the user to familiarize himself with the operation of the program and can also be used for analyzing a particular overlay design problem using a minimum of computer time. However, the LAYER submodel should be used if the program is to be used for the selection of an optimal rehabilitation design strategy.



```
**PAVEMENT STRESS AFTER OVERLAY**

          First      Second     Critical    Overlay     Crit/Inter.
          Overlay    Overlay    Stress      Shoulder    Stress
          Type       Type       Location    Type        Factor
          -------    -------    --------    --------    -----------

  23.1    ACP        (NONE)     EX PAVT     ACP         0.0
  24.1    ACP        ACP        EX PAVT     ACP         0.0

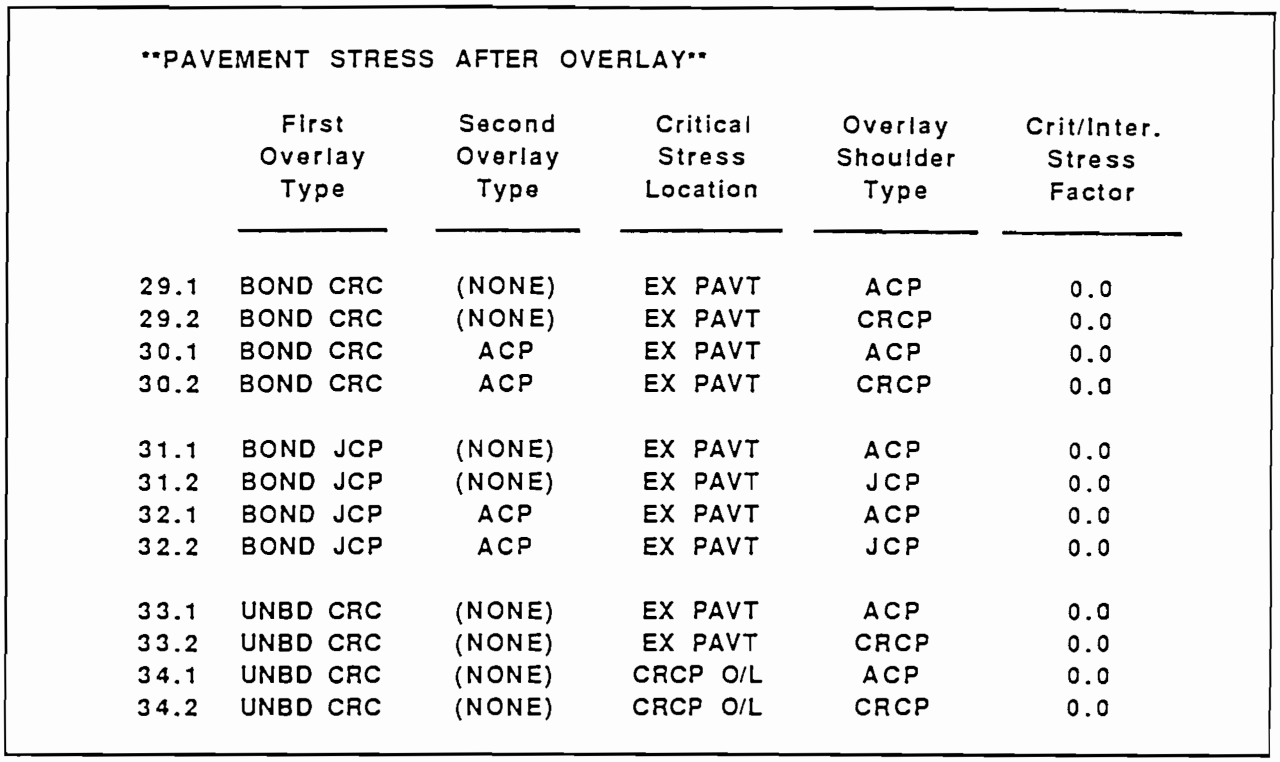
  25.1    ACP        CRCP       EX PAVT     ACP         0.0
  25.2    ACP        CRCP       EX PAVT     CRCP        0.0
  26.1    ACP        CRCP       CRCP O/L    ACP         0.0
  26.2    ACP        CRCP       CRCP O/L    CRCP        0.0

  27.1    ACP        JCP        EX PAVT     ACP         0.0
  27.2    ACP        JCP        EX PAVT     JCP         0.0

  28.1    ACP        JCP        JCP O/L     ACP         0.0
  28.2    ACP        JCP        JCP O/L     JCP         0.0

41.1 LAYER PACKAGE USED TO PREDICT RESPONSE................. 1.0
```

Screen 12: Pavement Stress after Overlay, Inputs 23-28,41



```
**PAVEMENT STRESS AFTER OVERLAY**

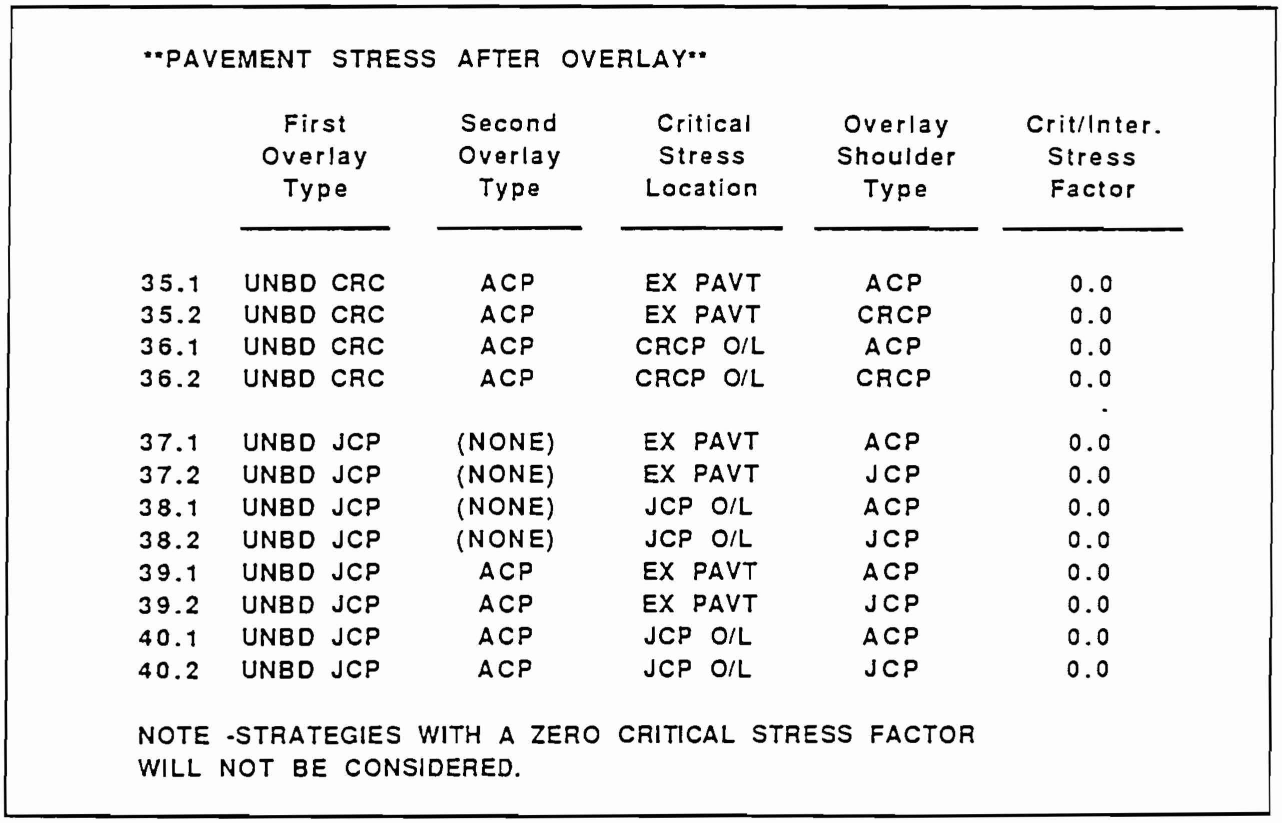
         First      Second     Critical    Overlay    Crit/Inter.
        Overlay    Overlay      Stress    Shoulder      Stress
         Type       Type       Location     Type        Factor
      _________   ________   __________  __________  ___________

29.1  BOND CRC    (NONE)      EX PAVT      ACP          0.0
29.2  BOND CRC    (NONE)      EX PAVT      CRCP         0.0
30.1  BOND CRC     ACP        EX PAVT      ACP          0.0
30.2  BOND CRC     ACP        EX PAVT      CRCP         0.0

31.1  BOND JCP    (NONE)      EX PAVT      ACP          0.0
31.2  BOND JCP    (NONE)      EX PAVT      JCP          0.0
32.1  BOND JCP     ACP        EX PAVT      ACP          0.0
32.2  BOND JCP     ACP        EX PAVT      JCP          0.0

33.1  UNBD CRC    (NONE)      EX PAVT      ACP          0.0
33.2  UNBD CRC    (NONE)      EX PAVT      CRCP         0.0
34.1  UNBD CRC    (NONE)     CRCP O/L      ACP          0.0
34.2  UNBD CRC    (NONE)     CRCP O/L      CRCP         0.0
```

Screen 13: Pavement Stress after Overlay, Inputs 29-34



```
**PAVEMENT STRESS AFTER OVERLAY**

         First      Second     Critical    Overlay    Crit/Inter.
        Overlay    Overlay      Stress    Shoulder      Stress
         Type       Type       Location     Type        Factor
      _________   ________   __________  __________  ___________

35.1  UNBD CRC     ACP        EX PAVT      ACP          0.0
35.2  UNBD CRC     ACP        EX PAVT      CRCP         0.0
36.1  UNBD CRC     ACP       CRCP O/L      ACP          0.0
36.2  UNBD CRC     ACP       CRCP O/L      CRCP         0.0

37.1  UNBD JCP    (NONE)      EX PAVT      ACP          0.0
37.2  UNBD JCP    (NONE)      EX PAVT      JCP          0.0
38.1  UNBD JCP    (NONE)      JCP O/L      ACP          0.0
38.2  UNBD JCP    (NONE)      JCP O/L      JCP          0.0
39.1  UNBD JCP     ACP        EX PAVT      ACP          0.0
39.2  UNBD JCP     ACP        EX PAVT      JCP          0.0
40.1  UNBD JCP     ACP        JCP O/L      ACP          0.0
40.2  UNBD JCP     ACP        JCP O/L      JCP          0.0

NOTE -STRATEGIES WITH A ZERO CRITICAL STRESS FACTOR
WILL NOT BE CONSIDERED.
```

