TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-84/13+318-1F		

4. Title and Subtitle ASPHALT CONCRETE OVERLAY DESIGN CONSIDERATIONS	5. Report Date February 1984
	6. Performing Organization Code
7. Author(s) Freddy L. Roberts and Thomas W. Kennedy	8. Performing Organization Report No. Research Report 318-1F
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin Austin, Texas 78712-1075	10. Work Unit No.
	11. Contract or Grant No. Research Study 3-9-82-318
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Final
	14. Sponsoring Agency Code

15. Supplementary Notes

Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration
Research Study Title: "Mixture Design for ACP Overlays"

16. Abstract

This report contains the results of a literature survey and small computer study using the ELSYM 5 computer program to investigate the state of stresses and strains in asphalt mixtures used as overlays as compared to those used in conventional pavement layers. Results from the literature survey indicate that very thin overlays on old flexible pavements should probably be avoided since the tensile stresses between dual tires are very high, in fact, several of the overlay design procedures avoid thicknesses of less than 3 inches because of the high tensile stress state in the overlays. As the overlay thickness increases beyond 3 inches the stresses decrease and fatigue cracking problems become less severe. However, overlays on rigid pavements appear to fail either by permanent deformation due to repeated loads or stripping or cracking caused by reflection of underlying cracks. The use of elastic layered theory to study the shear stresses in overlays on rigid pavements showed that shear stresses decreased with increase in stiffness of the underlying layer. However, as the modulus of the overlay decreased these shear stresses increased dramatically, such is probably the case when low density or moisture damage is sustained by the overlay. Results of this study indicate that there are mixture design questions that should be considered further including the effects of low density and moisture damage on the stability and permanent deformation characteristics of overlay mixtures.

17. Key Words	18. Distribution Statement
overlay, elastic layered theory, stresses, strains, permanent deformation, reflection cracking, stripping, density	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	32	

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ASPHALT CONCRETE OVERLAY DESIGN CONSIDERATIONS

by

Freddy L. Roberts

Thomas W. Kennedy

Research Report No. 318-1F

Mixture Design for ACP Overlays

Research Project 3-9-82-318

conducted for

Texas

State Department of Highways and Public Transportation

by the

Center for Transportation Research

Bureau of Engineering Research

The University of Texas at Austin

February 1984

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 Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

PREFACE

The first year of this project was designed to identify the primary causes of premature distress in overlays in Texas and to use information from a literature survey and small computer analysis to determine if there were areas of mixture design that should be further evaluated. Results from this report indicate that permanent deformation resulting from stability and moisture problems should be considered in developing additional mixture design criteria. The objectives of the study for the first year were to determine causes of distress in asphalt concrete overlays and to relate the causes to mixture design and construction.

The work required to develop this report was provided by people both at the Center for Transportation Research (CTR) and the Texas State Department of Highways and Public Transportation (SDHPT). The authors would like to express their thanks to Messrs. Paul E. Krugler and Billy R. Neeley of the SDHPT and to the research staff of the CTR for their assistance in preparation of the manuscript. The support of the Federal Highway Administration, Department of Transportation, is acknowledged.

Freddy L. Roberts
Thomas W. Kennedy

February 1984

LIST OF REPORTS

Report No. 318-1F, "Asphalt Concrete Overlay Design Considerations," by Freddy L. Roberts and Thomas W. Kennedy, summarizes a limited study of possible mixture design considerations for asphalt overlay mixtures.

ABSTRACT

This report contains the results of a literature survey and small computer study using the ELSYM 5 computer program to investigate the state of stresses and strains in asphalt mixtures used as overlays as compared to those used in conventional pavement layers. Results from the literature survey indicate tht very thin overlays on old flexible pavements should probably be avoided since the tensile stresses between dual tires are very high, in fact, several of the overlay design procedures avoid thicknesses of less than 3 inches because of the high tensile stress state in the overlays. As the overlay thickness increases beyond 3 inches the stresses decrease and fatigue cracking problems become less severe. However, overlays on rigid pavements appear to fail either by permanent deformation due to repeated loads or stripping or cracking caused by reflection of underlying cracks. The use of elastic layered theory to study the shear stresses in overlays on rigid pavements showed that shear stresses decreased with increase in stiffness of the underlying layer. However, as the modulus of the overlay decreased these shear stresses increased dramatically, such is probably the case when low density or moisture damage is sustained by the overlay. Results of this study indicate that there are mixture design questions that should be considered further including the effects of low density and moisture damage on the stability and permanent deformation characteristics of overlay mixtures.

KEY WORDS: overlay, elastic layered theory, stresses, strains, permanent deformation, reflection cracking, stripping, density

SUMMARY

This report contains the results of a literature survey and small computer study of the state of stresses and strains in overlays using elastic layered theory. The results of the study show that there is little difference between the tensile and shear stresses and strains for overlays and conventional asphalt concrete layers. However, field studies indicate that there are significant performance problems with overlays especially on rigid pavements. These problems are associated with rutting and shoving usually caused by either stability or stripping problems in the mixtures.

Since these layered programs deal only with elastic strains, it would be desirable for additional studies to be conducted using viscoelastic programs to evaluate the nature and extent of the permanent strains that occur in overlays.

IMPLEMENTATION STATEMENT

Mixture design procedures for overlays should be investigated with respect to improving the resistance of overlays to permanent deformation, reflection cracking, and moisture damage. Even though the elastic analysis showed no significant difference between stresses and strains in mixtures used as overlays and those used in conventional pavement layers, an investigation of the stresses and strains using viscoelastic models is probably justifiable.

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CHAPTER 1. INTRODUCTION

Distress of asphalt concrete overlays over both rigid and old flexible pavements has become a major problem for highway agencies throughout the United States and has caused problems for the traveling public. This distress, manifested by stripping and rutting, often has required costly emergency maintenance and rehabilitation. In a number of cases the deterioration has developed rapidly within a year or two after construction and in at least two cases in Texas (Refs 1 and 2), prior to completion of construction. In addition, reflection cracking generally occurs which adds to the magnitude of the problem.

The problem involves possible moisture effects resulting when moisture penetrates into the asphalt mixture and is trapped because the water either cannot evaporate or cannot pass through the mixture into underlying layers. This moisture ultimately can lead to stripping and softening and result in excessive deformation, slippage, and potholes. In addition, extremes in temperature can produce vapor movements and accelerate moisture-related problems. This distress can be aggravated further by the loss of stability produced by extremely high temperatures and possibly increased stresses due to the rigid underlayer.

The overall objective of the study summarized in this report was to conduct a limited preliminary evaluation to determine whether special mixture design considerations are needed for asphalt mixtures used for overlays, especially under heavy traffic conditions. Special consideration is given to

stresses and strains in overlays,
reflective cracking, and
moisture damage.

Chapter 2 contains a summary of the evaluation based on the literature and a limited theoretical evaluation. Chapter 3 contains the conclusions and recommendations for mixture design criteria.

CHAPTER 2. EVALUATION OF ASPHALT OVERLAY MIXTURES

MIXTURE DESIGN FACTORS

Traditional mixture design methods generally were developed for new construction of flexible pavements with criteria to sustain applied wheel loads in all weather conditions without excessive deformations. Subsequently consideration was given to fatigue and thermal or shrinkage cracking. In addition, tests that measured these characteristics were included in the mix design procedures. These same methods and criteria have continued to be used for asphalt mixtures used as overlays on either portland cement concrete or asphalt concrete pavements. These overlays often have experienced severe cracking resulting from concentrated strains over defects or constructed joints in the underlying pavement. This reflection cracking is often accompanied by rutting and moisture damage when moisture-susceptible mixtures were used in the overlays.