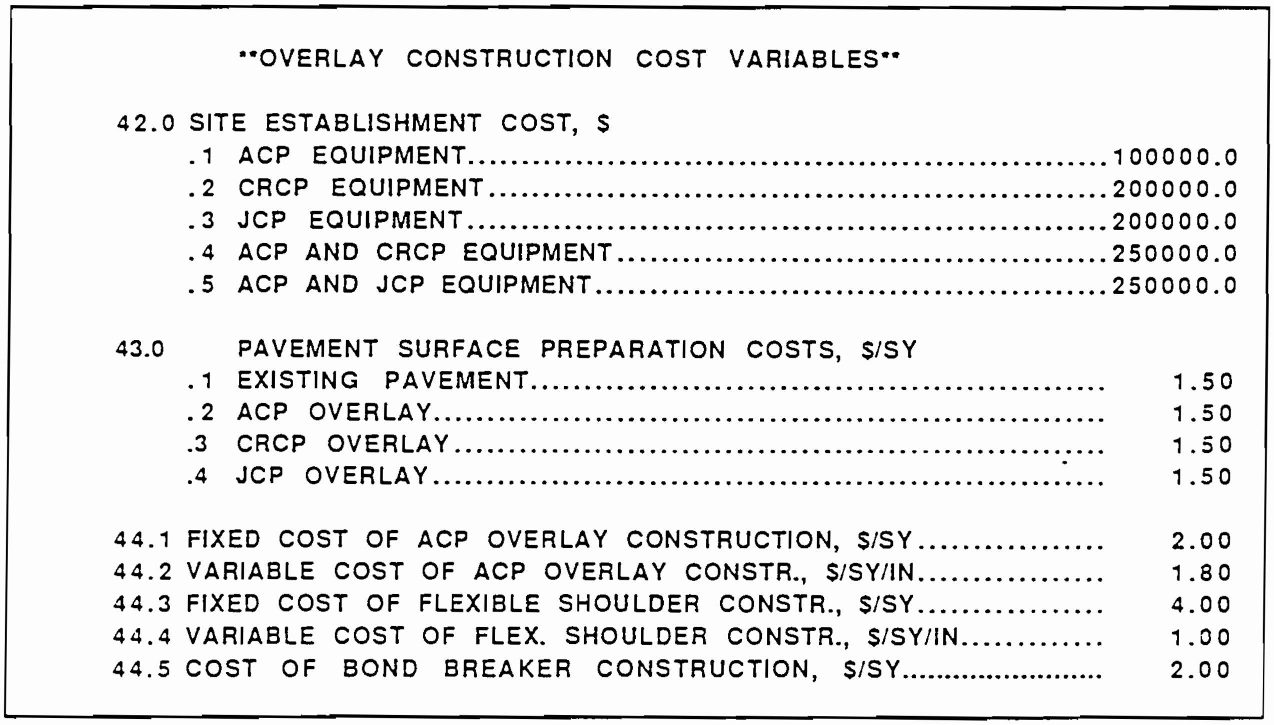
Screen 14: Pavement Stress after Overlay, Inputs 35-40

G. Overlay Construction Cost Variables

This begins the description of the inputs associated with the cost of an overlay strategy and is shown on Screens 15 to 17. If current assumed Texas values are to be used, and the REHAB.DAT file is edited, the user can terminate the input session by pressing F1. The typical values already in REHAB.DAT will be used.

42.0 Site Establishment Cost. This value identifies the cost associated with mobilization. This cost is considered because the cost of mobilizing manpower and equipment may differ according to overlay type. Consequently, there are five different costs that may be specified. Variables 42.1, 42.2, and 42.3 represent the costs for ACP, CRCP, and JCP equipment, respectively. In cases where both PCC and ACP construction equipment are required for a particular strategy, such as a CRCP overlay with an ACP bond breaker and ACP shoulder, Variables 42.4 and 42.5 are provided. They may be used to reflect a lower equipment unit cost when the two types are required. It should be noted that each represents a total cost for the entire project, regardless of length.

43.0 Pavement Surface Preparation Cost. This cost should represent the cost of preparing the pavement surface (i.e., cleaning and milling) prior to overlay placement. Variable 43.1 applies to the existing pavement while Variables 43.2, 43.3, and 43.4 apply to the first overlay prior to the second and may be neglected if no two-overlay strategies are to be considered. Note that the units on this cost are dollars per square yard of surface area.



```
                **OVERLAY CONSTRUCTION COST VARIABLES**

42.0 SITE ESTABLISHMENT COST, $
     .1 ACP EQUIPMENT.........................................100000.0
     .2 CRCP EQUIPMENT........................................200000.0
     .3 JCP EQUIPMENT.........................................200000.0
     .4 ACP AND CRCP EQUIPMENT................................250000.0
     .5 ACP AND JCP EQUIPMENT.................................250000.0

43.0    PAVEMENT SURFACE PREPARATION COSTS, $/SY
     .1 EXISTING PAVEMENT....................................     1.50
     .2 ACP OVERLAY..........................................     1.50
     .3 CRCP OVERLAY.........................................     1.50
     .4 JCP OVERLAY..........................................     1.50

44.1 FIXED COST OF ACP OVERLAY CONSTRUCTION, $/SY.............     2.00
44.2 VARIABLE COST OF ACP OVERLAY CONSTR., $/SY/IN............     1.80
44.3 FIXED COST OF FLEXIBLE SHOULDER CONSTR., $/SY............     4.00
44.4 VARIABLE COST OF FLEX. SHOULDER CONSTR., $/SY/IN.........     1.00
44.5 COST OF BOND BREAKER CONSTRUCTION, $/SY..................     2.00
```

Screen 15: Overlay Construction Cost Variables, Inputs 42-44

44.1 Fixed Cost of ACP Overlay Construction. This input defines the fixed component of the ACP overlay placement cost. It is used along with the variable cost to predict the total placement cost. This method allows some flexibility to account for the sensitivity of placement cost to overlay thickness. The units of fixed cost are dollars per square yard while the units for variable cost are dollars per square yard per inch of thickness.

An example is to specify a fixed cost of 6.00 dollars per square yard and a variable cost of 0.50 dollar per spare yard per inch, so that the cost of a 6-inch ACP overlay would be 6.00 + (6 x 0.50) or 9.00 dollars per square yard.

44.2 Variable Cost of ACP Overlay Construction. This variable, along with the fixed component (Variable 44.1) is used to compute the total cost of ACP overlay placement. The units of variable cost are dollars per square yard per inch.

44.3 Fixed Cost of Flexible Shoulder Construction. This input defines the fixed component of flexible shoulder placement cost. The units are dollars per square yard, and the input is similar in application to Variable 44.1.

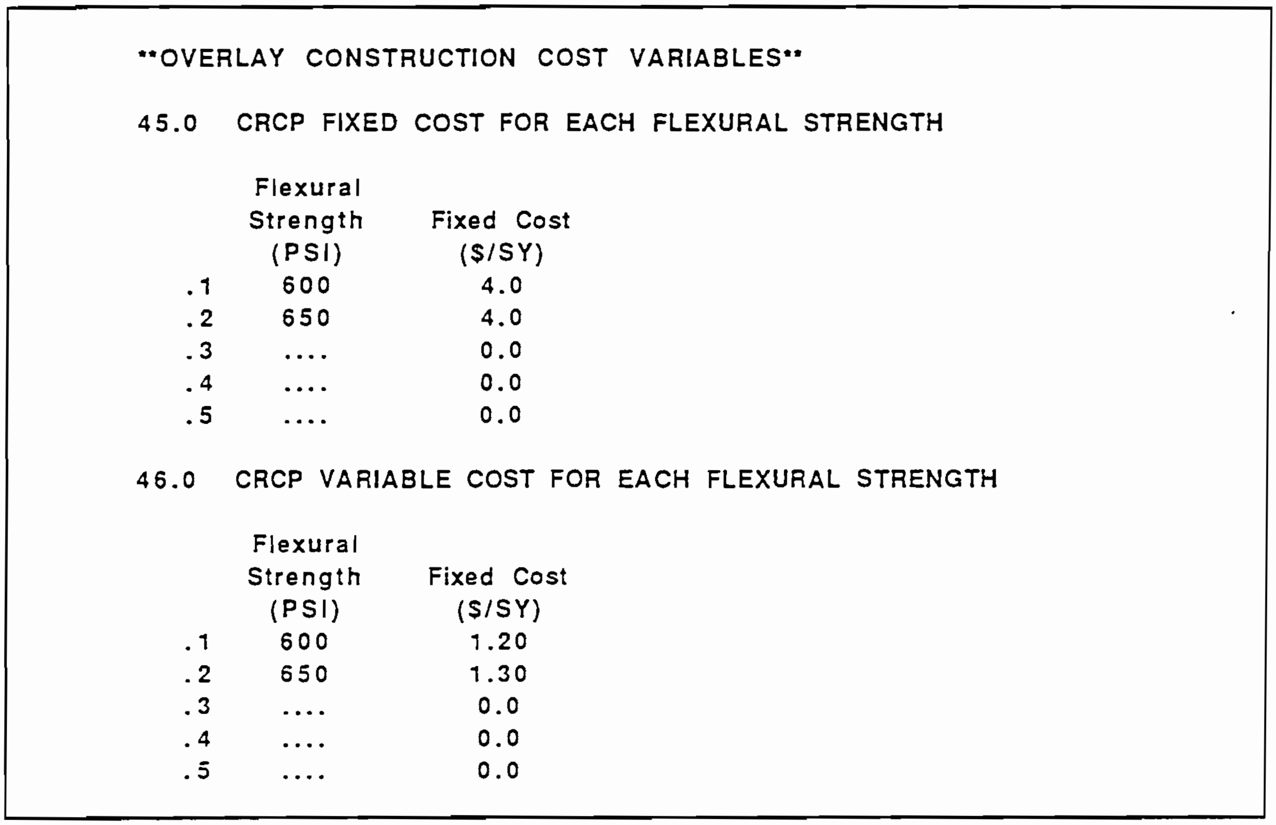
44.4 Variable Cost of Flexible Shoulder Construction. This input defines the variable component of flexible shoulder construction. Its units are dollars per square yard per inch. See the description of Variables 44.1 and 44.2 for further discussion on fixed and variable costs.

44.5 Cost of Bond Breaker Construction. Unlike ACP overlay and flexible shoulder placement cost, the cost for bond breaker placement has only one component since only one thickness (Variable 19.3) is ever considered. Consequently, the units of this variable are dollars per square yard.

45.0 CRCP Fixed Costs. These inputs define the fixed component of CRCP overlay placement cost. They are similar in nature to Variable 44.1, with one exception. The user must specify a fixed cost for each PCC flexural strength specified in Variable 22.0. Once again, the units are dollars per square yard. This value should be left blank if no CRCP overlays are to be considered. If the cost of placing reinforcing is not included in this value it should be stated in input value 49.3.

46.0 CRCP Variable Costs. These inputs define the variable component of CRCP overlay placement cost. They correspond to the fixed cost specified for each PCC flexural strength to be used for CRCP overlay construction. The units are dollars per square yard per inch. These values should be left blank if no CRCP overlays are to be considered.

47.0 JCP Fixed Costs. These inputs define the fixed component of JCP overlay placement cost. They are similar in nature to Variable 44.1. The difference is that the user must specify a fixed cost for each PCC flexural strength specified in value 22.0. The units are dollars per square yard. These values should be left blank if no JCP overlays are to be considered.



```
**OVERLAY CONSTRUCTION COST VARIABLES**

45.0   CRCP FIXED COST FOR EACH FLEXURAL STRENGTH

        Flexural
        Strength     Fixed Cost
          (PSI)        ($/SY)
   .1      600          4.0
   .2      650          4.0
   .3      ....         0.0
   .4      ....         0.0
   .5      ....         0.0

46.0   CRCP VARIABLE COST FOR EACH FLEXURAL STRENGTH

        Flexural
        Strength     Fixed Cost
          (PSI)        ($/SY)
   .1      600          1.20
   .2      650          1.30
   .3      ....         0.0
   .4      ....         0.0
   .5      ....         0.0
```

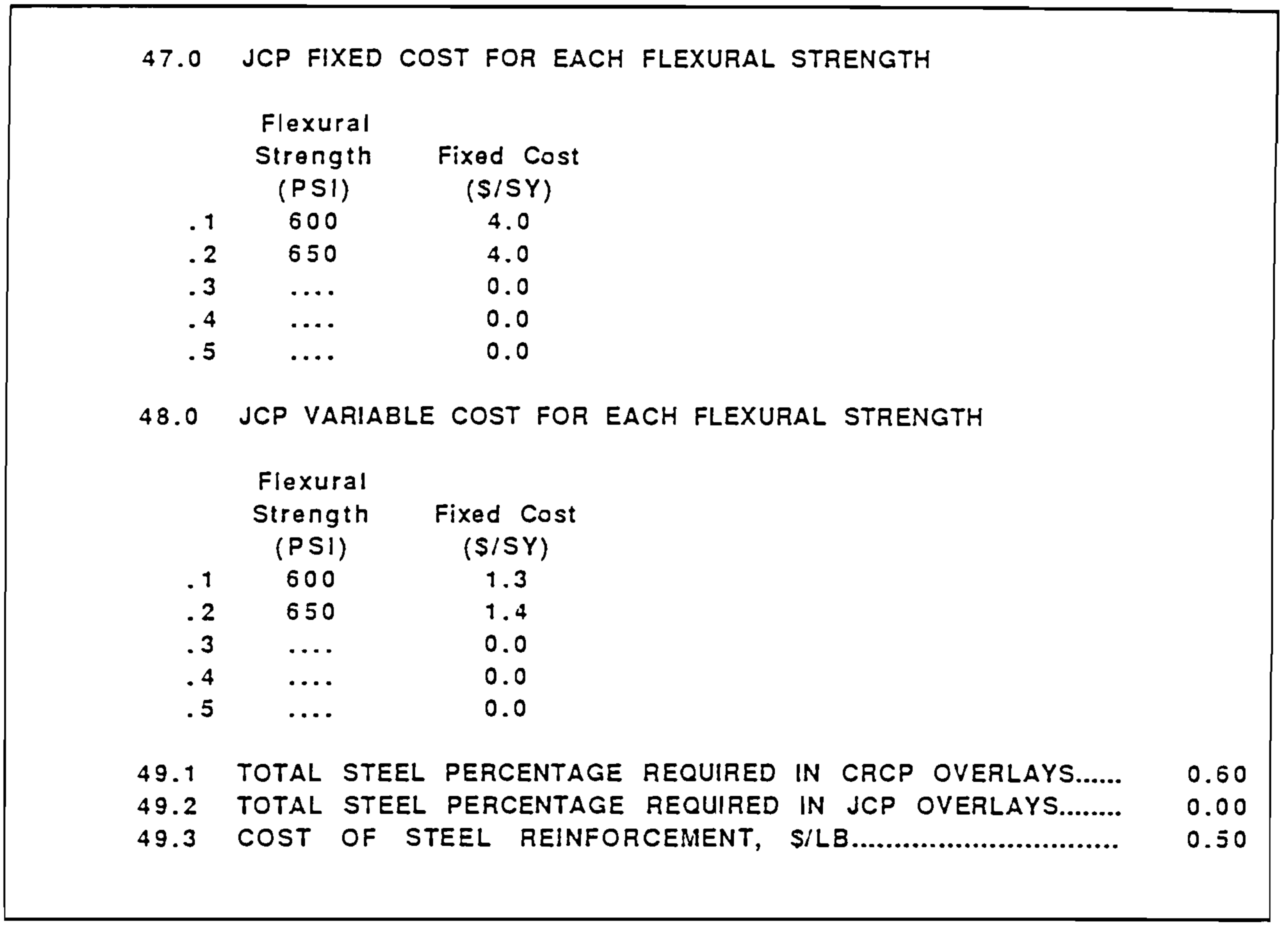
Screen 16: Overlay Construction Cost Variables, Inputs 45-46

48.0 JCP Variable Costs. These inputs define the variable component of JCP overlay placement cost. They correspond to the fixed cost specified for each PCC flexural strength to be used for JCP overlay construction. The units are dollars per square yard per inch. It should be left blank if no JCP overlays are to be considered.

49.1 Total CRCP Overlay Steel Percentage. This variable defines the total percentage of steel, both longitudinal and transverse required in a CRCP overlay. Generally, this value ranges between 0.5 and 0.7 percent for CRCP overlays, but may be left blank if no CRCP overlays are to be considered.

49.2 Total JCP Overlay Steel Percentage. This variable defines the total steel percentage, both longitudinal and transverse, required in a JCP overlay. Generally this value ranges between zero and 0.4 percent for JCP overlays. (The higher end represents a jointed reinforced concrete pavement, JRCP.) This variable may be left blank if no JCP overlays are to be considered.

49.3 Cost of Steel Reinforcement. This variable defines the cost per unit weight of steel used in a reinforced concrete overlay. The user need not consider the cost of placement if it was considered in the fixed cost of placement. The units of this variable are dollars per pound. Also, it may be left blank if no PCC overlays are to be considered.



```
47.0   JCP FIXED COST FOR EACH FLEXURAL STRENGTH

        Flexural
        Strength     Fixed Cost
         (PSI)        ($/SY)
  .1      600           4.0
  .2      650           4.0
  .3      ....          0.0
  .4      ....          0.0
  .5      ....          0.0

48.0   JCP VARIABLE COST FOR EACH FLEXURAL STRENGTH

        Flexural
        Strength     Fixed Cost
         (PSI)        ($/SY)
  .1      600           1.3
  .2      650           1.4
  .3      ....          0.0
  .4      ....          0.0
  .5      ....          0.0

49.1   TOTAL STEEL PERCENTAGE REQUIRED IN CRCP OVERLAYS......     0.60
49.2   TOTAL STEEL PERCENTAGE REQUIRED IN JCP OVERLAYS........    0.00
49.3   COST OF STEEL REINFORCEMENT, $/LB..............................  0.50
```

Screen 17: Overlay Construction Cost Variables, Inputs 47-49

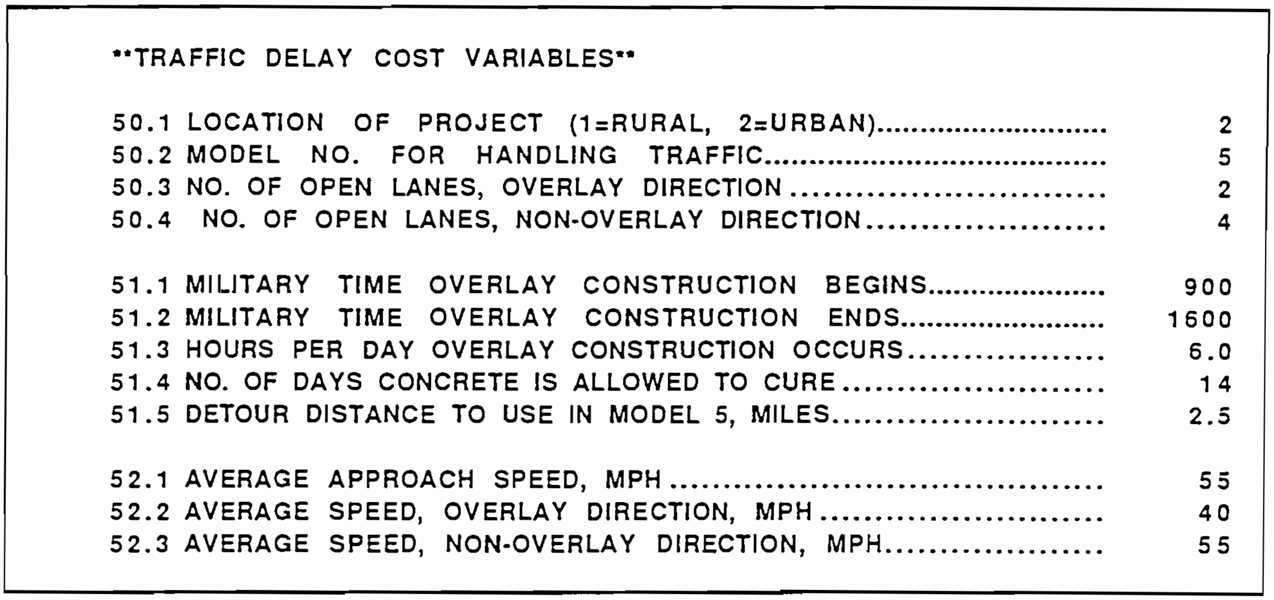
H. Traffic Delay Cost Variables

This section describes the variables associated with user costs arising from traffic delay during overlay construction. It is shown on Screens 18 and 19.