Efforts to alleviate reflective cracking have involved the use of stress relieving interlayers, use of large aggregates in crack relief layers, use of fabrics as interlayers or as reinforcement, use of rubberized layers or rubberized asphalt concretes, etc. In some cases these techniques have reduced reflection cracking and excessive permanent deformations; however, the problem has not been eliminated. In the study summarized in this report the elastic stresses and strains produced by loads in asphalt concrete overlays were evaluated to determine whether additional study was warranted and, if possible, to recommend criteria that should be considered in the design of overlay mixtures which would minimize the occurrence of premature distresses.

STRESSES AND STRAINS IN OVERLAYS

The stresses most often considered in the design of asphalt concrete overlays are the horizontal elastic tensile strains at the bottom of the overlay and elastic compressive strain at the top of the subgrade. The tensile strains, produced by repeated wheel load applications, cause fatigue cracking. Vertical compressive strain at the top of the subgrade relates to permanent vertical strains causing wheel path ruts to develop. Either or both of these considerations have been included in a number of design procedures detailed in the technical literature (Refs 3, 4, 5, 6, 7, 8, and 9).

To evaluate the elastic stresses and strains, the effect of pavement characteristics, such as the modulus and thickness of the various pavement layers, was evaluated from the literature and using an elastic 3-layer pavement computer program, ELSYM 5. While this program does not predict permanent deformation, it does provide insight into the nature of the stresses and strains which develop.

Stresses

In Texas thin overlays (less than 2 inches in thickness) have been used extensively for many years. The materials used in these thin overlays generally satisfy specifications for asphalt concrete surface materials and if placed at high densities should produce a dense graded mixture that has a high modulus of elasticity. Lu and Scrivner (Ref 10) investigated the stress and strain conditions induced in thin pavements under dual tire loads using elastic layered theory and demonstrated that fairly high tensile stresses can occur in these pavements

(1) at the bottom of the layer under the wheel load, and
(2) at the top of the layer, both between the wheel loads and toward the outside edge (Fig 1).

Stresses of the same magnitude can occur in thin overlays placed over badly cracked asphalt concrete surfaces; these layers often have stiffness or modulus values about the same as those of a flexible (granular) base. Tensile stresses of this magnitude can occur in overlays, especially if adequate compaction is not achieved or moisture penetrates the mixture, both of which produce mixtures with low stiffnesses or moduli.

Strains

The effect of changing the overlay thickness in a 3-layered elastic solution is shown in Fig 2 where a badly cracked surface and flexible base

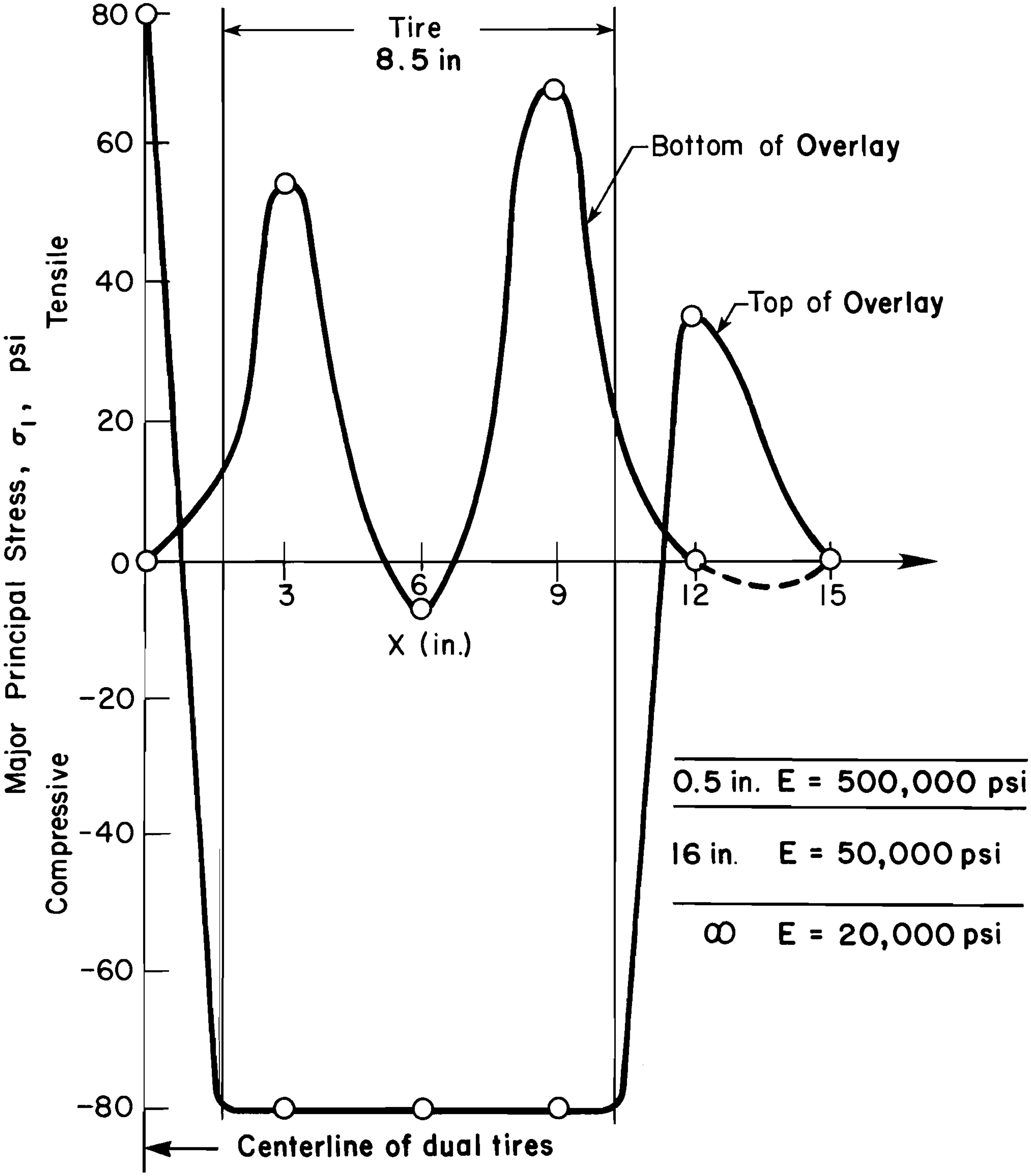
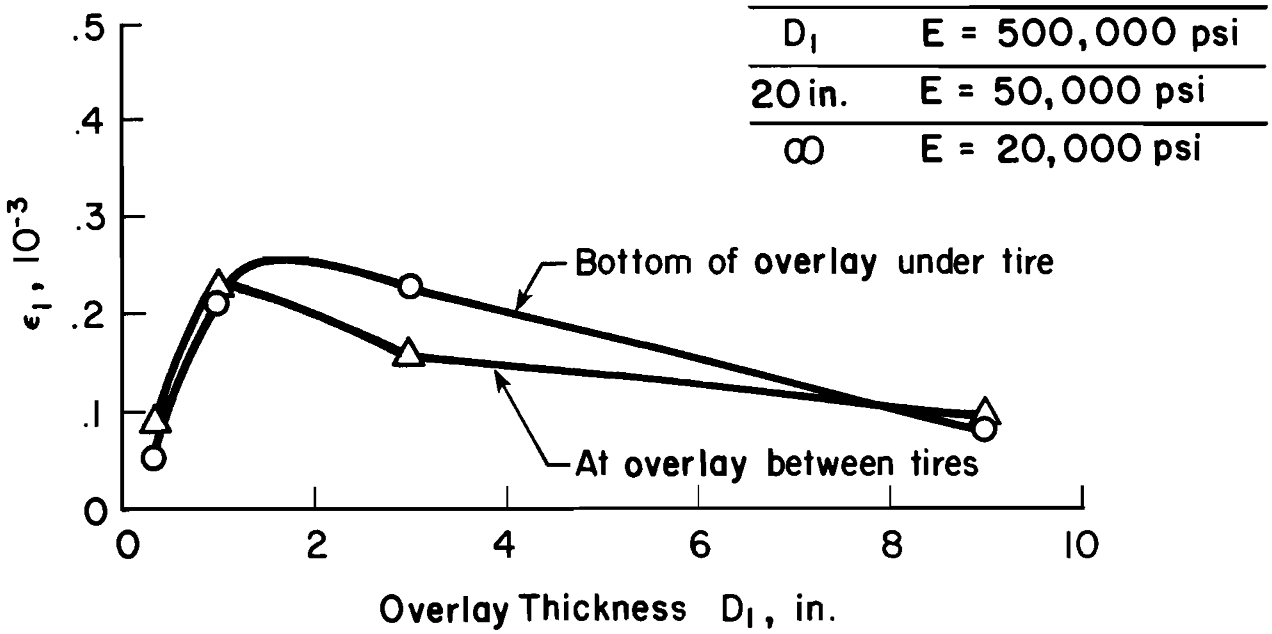
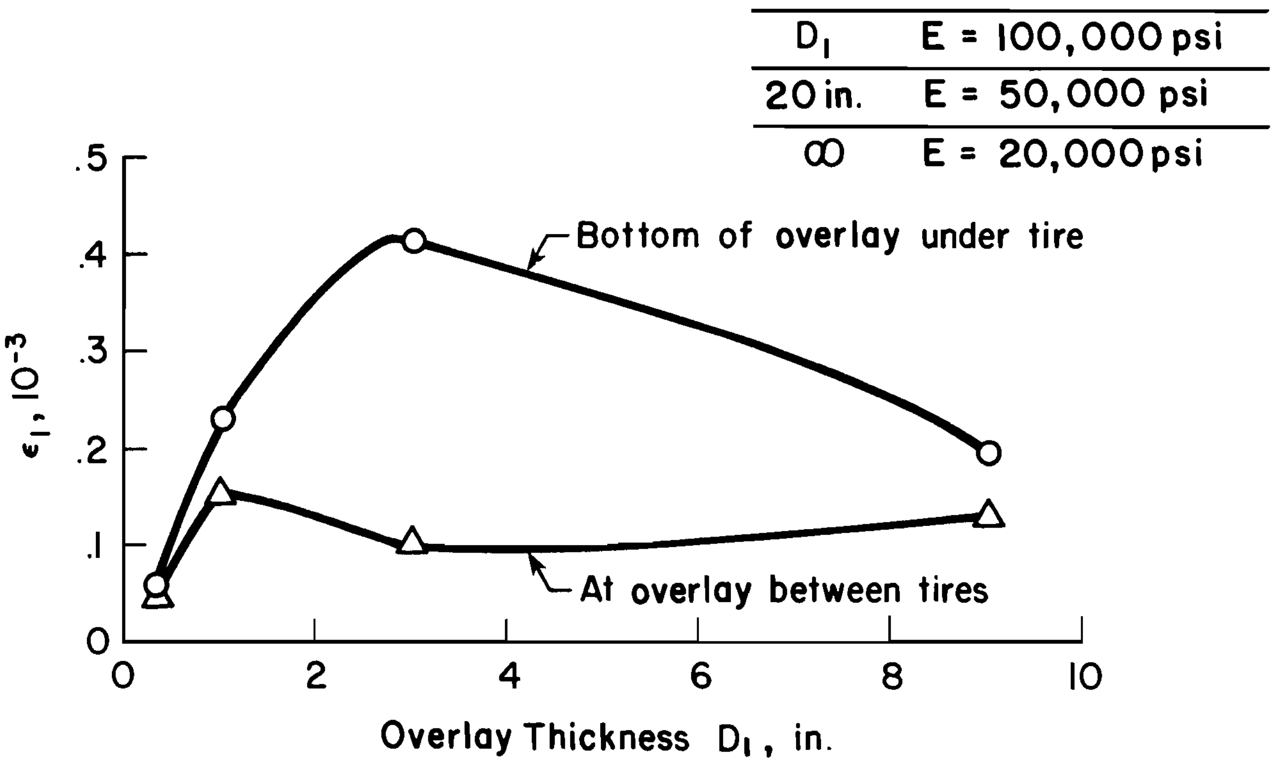