50.1 Location of Project. The model uses "built-in" average daily distributions of traffic to predict the amounts of traffic which will be delayed during the periods when traffic is detoured or constricted. Since these average daily distributions are different in rural areas than in urban, the user must specify which of the two best applies to his conditions.

50.2 Model Number for Handling Traffic. Since the delay duration and the number of vehicles delayed are dependent upon the method in which traffic is detoured, it is necessary for the user to specify which method will be used. The choices available are shown in Fig 2.

50.3 Number of Open Lanes, Overlay Direction. This variable specifies how many lanes are open to traffic in the overlay direction. This includes detour lanes, the lane provided by the shoulder (if it is used to carry traffic), and a lane which may be shared with traffic in the non-overlay direction. This variable should never be zero.



```
**TRAFFIC DELAY COST VARIABLES**

50.1 LOCATION OF PROJECT (1=RURAL, 2=URBAN)..........................     2
50.2 MODEL NO. FOR HANDLING TRAFFIC.....................................     5
50.3 NO. OF OPEN LANES, OVERLAY DIRECTION.............................     2
50.4  NO. OF OPEN LANES, NON-OVERLAY DIRECTION......................     4

51.1 MILITARY TIME OVERLAY CONSTRUCTION BEGINS.....................   900
51.2 MILITARY TIME OVERLAY CONSTRUCTION ENDS........................  1600
51.3 HOURS PER DAY OVERLAY CONSTRUCTION OCCURS..................   6.0
51.4 NO. OF DAYS CONCRETE IS ALLOWED TO CURE........................    14
51.5 DETOUR DISTANCE TO USE IN MODEL 5, MILES.........................   2.5

52.1 AVERAGE APPROACH SPEED, MPH.........................................    55
52.2 AVERAGE SPEED, OVERLAY DIRECTION, MPH..........................    40
52.3 AVERAGE SPEED, NON-OVERLAY DIRECTION, MPH...................    55
```

Screen 18: Traffic Delay Cost Variables, Inputs 50-52

50.4 Number of Open Lanes, Non-Overlay Direction. This variable specifies how many lanes are open to traffic in the non-overlay direction. Unless it is necessary to close a lane in this direction due to encroachment of overlay construction equipment and personnel, this variable should be equal to Variable 2.3, number of pavement lanes.

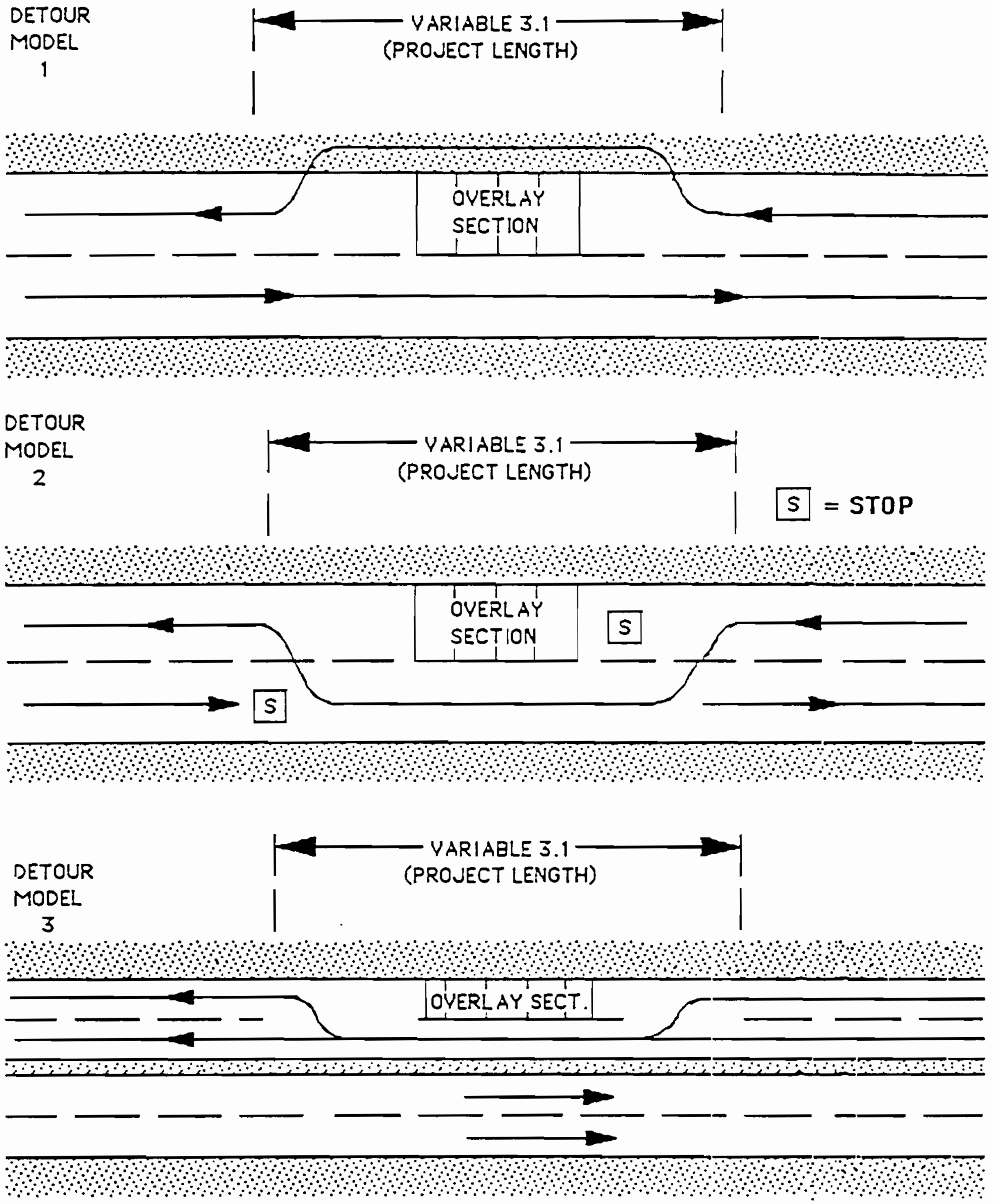
51.1 Time of Day Overlay Construction Begins. This variable, along with the next, is used to define the period during the day during which traffic will be delayed. In the case of PCC overlays, where traffic may be detoured for two weeks or more, this period should cover the entire day. For ACP overlays, however, these variables may correspond to the beginning and ending of construction since the overlay lanes may be opened to traffic immediately after the hour that construction ends. Note that the hours are specified using military time where 4:00 a.m. is 0400 hours, 4:00 p.m. is 1600 hours, etc.

51.2 Time of Day Overlay Construction Ends. This variable and the preceding one are used to specify a total daily traffic delay period. Its units are also in military time (see Variable 51.1).

51.3 Hours Per Day Overlay Construction Occurs. This variable is used to determine how many days it will take to complete overlay construction. This variable is not necessarily the difference (in standard hours) between Variables 51.2 and 51.1, since they define the period during the day during which traffic will be delayed. The value of this variable must be greater than zero.

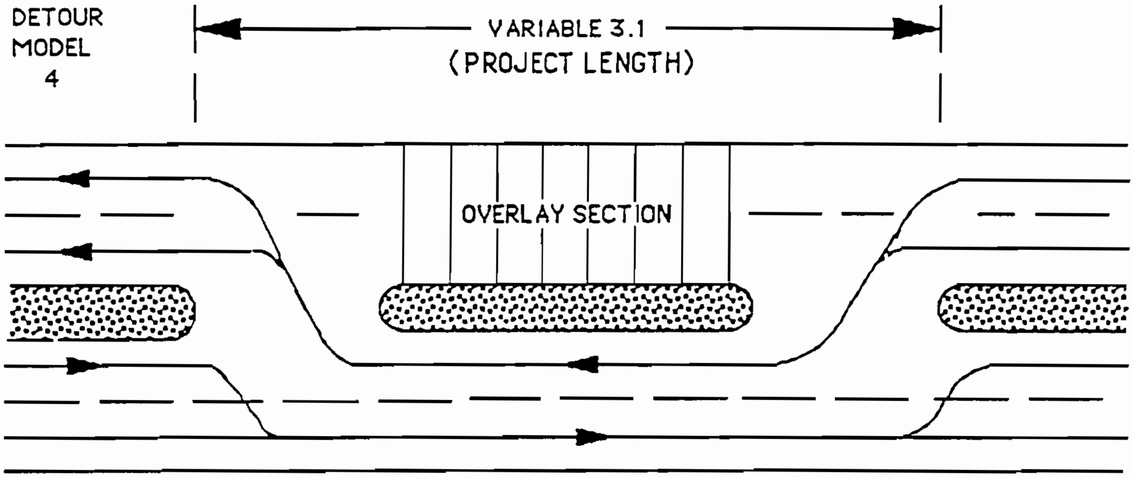
51.4 Number of Days Concrete is Allowed to Cure. This variable is used to account for the additional period of traffic delay after PCC overlay construction for concrete curing.

51.5 Detour Distance. This variable defines a length over which traffic will be detoured. It applies to Model 5 only (see Fig 2).



(Continued)

Fig 2. Detour models available for estimating traffic delay cost.



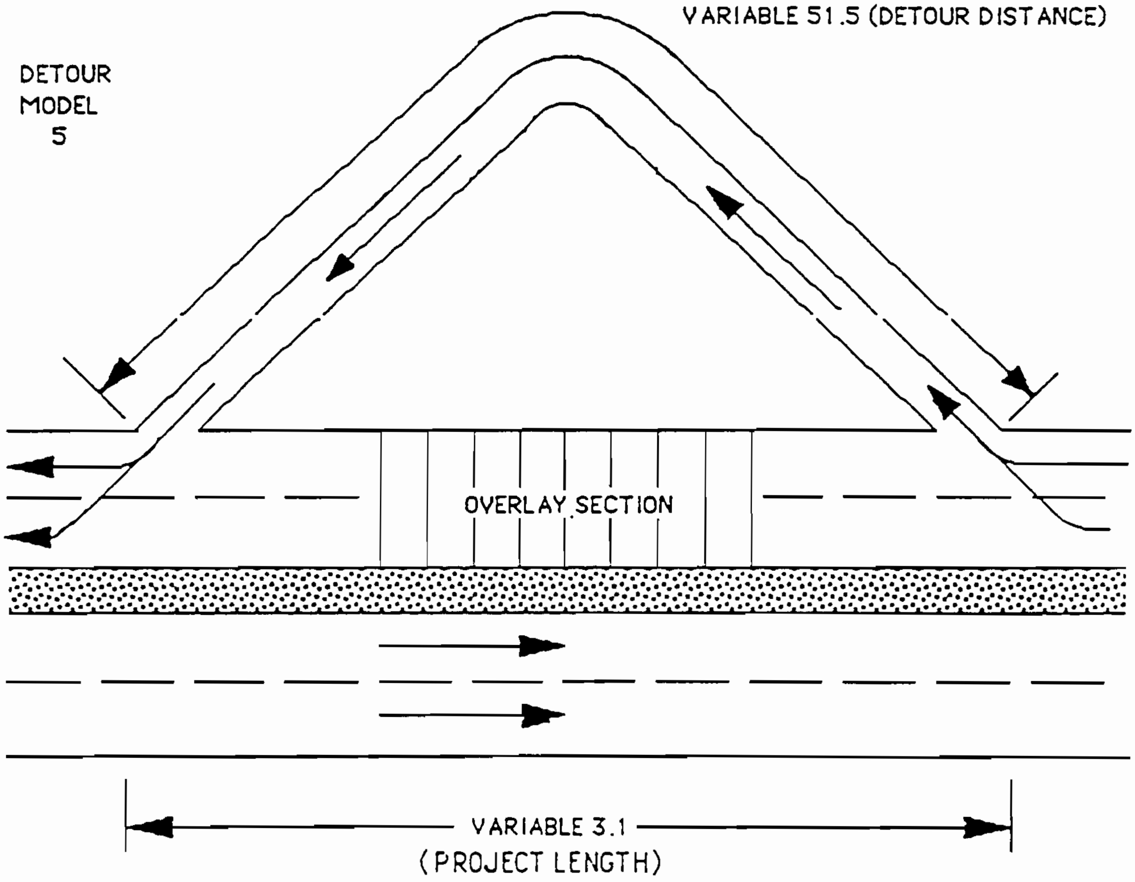


Fig 2. (Continued).

52.1 Average Approach Speed. This variable, along with the other Variables in unit 52, is used to calculate how much time each vehicle will be delayed due to the reduction of speed through the overlay zone. This variable is basically the average speed of traffic under unrestricted conditions.

52.2 Average Speed, Overlay Direction. This variable defines the average speed of vehicles traveling through the restricted zone in the overlay direction. It is used with Variable 52.1 to calculate the vehicle delay due to reduced speed.

52.3 Average Speed, Non-Overlay Direction. This variable defines the average speed of vehicles traveling through the restricted zone in the non-overlay direction. It is used with Variable 52.1 to calculate the vehicle delay due to reduced speed and may be equal to Variable 52.1 if traffic in the non-overlay direction is not disturbed.

53.1 Distance Traffic is Slowed, Overlay Direction. This variable accounts for the length over which traffic is slowed in the overlay direction during overlay construction. Its value is not necessarily the length of the project since the restricted zone may be much shorter.

53.2 Distance Traffic is Slowed, Non-Overlay Direction. This variable is similar to Variable 53.1 except that it is for traffic in the non-overlay direction. In many cases where traffic is not disturbed in the non-overlay direction, this variable will have a value of zero.

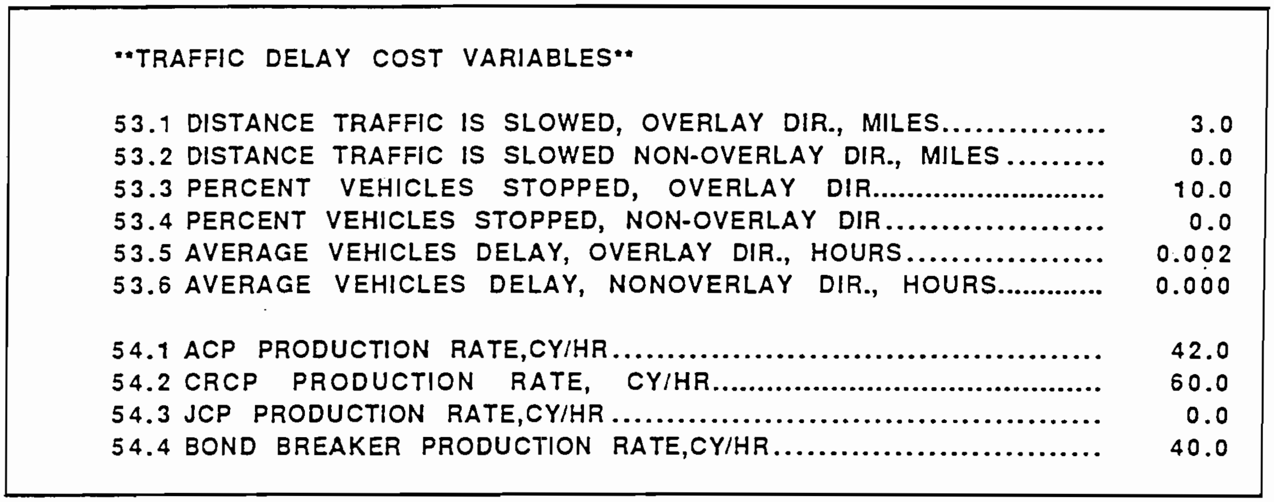
53.3 Percent of Vehicles Stopped, Overlay Direction. In some cases where traffic is heavy or forced to share a traffic lane (such as in Detour Model 2, Fig 2), the closing of a single lane for overlay construction may force many vehicles to slow down and stop.

This variable attempts to account for the percentage of these vehicles which are stopped, due to either traffic or overlay construction equipment and personnel.

53.4 Percent of Vehicles Stopped, Non-Overlay Direction. This variable is the same as Variable 53.3 except that it is for the non-overlay direction. Depending on the detour model, the value may vary from zero to the value for the overlay direction.

53.5 Average Vehicle Delay, Overlay Direction. This variable defines the average amount of delay incurred by stopped vehicles (during the stopped period only). This variable, along with Variable 53.3, defines the total amount of vehicle stop time during overlay construction in the overlay direction. This value is then added to the time lost due to slowing down, to get the total vehicle delay time in the overlay direction.

53.6 Average Vehicle Delay, Non-Overlay Direction. This variable is the same as Variable 53.5 except that it is for the non-overlay direction. This value may be zero if no delay occurs in the non-overlay direction.



```
**TRAFFIC DELAY COST VARIABLES**

53.1 DISTANCE TRAFFIC IS SLOWED, OVERLAY DIR., MILES...............      3.0
53.2 DISTANCE TRAFFIC IS SLOWED NON-OVERLAY DIR., MILES.........      0.0
53.3 PERCENT VEHICLES STOPPED, OVERLAY DIR..........................     10.0
53.4 PERCENT VEHICLES STOPPED, NON-OVERLAY DIR....................      0.0
53.5 AVERAGE VEHICLES DELAY, OVERLAY DIR., HOURS..................    0.002
53.6 AVERAGE VEHICLES DELAY, NONOVERLAY DIR., HOURS............    0.000

54.1 ACP PRODUCTION RATE,CY/HR...........................................     42.0
54.2 CRCP PRODUCTION RATE, CY/HR.........................................     60.0
54.3 JCP PRODUCTION RATE,CY/HR............................................      0.0
54.4 BOND BREAKER PRODUCTION RATE,CY/HR..............................     40.0
```

Screen 19: Traffic Delay Cost Variables, Inputs 53-54

54.1 **Asphaltic Concrete Production Rate.** This variable, along with the overlay thickness and length of the construction day, is used to compute the total number of days required to complete overlay construction. It is assumed, then, that this calculated number of days is the period over which the traffic delays will occur. Note that the units for this variable are in cubic yards per hour so that a thick overlay will require more construction time than a thin overlay.

54.2 **CRCP Production Rate.** This variable is the same as Variable 54.1 except that it is for a CRCP overlay. Note that the placement of steel reinforcement may have an effect on this value.

54.3 **JCP Production Rate.** This variable is the same as Variables 54.1 and 54.2 except that it is for a JCP overlay. Also, some consideration should be given here to the time required for joint preparation as well as for the placement of steel reinforcement.

54.4 **Bond Breaker Production Rate.** This variable is similar to the production rates discussed previously. In fact, the value for this variable may be the same as that for an ACP overlay (Variable 54.1). The difference is that this variable will be used to estimate construction time required for a bond breaker used in an unbonded PCC overlay strategy.

I. Distress/Maintenance Cost Variables

These data are used to compute the maintenance cost of each feasible strategy. Basically, the data required on the next four variables (55 through 58) consist of the cost to repair a defect and the yearly rates of defect or distress development for different periods during the life of the strategy. These values are entered for four possible overlay combinations, (1) CRCP, (2) JCP, (3) ACP on CRCP, and (4) ACP on JCP, which correspond to the four variables required, and which are shown on Screens 20 to 23.