Fig 1. Stresses in a 0.5-inch asphalt concrete surface (Ref 10).



a. High modulus asphalt concrete overlay



b. Low modulus asphalt concrete overlay

Fig 2. Strains in an asphalt concrete surface layer at 2 locations for various surface thicknesses and moduli of elasticity (Ref 10).

with an equivalent thickness of 20 inches was covered by both a high modulus and a low modulus asphalt concrete overlay of varying thickness. As can be seen in Fig 2, the strain at the bottom of the overlay layer increases as the thickness increases and reaches a maximum between 2 and 4 inches. One would conclude from this analysis that fatigue cracking will be at a maximum when the overlay modulus of elasticity is low and the thickness is approximately 3 inches.

For high modulus asphalt concrete layers the maximum tensile strains occur when the surface thickness is around 2 inches. Figures 2(a) and (b) suggest that thin asphalt concrete layers probably should not be used if fatigue cracking is anticipated to be the primary failure mode because of the predicted strain levels. This is especially true if thin overlays are planned for use over an existing asphalt concrete pavement that is so badly cracked that the modulus of elasticity of the old pavement approximates that of a flexible base (Fig 2b).

These general observations are borne out by Finn et al (Ref 11) in an NCHRP study in which it was concluded that

(1) it must be recognized that each of the fatigue criteria evaluated suggests that, for a given level of strain, the cycles to failure (fatigue properties) will increase as the stiffness modulus of the asphalt concrete decreases;

(2) the use of softer asphalts is probably preferable for thin layers of asphaltic concrete surfacing (Ref 12);

(3) damage, for the intermediate range of stiffness moduli, does not appear to be particularly sensitive to stiffness modulus regardless of the fatigue properties; and

(4) the designer must consider other forms of distress, such as plastic deformation in hot climates and transverse cracking in severely cold climates. Such factors as asphalt stripping and disintegration should also be a consideration.

Certain of these observations have been applied to overlay design (Ref 13). As shown in Fig 3, a decrease in the thickness produced a decrease in the elastic strains for overlay thicknesses below about 3 inches for cracked sections with moduli of 25,000 and 70,000 psi, which were assumed from laboratory and field tests. For overlay thicknesses greater than 3 inches, an increase in the overlay thickness produced a

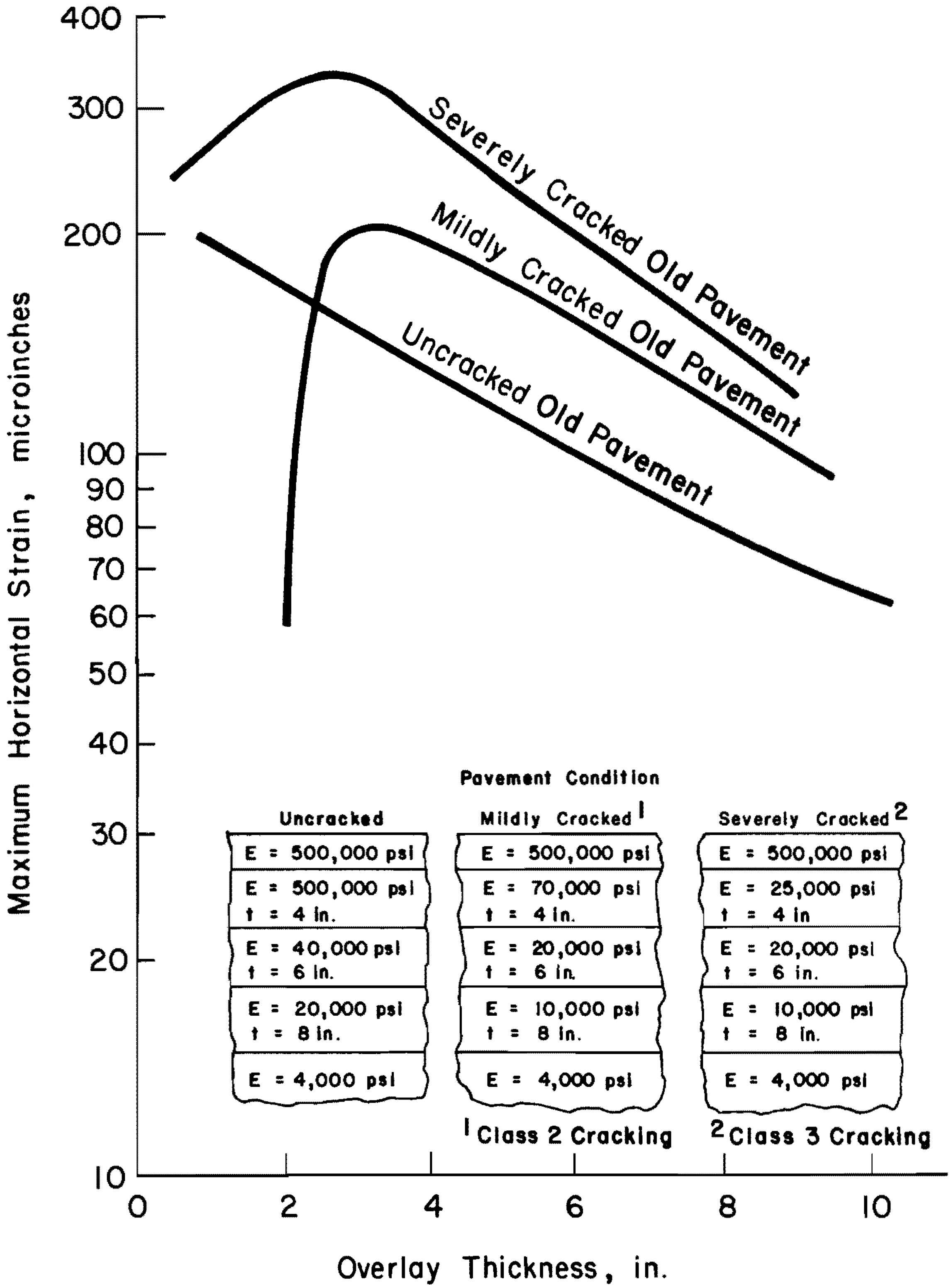


Fig 3. Relationship between critical strain and overlay thickness with a reduction in the existing modulus for various conditions (Ref 13).

decrease in the elastic strains. This again points to a distinct difference between the elastic stress and strain conditions for thin and thick overlays. Of course permanent deformations must consider the viscoelastic or time-dependent deformation characteristics of the asphalt concrete overlay. Nevertheless, generally it would be expected that the magnitude of the permanent strains would be related to the magnitude of the elastic strains.

Shear Stresses and Strains

Shear stresses and strains are not usually considered in the design of asphalt concrete overlays over old asphalt surfaces. This is because the elastic stress and strain levels are not generally sufficiently high to produce shear failures. This is thought to be true if the mixture stabilities meet those normally specified in standard mixture design procedures. To evaluate the shear strain levels expected for an overlay of moderate and heavy pavement structures, a series of conditions were evaluated in which an overlay of variable thickness and a modulus of 500,000 psi was placed over existing pavements in various conditions. These conditions included the old pavement with (a) no cracking (E = 500,000 psi), (b) Class 2 cracking (E = 70,000 psi), and (c) Class 3 cracking (E = 20,000 psi). The underlying base layer was either a granular base (E = 40,000 psi) or a stabilized base (E = 110,000 psi) and the subgrade had a modulus of elasticity of 10,000 psi.

The shear strain for this set of conditions is shown in Figs 4 and 5 for the stabilized base and flexible (granular) base, respectively. As anticipated, the vertical shear strains at the bottom of the overlay are highest when the underlying pavement is the thinnest, i.e., the 4-in. thick underlying old pavement for both the stabilized and flexible base conditions. To determine whether these shear strains are high enough to produce a shear crack under repeated loading, an analysis was conducted to compare the shear strains against a shear strain criterion, proposed by Schnitter et al (Ref 14), and shown in Fig 6. The maximum calculated shear strains (Figs 4 and 5) indicate that a repeated-load shear failure is highly improbable for the asphalt concrete overlay on flexible pavements. However, it must be remembered that these shear strains are elastic and