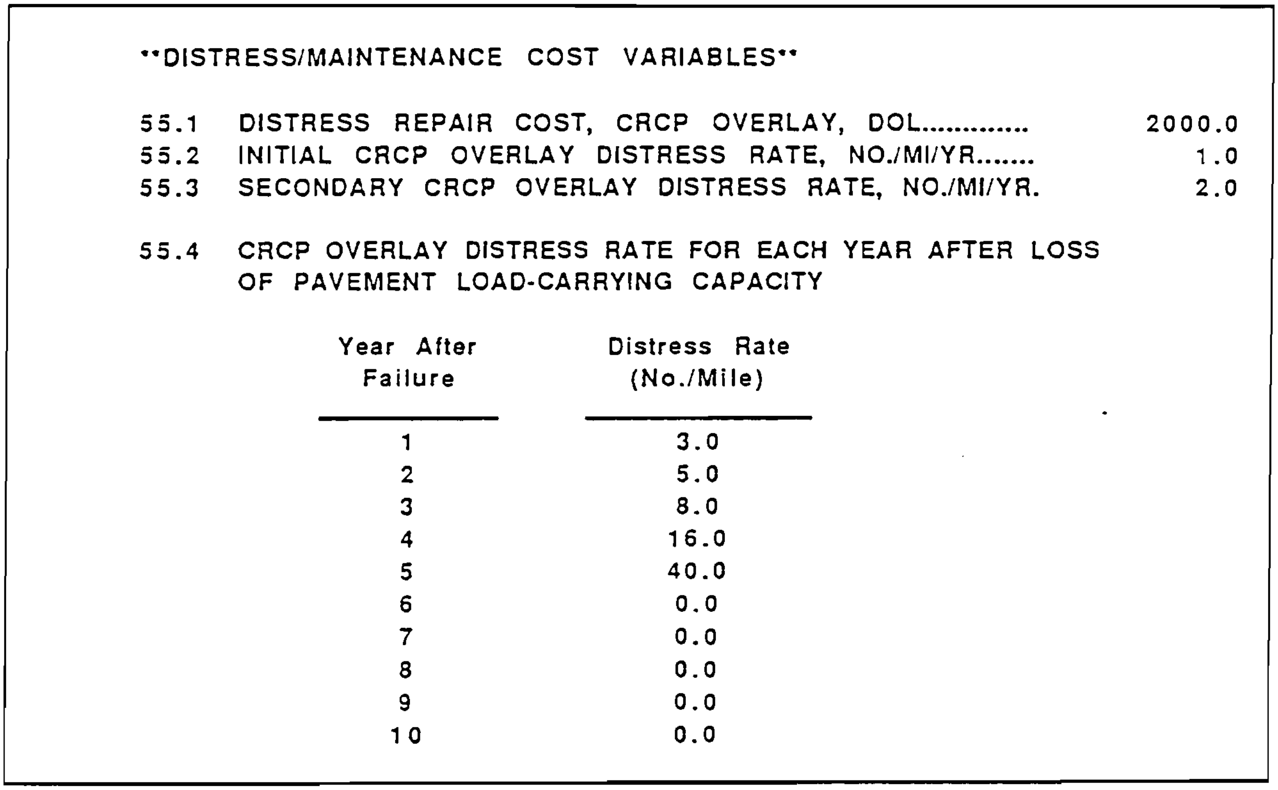
55.1 CRCP Overlay Distress Repair Cost. This variable should represent the cost of repairing a severe distress manifestation such as a punchout in a CRCP overlay. This cost should reflect the manpower, material, and equipment required to repair a single severe defect.

55.2 Initial CRCP Overlay Distress Rate. This variable defines the initial CRCP distress rate that is exhibited during the period between 80 and 40 percent of the remaining overlay life. Results of statewide condition surveys in Texas indicate that this value is about one defect per mile per year.

55.3 Secondary CRCP Overlay Distress Rate. This variable defines the secondary CRCP distress rate that is exhibited during the period between 40 and 0 percent of the remaining overlay fatigue life. Results of statewide condition surveys in Texas indicate that the maximum value is about two per mile per year.

55.4 CRCP Overlay Distress Rate for Each Year After Loss of Pavement Load Carrying Capacity. This actually consists of a set of CRCP distress rates, one for each year up to the maximum allowable number of years of heavy maintenance (Variable 10.3). Once again, results of the statewide Texas condition survey indicate a progression for each year after the loss of pavement load-carrying capacity.

56.1 JCP Overlay Distress Repair Cost. This variable should represent the cost of repairing a distress manifestation, such as a defective joint or badly cracked slab in a JCP overlay. This cost should reflect the manpower, material, and equipment required to repair a single severe defect.



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**DISTRESS/MAINTENANCE COST VARIABLES**

55.1  DISTRESS REPAIR COST, CRCP OVERLAY, DOL.............      2000.0
55.2  INITIAL CRCP OVERLAY DISTRESS RATE, NO./MI/YR.......         1.0
55.3  SECONDARY CRCP OVERLAY DISTRESS RATE, NO./MI/YR.             2.0

55.4  CRCP OVERLAY DISTRESS RATE FOR EACH YEAR AFTER LOSS
      OF PAVEMENT LOAD-CARRYING CAPACITY

            Year After        Distress Rate
             Failure            (No./Mile)
           __________       ______________
                1                3.0
                2                5.0
                3                8.0
                4               16.0
                5               40.0
                6                0.0
                7                0.0
                8                0.0
                9                0.0
               10                0.0
```

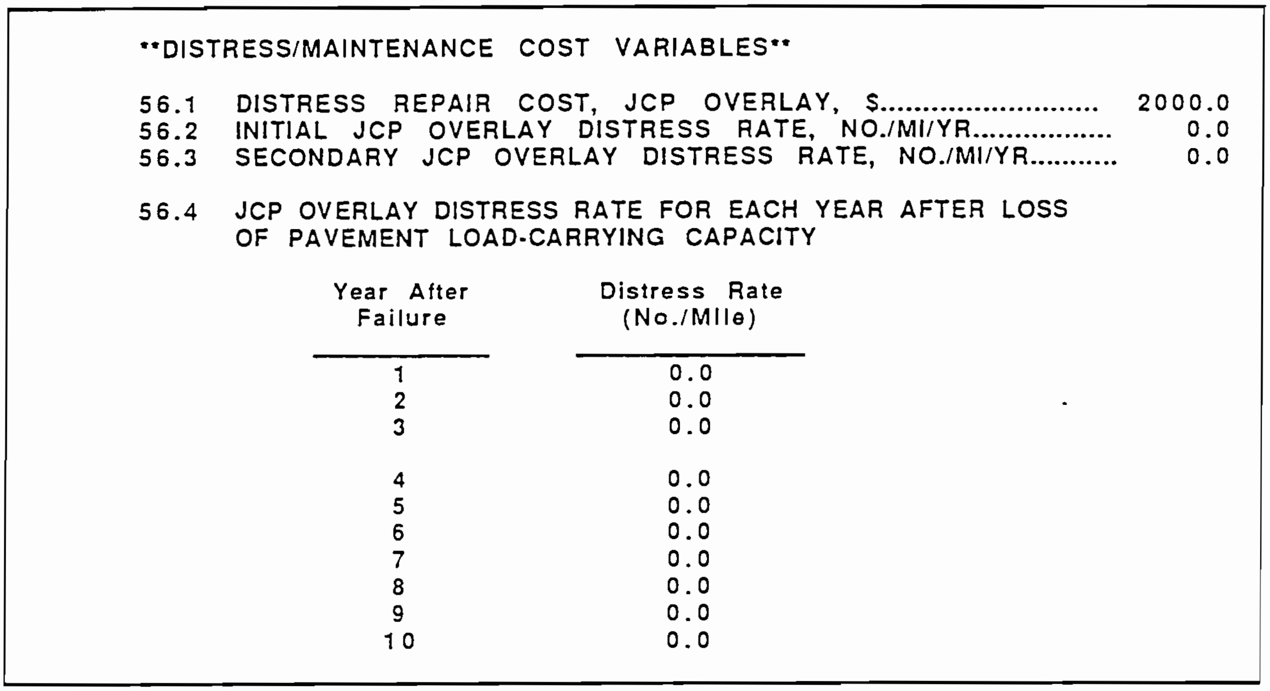
Screen 20: Distress/Maintenance Cost Variables, Input 55

56.2 Initial JCP Overlay Distress Rate. This variable defines the initial JCP distress rate that is exhibited during the period between 80 and 40 percent of the remaining overlay fatigue life. Due to a lack of field data and the fact that the definition of a JCP severe distress manifestation is highly subjective, no recommendation is made for this value. It is hoped that future research will provide better information on which to base a recommendation.

56.3 Secondary JCP Overlay Distress Rate. This variable defines the secondary JCP distress rate that is exhibited during the period between 40 and 0 percent of the remaining overlay fatigue life. For the same reasons given in Variable 56.2, no recommendation is made for this value.

56.4 JCP Overlay Distress Rate for Each Year After Loss of Pavement Load-Carrying Capacity. This actually consists of a set of JCP distress rates, one for each year up to the maximum allowable number of years of heavy maintenance (Variable 10.3). For the same reasons given in Variable 56.2, no recommendation is made for these values.

57.1 Distress Repair Cost, ACP Overlay on CRCP. This variable should represent the cost of repairing a distress manifestation in an ACP overlay over a CRCP. Once again, this cost should reflect the manpower, material, and equipment required to repair a single defect. Examples of such defects include punchouts and potholes. The cost of ACP repairs, however, should be relatively low compared to that of PCC pavement repairs.



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**DISTRESS/MAINTENANCE COST VARIABLES**

56.1  DISTRESS REPAIR COST, JCP OVERLAY, $..........................  2000.0
56.2  INITIAL JCP OVERLAY DISTRESS RATE, NO./MI/YR.................     0.0
56.3  SECONDARY JCP OVERLAY DISTRESS RATE, NO./MI/YR...........       0.0

56.4  JCP OVERLAY DISTRESS RATE FOR EACH YEAR AFTER LOSS
      OF PAVEMENT LOAD-CARRYING CAPACITY

             Year After         Distress Rate
              Failure            (No./Mile)
           ____________       ______________
                 1                 0.0
                 2                 0.0
                 3                 0.0

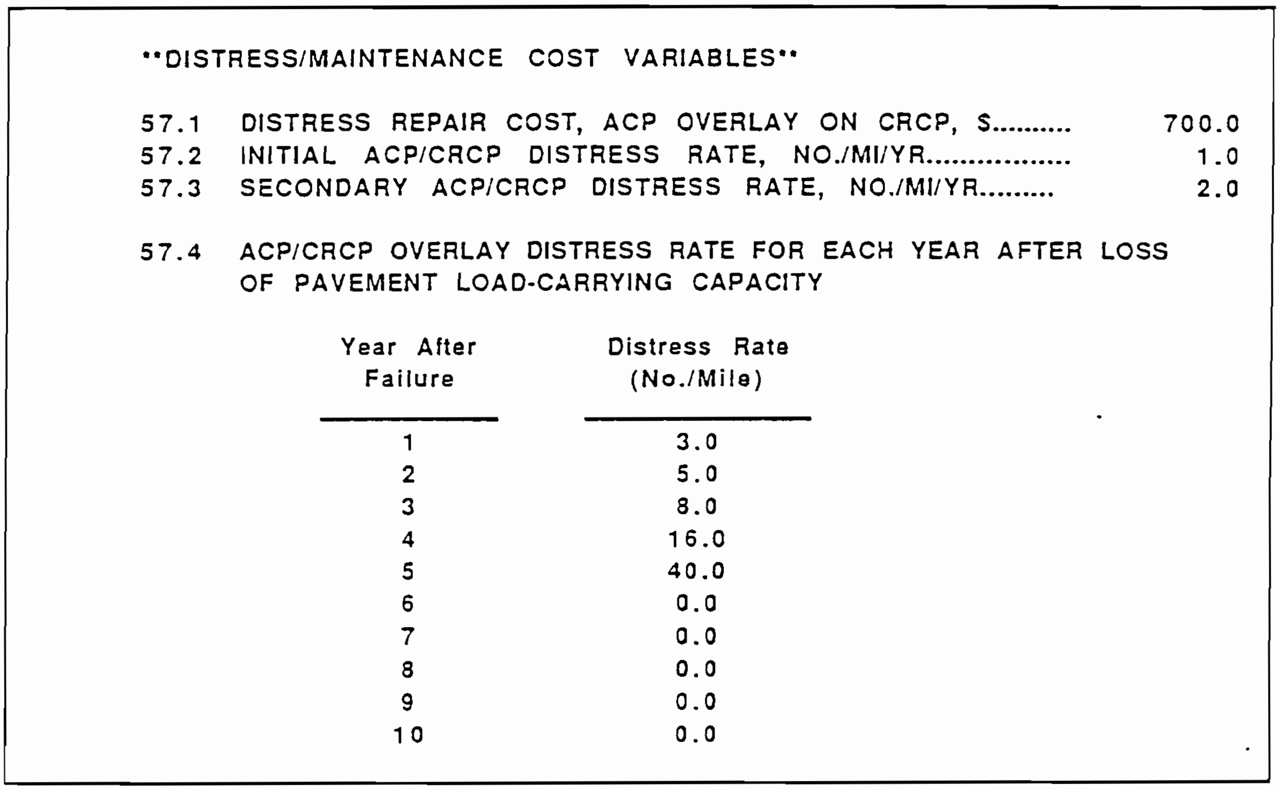
                 4                 0.0
                 5                 0.0
                 6                 0.0
                 7                 0.0
                 8                 0.0
                 9                 0.0
                10                 0.0
```