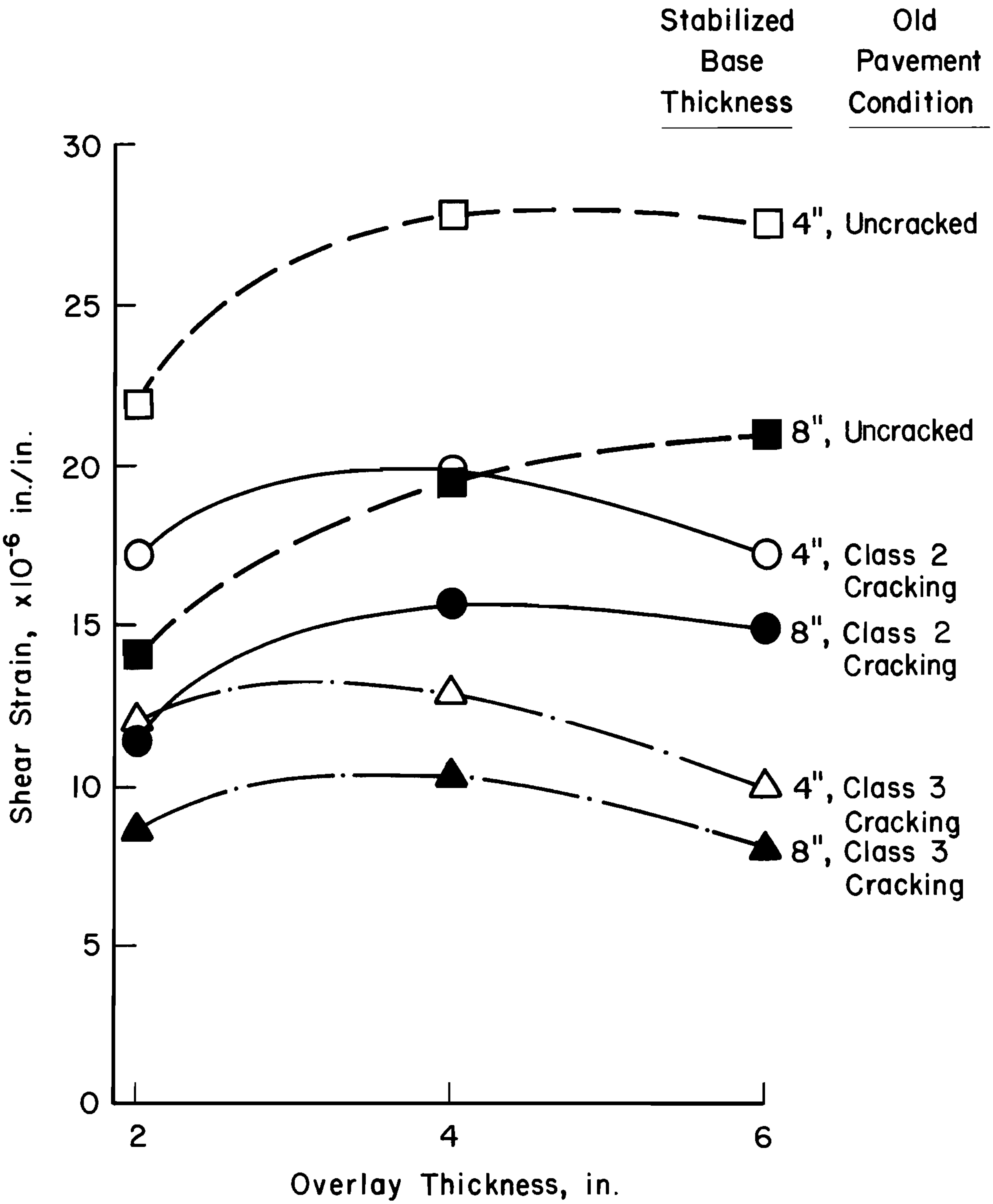


Fig 4. Shear strain at the bottom of an asphalt concrete overlay on flexible pavements with a stabilized base.

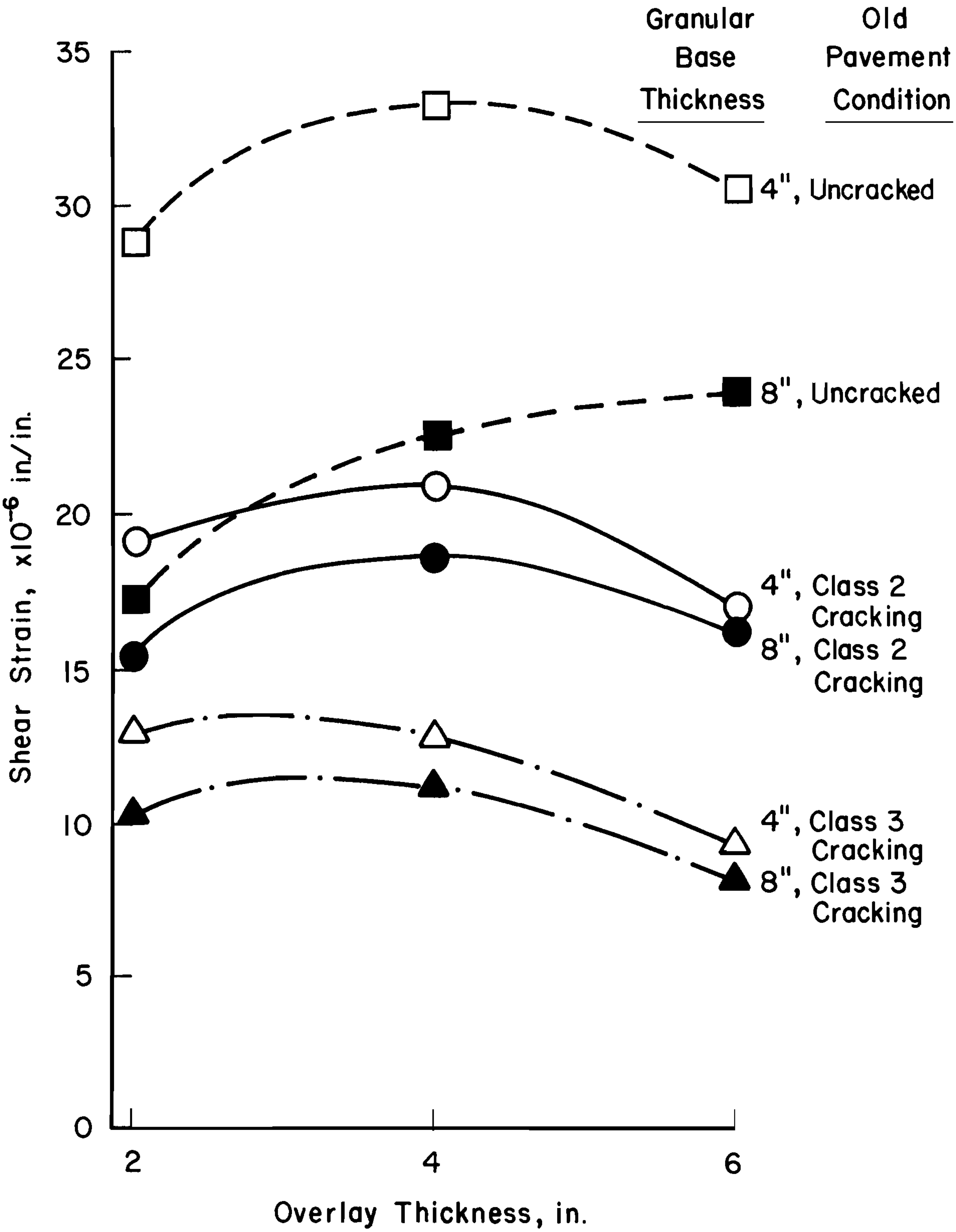


Fig 5. Shear strain at the bottom of an asphalt concrete overlay on flexible pavements with a granular base.

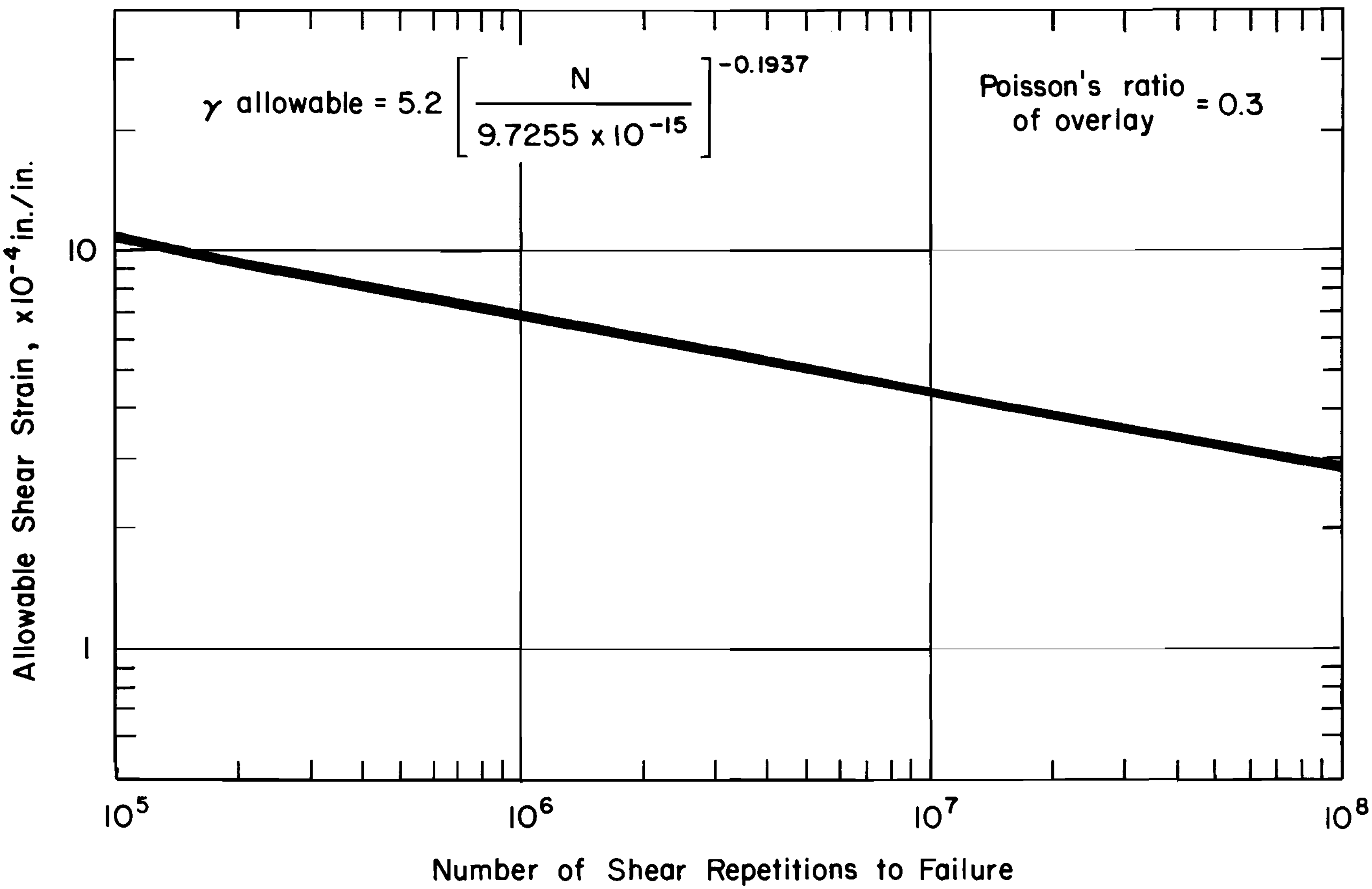


Fig 6. Relation between allowable shear strain and repetitions to failure (Ref 14).

recoverable, since ELSYM 5 is based on elastic theory. Field observations indicate that significant rutting does occur in overlays and much is due to nonrecoverable strains. This deficiency in the model could lead to a conclusion contrary to field observations. Therefore, there is a need to evaluate in a more definitive way the magnitude and significance of these nonrecoverable strains and the effect of mixture design variables on these strains. If, however, there are significant discontinuities in the underlying flexible pavement that allow differential vertical deflections, repeated-load shear failures become much more probable and the analysis and design of such an overlay should follow the procedures prescribed for overlays on portland cement concrete pavements.

STRESSES AND STRAINS IN RIGID PAVEMENTS

Probably the major problem with rehabilitating portland cement concrete pavements with an asphalt concrete overlay is the occurrence of reflection cracking. In addition, it appears that overlay mixtures which are placed on rigid pavements tend to exhibit more rutting, shoving, and permanent deformation than mixtures placed on old flexible asphalt pavements or conventional mixtures placed on granular base courses.

Reflection cracking occurs in the overlay as a result of movements of the cracks or joints in the underlying layer. These cracks may be induced by either environmental or traffic loads. The occurrence of such cracking must be controlled in order to retain the structural integrity of the overlay, prevent excessive amounts of water from penetrating to the base, and maintain a smooth riding surface. These cracks normally produce the need for maintenance and result in reduced serviceability of the overlay.

There has been a considerable amount of field observations and theoretical analysis of reflection cracking. There has also been a great deal of experimentation of various techniques for the control of reflection cracking (Refs 15 and 16). From these studies, it was determined that reflection cracking is developed primarily through horizontal and differential vertical movements between the original pavement and overlay. The effect of horizontal movements due to temperature or longitudinal volumetric changes is illustrated in Fig 7 and the effect of differential vertical deflections at joints or cracks is shown in Table 1.

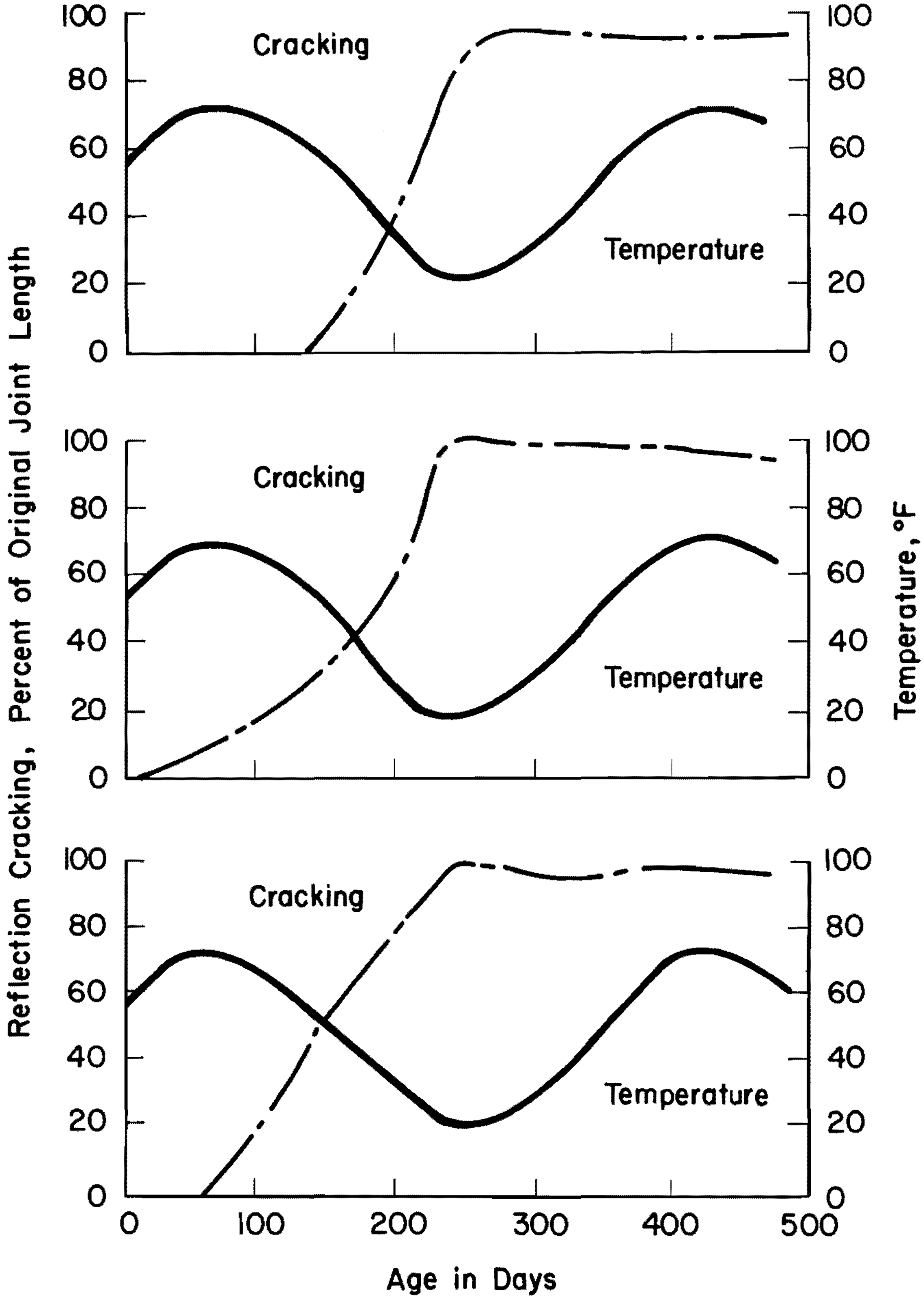


Fig 7. Reflection cracking caused by expansion-shrinkage phenomenon for three projects in New York state (Ref 17).