Screen 21: Distress/Maintenance Cost Variables, Input 56

57.2 Initial ACP/CRCP Overlay Distress Rate. This variable defines the initial distress rate for an ACP overlay (on a CRCP) for the period between 80 and 40 percent of the remaining overlay fatigue life. The results of an experimental CRCP with ACP overlays in Texas have shown good ACP overlay performance with little distress. On the other hand, other ACP overlay projects in Texas have shown poor performance. Due to the fact that there is a large variation in field data, no recommendation is made here except that this value should be at least as high as the recommended initial CRCP distress rate (one per mile per year).

57.3 Secondary ACP/CRCP Overlay Distress Rate. This variable defines the secondary distress rate for an ACP overlay (on a CRCP) for the period between 40 and 0 percent of the remaining overlay fatigue life. As discussed in Variable 57.2, there is considerable variation in the results of field observations of this overlay combination and, therefore, no recommendation is made here. It is recommended that this value should be at least as high as the recommended secondary CRCP distress rate (two per mile per year).

57.4 ACP/CRCP Overlay Distress Rate for Each Year After Loss of Pavement Load-Carrying Capacity. This consists of a set of ACP/CRCP distress rates, one for each year up to the maximum allowable number of years of heavy maintenance (Variable 10.3). For the same reasons discussed in Variables 57.1 and 57.2, no recommendation is made for these values. It is recommended that this value should be at least as high as those distress rates for a CRCP (Variable 55.4).



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**DISTRESS/MAINTENANCE COST VARIABLES**

57.1  DISTRESS REPAIR COST, ACP OVERLAY ON CRCP, $..........   700.0
57.2  INITIAL ACP/CRCP DISTRESS RATE, NO./MI/YR.................   1.0
57.3  SECONDARY ACP/CRCP DISTRESS RATE, NO./MI/YR.........   2.0

57.4  ACP/CRCP OVERLAY DISTRESS RATE FOR EACH YEAR AFTER LOSS
      OF PAVEMENT LOAD-CARRYING CAPACITY
```

Year After Failure	Distress Rate (No./Mile)
1	3.0
2	5.0
3	8.0
4	16.0
5	40.0
6	0.0
7	0.0
8	0.0
9	0.0
10	0.0

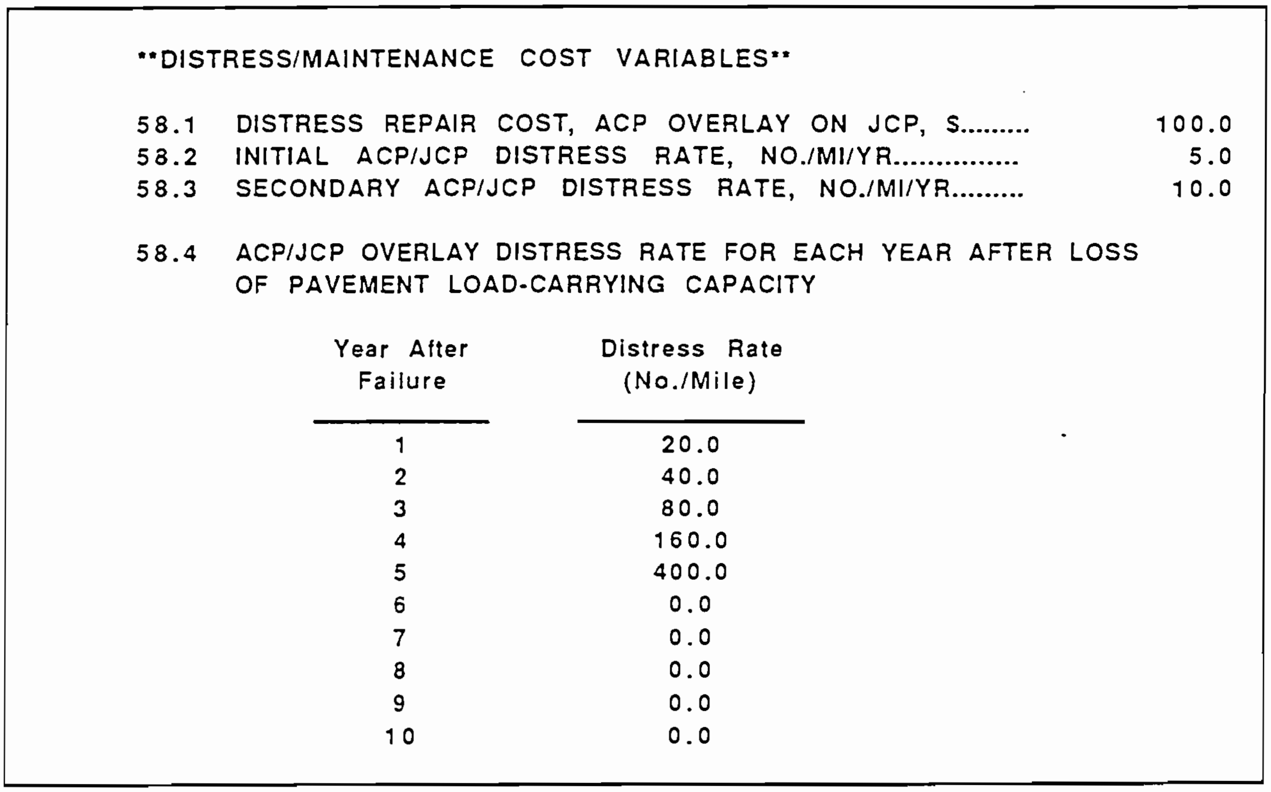
Screen 22: Distress/Maintenance Cost Variables, Input 57

58.1 Distress Repair Cost, ACP Overlay on JCP. This variable should represent the cost of repairing a distress manifestation in an ACP overlay over a JCP. The cost should reflect the manpower, material, and equipment required to repair a single defect. An example of such a defect would be a pothole. Also, the cost of such a repair should be relatively low compared to that of PCC pavement repairs.

58.2 Initial ACP/JCP Overlay Distress Rate. This variable defines the initial distress rate for an ACP overlay (on a JCP) for the period between 80 and 40 percent of the remaining overlay fatigue life. Due to the lack of information on ACP overlay performance on JCP, no recommendation is made for this value. This value should, however, be as least as high as that used for the initial JCP distress rate (Variable 56.2).

58.3 Secondary ASCP/JCP Overlay Distress Rate. This variable defines the secondary distress rate for an ACP overlay (on a JCP) for the period between 40 and 0 percent of the remaining overlay fatigue life. Once again, this value should be at least as high as that used for the secondary JCP overlay distress rate (Variable 56.3).

58.4 ACP/JCP Overlay Distress Rate for Each Year After Loss of Pavement Load-Carrying Capacity. This consists of a set of ACP/JCP distress rates, one for each year up to the maximum allowable number of years of heavy maintenance (Variable 10.3). As before, no recommendation is made here, but the values should be at least as high as those used for a JCP overlay (Variable 56.4).