TABLE 1. EFFECT OF DIFFERENTIAL DEFLECTIONS ON PERCENT REFLECTED CRACKS FOR TWO PROJECTS IN VIRGINIA (REF 18)

Differential Deflection* (in.)	Percent Joints Cracked, %			
	Route 460 Project		Route 13 Project	
	Fabric	Control	Sanded	Control
0	0	44	24	100
0.002	29	54	57	100
0.004	88	74	77	100
0.006	88	100	93	100
0.008	100	100	--	--

*Measurements were taken with the Benkleman Beam using an 18-kip single axle load.

Tensile Strains

It has been generally accepted that the major cause of reflection cracking is horizontal movements produced by expansion and contraction of the old existing pavement caused by temperature and moisture changes (Ref 15). Reflection cracking often begins to occur within the first year of service and accelerates with traffic loads. Hairline cracks have been observed within a few months after overlay placement, usually during the first cool weather experienced by the pavement, and progress to a stage detrimental to performance within a few years.

Tensile stresses in the overlay are produced by the movements of the underlying layer, with these stresses reaching failure levels in the area of the concrete joints when there is good bond between the overlay and concrete pavement. The rate of development of reflection cracking due to environmental loadings is dependent upon the magnitude and rate of temperature drop, slab length, joint width, and engineering properties of the overlay material. To resist this cracking, material properties and thicknesses must be selected to be compatible with the strains induced by the environment. Decisions on construction procedures are very important since bond between the overlay and the PCC pavement is so important.

Shear Strains

McCullagh (Ref 17) and McGhee (Ref 18) have reported that in some cases reflection cracking is primarily due to axle load induced differential deflections (Table 1). In most field studies the differential vertical deflections across joints are not obtained, thus it is very difficult if not impossible to differentiate between the cracks resulting from horizontal or differential vertical movements. Differential vertical movements are caused by traffic loadings which depress abutting slab ends resulting in shear-stress concentrations of the overlay material at the joints. The magnitude of these shear stresses and strains varies with temperature or season. Therefore, reflection cracking caused by differential vertical deflections is a shear-fatigue phenomenon and is dependent on the magnitude of the shear strain induced by the differential deflection across the joint or crack. Estimates of the number of loads sustained to failure can be made using the criteria developed by Schnitter et al (Ref 14) shown in Fig 6. The factors which are important in differential deflections are magnitude of load, amount of load transfer across the joint or crack, and the differential subgrade support under the slab. Overlay design procedures have been developed for the Texas SDHPT by Schnitter et al (Ref 14) as part of Project 177.

Shear Stresses

Figure 8 illustrates the difference in shear strains produced in an asphalt layer over a rigid pavement ($E = 4 \times 10^6$ psi) as compared to a more flexible old pavement layer ($E = 0.5 \times 10^6$ psi). As shown, the shear strains in the overlay mixture on a more flexible surface are more than double the strains produced in the mixture over a more rigid surface. This effect occurs because the shear stresses imposed on the overlay are essentially deflection dependent. Burmister (Ref 19) says that shear stresses in the top layer cannot be created and shear strength cannot be mobilized without first having appreciable shear displacements caused by the deflection of the layered system. The strains shown in Fig 8 are elastic and recoverable. Along with large elastic strains will occur plastic, nonrecoverable shear strains. The fact that permanent shear strains do occur in overlays on rigid pavements has been noted in Refs 1 and 2. Since many overlays on rigid pavements have developed serious shoving and rutting problems, there are important mixture characteristics that are not included in this type of analysis. The types of mixture design considerations affecting shear strains that are not included in current design procedures are the viscoelastic characteristics of the mixture, the effects of load duration on test specimens, and the evaluation criteria for shear strains in the overlay as related to the underlying layer.

The effect of overlay modulus of elasticity on shear strains was also evaluated for a fairly weak underlying layer and those results are plotted in Fig 9. As can be seen, as the overlay modulus is lowered the shear strains increase dramatically. For all thicknesses, the shear strains doubled as the modulus reduced from 500 ksi to 200 ksi, while the shear strains increased even more dramatically as the modulus was reduced to

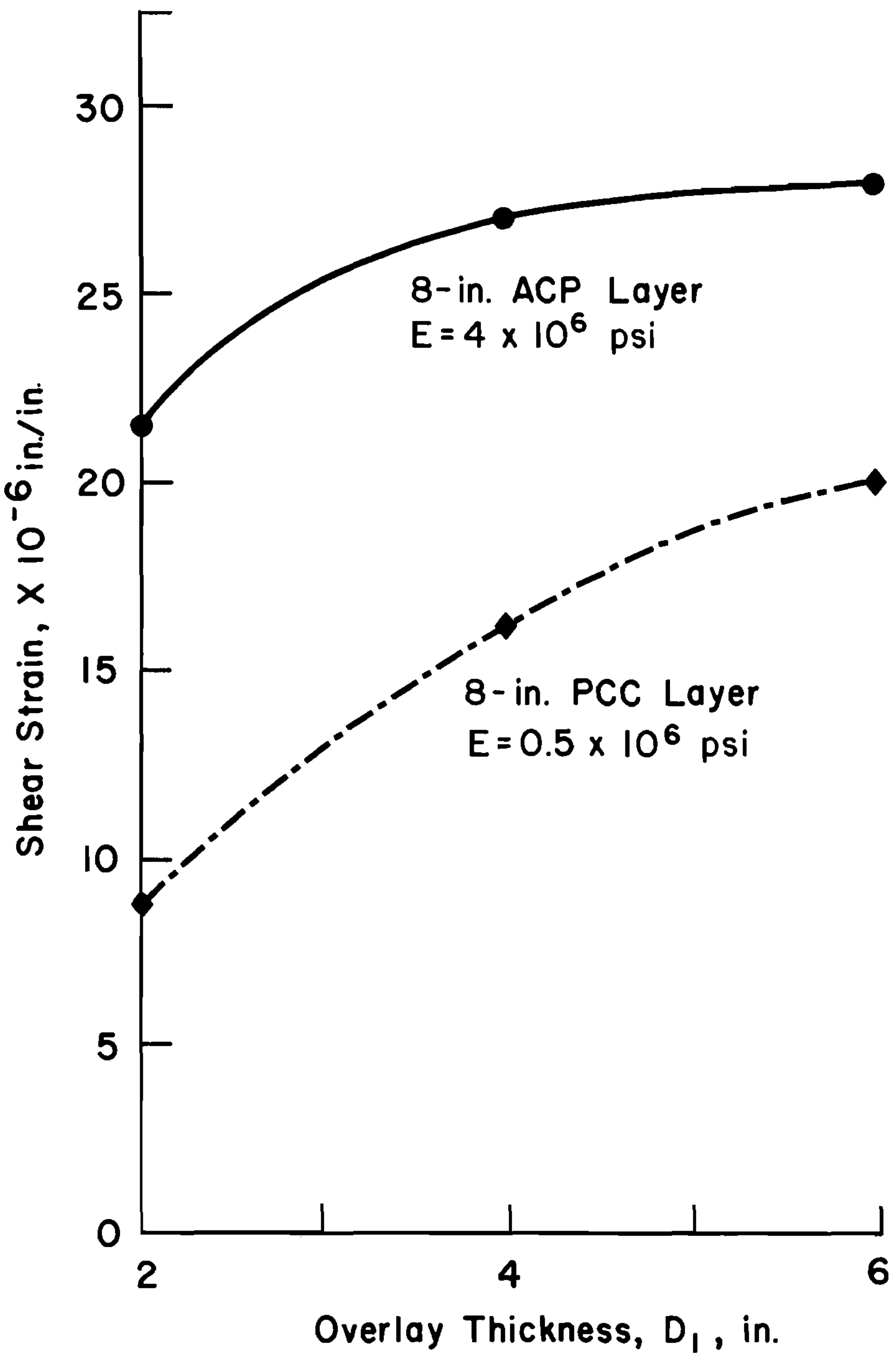


Fig 8. Shear strains at the bottom of an asphalt concrete overlay on Portland cement and asphalt concrete underlying layers each on an 8-in. granular base.

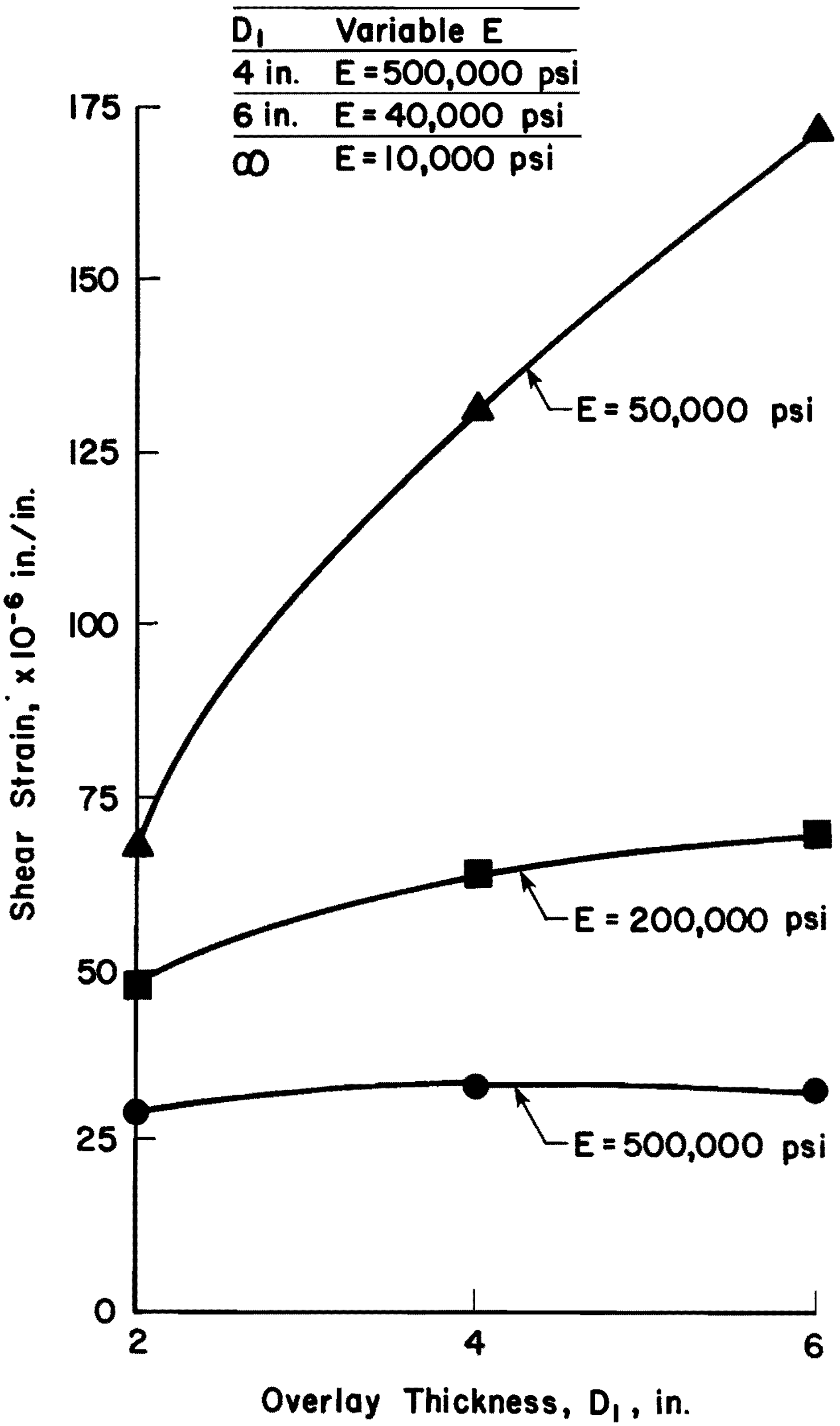


Fig 9. Effect of overlay modulus on shear strains at the bottom of the overlay.

50 ksi. While this lower modulus is probably lower than any construction project, if low compaction is coupled with moisture susceptible mixtures, such values might occur. Again, since these shear strains are elastic, accompanying plastic shear strains would also be expected to be very high.

MOISTURE CONSIDERATIONS

Moisture damage in the form of softening and stripping may well be more extensive in overlay mixtures than in conventional mixtures because of drainage and the tendency for concrete pavements to bring water from the subgrade upward into the overlay mixture.

Thus, water which penetrates the asphalt overlay may collect at the bottom and result in stripping or weakening of the mixture. This is accentuated if reflection cracking has occurred or if open-graded friction courses have been utilized which tend to collect and transmit water to the underlying layers. Unlike conventional mixtures, the underlying layer prevents drainage of the water which is moving downward through the overlay. Inadequate compaction of the overlay will accentuate the problem even more. In addition, it is generally felt that portland cement concrete pavements will tend to move moisture from the subgrade allowing it to collect at the interface between the old concrete pavement and the overlay.

Thus, moisture damage, which is important to all asphalt mixtures, may be more important in asphalt overlay mixtures and may require special considerations in mixture design. Moisture susceptibility has received considerable attention during the last few years, primarily as the result of Research Project 3-9-79-253, "Moisture Effects on Asphalt Mixtures." Several test methods have been identified and developed which can provide an estimate of the moisture susceptibility of asphalt-aggregate mixtures. In addition, techniques for minimizing the damage have been recommended (Refs 20, 21, and 22).

LOW TEMPERATURE CRACKING

Low temperature cracking is of predominant interest in the panhandle and far western portions of Texas. Finn et al (Ref 11) summarize the factors that affect low temperature cracking and indicate that the designer controlled variables include the type of asphalt cement and the thickness of the overlay. Criteria are included by Finn et al that have been developed primarily using Canadian data and include a viscosity selection chart developed by McLeod (Ref 23) and a thickness selection chart developed by Hajek and Haas (Ref 24), both of which allow the designer to select materials and thicknesses that will prevent development of low temperature cracking.

SUMMARY

Generally the limited analysis conducted in this study suggests that loading conditions do not produce more severe stress and strains in overlay mixtures compared to conventional asphalt mixtures. This analysis, however, was based on elastic layered theory which does not adequately consider permanent deformations which occur with time and repeated applications of load. Additional analyses utilizing a program such as VESYS are probably justified since field evidence suggests that permanent deformations are a serious problem in asphalt overlays.

Reflection cracking, however, must be addressed and mixture design procedures should attempt to develop properties which will resist the formation of reflection cracks. In addition, mixture design and construction procedures must consider the increased potential for moisture damage.

CHAPTER 3. CONCLUSIONS AND RECOMMENDATION

Based on the limited theoretical study and literature and field surveys, the following conclusions and recommendation are proposed.

CONCLUSIONS

1. Based on elastic theory, the stresses and strains are not significantly different than obtained in asphalt mixtures in a traditional pavement structure; however, additional analyses using a pavement program such as VESYS are probably justified.
2. Field evidence suggests that permanent deformation in the form of rutting and shoving is prevalent in overlay mixtures.
3. Field evidence indicates that moisture damage in the form of stripping and softening is a major concern in overlay mixtures.
4. Reflection cracking and possibly thermal cracking should be given special consideration during mixture design.
5. Permanent deformation and rutting will be increased by poor compaction and moisture, both of which often occur in conjunction with asphalt overlays.

RECOMMENDATION

It is recommended that mixture design procedures for overlays be investigated with respect to improved resistance to permanent deformation, reflection cracking, and moisture damage.

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