```
**DISTRESS/MAINTENANCE COST VARIABLES**

58.1  DISTRESS REPAIR COST, ACP OVERLAY ON JCP, $.........     100.0
58.2  INITIAL ACP/JCP DISTRESS RATE, NO./MI/YR...............     5.0
58.3  SECONDARY ACP/JCP DISTRESS RATE, NO./MI/YR.........       10.0

58.4  ACP/JCP OVERLAY DISTRESS RATE FOR EACH YEAR AFTER LOSS
      OF PAVEMENT LOAD-CARRYING CAPACITY

            Year After        Distress Rate
             Failure           (No./Mile)
           ____________     ________________
                1                20.0
                2                40.0
                3                80.0
                4               160.0
                5               400.0
                6                 0.0
                7                 0.0
                8                 0.0
                9                 0.0
               10                 0.0
```

Screen 23: Distress/Maintenance Cost Variables, Input 58

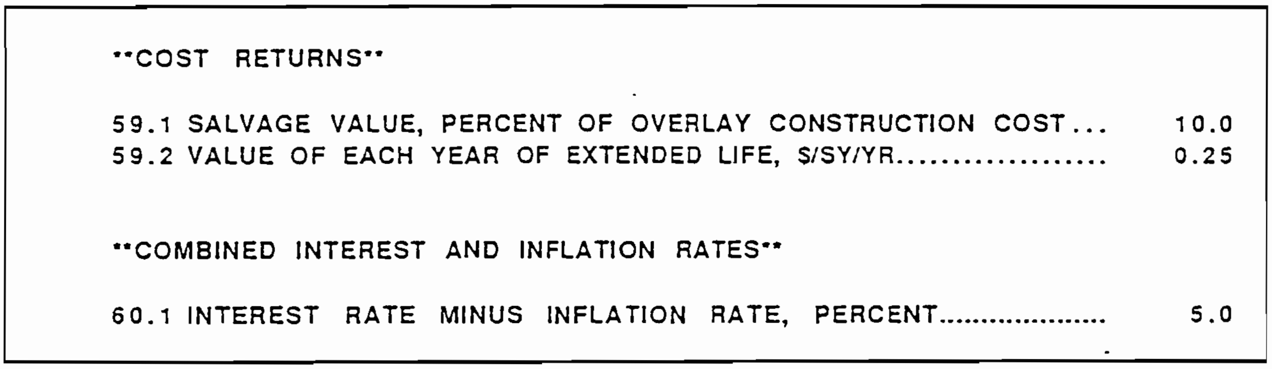
J. Cost Returns

There are two input variables that fall under the heading of cost returns and which are shown in Screen 24. They are both included in Variable 59, and they are both used to estimate the return (a negative cost) from an overlay design strategy at the end of the analysis period.

59.1 Salvage Value. This variable refers to the value (expressed as a percent of the construction cost) an overlay structure has after it has reached the end of its life. Salvage value may refer to the value the pavement has as a base layer for some future overlay, or it may refer to the value the concrete and steel have for other uses. Note, however, that it refers to the value of the overlay only, and that the computed value for the future year is brought back to net present value.

59.2 Value of Each Year of Extended Life. Due to the nature of the method for generating overlay design strategies in PRDS-1, all strategies do not last the same period of time. In fact, some may last well beyond the analysis period. Accordingly, the purpose of this variable is to account for the additional life so that feasible strategies with different lifetimes may be compared on a somewhat equal basis.

The selection of the value of the extended life should be based on estimated cost of the optimum strategy and some other factors namely (1) the present availability of funds for initial construction, (2) the uncertainty in costs and traffic beyond the analysis period, (3) the fact that RPRDS computes maintenance costs only up to the end of the analysis period, and (4) the fact that salvage value is computed at the end of the strategy life and at the end of the analysis period.



```
**COST RETURNS**

59.1 SALVAGE VALUE, PERCENT OF OVERLAY CONSTRUCTION COST...     10.0
59.2 VALUE OF EACH YEAR OF EXTENDED LIFE, $/SY/YR..................     0.25


**COMBINED INTEREST AND INFLATION RATES**

60.1 INTEREST RATE MINUS INFLATION RATE, PERCENT....................      5.0
```

Screen 24: Cost Returns

If, on the other hand, the user elects not to consider the value of extended life (especially in cases where construction funds are limited), he may do so by specifying a value of zero for this variable.

K. Combined Interest and Inflation Rate

60.1 Interest Rate Minus Inflation Rate. This variable is the numeric difference between the interest rate and inflation rate that may be expected during the analysis period. This variable is used to determine the net present value of some cost incurred at some future date. It is also shown on Screen 24.

The estimation of this value may be illustrated by the following example. If the average prime interest rate (or the opportunity cost of capital) anticipated during the analysis period is 18 percent and inflation is 13 percent. then the value of this variable would be the difference between the two, or 5 percent. Long term studies indicate this value to be 4 percent although it may differ for specific periods.

It is important to note that a high value will favor stage (or delayed) overlay construction strategies while a low value will favor early overlay construction strategies.

DESCRIPTION OF PRDS-1 PRINTOUT

The printout of the PRDS-1 program can be divided into two parts, the input summary and the output. The input summary is, basically, an echo print of all the inputs specified by the user, complete with any error diagnostics detected by the INPUT routine.

(Note here that any error in the data will cause the program to terminate execution, but only after it completes its error scan of the input data.) If an error did occur, the program will print the input listing and give error messages at the end of the printed listing. The user will then have to go back and check the input values. Some needed values for analysis of a specific strategy may be missing or some values may be out of range.

The output of the program basically consists of a list of all the feasible strategies that were generated plus a full-page printout for each of the optimal 20 strategies. The list of feasible strategies (provided first) allows the user to inspect all of those that were generated. The full-page printouts of the optimal strategies provided afterwards, then, allow the user to inspect the best strategies and select one or two for use as his recommended design. An example of the printout of such a optimal strategy is shown in Table 5.

The printout shows the typical values listed for each strategy. The output gives the construction sequence, overlay type and amount as well as the time interval between overlays. The strategies are compared by means of the NET PRESENT VALUE OF STRATEGY, which enables the user to choose between certain strategies. The lower this value, the more economical the strategy.

After the strategy values are printed, the program will automatically go back to the DOS prompt, and therefore the user can start another analysis by again typing C>PRDS.

TABLE 5. STRATEGY PRINTOUT

PROJECT DESCRIPTION
PRDS1-REDESIGN FOR FRATT INTCHNG O/L PROJECT, S A TX, SBS/11/80
OPTIMAL STRATEGY NO. 1

Component of Strategy	Quantity
1. EXISTING PAVEMENT REMAINING LIFE AT 1ST OVERLAY, PERCENT	0.00
2. YEAR OF 1ST OVERLAY PLACEMENT	2.00
3. TOTAL 18-KIP ESAL CYCLES (NOW TILL 1ST OVERLAY), MILLIONS	1.17
4. COST OF MAINTAINING EXISTING PAVEMENT, DOL/SQ YD	1.24
5. 1ST OVERLAY TYPE	ACP
6. TYPE OF SHOULDER	FLEX
7. 1ST OVERLAY THICKNESS, INCHES	6.00
8. PCC FLEXURAL STRENGTH OF 1ST OVERLAY, PSI	0.00
9. FATIGUE LIFE AFTER 1ST OVERLAY, YEARS	10.30
10. FATIGUE LIFE AFTER 1ST OVERLAY, 18-KIP ESAL IN MILLIONS	5.85
11. 1ST OVERLAY CONSTRUCTION COST, DOL/SQ YD	7.83
12. 1ST OVERLAY TRAFFIC DELAY COST, DOL/SQ YD	0.36
13. 1ST OVERLAY MAINTENANCE COST, DOL/SQ YD	0.08
14. 1ST OVERLAY REMAINING LIFE AT 2ND OVERLAY, PERCENT	60.00
15. YEAR OF 2ND OVERLAY PLACEMENT	7.00
16. TOTAL 18-KIP ESAL CYCLES (NOW TILL 2ND OVERLAY), MILLIONS	4.08
17. 2ST OVERLAY TYPE	ACP
18. TYPE OF SHOULDER	FLEX
19. 2ND OVERLAY THICKNESS, INCHES	3.00
20. PCC FLEXURAL STRENGTH OF 2ND OVERLAY, PSI	0.00
21. FATIGUE LIFE AFTER 2ND OVERLAY, YEARS	19.20
22. FATIGUE LIFE AFTER 2ND OVERLAY, 18-KIP ESAL IN MILLIONS	12.20
23. 2ND OVERLAY CONSTRUCTION COST, DOL/SQ YD	4.07
24. 2ND OVERLAY TRAFFIC DELAY COST, DOL/SQ YD	0.15
25. 2ND OVERLAY MAINTENANCE COST, DOL/SQ YD	0.20
26. VALUE OF EXTENDED LIFE, DOL/SQ YD	0.00
27. OVERLAY SALVAGE VALUE, DOL/SQ YD	0.53
28. TOTAL NET PRESENT VALUE OF STRATEGY, DOL/SQ YD	13.41

Appendix B

PAVLIF Program

The PAVLIF computer program is used to estimates the remaining life of a CRC pavement. PAVLIF uses the failure prediction developed by CTR (Refs 24, 25) to estimate a failure-versus-ESALs relationship. The prediction model, calibrated using TxDOT's Rigid Pavement Database, uses the actual early-age crack spacing of the pavement as its main predictor of performance.

Based on the failures-versus-ESALs curve produced by the prediction model, the program calculates the current number of ESALs the pavement has endured by correlating the current number of failures (severe punchouts and patches) per mile the pavement has accumulated since its construction. This procedure is illustrated in Figure B.1, where the dotted lines mark the intersection of current failures and current ESALs on the failure curve. Once PAVLIF determines the current ESALs, the remaining life of the pavement in years is calculated by the program using a traffic model (Ref 30).

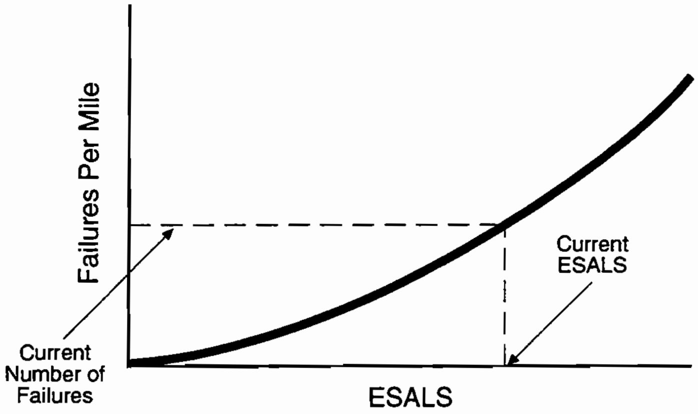


Figure B.1 Example of estimating the current number of ESALs from the failure curve based on current failures per mile (Ref 30)